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COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

LOW VISION

Lighting needs for the partially sighted

CIE 123- 1997

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2. To develop basic standards and procedures of metrology in the fields of light and lighting.
3. To provide guidance in the application of principles and procedures in the development of international and national standards in the fields of light and lighting.
4. To prepare and publish standards, reports and other publications concerned with all matters relating to the science, technology and art in the fields of light and lighting.
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La Commission Internationale de l'Éclairage (CIE) est une organisation qui se donne pour but la coopération internationale et l'échange d'informations entre les Pays membres sur toutes les questions relatives à l'art et à la science de l'éclairage. Elle est composée de Comités Nationaux représentant 40 pays plus un territoire géographique, et de 12 membres individuels.

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1. De constituer un centre d'étude international pour toute matière relevant de la science, de la technologie et de l'art de la lumière et de l'éclairage et pour l'échange entre pays d'informations dans ces domaines.
2. D'élaborer des normes et des méthodes de base pour la métrologie dans les domaines de la lumière et de l'éclairage.
3. De donner des directives pour l'application des principes et des méthodes d'élaboration de normes internationales et nationales dans les domaines de la lumière et de l'éclairage.
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5. De maintenir une liaison et une collaboration technique avec les autres organisations internationales concernées par des sujets relatifs à la science, la technologie, la normalisation et l'art dans les domaines de la lumière et de l'éclairage.

Les travaux de la CIE sont effectués par 7 Divisions, ayant chacune environ 20 Comités Techniques. Les sujets d'études s'étendent des questions fondamentales, à tous les types d'applications de l'éclairage. Les normes et les rapports techniques élaborés par ces Divisions Internationales de la CIE sont reconnus dans le monde entier.

Tous les quatre ans, une Session plénière passe en revue le travail des Divisions et des Comités Techniques, en fait rapport et établit les projets de travaux pour l'avenir. La CIE est reconnue comme la plus haute autorité en ce qui concerne tous les aspects de la lumière et de l'éclairage. Elle occupe comme telle une position importante parmi les organisations internationales.

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2. Grundnormen und Verfahren der Meßtechnik auf dem Gebiet der Lichttechnik zu entwickeln.
3. Richtlinien für die Anwendung von Prinzipien und Vorgängen in der Entwicklung internationaler und nationaler Normen auf dem Gebiet der Lichttechnik zu erstellen.
4. Normen, Berichte und andere Publikationen zu erstellen und zu veröffentlichen, die alle Fragen auf dem Gebiet der Wissenschaft, Technik und Kunst der Lichttechnik betreffen.
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Die Arbeit der CIE wird in 7 Divisionen, jede mit etwa 20 Technischen Komitees, geleistet. Diese Arbeit betrifft Gebiete mit grundlegendem Inhalt bis zu allen Arten der Lichtenwendung. Die Normen und Technischen Berichte, die von diesen international zusammengesetzten Divisionen ausgearbeitet werden, sind von der ganzen Welt anerkannt.

Tagungen werden alle vier Jahre abgehalten, in der die Arbeiten der Divisionen überprüft und berichtet und neue Pläne für die Zukunft ausgearbeitet werden. Die CIE wird als höchste Autorität für alle Aspekte des Lichtes und der Beleuchtung angesehen. Auf diese Weise unterhält sie eine bedeutende Stellung unter den internationalen Organisationen.

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Ce rapport technique a été préparé par le Comité Technique CIE 1-16 de la Division 1 "Vision et Couleur" et a été approuvé par le Bureau d'Administration de la Commission Internationale de l'Eclairage, pour étude et application. Le document traite des connaissances courantes et de l'expérience dans le domaine spécifique indiqué de la lumière et de l'éclairage, et il est établi pour l'usage des membres de la CIE et autres groupements intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire. Pour connaître d'éventuels amendements, consulter les plus récents comptes rendus de la CIE ou le CIE NEWS.

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Foreword

The following members of TC 1-16 "Lighting needs for the partially sighted" took part in the preparation of this technical report. The Technical Committee was chaired during the preparation of the report by the late Professor Verriest, and after his untimely death it was taken care of by the Secretary of the Technical Committee, Prof. Warren Julian. Special thanks are due to the Lighting and Low Vision Panel of the CIBSE of Great Britain and to its Chairman, Dr. John Baker, for arranging the material for printing. TC 1-16 comes under CIE Division 1 "Vision and Colour".

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Low Vision, Lighting needs for the partially sighted

The report brings together a wide range of material from various specialists to produce, for the first time, a comprehensive annotated review of the subject. It also draws conclusions from the various studies and it is hoped that it will provide the basis for further research. It is intended for all those that have dealings with the visually handicapped and the provision of lighting regardless of their professional discipline.

Partial sight refers to a permanent condition of visual impairment which cannot be rectified by routine refraction and which is intermediary between normal vision and (total) blindness (and can include the legal blind).

This document summarises the features of the major diseases causing partial sight. It also reviews some studies that have been undertaken into the effects of light on refraction, accommodation and ocular movement, and of its effects on visual functions such as visual acuity, contrast sensitivity, visual field and colour vision.

A section is devoted to the lighting aspects of visual aids, such as neutral and selective absorbing glasses, light amplification systems, high power additions, magnifiers, telescopes, closed circuit television systems, etc. Finally, detailed recommendations are made for the adaptation of a range of lighting environments to the needs of the partially sighted.

Basse vision, besoins d'éclairage pour les malvoyants

Le rapport rassemble un vaste ensemble de matériaux originaires de spécialistes variés afin de constituer, pour la première fois, une revue complète et commentée du sujet. Il tire aussi des conclusions des diverses études; on peut espérer qu'il servira de base à de nouvelles recherches. Il est destiné à tous ceux qui sont en relation avec les handicapés visuels et chargés de l'aménagement de l'éclairage, quelle que soit leur discipline professionnelle.

La vision partielle fait référence à une condition permanente de déficit visuel impossible à corriger par une méthode de réfraction courante et qui se situe entre la vision normale et la cécité (total) (y compris l'aveugle légal).

Ce document résume les caractéristiques des affections majeures causes de vision partielle. Il passe aussi en revue quelques études menées sur les effets de la lumière sur la réfraction, l'accommodation, et les mouvements oculaires, ainsi que sur des fonctions visuelles comme l'acuité, la sensibilité au contraste, le champ visuel et la vision des couleurs.

Une section est dévolue aux aspects d'éclairage des aides visuelles, tels que les verres absorbants neutres ou sélectifs, les systèmes d'amplification de lumière, les additions élevées de puissance, les loupes, les télescopes, les systèmes de télévision en circuit fermé, etc. Finalement, des recommandations détaillées sont faites pour adapter toute une gamme d'environnements lumineux aux besoins des malvoyants.

Sehschwäche, Beleuchtung für Fehlsichtige

Dieser Bericht stellt eine breite Auswahl an Material von verschiedenen Spezialisten zusammen und bietet erstmals eine umfassende, kommentierte Übersicht über das Thema. Er zieht auch Schlußfolgerungen aus den verschiedenen Studien, und man hofft, daß er die Grundlage für weitere Forschungen bilden wird. Er ist für all jene gedacht, die mit Sehbehinderten und der Bereitstellung von Beleuchtung zu tun haben, unabhängig von ihrer Berufssparte.

Fehlsichtigkeit bedeutet den andauernden Zustand visueller Beeinträchtigung, die nicht durch Routine-Brechung korrigiert werden kann und die zwischen normalem Sehvermögen und (völliger) Blindheit steht (sie kann die amtlich anerkannten Blinden einschließen).

Dieses Dokument faßt die Aspekte der Hauptkrankheiten zusammen, die Fehlsichtigkeit verursachen. Es erwähnt auch Studien über die Wirkung von Licht auf Brechung, Akkomodation und Augenbewegung, und über deren Wirkungen auf visuelle Funktionen wie Sehschärfe, Kontrastempfindlichkeit, Gesichtsfeld und Farbsehen.

Ein Kapitel ist den Beleuchtungsaspekten von Sehbehelfen gewidmet, wie neutrale und selektive absorbierende Gläser, Lichtverstärker, stark vergrößernde Zusatzlinsen, Lupen, Teleskope, CCTV, etc. Schließlich werden detaillierte Empfehlungen gegeben zur Anpassung einer Reihe von Beleuchtungsumgebungen auf die Bedürfnisse der Fehlsichtigen.

INTRODUCTION

It was suggested at the 1983 Session of the Commission Internationale de l'Éclairage (CIE) that the problems involved in the provision of lighting for the partially sighted should be investigated. The work was originally started by Guy Verriest of Belgium and continued upon his death by Warren Julian of Australia. Subsequent editing was undertaken by the Lighting and Low Vision Panel of the CIBSE of Great Britain.

The report brings together a wide range of material from various specialists to produce, for the first time, a comprehensive annotated review of the subject. It also draws conclusions from the various studies and it is hoped that it will provide the basis for further research. It is intended for all those that have dealings with the visually handicapped and the provision of lighting regardless of their professional discipline.

Partial sight refers to a permanent condition of visual impairment which cannot be rectified by routine refraction and which is intermediary between normal vision and (total) blindness (and can include the legal blind). The clinically most affected visual function is visual acuity, but can also include visual field and/or contrast sensitivity; although these three impairments are fundamentally different and lead to different types of low vision: visual acuity impairment allows the subject to walk without colliding obstacles, visual field impairment allows the subject to read, as normal people could read across a long and narrow tube.

In the young the major causes are congenital defects; in adults diabetic retinopathy and in the elderly, who represent some 65 per cent of the partially sighted, glaucoma, macular degeneration and cataract.

This document summarises the features of the major diseases causing partial sight. It also reviews some studies that have been undertaken into the effects of light on refraction, accommodation and ocular movement, and of its effects on visual functions such as visual acuity, contrast sensitivity, visual field and colour vision.

A section is devoted to the lighting aspects of visual aids, such as neutral and selective absorbing glasses, light amplification systems, high power additions, magnifiers, telescopes, closed circuit television systems, etc. Finally, detailed recommendations are made for the adaptation of a range of lighting environments to the needs of the partially sighted.

It has to be emphasised, however, that despite the fact that the report is published in 1997, the research was conducted in the 1980s, and new results will be only considered in a follow up publication. It is felt that the comprehensive review offered first in this report is, despite of its late publishing, providing many important aspects to be considered both by researchers of the subject and by the practitioner.

Throughout the document Snellen acuity in metric measures (6/x) is used as being widely understood by both lay and professional workers, although in some instances the US system of imperial measure (20/x) is also shown. The international standard for log MAR (Minimum Angle of Resolution) may be preferred by some where $6/60 = 1,0$; $6/6 = 0,0$ and $6/600 = 2,0$. In this case partial sight would be $< 0,6 \log \text{MAR}$ ¹.

1 BAILEY H, LOVIE JE — New design principles for visual acuity letter charts, *Am. J. Optom. Physiol. Opt.* **53**, 740 - 745, 1976.

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1. DEFINITION AND INCIDENCE OF LOW VISION

1.1 Definition

Low vision (or partial sight) refers to a permanent condition of diminished visual performance which cannot be rectified by routine refraction and which is intermediary between normal vision and legal blindness. Typically, even with the best spectacle correction, the affected subject cannot read a newspaper at a normal reading distance (40 cm) but often has no orientation or walking problems. The clinically most affected visual function is visual acuity, but a reduction of visual field and/or contrast sensitivity may also feature in the loss of function.

Although there is no generally accepted single definition of partial sight, an uncorrectable central vision of the better eye of between 0,3 (6/18) and 0,02 (6/300) is the visual acuity criterion most commonly used. Distinction is made between normal response, impairment, disability and handicap, and these are defined in the Recommendation on the Classification of Visual Performance¹ and in the International Classification of Impairments, Disabilities, and Handicaps².

Visual impairment refers to vision. It indicates a limitation in one or more of its basic functions: visual acuity, field of vision, night vision, etc.

Visual disability refers to the individual. It indicates a limitation of the ability to perform certain defined visual tasks such as reading, writing, orientation or mobility.

Visual handicap refers to the individual's general functioning in the actual environment. It may indicate a lack of physical independence, lack of economic independence, or lack of social integration. Reading disability is not a handicap to an illiterate individual. A disability that prevents safe driving only becomes a handicap to an individual who wishes to drive and the stronger the need to drive, the more severe is the handicap.

Table 1 represents a classification system for grading visual impairment, visual disability and visual handicap according to severity, with a reference to contrast sensitivity impairment.

Partial sight can result from either visual acuity impairment alone, from visual field impairment alone, from contrast sensitivity impairment alone, or from a simultaneous impairment of more than one of these visual functions. In some cases it might be more appropriate to define the retention of any usable form of vision.

In many countries "legal blindness" is defined as corresponding to a reduction of the visual acuity of the better eye to less than 0,1 (6/60), thus making some of the partially sighted legally blind. As will be seen in section 2.4, 'Behavioural Aspects', an ideal definition of partial sight should include reference to any relevant socio-economic factors.

1.2 Prevalence and incidence

Statistics on the frequency of partial sight are less common than those on the frequency of blindness because the partially sighted are not registered unless they are legally blind. However, useful information can be gained from different sources, for example, by combining the data from blindness registers with the vision screening surveys of representative communities.

In most western nations, the prevalence of legal blindness is in the order of 0,2 percent. The reported incidence, however, is only about one-tenth of the prevalence; that is, the incidence of legal blindness is in the order of 0,02 percent. Analysis of statistics from the United States suggests that, within the legally blind group, only about 15 to 25 percent are found to be functionally blind: that is, at least three-quarters of the legally blind population have some useful vision. Furthermore, the group that has low vision but is not legally blind is about 3 to 4 times larger than the legally blind population. Thus, in the United States, the prevalence of visual handicap is about 0,8 to 1,0 percent of the total population (Bailey, 1978³; see also Fonda, 1975⁴ and the National Society for the Prevention of Blindness, 1980), and its reported incidence about 0,1 percent (Bailey, 1978⁵).

Comparison across nations is difficult because different criteria are used to determine legal blindness and because the efficiency of identifying legally blind people is also variable. There are also many contradictions. The prevalence of legal blindness in the United Kingdom is 0,21 percent according to Sorsby (1966)⁶, but only 3,4 percent of them are totally blind, while Cullinan et al (1979)⁷ estimated that of every 100 000 people over 16 years old living at home in England and Wales, only 520 (thus 0,052 percent) have a distance visual acuity of less than 6/18 and are, therefore, visually disabled by WHO criteria.

On the other hand, blindness and partial sight are surely more frequent outside the Western World, so that we might accept with Julian (1983⁸, 1984⁹) that about 1 percent of the world population are partially sighted.

Table 1. Classification of visual performance.

(Near-) Normal		Low Vision		Blindness		Total
Normal	Near-Normal	Moderate	Severe	Moderate	Severe	

ASSESSMENT OF VISUAL IMPAIRMENT**Visual acuity impairment**

None	Slight	Moderate	Severe	Profound	Near-total	Total
Snellen 6/3m8 - 6/7m5	6/9m5 - 6/19	6/24 - 6/48	6/60 - 6/120 3/30 - 3/60	6/150 - 6/300 3/75	HM, LP	NLP
20/12 - 20/25	20/32 - 20/64	20/80 - 20/160	20/80 - 20/400	20/500-20/1000	HM, LP	NLP
Decimal 1,7 - 0,8	0,67 - 0,33	0,25 - 0,13	0,1 - 0,05	0,04 - 0,02	≤ 0,013	
logMAR -0,2 - 0,1	0,2 - 0,5	0,6 - 0,9	1,0 - 1,3	1,4 - 1,7	≥ 1,8	

Visual field impairment

(constriction to...)			(hemianopsia?)				
180°	140°	120° 100° 80°	60° 40° 30°	20° 15°	10°	5°	0°

Contrast sensitivity impairment

Threshold contrast						
≤ 0,01	0,013 - 0,025	0,032 - 0,063	0,08 - 0,016	0,2 - 0,4	0,5 - 1,0	NLP
Sensitivity (1/contrast) dB = -10 log (threshold contrast)						
≥ 20 dB	19 - 16 dB	15 - 12 dB	11 - 8 dB	7 - 4 dB	3 - 0 dB	

ASSESSMENT OF VISUAL DISABILITY

(Near-) Normal		Low Vision		Blindness		Total
Normal	Near-Normal	Moderate	Severe	Moderate	Severe	
can perform all visual tasks		needs aids for detailed visual tasks		needs aids and other senses for gross visual tasks		
		near-normal with aids	subnormal with aids	aids as an adjunct	vision as an adjunct	no vision

ASSESSMENT OF VISUAL HANDICAP

can meet societal expectations visually			cannot meet societal expectations visually		
meets all	meets most	meets many	fails many	fails most	fails all

ALTERNATIVE DEFINITIONS OF BLINDNESS

Normal	Near-Normal	Moderate	Low vision Severe	Profound	Near-blind	Blind
WHO (1972) classification Group I		Group II	Group III		Group IV	Group V
Genensky (1978) classification			Partial sight & legal blindness		Functional & legal blindness	
Normal	Partial sight but not legal blindness					

PROPOSED DEFINITION

(Near-) Normal		Low vision		Blindness		Total
Normal	Near-Normal	Moderate	Severe	Moderate	Severe	

REJECTED DEFINITION

"Legally seeing"	"Legally blind" (pensionable as an invalid)
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Fonda (1981)¹⁰ suggested that the blind (and partially sighted) population is increasing at nearly twice the rate of the general population due mainly to augmenting life expectancies of both the aged and the diabetic. Indeed visual impairment is very strongly related to aging: the age of onset of partial sight in the U.S. is 20 percent between birth and 40 years; 21 percent between 41 and 60 years and 59 percent over 61 years (Kahn and Moorhead, 1973¹¹). The percentage of visually handicapped grows nearly exponentially with age as shown by figure 1.1 (source: Census of the Handicapped, 1971-72, by the Dutch Central Office for Statistics, referred to by Zabel, Bouma and Mélotte, 1982¹²).

People aged 65 years and over represent 60 percent of the visually impaired population according to a Dutch survey, and even 71 percent according the previously mentioned American survey of the National Society to Prevent Blindness.

Although the elderly are the most vulnerable group for visual impairment, visual rehabilitation services have been directed primarily to children and those in the employable age range. There are a number of reasons why the elderly seem to have been neglected in the provision of services. Many of the elderly tend to accept gradual failure of sight as one of the inevitable consequences of growing old and consequently fail to seek appropriate help for their visual disability. Older people who have enjoyed perfect vision in their youth, in contrast to those who never did, often expect too much and are not prone to settle for some small improvement produced by an optical aid (Fonda, 1984¹³).

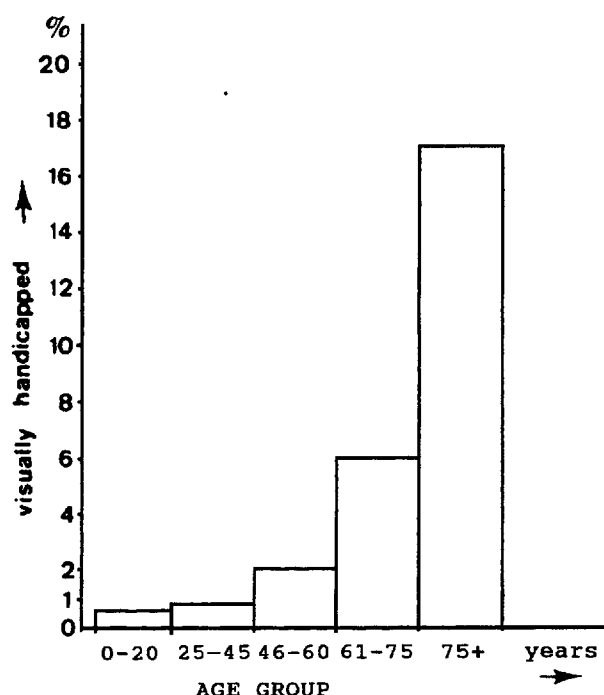


Figure 1.1: The percentage of visually handicapped versus age group.

Gender does show some relationship to visual impairment. British statistics show that up to about the fifth decade, legal blindness is most common in men (the ratio being about 55:45), mainly because men are more prone to vision loss due to genetic and traumatic causes. After the age of 60, the propensity for visual impairment is about equal for men and women but, because of their greater longevity, there are more visually impaired elderly women than there are visually impaired elderly men (the ratio being about 60:40): Bailey (1978)³.

Hartmann, Scheffzyk-Hagl and Lachenmayr (1980)¹⁴ estimate that 0,1 percent of the population in the industrial countries involved in the working process are partially sighted. In addition, according to Bätz (1964)¹⁵, nearly 0,2 percent of all children of school age are so handicapped by partial sight that they have to be specially educated.

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2. THE CAUSES OF LOW VISION AND ITS EFFECTS

2.1 Causes

There is less statistical data on the causes of low vision than on the cause of total blindness. The statistics of the two conditions cannot be integrated because some diseases are more likely to cause blindness than partial sight, owing to a more rapid progression. Also, it is difficult to compare statistics of causes of blindness from different authors because of the discrepancies in the classification systems used and even in the diagnosis of the blinding disease: for example, cataract as a cause of (generally curable!) blindness is obviously over-estimated by some authors and underestimated by others. The variations in assessing incidence are shown by the following examples of data concerning the causes of blindness and low vision in global western populations. Some data, such as Faye's, are from a self-selected population who sought or were referred for specialist care.

Faye, 1984¹, US

macular degeneration	49,0 %
complicated cataract	16,0 %
glaucoma	11,0 %
diabetic retinopathy	8,0 %
optic atrophy	7,0 %
degenerative myopia	5,0 %
retinitis pigmentosa	4,0 %

Cullinan; 1980² ; UK

cataract	25,0 %
macular degeneration	16,0 %
glaucoma	8,0 %
diabetic retinopathy	6,0 %
myopia	6,0 %
aphakia	6,0 %
retinal detachment	6,0 %
congenital conditions	6,0 %
optic atrophy, keratitis, injury, etc.	2,0 %

Dowling, 1980³, Australia

cataract	38,0 %
retinal deterioration	22,0 %
glaucoma	21,0 %
vascular conditions	8,0 %
diabetes	7,0 %
other	11,0 %

Rudobielski et al, 1979⁴, Poland

myopia	30,4 %
senile cataract	24,2 %
retinal and choroidal diseases	11,6 %
glaucoma	9,0 %
corneal diseases	6,4 %
diseases of the optic nerve	6,1 %
injuries	4,4 %
congenital cataract	3,6 %
iridocyclitis	1,3 %
microphthalmos	1,1 %
diabetes	1,1 %
retinal detachment	0,7 %
albinism	0,4 %

We can infer from these data that the principal causes of low vision in the western population are retinal degeneration (especially macular), cataract and glaucoma (in about 10 percent of the cases), followed by diabetes, congenital conditions, corneal diseases and (non glaucomatous) optic atrophy.

Strabismic amblyopia is not mentioned as a cause of partial sight although it is very common (3 to 5 percent of the western population: Hess & Jenkins, 1980⁵) while the other eye can be blinded by another disease.

The differences in classification by various authors means that the incidence of causes of impaired vision in different age groups can be compared only in material from the same author, as is shown below in order of frequency.

Kahn and Moorhead, 1973⁶, US

0 to 20 years

- 1 congenital hereditary defects
- 2 infectious diseases
- 3 tumours
- 4 injuries
- 5 retrolental fibroplasia
- 6 miscellaneous (for example, cerebral blindness)

21 to 40 years

- 1 diabetic retinopathy
- 2 heredo-degeneration of the retina uveitis
- 4 optic atrophy
- 5 pathologic myopia
- 6 injuries

41 to 60 years

- 1 diabetic retinopathy
- 2 cataracts
- 3 glaucoma
- 4 macular degeneration, disciform degeneration, choroidal sclerosis
- 5 vascular retinopathy other than diabetes

over 60 years

- 1 macular degeneration, disciform degeneration, choroidal sclerosis
- 2 cataracts
- 3 glaucoma
- 4 diabetic retinopathy
- 5 vascular retinopathy other than diabetes

Fonda, 1978⁷, US

3 to 21 years

1	albinism	15,6 %
2	congenital cataract	13,8 %
3	optic atrophy	10,5 %
4	retrolental fibroplasia	9,4 %
5	generalized fundus degeneration	6,3 %
6	high myopia	5,6 %
7	heredo-degeneration of macula	5,3 %
8	aplasia of macula	5,1 %
9	chorio-retinitis	5,0 %
10	cortical blindness	3,4 %

Fonda, 1984⁸, US

65 to 100 years

1	macular degeneration	44,0 %
2	other retinal pathology	38,0 %
3	cataract, corneal dystrophy etc.	11,0 %
4	optic atrophy (incl. glaucoma)	7,0 %

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Hill and Cameron, 1986⁹, UK have produced the following percentage incidences in various age groups:

Age	Patients	Age related maculopathy	Myopic degeneration	Diabetic Retinopathy	Corneal conditions	Glaucoma	Disseminated Choroiditis	Macular dystrophy
6 - 20	59	-	1,7	-	3,4	1,7	5,1	8,5
21 - 65	331	9,7	14,8	13,9	5,8	4,5	6,9	12,4
66 - 95	510	63,7	6,1	6,1	4,1	6,7	3,5	1,2
6 - 95	900	39,7	9,0	8,6	4,7	5,6	4,9	5,8

Age	Patients	Cataract	Optic opathy	Vascular conditions	Hereditary macular dystrophies	Albinism	Chronic uveitis	Retinal detachment
6 - 20	59	22,0	15,3	-	1,7	13,5	0,1	1,7
21 - 65	331	1,8	7,3	4,2	4,5	1,3	-	1
66 - 95	510	3,3	-	3,9	6,7	-	-	1,3
6 - 95	900	4,0	3,7	3,8	5,6	1,36	0,01	1,2

Note: Other conditions accounted for less than 1,0 percent for all age groups

We can infer from all these data that the main causes of low vision are congenital defects in the young; diabetic retinopathy, cataract and glaucoma in adults; and (age-related) macular degeneration and cataract in the elderly. Men are more liable to vision loss due to congenital disorders, retinitis pigmentosa, retinal detachment, glaucoma, optic atrophy, and trauma. Conversely, women are more susceptible to degenerative myopia, cataract, diabetic retinopathy, iritis, keratitis, and interstitial keratitis (Bailey, 1978)¹⁰.

The discussion and data above relate to developed nations where the three major causes of partial sight (macular degeneration, cataract and glaucoma) are diseases which usually appear late in life. However, if the world's population is considered rather than the developed countries, then the causes of blindness change from the diseases of old age to disease related to public health, malnutrition, parasitic attack and accidents. The six main causes of world blindness are trachoma, onchocerciasis, blinding malnutrition (xerophthalmia and keratomalacia), cataract, glaucoma and trauma. In India 5 percent of the population suffer from cataract. Even in the US, non-whites are more likely to become visually handicapped than whites because of a more frequent occurrence of glaucoma and cataract (Bailey, 1978)¹⁰.

2.2 Effects on vision

Ocular diseases causing partial sight can interfere with vision in many different ways. Some diseases affect principally the central part of the visual field, creating a central scotoma, which often dramatically reduces central visual acuity. Other diseases affect more peripheral parts of the visual field, for example narrowing it concentrically, and still other diseases affect disseminated areas, causing patches in the visual field.

There are also hemianopic field defects, which affect vision either at the left side of the fixation point, or at the right side of the fixation point, or even above or below the fixation point. Every visual field defect can be absolute (when the concerned area is blind) or relative (when its sensitivity is diminished but not abolished). Moreover, the defect can have gradual or abrupt borders.

Visual acuity and visual field are not the only visual functions to be studied in partial sight. Ophthalmologists and optometrists now determine visibility thresholds for targets of different contrast, for

example, by a threshold contrast for gratings of several spatial frequencies. In pathologies, the contrast sensitivity function may be selectively lowered for either the higher or the lower spatial frequencies.

Furthermore, some diseases affect mainly photopic vision, mediated by the cones, while others affect scotopic vision, mediated by the rods. When compared with that of normal subjects, visual performance will, in the first case, be worst in daytime (nyctalopia) and, in the second case, be worst at night (hemeralopia). There may also be problems due to a reduced speed of dark and/or light adaptation.

Colour discrimination is mediated by the cones. Approximately 8 percent of the male population and 1 percent of the female population suffer from congenital colour discrimination impairments. Colour discrimination is also affected by diseases, some of which give rise to red-green (RG) defects and others to blue-yellow (BY) defects. Red-green deficiency can be subdivided into a Type I RG defect, which is of retinal origin and in which there is red darkening, and a Type II RG defect, which occurs in the optic nerve and from other neural diseases, and in which there is no red darkening. Similarly, there are BY defects with pseudoprotanomaly giving an excess of red in the Rayleigh match between a monochromatic yellow and a mixture of red and green lights (as in macular oedema), and BY defects with a normal Rayleigh match (as in glaucoma). Some acquired colour vision defects do not have a predominant axis. There are some diseases which do not seriously affect colour vision while some congenital or acquired diseases result in total colour blindness (achromatopia). See also Fletcher & Voke, 1985¹¹

Fusion (single binocular vision) is not present in strabismus patients nor in some congenital eye disorders with nystagmus. Patients with an acquired macular disease who no longer have central binocular vision may still have peripheral binocular vision as an extramacular function. This peripheral vision is of major importance for orientation in space. Its disruption (for example, by monocular aphakia) has severe functional consequences in the loss of simultaneous perception of peripheral images (Faye, 1984¹).

In a more fundamental way it is necessary to distinguish any reduction of vision by disease in the refractive media of the eye (namely cornea, crystalline lens and vitreous body) from that caused by retinal disease and from that caused by lesions in the optic pathways and in the cerebral centres. Opacities or structural abnormalities that alter the clarity of the refractive structures result in haziness, i.e. reduced contrast sensitivity and reduced acuity throughout the entire field of view. If a contrast target is presented within an equi-luminous surround, the retinal illuminance in the area of interest does not change due to an increase in light. This is because as much light is scattered towards the area of interest as is scattered away. So only the modulation depth changes, not the retinal illuminance. As a result the whole spatial transfer function drops (Van den Berg, 1986¹²). Another consequence of the increased scatter is that almost everyone with media opacities is disability glare sensitive, reporting "hazy vision" outdoors. Media opacities do not harm dark adaptation (if the drop in visual acuity does not prevent detection of the target). Colour vision is affected only when the normal transmission of light depends markedly on the wavelength: so brownish nuclear cataract gives rise to a BY defect because it absorbs much more light of shorter wavelengths.

Lesions of the fundus can affect vision either by absorbing and scattering light as prereceptoral opacities, or by malfunction of the photoreceptors, or by malfunction of the neurons of the inner retinal layers. Examples of the first mechanism are the scotomas created by intraretinal haemorrhages and exudates, or the glare by increased light reflection in cases of coloboma or of atrophic fundal areas. Receptor lesions affect, often selectively, photopic or scotopic vision by selective damage of the cones or the rods. Such receptor damage can be due to primary or secondary degeneration due to choroidal disease. Destruction of the rods gives night blindness while destruction of the cones gives rise to decreased visual acuity and colour vision defects, namely Type I RG defects when the red-sensitive cones are more affected, and BY defects when the blue-sensitive cones are more affected. Receptor disorientation is frequent and gives rise to pseudoprotanomaly. Damage to the inner nuclear retinal layer can sometimes be identified, for example from evidence of increased opponent activity.

Lesions of the optic nerve can be recognized by normal retinal functioning as revealed by electroretinography, and by features such as reduction of contrast sensitivity for greater spatial frequencies, Type II RG defects by selective impairment of the chromatic channels, delay of the evoked visual potentials etc. Some symptoms, such as lateral hemianopia and agnosia, are typical for intracranial lesions.

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2.2.1 *Major causes of partial sight*

The following review, from here to the end of this section, is for the benefit of readers who are not clinicians, and provides a short account of the various diseases which are major causes of partial sight. They will be discussed mainly from the point of view of identifying the features of each condition which are of interest to vision and the relationship with the visual environment.

Albinism is a congenital, hereditary and non-progressive, complete or partial lack of pigment affecting various structures. In cases where only the eyes are affected the condition is referred to as ocular albinism. The fundus is pale and there is a macular aplasia. The visual acuity is most commonly in the range between 0,4 (6/15) to 0,1 (6/60). Pendular nystagmus and photophobia are usual symptoms. High refractive errors and strabismus are frequent. The visual fields can present a faint central scotoma. Dark adaptation is normal but, owing to the fundus depigmentation, there is increased sensitivity to glare. Colour vision is normal. See also Abadi, 1989¹³.

Aniridia is a congenital or acquired (almost complete) absence of the iris. Cataract, displaced lens and underdevelopment of the retina are frequently associated ocular defects. The aniridia patients are very sensitive to light, have decreased visual acuity and may demonstrate nystagmus. Peripheral vision and colour vision are not affected. Glaucoma (high intraocular pressure) is a secondary problem in many of these cases. This increased pressure may cause constriction of the visual fields and cloudiness of the cornea further decreasing visual ability.

Aphakia is the absence of lens in the eye, consecutive to cataract operation. It results in high hyperopia, in the inability to accommodate and in increased sensitivity to blue light and UV radiation. It is not in itself a cause of partial sight, but is often present in partially sighted people. The ametropia caused by aphakia can be corrected by spectacles, better by contact lenses, and still better by implantation of an intraocular lens (pseudophakia).

Cataract is any opacity of the lens. There are congenital and acquired cataracts. Congenital cataracts can be due to genetic disorders or to maternal infection (rubella). The most common acquired types of cataract are age-related (senile) cortical cataract (with radial, white, wedge-shaped opacities in the outer layers of the lens), age-related (senile) nuclear cataract (opacification of the core of the lens), and posterior subcapsular cataract (opacification of the centre of the posterior surface of the lens, which is generally the consequence of endocrine disorders, as in diabetes, and/or chorioretinal disorders). According to Witmer et al, 1987¹⁴ vision is impaired in cataract by three mechanisms: increased light absorption in the lens and thus decreased retinal illuminance, increased light diffusion at small angles (less than 1°) and thus decreased visual acuity, and increased light diffusion at large angles and thus increased disability glare. Pupil contraction exaggerates the reduction of visual acuity in case of nuclear or posterior subcapsular cataract. Nuclear cataract causes myopia, a relative central scotoma and, if it is brownish, a BY colour vision defect. The other types of cataract do not affect colour vision nor the visual field and dark adaptation extents. Cataract is still a major cause of blindness although nearly all cases can be cured by extraction. After the extraction the eye presents aphakia or pseudophakia (see aphakia). Extraction can be followed by complications such as secondary cataract (opacification of the remaining lens capsule). Bilateral congenital cataracts have to be removed as early as possible in order to allow normal visual development. See also Hess & Woo, (1978)¹⁵

Coloboma. An iris coloboma is a congenital notch or cleft appearance of the pupil, which has a characteristic tear-drop shape. This malformation may extend to the choroid and to the optic nerve. If the choroid is involved, visual acuity can be reduced and there is an associated upper field loss, since the coloboma affects the lower portion of the eye. The patient may experience glare problems, possibly due to the tear-drop shaped pupil and the white fundus lesion.

Cone degenerations and cone-rod degenerations are diffuse retinal degenerations affecting photopic vision relatively more than does retinitis pigmentosa (see retinitis pigmentosa).

Congenital achromatopia is hereditary total colour blindness. In its typical form it is due to the functional absence of cones and the absence of rod inhibition in photopic conditions. It is characterized by a visual acuity reduced to about 0,1 (6/60), pendular nystagmus of small amplitude and photophobia. The affected subjects can read and follow regular school work despite the low visual acuity. Astigmatism is

frequent. The visual fields present a faint central scotoma but are otherwise unaffected in the absence of concomitant retinal degeneration. Dark adaptation is usually normal. In many cases there are some macular functional cones providing some abortive colour vision.

In the sex-linked variety of congenital achromatopia which is called blue monocone monochromasy there are, in addition to the rods, a lot of functioning blue-sensitive cones. The affected subjects are myopic and their visual acuity is often somewhat better than in the typical form.

There are also acquired achromatopias of retinal, optic or central origin.

Corneal dystrophies are a group of rare, degenerative, slowly progressive, bilateral corneal opacifications which include keratitis and usually appear in the second or third decades of life. They cause a drop in visual acuity and increased disability glare. Corneal transplants improve vision significantly in most cases. Corneal scars due to injuries or to corneal ulcers also blur vision by opacification and/or by astigmatism. The blurring is greater if the lesion is more centrally located. Perforation due to corneal ulceration is a major cause of blindness throughout the Third World.

Degenerative myopia is a condition featuring a large eye and excessive growth. Afflicted individuals generally are myopic from a very early age and undergo progressive increase in nearsightedness through the years. As the condition progresses, the decreased visual acuity may not be correctable to 1,0 (6/6) with conventional spectacles or contact lenses. This is due to the stretching of the retina and accompanying degenerative changes, especially macular lesions which produce a condition of low vision with a central scotoma and a BY colour vision defect. Night vision can be affected. There are usually fewer functional difficulties at near vision tasks because individuals with high myopia can often maintain a satisfactory focus to quite close distances when they wear their spectacles and at very close distances they may achieve clearer focus by removing their spectacles. Holding objects closer provides a larger retinal image and therefore better functional resolution. Degenerative myopia is more frequent in females and in some racial groups (Chinese, Japanese, Arabs and Jews). There is a high incidence of retinal detachments.

Diabetes mellitus is a systemic condition due to the lack of insulin (produced by specific cells in the pancreas) in the bloodstream. Diabetes affects the circulatory system in many parts of the body including the eyes, kidneys, and skin. The main ocular problems associated with diabetes stem from blood vessel changes in the retina. Such a diabetic retinopathy is initially characterised by microaneurysms (localised dilation of capillary blood vessels) dot and blot haemorrhages and hard exudates. Many affected retinas suffer from oedema, especially in the macular region. Closure of much of the fine vasculature results in patches of retinal ischaemia. Later on there is patent neovascularisation, recurrent preretinal haemorrhages and proliferation of blood vessels in the vitreous body (proliferative retinopathy). Retinal detachment can follow the shrinkage of the vitreous. Some diabetics develop posterior subcapsular cataracts, while other become blind by haemorrhagic glaucoma.

Initial functional symptoms of diabetic retinopathy include retardation of the initial phase of dark adaptation and BY colour vision defects. Macular oedema causes first the apparition of a dark central spot (positive scotoma), deformation (metamorphopia) and size reduction (micropia) of the seen objects, and later a not seen (negative) central scotoma with reduced visual acuity. Retinal atrophy and retinitis proliferans cause disseminated defects in the visual field and further reduction of visual acuity. At all stages many individuals experience fluctuations of vision. Photocoagulation is an excellent treatment of diabetic retinopathy but causes functional damage (disseminated patches of reduced sensitivity in the visual field, macular BY colour vision defect, reduced contrast sensitivity and adaptation).

Glaucoma covers all eye diseases associated with increased intraocular pressure. We have to distinguish congenital glaucoma, narrow angle glaucoma, open angle glaucoma and secondary glaucoma. The increased intraocular pressure often damages the retina and especially the entrance of the optic nerve in the eyeball (optic disc). This gives rise to the appearance, and the development in the visual field, of nerve fibre bundle defects, which are first more evident in the middle periphery of the field (arcuate scotomas), but thereafter merge in the periphery and, moreover, destroy central vision. Before blindness the narrowing of the visual field can make vision tubular as in retinitis pigmentosa. The functional symptoms include not only these visual field defects but also reduction of contrast sensitivity (also for small

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spatial frequencies), a BY colour vision defect and defective night vision (which is aggravated by the pupil reduction induced by pilocarpine eyedrops which may also compromise light adaptation). Glaucoma sufferers are said to be hypersensitive to glare. Medical and/or surgical treatment can often stop the progression of the disease.

Homonymous hemianopia is the loss of right or left halves of the visual fields of both eyes. It is most commonly associated with strokes or head trauma. Homonymous defects to the right interfere with reading to the end of a line. Homonymous defects to the left interfere with perception of objects in the left field and with finding the beginning of the next line of print.

Loss of both superior or inferior halves of the visual fields also occurs. Superior defects may obscure overhanging structures for the walking patient. Objects high on a shelf may be lost in the scotoma; reading is not a problem. Inferior hemianopia blocks the lower half of the field and is more troublesome. In reading, the patient may have difficulty finding the next line or seeing objects on the table.

Hemianopias can be complete or incomplete. They can be linked with visual acuity, colour vision and night vision defects.

Keratoconus is what its name indicates: a cone-shaped cornea. As myopia and astigmatism is induced the patient may initially need a new prescription every year or six months. Visual acuity will depend upon the extent of the condition and may range from mild distortion to severe visual impairment that cannot be adequately corrected with spectacles or contact lenses. There is generally no observable loss of visual field, but rather an overall distortion. The condition may progress to the point where the cornea ruptures resulting in blindness but this can be prevented by corneal transplantation.

Lens dislocation may be hereditary or may result from trauma. Hereditary lens dislocation is usually bilateral and may be associated with systemic disease (e.g. Marfan's syndrome). Slight dislocation causes astigmatism, while more marked dislocation causes monocular diplopia (double vision) and even the symptoms of aphakia. The condition can give rise to glaucoma and can be treated by lens extraction.

Macular degeneration implies destruction of the central part of the retina and thus loss of central vision. Specialists in low vision have to distinguish juvenile macular degeneration from senile macular degeneration (which is nowadays called age-related macular degeneration).

Juvenile macular degeneration, one form of which is Stargardt's disease, usually begins before the age of 10 years. The ophthalmoscopic symptoms are slight but visual acuity is progressively reduced to about 0,05 (6/120). The visual field presents a big central scotoma with gentle slopes. It is a selective cone degeneration as there is a Type I RG colour vision defect and photophobia, while the subject sees relatively better in scotopic conditions (nyctalopia). The disease is bilateral and symmetrical. It is rarely associated with retinitis pigmentosa, producing so-called cone-rod dysfunction.

Age-related macular degeneration is the most common eye disease among people 65 years and older. Ophthalmoscopically one of three types, i.e. atrophic, exudatic or choroidal sclerosis. The visual acuity drops gradually to (often) less than 0,05 (6/120) with a dense central scotoma with sharp slopes. There is loss of contrast sensitivity and a BY colour vision defect. The subject sees relatively worse in scotopic conditions and dark adaptation can be very slow. The peripheral visual field remains normal. The disease is bilateral but the condition in one eye usually proceeds the other by months or years.

Nystagmus is involuntary rapid oscillatory eye movement. It accompanies many of the visual impairments present at birth or acquired in infancy. There is also a form with no other ocular disorder but in which visual acuity is reduced to about 0,2 (6/30). Nystagmus can usually be partly blocked and vision becomes better in a given gaze direction. Sensitivity to gratings with an orientation of 90° to the nystagmus is reduced. Visual field, colour vision and night vision are not affected.

Optic atrophy shows as a pallor of the entrance of the optic nerve in the eyeball (optic disc) due to hereditary or non-hereditary, congenital or acquired infectious degenerative tumoral or traumatic diseases of the optic nerve. Bilateral optic atrophy as a cause of partial sight is chiefly due to

- (1) dominant juvenile optic atrophy, a hereditary progressive disease beginning in childhood causing a moderate decrease in visual acuity, a centrocoecal scotoma (this is a scotoma including the fixation point and the normal blind spot) and a BY colour vision defect (rarely a RG colour vision defect);
- (2) Leber's optic atrophy disease, a hereditary acute optic neuritis at the age of about 20 years leaving a very reduced visual acuity, a big central scotoma with gentle slopes and a Type II RG colour vision defect.

Retinal detachment is separation of the retina from the choroid or of the neural retina from the retinal pigment epithelium. It can be due to several causes including high myopia and injuries. An early sign is the patient complaining of seeing 'flashing lights'. Retinal detachment harms all visual functions including acuity (if the macula is involved or if the detachment hangs before it), visual field (blind areas corresponding to the detachment), colour vision and dark adaptation. If not treated it is rapidly progressive and blinds the affected eye.

Retinitis pigmentosa is a hereditary, progressive, bilateral retinal degeneration. Night blindness is often the first symptom. Scotomas appear in the mid periphery of the visual field; they extend more rapidly toward the periphery than toward the centre, so that there is, before blindness, a long stage of tunnel vision (extremely narrowed visual fields). There is a BY or Type I RG colour vision defect. Visual acuity is affected earlier in the cases of associated macular degeneration. Retinitis pigmentosa in infants is called Leber's disease (no relationship with Leber's optic atrophy cited above). There are many other hereditary peripheral chorioretinal degenerations functionally reassembling retinitis pigmentosa.

Retinopathy of prematurity (RoP) is a condition commonly seen among premature infants who received oxygen therapy and there is some evidence to suggest that this is due to subdued lighting in incubator wards (if a dark/light cycle operates the incidence reduces)¹⁶. New vessels and fibrous tissue cause a stretching of the retina and may eventually lead to retinal detachment. Myopia is frequent. The condition is highly variable, and may range from minimal ocular damage with no visual impairment to total blindness. Sectorial field losses correspond to cicatricial changes in the retina or the detachments.

Most tropical causes of blindness harm vision by opacification of the cornea. However, night blindness is an early symptom in case of avitaminosis A. In onchocerciasis there are, besides keratitis and uveitis, lesions of the fundus and of the optic nerve with impairment of visual acuity, visual field (which can become tubular) and night vision.

Uveitis is inflammation of the vascular layer of the eye. It can cause permanent loss of vision by scars in the retina, deposits on the cornea and on the lens, cataract and glaucoma.

2.3 Multiple handicaps

People with low vision can have special visual problems because lesions of different parts of the eye may be present. For example, cataracts are a frequent secondary handicap in many retinal diseases causing impaired vision such as retinitis pigmentosa, age-related macular degeneration and diabetic retinopathy. These retinal disorders require high illumination but often less when cataracts develop because intense illumination causes glare and constriction of the pupil, thereby further impairing vision. Both glaucoma and age-related macular degeneration are more prevalent in the elderly, and sometimes they occur within the one eye. Both conditions often create a need for greater illumination. In addition, topical medication such as pilocarpine for glaucoma causes constriction of the pupil demanding more illumination. Rumney & Leat, 1990¹⁷ found that the most common dual condition was age-related macular degeneration and cataract.

2.3.1 Simultaneous impairment of vision and other functions

Many impairments of vision that occur early in life are accompanied by other handicaps with sensory deficits. Common examples are the simultaneous deficits of vision and audition which occur in Usher's syndrome (retinitis pigmentosa and hearing loss), in maternal rubella (congenital cataract, hearing loss and heart defect) and dominant juvenile optic atrophy.

When such multiple handicaps are present total disability is often more serious than the sum of the impairments would suggest. Deaf-blindness causes special problems because it affects both vision and

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hearing, the two sensory modalities that we use to get information from a distance and for communication, and either of which would usually partially compensate for the loss of the other. Thus, a deaf person who becomes partially sighted is far more disabled than a hearing person with a similar visual impairment, i.e. the visually impaired person cannot lip-read. (Hyvärinen, 1985¹⁸).

Mental retardation is also often associated with partial sight especially when the cause of bad vision is a metabolic disorder, a prenatal infection, or perinatal problems. It is a classical finding that the number of mentally retarded boys is larger than the number of mentally retarded girls: the same applies to a population of visually handicapped with mental retardation.

Visual impairment associated with impairments in other systems is particularly frequent in persons more than 65 years old in whom sensory and physical disorders as a consequence of aging become more prevalent. Many aged partially sighted persons do not even identify poor sight among their major problems, being overwhelmed by other disabilities. These include cardio-vascular, arthritic and neurologic (hand tremor, sequelae of cerebrovascular accidents). Hearing loss is also frequent.

2.4 Behavioural aspects of partial sight

Human beings are constantly involved in negotiations with their physical and social environments. Information is received by the senses: that information is then processed - it is given meaning through interpretation, organisation and classification. Finally, the individual expresses some behaviour in the form of words or actions as a response to the original stimulus - the information received by the senses. Clearly, the behaviour we express may then result in a further stimulus being presented to us, and the cycle of information processing moves forward once more. Anything which disturbs the information processing cycle will lead to difficulties in undertaking successful negotiations with our environments. Sight is the most important sense for acquiring information, therefore disturbance or disruption of the visual system will lead to negotiation difficulties.

People with partial sight receive distorted or disturbed visual pictures. This means that individuals have to make inferences about visual information. Incorrect inferences can lead to incorrect behavioural responses. The partially sighted person is thus constantly solving mysteries of visual perception. This process of inferring is fatiguing and consequently it is sometimes found that partially sighted people are less able to concentrate for long periods. Sometimes it is thought that they are lazy. In today's society there are a number of visually dependent tasks that are important in the common activities of daily living. These include:

- (a) orientation and mobility,
- (b) reading and writing,
- (c) observing human activity,
- (d) manipulative tasks, and
- (e) appreciation of visual aesthetics.

Inadequacies of visual field, visual acuity, contrast sensitivity, adaptation, colour vision, eye movement control and binocular coordination can each contribute to limiting an individual's ability to perform such visually-dependent activities.

Orientation and mobility involve becoming aware of the nature and location of major features in the immediate environment and being able to safely navigate while travelling purposefully from one place to another.

Reading and writing are important in modern society and for most individuals, even for private life (reading personal correspondence, financial documents, labels, price tags, telephone directories etc.). Optical devices can greatly enhance reading abilities of persons with low vision. Writing and typing can present special problems to the person with low vision.

Participating in society involves interactions with, and observation of, other human beings. Vision facilitates these interactions because it allows visual recognition, the reading of facial expressions, and the immediate appreciation of movement.

Vision often plays an important role in guiding manipulative tasks. In the lives of most people, important visually-guided tasks include the preparation and eating of food, performing household repairs and maintenance, repairing and maintaining clothing, and self-grooming. For other individuals, manipulative tasks can be an important part of their recreation or occupational activities. This could include sewing, knitting, carpentry, metalwork, mechanical assembly, etc. Vision is important in all of these tasks.

The appreciation of visual beauty necessarily becomes restricted when there is visual loss. Many judgements of relative beauty to the eye depend on appreciation of subtle differences in form, shading, colour, detail, or composition. With many kinds of visual impairment, the ability to appreciate the subtleties and distinctions that underlie judgement of beauty becomes diminished.

These diverse tasks depend variously on the several visual functions. For example Marron and Bailey, 1982¹⁹ have shown that visual field and contrast sensitivity are more important than visual acuity for mobility, which is enhanced by any residual vision, even if it is only light perception. Loss of low contrast sensitivity affects mobility in dim light and in rain (Hyvärinen et al, 1983^{20,21}). Reading depends chiefly on visual acuity, but can be made very difficult by strong concentric visual field narrowing or by paracentral visual field defects. Colour vision is an important factor in appreciation of beauty.

The behavioural problems associated with partial sight are not quantifiable quite as easily as testing visual acuity or visual field because we are considering a complex rather than a simple function. However, it may not be necessary to quantify problems, but rather to establish precisely what they are. Because the problems are unique to individuals, the solutions are also likely to be unique.

Factors in addition to partial sight can affect the behaviour of partially sighted people. These include age, associated non-visual handicaps, living conditions or occupations, age of onset of the visual loss, intelligence, mental orientation (the ability to recognise surroundings and their temporal or spatial relationship to oneself), education, motivation and training.

People who acquire a visual loss late in life may not perform well because of the lack of an ability to adapt to new situations. Other reasons for poor performance can include slower response rate, depression, lack of motivation, senility, illness, reaction to medication, organic brain damage from various causes and neurological or orthopaedic handicaps.

Partially sighted people can develop postural characteristics which may seem unacceptable to the normally sighted population. Such mannerisms as screwing up the eyes, holding the head on one side, not looking at an individual during conversation, always looking down when walking and so on. Other postural problems can be stooped shoulders caused by bending over visual material for prolonged periods. They arise when a partially sighted person has to read at a very short distance (especially with optical aids) and which can cause back and neck fatigue and pain. Particularly difficult are the cases of congenital nystagmus in which the subject has to adopt a head and eye posture that cause the nystagmus to reduce in magnitude. Remedies include: changes of reading position (periods of reading lying on a carpet reverses the bending-over of one's work); the use of a well conceived and well lighted reading stand (taking account of the reading habits and of the respective lengths of the relevant parts of the body: Gabriëls and Mélotte, 1982²²); practice of body movements (sport, ballet) and, of course, the use of magnifiers which allow a normal reading posture (fibrescope: Pelli et al, 1985²³). A more detailed account of aids to better seeing is given in sections 6, 7 & 8.

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3. RELATIONS BETWEEN LIGHTING LEVEL AND VISUAL FUNCTIONS

3.1 Introduction

This section is devoted to the relationships between the level of target luminance (or illuminance) and visual functions in partially sighted persons. The normal relationships between lighting level and certain visual functions are considered in the CIE TC 1-14 report "Lighting Effects on Vision", 1994¹ and aspects of it will be repeated when a comparison with the pathological data is necessary.

In literature, three different measures of task lighting conditions are commonly quoted: illuminance, luminance, and retinal illuminance. The first two are photometric quantities defined in the CIE Lighting Vocabulary, 1987² but brief descriptions are given here for the non-specialist. It should be noted that illumination is the process of lighting and is not a unit of measurement.

Illuminance is a measure of the lightflux arriving on a surface and is, therefore, independent of the nature of the surface but dependent upon the characteristics of the light source and the geometrical relationship between the source and the surface. Illuminance is the quotient of the luminous flux (measured in lumen) arriving on the surface and the area of the surface (m²). Illuminance (E) has the units of lumen per square metre (lm·m⁻²) or lux (lx). Planar illuminances are those most commonly used in practice although cylindrical and semi-cylindrical illuminances are important in some applications. Illuminances can be measured with illuminance or lux meters.

Luminance (sometimes called brightness, although this is not correct: brightness is the visual sensation, produced by the stimulus luminance) is a measure of the light emitted by, or reflected from, a surface in a given direction and, when reflected, is dependent upon the surface illuminance and the nature (reflectance characteristics) of the surface. Luminance (L) has the unit of the candela per square metre (cd·m⁻²). If a surface is a diffuse reflector (Lambert-surface) then illuminance and luminance are related by the reflectance r of the surface. In this case the luminance (in any direction) is E/π . In the case of non-diffusely reflecting surfaces the relationship is more complex and requires knowledge of the reflectance characteristics of the surface, as well as of the directions of light incidence and observation. Luminances can be measured using luminance meters.

The (real) **retinal illuminance** E_r , expressed in lux, depends upon the luminance (L) of the surface being observed, the transmittance (τ) of the optical media, the pupil area (ρ) (corrected for incidence angle), the distance (f) between the retina and the nodal point of the eye and the refractive index (η) of the vitreous body:

$$E_r = \frac{\tau \rho \eta^2}{f^2} L$$

It can be appreciated that many of the terms in the expression for E_r are difficult to determine and will vary from individual to individual (for example, τ is greatly age-dependent).

Physiologists use a (practical) retinal illuminance, expressed in trolands (Td), which is the product of field luminance (cd·m⁻²) and pupil area (mm²). Pupil area is determined from the measured pupil diameter. Note that the retinal illuminance depends not only upon the luminance but also on the observer's pupil area.

The photometric quantities referred to above are derived from the radiometric quantities irradiance (W·m⁻²) and radiance (W·sr⁻¹·m⁻²), using the CIE 1924 $V(\lambda)$ function. Theoretically, these should be used in preference to the photometric quantities, together with luminosity functions of the actual eye, because the photometric quantities ignore the individual effects of the eye. However, in ergonomic studies it is common, practical and often necessary to use luminance (because the observer's pupil size is unknown, etc.) or illuminances, provided that a satisfactory description is given of the task characteristics.

3.2 Refraction, accommodation and eye movements

Visual functions depend not only on the lighting level and on the eventual presence of media opacities and retina, optic nerve or brain lesions, but also on refraction by the ocular media, accommodation and extrinsic ocular movements. Indeed most visual functions cannot be optimal if the image of the external world on the retina is blurred or if this image is not scanned properly by means of the action of the extraocular muscles.

This is particularly important in partial sight because low vision is often associated with ametropia, defective accommodation, nystagmus and strabismus.

Ametropia is very frequent in partially sighted children not only because it is often a part of the causal disease (as hypermetropia in microphthalmos, myopia in many chorioretinal degenerations and astigmatism in albinism or in achromatopia), but also because emmetropisation cannot occur when vision is congenitally bad. As partial sight is much more frequent in old age, it must be remembered that the incidence of refractive errors of clinical significance will increase. At the age of 60 the incidence is about 60 percent.

Accommodation is absent in aphakia and could be weak in many cases of partial sight. Indeed, Lindstedt, 1986³ observed in visually impaired children that near visual acuity is often more reduced than distant visual acuity and she attributed this discrepancy to reduced accommodation. A child suffering from reduced vision might fail in detecting blur and lack the sensorimotor stimulation and feedback which should give rise to the development of accommodation accuracy. Accommodation has also been found defective in achromatopia, while Otto & Safra, 1979⁴ described failing accommodation in patients with central retinal affections. Accommodation is usually defective in the third age and thus in most cases of partial sight.

Failure of control over eye movements may be an added condition to existing visual defects. For example, in achromatopia there is not only nystagmus but also imprecision of pursuit eye movements (Yee et al, 1985⁵; Sharpe et al, 1986⁶). Eye movement control is also abnormal in subjects with maculopathies: 30 percent of them developing two or more preferred viewing loci for fixation (Whittaker & Cummings, 1986⁷). The oculomotor behaviour of persons with defects affecting only part of the visual field needs to be studied to identify eye movement strategies and adaptations that may help overcome the handicaps created by visual loss.

Let us now examine how the lighting level itself can influence refraction, accommodation and ocular movements in normal and pathological eyes.

The effect of astigmatism in reducing visual acuity increases with decreasing lighting level (Le Grand, 1952-56⁸) due, possibly, to pupil enlargement. Thus, the clinical use of low target luminances may be of advantage when measuring refractive error and the effects of its correction.

It is well known that as luminance drops to mesopic levels a reduction of the accommodation amplitude of the normal subject takes place by both approaching far point (twilight myopia) and by receding near point (twilight presbyopia) (Ronchi & Serra, 1978⁹, Ronchi & Serra, 1980¹⁰, Padmos & Vos, 1979¹¹) (see figure 3.1).

According to Hartmann¹², the time taken to effect 3 dioptries of accommodation is reduced from 1,3 s at 0,3 cd·m⁻² to 0,3 s at 30 cd·m⁻². However, Collins and Pruen (1962)¹³ did not find a change in the speed of accommodation between 10 and 300 lux, while Eng and Woo (1982)¹⁴ found that the strength of the necessary reading addition is not significantly affected by task luminances between 3,5 and 220 cd·m⁻². Luckiesh and Moss (1936)¹⁵ found the decrement in the amplitude of convergence due to reading for 1 hour under an illuminance of 1 footcandle (10,8 lux) to be three times as great as under 100 footcandle (1080 lux). In normal subjects fixation instability was found greater at 3 cd·m⁻² (Hebbard, 1969¹⁶).

Sharpe et al (1986)¹⁷ found that the pendular component of the spontaneous nystagmus of an achromat can disappear completely in darkness unless the subject tries to fixate on a remembered spot. However, above the optimal lighting level the eye movements increase while vision drops.

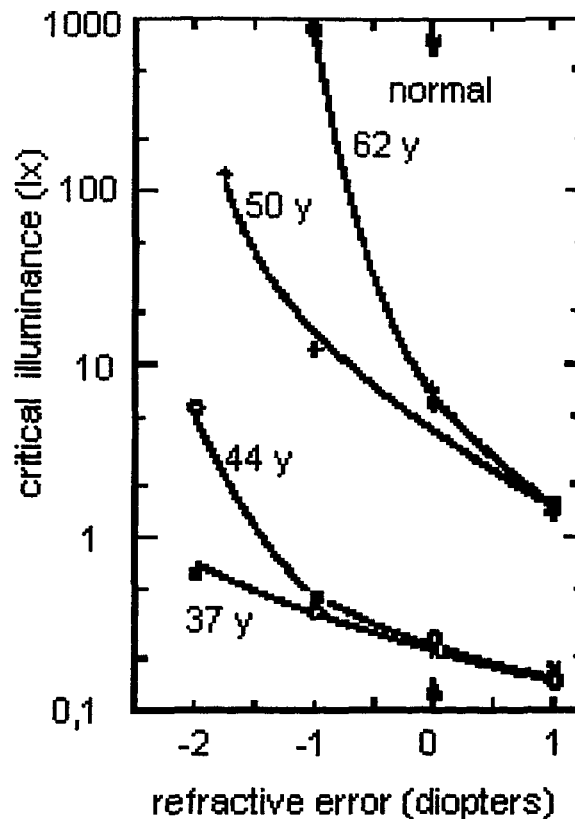


Figure 3.1.: Illuminances which are necessary for compensating refractive errors¹¹.

3.3 Visual acuity, ocular pathology and lighting levels

The following sections will discuss how and to what degree the lighting level influences specific visual functions, such as visual acuity, contrast sensitivity, visual field and colour vision. Other elementary visual functions, such as flicker fusion or depth perception, is not included as no data could be found on the influence of the lighting level in pathology.

Visual resolution is usually expressed in visual acuity, which is the reciprocal of the value in minutes of arc of the angular separation of two neighbouring objects which the eye can just see as separate. This report uses the decimal notation obtained by dividing the numerator by the denominator of a Snellen fraction (therefore, 6/12 equals 0,5). Some authors use the minimum angle of resolution (or MAR), which is the visual angle in minutes of arc subtended by the gap between two neighbouring objects and is thus the inverse of visual acuity, or even the decimal logarithm of the minimum angle of resolution (log MAR). Visual acuity for distance is generally measured by means of optotypes, such as, the Landolt ring. It is difficult to relate exactly the results of such measurements with those obtained in contrast sensitivity functions or by interference measures of resolution.

In the normal eye visual acuity is highest at the level of the fixation point in the visual field and thus at the level of the foveola in the retina. Accordingly, normal visual acuity refers to that at the fixation point and at the foveola when not specified otherwise.

The normal relation between lighting level and foveal visual acuity was chiefly studied by König, 1987¹⁸, Lythgoe, 1932¹⁹ and Hecht, 1928²⁰. This normal curve consists of a scotopic segment and a photopic segment, whereby the link between the two segments corresponds to a visual acuity of about 0,1. Within the photopic segment and over a wide range (to about 30 cd·m⁻²) the relationship between visual acuity and the logarithm of luminance is nearly linear.

Visual acuity continues to increase with luminance at least to beyond 1 200 $\text{cd}\cdot\text{m}^{-2}$.

Sloan, 1969²¹ showed that for eccentric locations in the normal visual field there is also a linear increase of visual acuity with the logarithm of luminance, but that the maximum acuity decreases with increasing eccentricity, while the rate of increase becomes smaller and the maximum acuity is reached at lower luminances (see figure 3.2).

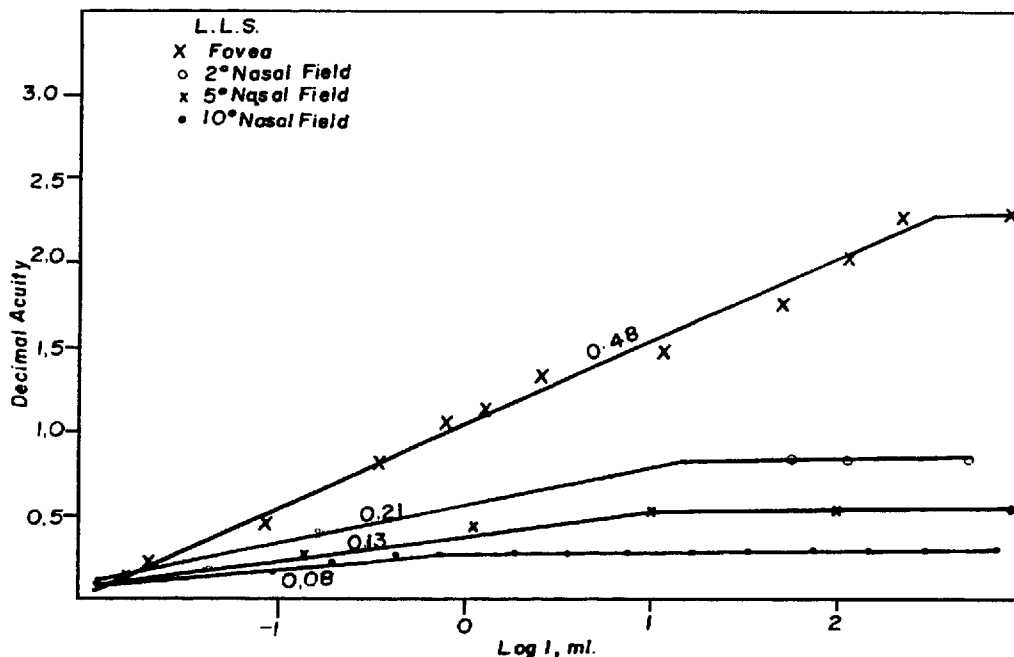


Figure 3.2: Variation of visual acuity with luminance for different retinal locations in a normal eye²¹.

In partial sight foveal visual acuity is typically reduced and fixation is then often shifted from the foveola to another point of the retina. In these conditions clinical visual acuity refers to the new (stable or unstable) fixation point.

Research on defective vision and the relationship between illumination and visual acuity has been conducted for more than 60 years. The earliest experiments were conducted by inducing refraction errors in normally sighted subjects by means of lenses. When Ferree & Rand, 1920²² produced artificial astigmatism in one eye of each subject and tested visual acuity under different illuminances, they found that astigmatic eyes required levels of illuminance up to 178 percent higher than the levels required by normal eyes. The more severe the defect and the greater the amount of correction required, the higher the illuminance that was needed to attain adequate acuity.

Hopkinson, 1949²³ obtained similar results when he compared the visual acuity of normally sighted subjects and those with refractive errors of acuity of 6/24 to 6/60 (0,25 to 0,1) at levels 0,1, 3 and 100 footcandles (1,1, 32 and 1080 lux). Whereas the acuity of subjects with defective vision continued to improve at higher levels of illumination, the acuity of subjects with normal vision did not. Moreover, the degree of improvement in the group with defective vision was the same between 3 and 100 footcandles (32 and 1080 lux) as it was between 0,1 to 3 footcandles (1,1 and 32 lux). Sloan, 1968²⁴ showed that the visual acuity response of a blurred foveal image to increasing luminance resembles that of a clearly focused eccentric image.

Strabismic amblyopia was also the object of early interest. Ammann, 1921²⁵ and Von Noorden and Burian, 1959²⁶ showed that in this condition visual acuity is not, or only minimally decreased, by the interposition of a 2-log neutral density filter, which always reduces visual acuity in normal subjects and greatly reduces visual acuity in optic nerve conduction defects, such as, neuritis retrobulbaris.

In an attempt to replicate Von Noorden's and Burian's results, Caloroso and Flom, 1969²⁷ used six luminance levels ranging from 0,001 to 100 footlambert (0,0034 $\text{cd}\cdot\text{m}^{-2}$ to 343

$\text{cd}\cdot\text{m}^{-2}$). Although the acuity of both the normal and amblyopic eye declined as luminance decreased, the normal eye exhibited a greater total reduction in acuity over four of the six ranges. Early interest was also devoted to achromatopia and other congenital functional abnormalities implying selective involvement of the rods and of the cones. Hirota, 1927²⁸, and other authors, including François et al, 1964²⁹, showed that the scotopic segment of the normally biphasic curve is missing in congenital night blindness, while the photopic segment is absent in congenital typical achromatopia. In fact, typical achromatopia is characterised by a decrease of acuity at higher lighting levels. Shimizu had shown in 1933³⁰, for two achromats, that when "squinting" (blinking and narrowing the eyes) was not permitted, acuity started to decrease at about 0,2 millilambert ($0,64 \text{ cd}\cdot\text{m}^{-2}$) and fell to 6/600 (0,01) or less at 7 millilambert ($22,3 \text{ cd}\cdot\text{m}^{-2}$).

Sloan and Feiock, 1972³¹ examined 6 subjects with typical achromatopia and also showed that visual acuity increases until an optimal lighting level is reached and then decreases. "Squinting" permitted maintenance of the maximum acuity at higher lighting levels (see figure 3.3). There were marked individual differences regarding the lighting level at which acuity starts to decrease (when "squinting" is not permitted). The decrease in acuity in bright light was less severe in patients who had either photopic rods or cones in the area used for fixation.

According to Young et al, 1982³² the retinal illuminance corresponding to optimal visual resolution in achromats is about 50 scotopic trolands.

Some authors have been anxious to state that the same relation between luminance and acuity occurs in cone degenerations as in achromatopia.

Zweifach and Wolf, 1968³³ claimed that improvement in acuity with reducing illuminance, as seen in congenital achromatopia, never occurs in cone dysfunction associated with optic nerve or macular disease, but these authors did not confirm their clinical observation by an acuity versus $\log L$ function. In fact, Jaeger and Krastel, 1980³⁴ observed increased visual acuity at lower lighting levels (as achromatopsia) in diffuse progressive cone degeneration, in macular progressive cone degeneration and in what they call "progressive receptor asthenopia" (acuity reduced to about 0,2 in the standard condition).

This was also stated by Schachar et al, 1973³⁵, who found in 4 cases of cone degeneration maximum visual acuity at luminances between 0,0 to 1,0 log millilambert (3,2 and $32 \text{ cd}\cdot\text{m}^{-2}$). All patients noticed a marked subjective improvement when using pilocarpine drops.

While the older papers always considered only one or a few diseases, there are more recent papers trying to survey the acuity-luminance relationship in the whole ocular pathology. So Sloan, 1969³⁶ and Sloan et al, 1973³⁷ demonstrated two kinds of variation of acuity with luminance in ocular pathology. The first kind is similar to the normal relation at peripheral locations in the normal eye (decreased maximal acuity, decreased slope, maximal acuity reached at lower luminances) and was observed in strabismic amblyopia, in optic atrophy and in cicatricial macular lesions. The second kind is characterized by the requirement of extremely high luminances to attain maximal acuities and was observed chiefly in eyes with active oedema or haemorrhage at the macula (as in disciform degeneration).

Silver, 1976³⁸ had an impression that the highest illuminances were required by the diabetics who had haemorrhaged into the vitreous, and by the macular degeneration group, particularly the elderly. Many retinitis pigmentosas required a lot of light, but a few required among the lowest levels recorded.

Lie, 1977³⁹ studied a few cases of several diseases. He found in 4 of 5 subjects, who had retinitis pigmentosa, a strong increase of visual acuity with increasing illuminance, while in two cases of albinism visual acuity varied little with changes in illuminance (Schultz had observed, in 1960⁴⁰, in albinism a decrease of visual acuity at higher lighting levels).

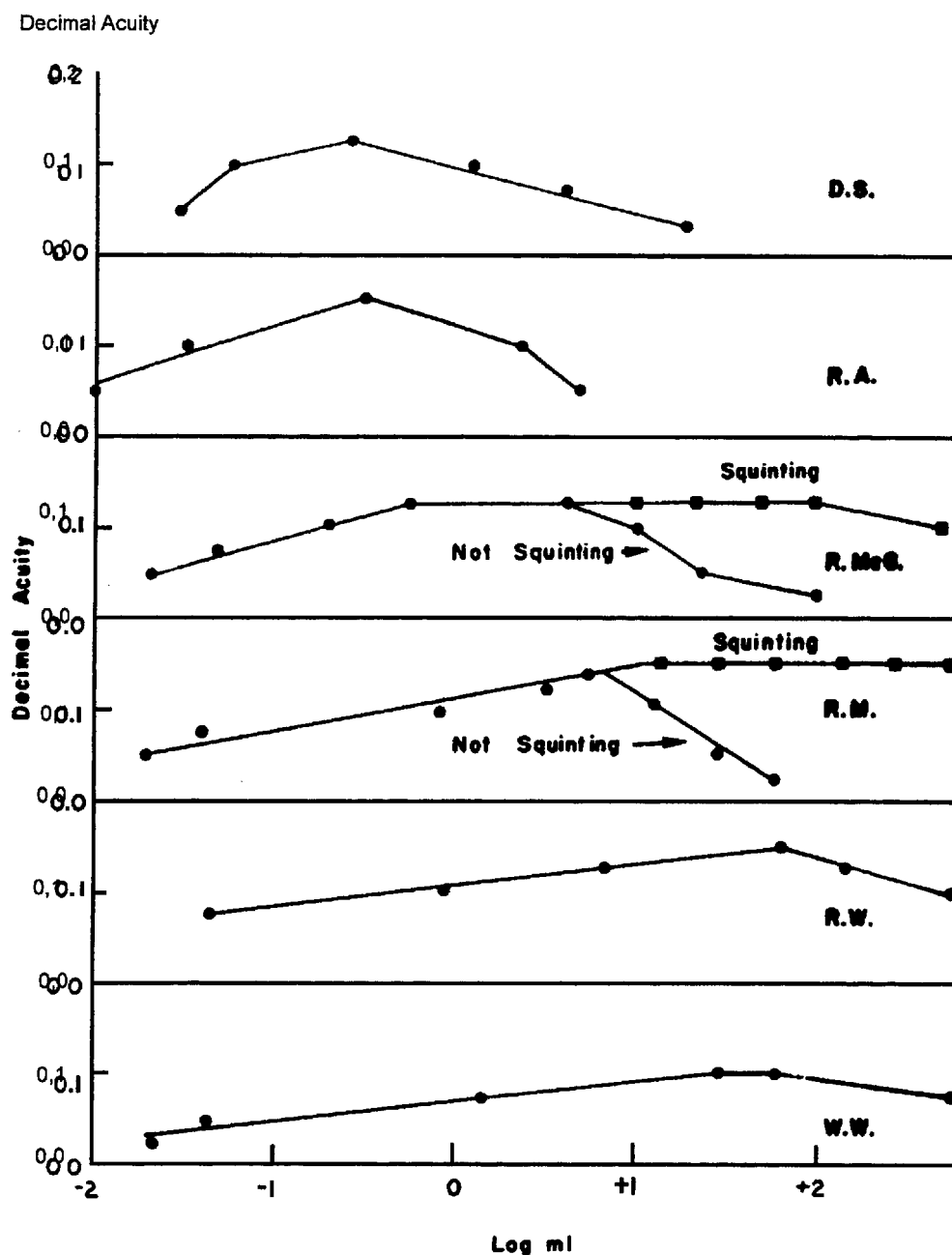


Figure 3.3.: Variation of visual acuity with luminance in subjects with typical achromatopsia³¹.

Hartmann et al, 1980⁴¹ examined many cases and stated that very high (il)luminances are necessary for obtaining maximal visual acuity in age-related macular degeneration, myopia and glaucoma. Conversely, patients suffering from astigmatism, cataract and juvenile macular degeneration had maximal acuity at low lighting levels. The results were unclear in some diseases including aphakia, aniridia, lens luxation and chorioretinitis (see figure 3.4).

Some very recent Australian papers concern specifically age-related macular degeneration. The subjects of Brown and Lovie-Kitchin, 1983⁴² suffering from that disease showed a normal increase of acuity with luminance, although their acuities are depressed. There is greater variability in the group than among the normals, with some extremely flat functions (showing almost no effect of luminance on acuity) and some functions with a discontinuity at 3,5 cd·m⁻² to an extremely steep function at higher luminances. In a study of patients with age-related macular degeneration by Bailey and Lovie, 1976⁴³, 6 of the 16

subjects showed improved distance visual acuity with higher than normal illumination levels. However, other patients showed a marked drop in performance at high levels of illumination, preferring to function at low levels.

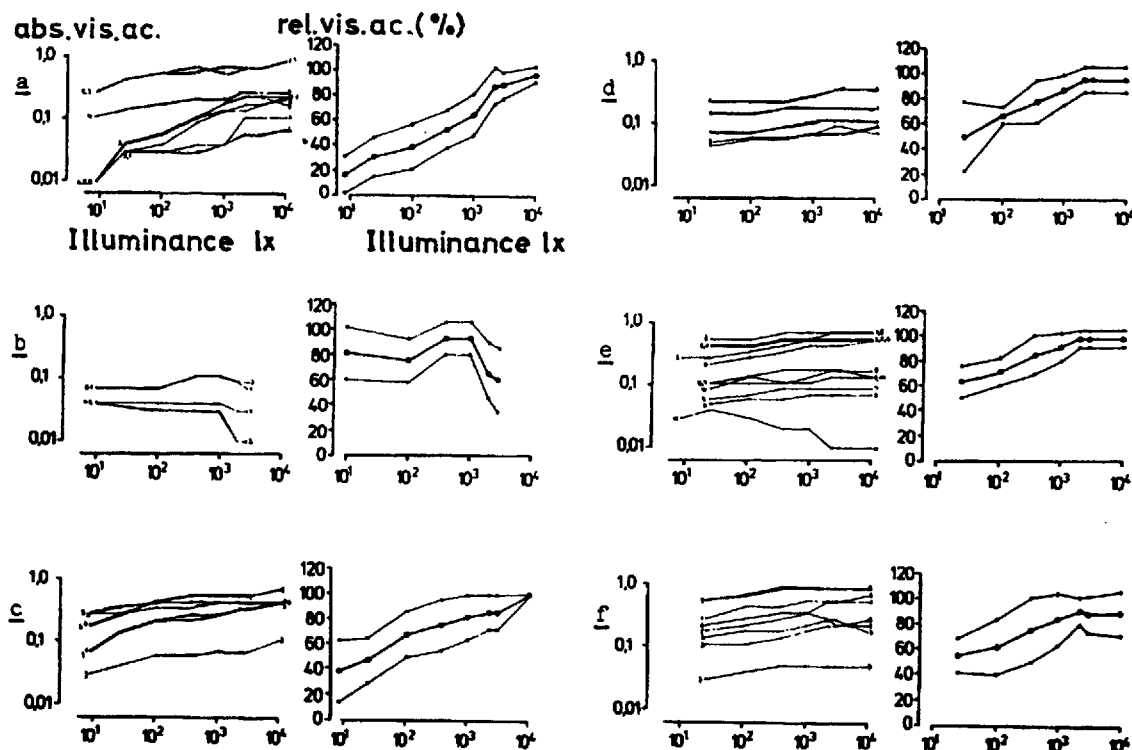


Figure 3.4. Variation of absolute and relative visual acuity with task illuminance in age-related macular degeneration (a), juvenile macular degeneration (b), chronic glaucoma (c), juvenile glaucoma (d), optic atrophy (e) and nystagmus (f)⁴¹.

Finally, Brown et al, 1984⁴⁴ showed that in age-related macular degeneration peripheral visual acuity (at 1°, 2°, 4° and 8°) for given background luminances is lower than normal.

Jacobsen et al, 1984⁴⁵ stated that in an infant with oculocutaneous albinism at certain ages visual acuity (measured by means of a preferential looking technique) was better than later in life, but was reduced when testing was performed with higher luminance targets.

Earlier in this section we stated that the difficulty with establishing the performance of the partially sighted, as a group, is the large individual differences that result within any sample and the differences between any sample and the whole population. The same applies within most subgroups, for example, people with age-related macular degeneration, where individual differences can make generalization difficult. To a large extent the study of the partially sighted must be the study of the individual.

3.4 Contrast sensitivity

The influence of lighting level on contrast sensitivity is well known in the CIE from Blackwell's, 1981⁴⁶ visual performance system.

The clinical investigation of contrast sensitivity now includes the spatial contrast sensitivity function. This is obtained by plotting horizontally the spatial frequency (reciprocal of spatial distance) and vertically the contrast sensitivity (expressed as threshold modulation depth). The effect of (mean) luminance on the spatial contrast sensitivity function can be easily studied by the interposition of neutral density filters in every case and by changing the

illuminance of a chart test.

According to Hyvärinen et al, 1981⁴⁷ and de Mattiello et al, 1984⁴⁸ such a decrease of the lighting level (and thus of the mean luminance) causes, in normal subjects, a narrowing of the contrast sensitivity function and a shift of its maximum towards the lower frequencies. De Mattiello obtained the same results by lowering visual acuity by means of positive lenses and predicted that the high spatial frequencies will also be the first to be degraded under such conditions as poor illumination, movement and viewing at greater distance.

On the other hand Hache, 1986 (pers.comm.) predicted that contrast sensitivity should improve at lower luminance levels in evolving retinal disease (because all photoreceptors of the concerned retinal area are then affected), while contrast sensitivity should improve at higher luminance levels in cicatricial retinal disease (because a part of the photoreceptors is inactive).

Brown et al, 1984⁴⁹ wrote that symptoms reported by patients with age related macular degeneration can be attributed to reduction of contrast sensitivity at low luminance levels. Concerning the opacities of the ocular media and according to Van den Berg, 1986⁵⁰ retinal illuminance in the area of interest does not change because of increased light scatter: If the mean luminance is about constant over the whole visual field, including the area of interest, as much light is scattered towards that area as is scattered away from that area. So only the modulation depth changes, not the retinal illuminance. As a result the whole spatial transfer function drops.

Although easy to undertake, there have been until recently few actual observations on the influence of lighting level on contrast sensitivity in partially sighted subjects. Hyvärinen et al, 1981⁴⁷ observed in retinitis pigmentosa patients that a 1 log decrease in luminance depressed the contrast sensitivity function much more than normally (see figure 3.5).

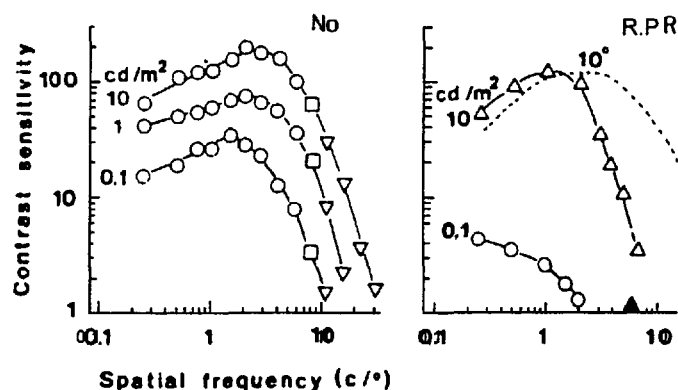


Figure 3.5. Effect of mean luminance on contrast sensitivity as a function of spatial frequency in a normal subject (left) and in a retinitis pigmentosa patient who had total loss of peripheral field but satisfactory photopic vision in the central field (right, the dashed curve is the corresponding normal contrast sensitivity function)⁴⁷.

Hyvärinen (pers.comm.) has also observed that dependence of contrast sensitivity on luminance is increased in persons affected by night blindness and by disability glare, so that they often suffer from marked loss of contrast sensitivity. She adds that the effect of different absorptive spectacles on contrast sensitivity should be assessed during clinical examination of each visually impaired person.

Julian, 1983a⁵¹ measured contrast sensitivity in a partially sighted group using the George Young Threshold Test. This test showed that the partially sighted had a significant but modest improvement in contrast sensitivity with increasing task illuminance and that 90 percent RVP (relative visual performance) was achieved at about 400 lux. Those subgroups with macular defects showed the greatest dependence upon task illuminance with 90 percent RVP being achieved at 1 000 lux. Those with cataracts achieved 90 percent RVP at 150 lux while those without central vision defects (such as glaucoma) achieved the same performance

as a normally sighted control group. According to Lindner et al, 1987⁵² contrast sensitivity can be substantially improved with increasing illuminance, in particular for cataract patients, with maximum figures around 1 000 lux. This tendency also prevailed after surgery.

3.5 Visual fields

The visual field can be defined as the angular extent of the space in which a target can be perceived when the body and the eye (or eyes) are at rest. The field may be monocular or binocular.

When a large target, which contrasts well with its background, is used for the determination of the visual field, one obtains the greatest possible extent and for many people this is the concept of visual field. It is, however, possible to determine the extent of the visual field for smaller and/or less contrasting targets. The smaller or less contrasting the target the smaller will be the extent of the visual field. Moreover by comparing in the same visual field the perception of several well chosen targets, at different eccentricities from the centre, it will be possible to evaluate the variation of the threshold sensitivity within the field. This brings a second meaning of the visual field concept namely an evaluation of sensitivity changes within the whole field of vision.

Before considering pathology, it must be understood that the sensitivities within the normal visual field change greatly according to the adaptation state: in diurnal (photopic) conditions sensitivity is maximal in the foveal fixation point and decreases steeply and regularly towards the periphery, while in nocturnal (scotopic) conditions sensitivity is low in the centre of the visual field (central scotoma in darkness due to the absence of rods in the fovea) while the peripheral parts of the visual field are more sensitive. Since the distribution of sensitivities within the normal visual field changes markedly with the lighting level, we can understand the influence of the lighting level on the visual field of pathological eyes only if we refer to the normal result for each condition.

It has been known since the end of the 19th century that, in retinitis pigmentosa and in other diseases of the epigmentosa group (choroideremia, retinitis punctata albescens), reduction of illuminance causes a further concentric narrowing of the visual field. It was also stated that glaucomatous field defects are more obvious in mesopic conditions than in photopic ones.

In a series of early papers (summarized in François and Verriest, 1956⁵³) Verriest showed by comparison of photopic and scotopic tangent screen measurements, that the extent of the visual field defects is greater in scotopic vision in most chorioretinal degenerations, angioid streaks, age-related macular degeneration, retinal detachment (even after healing), hypertensive retinitis, diabetic retinitis, vascular occlusions, disc oedema, and central serous chorioretinitis (see figure 3.6). François et al (1956)⁵⁴ described for the first time juvenile macular degeneration as cone dysfunction by evidencing, by means of the same technique that the visual field is less affected in scotopic conditions than in photopic conditions.

By using a neutral density filter absorbing about 75 percent of the incident light, Krastel et al, 1981⁵⁵ showed that reduced illumination reveals more distinctly the characteristic visual field defects in tapetoretinal degeneration, chiasmal compression, glaucoma and retrobulbar neuritis. Conversely, the visual field is increased in achromatopia. Jaeger and Krastel, 1980⁵⁶ described an enlargement of the concentrically narrowed visual field in a case of "progressive receptor asthenopia" by interposition of a neutral filter.

Young et al, 1983⁵⁷ found that 8 out of 9 patients with congenital achromatopia showed substantially larger visual field size when wearing absorptive lenses.

Lie, 1977³⁹ supposed that, in advanced retinitis pigmentosa and in other conditions with tubular visual fields, the visual field contraction is the critical factor in the observed strong dependence of visual acuity on illuminance.

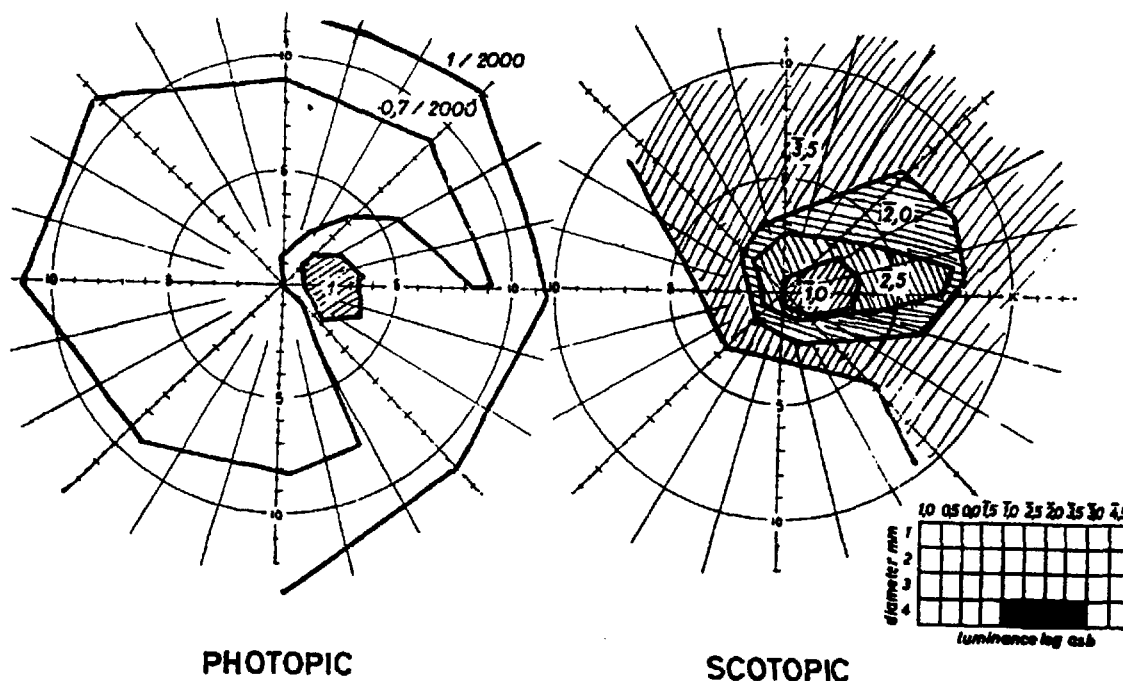


Figure 3.6.: Photopic and scotopic visual fields in the same eye suffering from beginning age-related macular degeneration⁵⁴.

3.6 Colour vision

In a normal subject colour vision undergoes only minimal changes within a wide range of photopic lighting levels. However at very high luminances blue and blue-green hues tend to appear bluer, while yellow-green, yellow, and red hues tend to appear yellower, leading to a relative RG defect. On the other hand at very low luminances blue-green, green and yellow-green hues tend to appear greener, while oranges and reds tend to appear redder, leading to a relative BY defect (so-called Bezold-Brücke effect, see Purdy, 1937⁵⁸). The luminance level beneath which the BY defect appears is at the limit between photopic and mesopic vision and corresponds to $3 \text{ cd}\cdot\text{m}^{-2}$ according to Grigorovici and Aricescu-Savopol, 1958⁵⁹ and to about $1 \text{ cd}\cdot\text{m}^{-2}$ according to the statements made by means of clinical colour vision tests by Verriest et al, 1963⁶⁰. When luminance is further reduced colour vision becomes wholly tritanopic before it disappears when scotopic vision is reached at about $0,002 \text{ cd}\cdot\text{m}^{-2}$.

Ohta, 1957⁶¹ was the first to describe that a moderate reduction of the level of retinal illuminance creates a BY defect in subjects suffering from retinitis pigmentosa. This was also observed by Verriest, 1963⁶² in choroideremia (a disease of the retinitis pigmentosa group), by Ourgaud et al, 1972⁶³ and others in glaucoma, and by Bowman, 1978⁶⁴ and Bowman and Cameron, 1984⁶⁵ in age-related macular degeneration (see figure 3.7).

Bowman showed that in age-related macular degeneration no further significant improvement in colour discrimination occurs above a given level of retinal illuminance. Julian, 1983⁶⁶ observed cases of macular degeneration in which increasing luminance led to no improvement of colour vision.

Aarnisalo, 1980⁶⁷ stated that reduction of illuminance deteriorates colour discrimination more in congenitally red-green defectives than in normal subjects, with scotopic patterns being observed at higher illuminance levels in the defectives. Conversely, the ability to discriminate wavelength differences deteriorates as illuminance increases in blue cone monochromats, but not in red cone monochromats (see Young and Price, 1985⁶⁸).

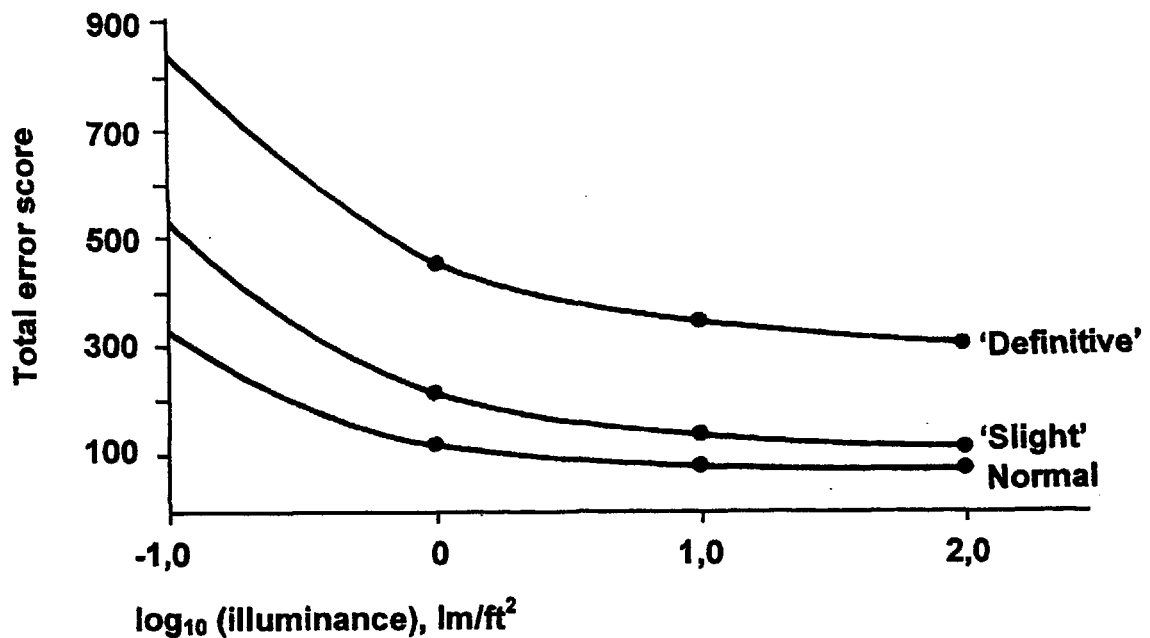


Figure 3.7.: Mean total error scores at the Farnsworth-Munsell colour vision test as a function of illuminance in normal, 'light' and 'definitive' age-related macular degeneration groups⁶⁴.

Ourgaud and Etienne, 1961⁶⁹ and Verriest, 1964⁷⁰ considered that the BY defect observed in the photopic condition in retinal diseases could be due to an increase of the thresholds for photopic vision so that the BY colour vision defect should be simply the physiological mesopic defect ("mesopization"). However, Bowman, 1978⁷¹ showed that this explanation does not hold in age-related macular degeneration as the curve giving the relation between illuminance and the 100 hue score is shifted not only horizontally but also vertically. Aarnisalo (1980)⁷² supposed that in congenital RG defectiveness the BY opponent colour mechanism should be weakened by a lack of antagonism from the RG colour mechanism.

3.7 Lighting levels and visual performance at practical tasks

As shown by Muck and Bodmann, 1961⁷³ for fully sighted subjects the determination of the (il)luminance levels corresponding to optimal work conditions can be made by means of three different methods:

- a direct method which measures the performance for given practical tasks under different well chosen (il)luminance levels (e.g., Weston, 1935⁷⁴);
- an indirect method in which the optimal lighting level is calculated from the relation between the luminance and an elementary visual function, such as contrast sensitivity (Blackwell, 1981⁴⁶), or estimated from a visibility level (Luckiesh and Moss, 1935⁷⁵); and
- a subjective method in which the preferred (il)luminance level is determined for a given task in a given site.

The three methods are complementary but the first has to be preferred, especially in the study of low vision. Relationships between lighting and visual performance for partially sighted people have been examined by various authors and their studies are reviewed in the ensuing sections.

3.7.1 Reading

Reading by normal subjects depends not only on near visual acuity, but also on control of eye saccades, foveal and parafoveal word recognition, and the integration of information across saccades. The actual perceiving takes place during the eye fixation pauses. These last approximately 200-400 ms. The amount seen during such a fixation pause is called the functional reading span. This is typically 18 character widths centred around the fixation point in the visual field, over a wide range of print sizes according to Rayner, 1975⁷⁶. The performance trend for fully sighted people is that speed of reading increases rapidly with increase in luminance level, until a point is reached where only very small further increases in speed result from standard increases in luminances. According to Luckiesh and Moss, 1936¹⁵ lower reading speed and greater fatigue at lower levels of illumination results from a larger number of fixational pauses. Legge et al, 1985⁷⁷ found that normally reading rate increases with field size only up to 4 characters. Research also indicates that reading with high contrast (such as is provided by 6 to 12 point black type on suitable white book stock) has adequate visibility at relatively low illuminance levels, while tasks with poor contrast, such as badly reproduced material, need higher levels (Kaufman, 1981⁷⁸).

It must be realised that for eyes affected by different pathologies reading ability is less well predicted by standard visual acuity tests involving the recognition of single optotypes, compared to tests in which the patient reads lines of printed text, such as Sloan's, 1977⁷⁹ M acuity test, or, still better, Bailey and Lovie's, 1976⁸⁰ reading chart consisting of rows of unrelated words that follow a systematic size progression (the words are unrelated to eliminate context as a contributor to reading efficiency). Visual field defects affect reading performance, sometimes in unpredictable ways. In every way, people with central field loss still read significantly more slowly than normally sighted subjects, independent of the lighting condition (Lehon, 1976)⁸¹. This is due either to unique incapacities of central vision, or to inadequate eye-movement control; in every way more time is expended trying to visualize and process the information. Sloan et al, 1973⁸² observed that there are many patients with macular disease in whom high illumination produced an increased inability to read continuous text, or who needed a weaker magnifier than that required in moderate illumination.

Hartmann, Scheffzyk-Hagl and Lachenmayr, 1980⁸³ found 4 optimal ranges while testing the reading performance of 113 partially sighted at different illuminances:

- group 1 requests illuminance values of >10 000 lux (high myopia without choroidosis, age-related macular degeneration, glaucoma);
- group 2 requests from 2 000 to 10 000 lux (high myopia with choroidosis, nystagmus, optic atrophy);
- group 3 requests from 380 to 2 000 lux (astigmatism, age-related cataract, corneal diseases, juvenile macular degeneration, tapetoretinal degeneration, diabetic retinopathy), while
- group 4 is indifferent to illuminance level (aphakia, congenital cataract, aniridia, lens luxation and chorioretinitis).

Pelling, 1980,⁸⁴ figure 3.8 observed that in a large number of partially sighted school children the performance trend was the same as that in fully sighted people with the speed of reading increasing rapidly with increasing luminance, until a point is reached where only very small further increases in speed occur. Subjects with cone dysfunction syndrome, however, showed a rapid fall of reading speed with increase in luminance level, and gave best performance at levels of luminance approaching that given by moonlight. Most subjects with aniridia followed the general trend of increase in reading speed with increase in luminance level, but only up to a certain point. Some subjects appear to fit into a fourth group which is mixed with respect to eye condition. The children in this group showed a remarkable ability to continue to increase reading speed with increase in luminance up to, and probably beyond, the maximum luminance level tested (500 cd-m⁻²). The main finding of Pelling's experiment was that, although the luminance requirements of the majority of partially sighted school children (that is, aphakes) were similar to those of fully sighted children, their illuminance

requirements are much higher. This is due mainly to shadowing of light by the head and hands.

Kitchin, 1981⁸⁵ found in age-related macular degeneration big inter-individual differences: in her subject L there was no improvement in word reading acuity above 100 $\text{cd}\cdot\text{m}^{-2}$, while in subject T peak acuity had not been reached even at 3 000 $\text{cd}\cdot\text{m}^{-2}$.

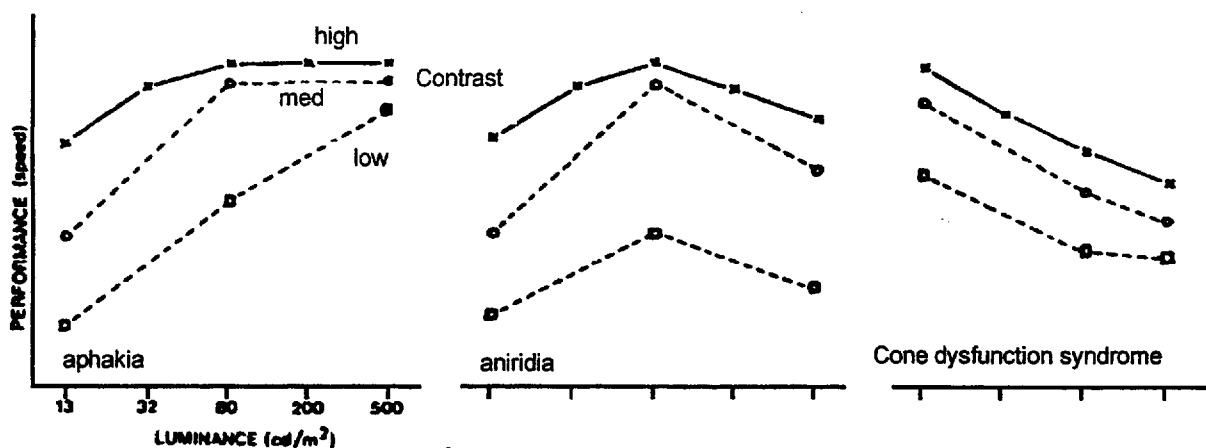


Figure 3.8.: Response in speed of reading to change in luminance and print contrast for three partially sighted children. Task contrast: high = 90 %, medium = 70 %, low = 50 %⁸⁴.

Stone and Gazely, 1981⁸⁶ studied the performance of 32 partially sighted school children using a back-lit transparency rather than a directly-lit paper task. This was done to avoid the problems of head and body positions interfering with the lighting conditions. Task luminances up to 80 $\text{cd}\cdot\text{m}^{-2}$ improved reading speeds significantly but further increments up to 500 $\text{cd}\cdot\text{m}^{-2}$ produced no significant advantages. The suggestion is that if light reaches the eyes, the illuminance requirements for many partially sighted children will be satisfied by illuminances for fully-sighted children. In practice, however, more light will be required for near tasks because of head shadowing and large individual differences in eye conditions.

Julian, 1983⁶⁶, 1984⁸⁷ found in a group of 27 partially sighted in real situations that an increase of illuminance from 50 to 1 800 lux improved the reading performance from 58 percent to 100 percent. He recommended 600 lux as a minimum and 1 000 lux for patients with macular degeneration and retinitis pigmentosa. Bullak, 1984⁸⁸ tested the near acuity of 30 partially sighted in combination with magnifier (2,5 x) and lighting. She noted big effects at illuminance values up to 4 000 lux for patients with myopia, retinitis and nystagmus. The effect was small in optic atrophy.

Aberson, 1984⁸⁹ investigated reading speed at three illumination levels (40, 400 and 4 000 lux) and stated that reading speed is optimal with the intermediate level of 400 lux for older people with both normal and low vision though the differences were small.

Southall, 1984⁹⁰ found that variation of task luminance from 13 to 500 $\text{cd}\cdot\text{m}^{-2}$ had no significant effect upon the reading times of a fully sighted group while significant effects were obtained for a partially sighted group. Group reading times were reduced significantly as luminance was raised from 13 to 80 and 80 to 200 $\text{cd}\cdot\text{m}^{-2}$ ($p < 0,01$ and $p < 0,05$). The further increase in luminance from 200 to 500 $\text{cd}\cdot\text{m}^{-2}$ failed to produce a significant effect upon mean reading times (see figure 3.9). Contrast was also found to have a significant effect on performance, especially under low luminance conditions.

3.7.2 Visual display screens

It is well known that reading visual display screens is easier when the luminance of the background of the screen is not very different from that of the surrounding scene.

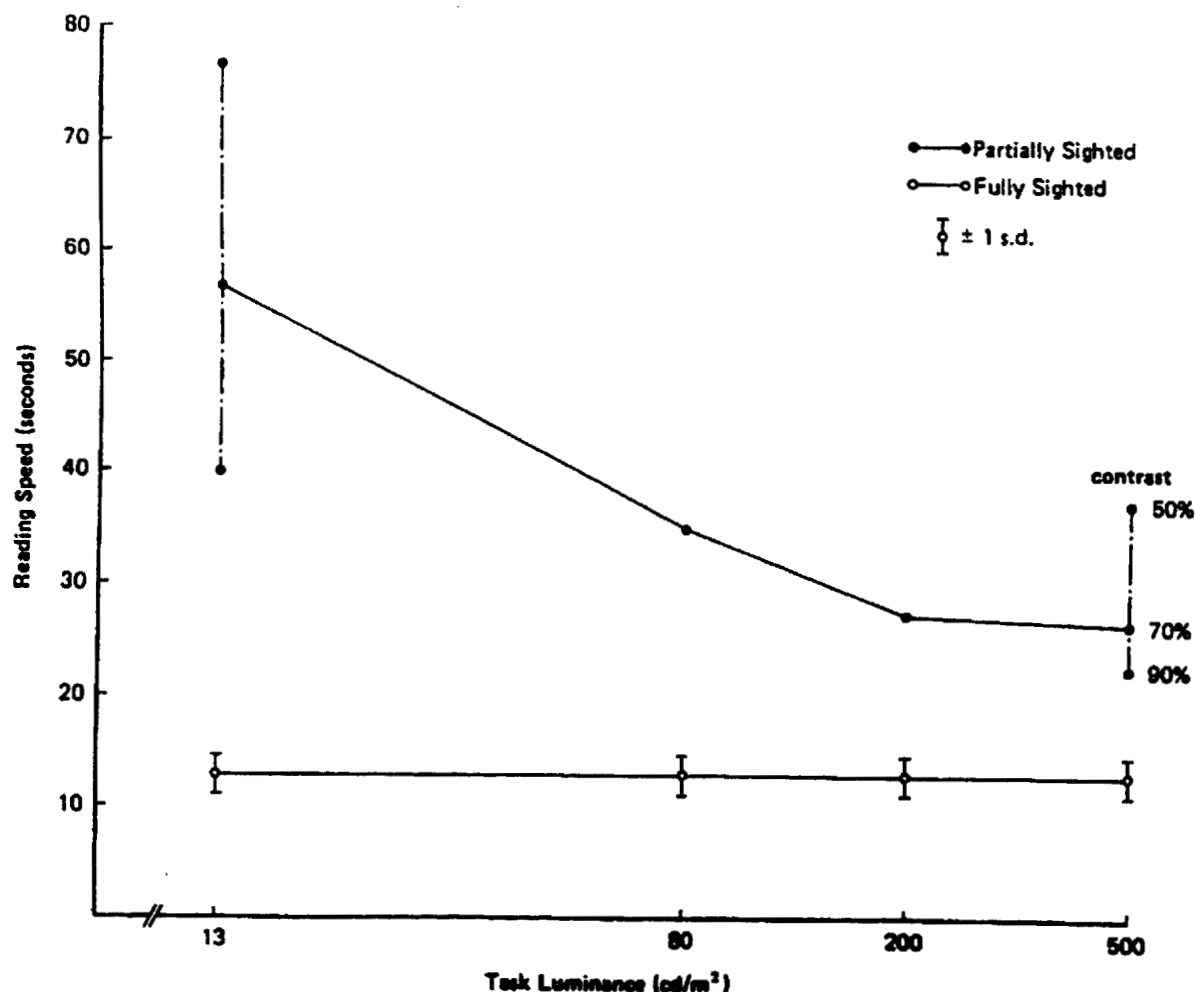


Figure 3.9. Mean reading time per passage (reading speed) as a function of luminance (solid line) and contrast (broken line). Standard deviation bars are shown for the full sighted group only⁹⁰.

Legge et al, 1985⁹¹ found that contrast polarity (black-on-white vs white-on-black text) has no effect on reading rate of normal subjects. Conversely, the partially sighted observers with cloudy media read better when white letters appear on a black background than vice versa. The magnitude of the effect varies across the range of legible character sizes, but peak reading rates for white-on-black text are 10 to 50 % greater than peak rates for black-on-white text. The observers with clear media show little difference in reading rate for the two contrast conditions, except for letters near their acuity limits (Legge et al., 1986⁹²).

3.7.3 Miscellaneous work tasks

Before the second World War, several researchers investigated the effects of illumination on the productivity of workers with defective vision in actual work situations. Thomson et al, 1924⁹³ compared the efficiency of 6 partially sighted persons ($V = 1,0$ to $0,5$) sorting cards in a post office with that of 6 normally sighted. To achieve the same performance the partially sighted persons needed a 75 percent higher illuminance.

White et al, 1928⁹⁴ reported the efficiency of 9 partially sighted ($V = 0,9$ to $0,55$) compared with 9 normally sighted. The task was letter sorting in a post office. Although the partially sighted subjectively requested higher illuminances their efficiency decreased at increasing illuminance. Luckiesh and Moss, 1936¹⁵ could demonstrate for partially sighted industrial workers that their efficiency increase is highest in the lower range of illuminance. The difference in efficiency between partially and normally sighted was 12 percent when the illuminance was increased from 30 to 120 lux, whereas an increase from 240 to 480 lux showed a difference in efficiency of only 1 percent.

Performance for visual tasks implying concentration or mental calculation increases at higher illuminance levels, although reaction time is shortest at medium levels (400 lux): Lindner et al, 1985⁹⁵.

The principal short coming of an indirect method (see section 3.7) is that it does not take into account the complexity of factors that make for visual efficiency in practical tasks. This efficiency depends not only on elementary visual functions, such as visual acuity or contrast sensitivity, but also on other physiological properties, such as eye movement patterns and binocular coordination, and moreover on many psychological factors, such as motivation, vigilance, directed attention, use of environmental cues etc. It is for such reasons that the common clinical measures of visual functions, such as visual acuity and contrast sensitivity are poor predictors of performance of everyday tasks as reading or face recognition, and it is for the same reasons that performance of even the most highly motivated observer will decline in time if the situation is such as to involve brief, or near threshold, or irregularly occurring, or infrequent signals with no feedback to the observer regarding performance (Ronchi & Serra, 1984⁹⁶). Conditions which are optimal for a task of limited duration are not necessarily always beneficial: for example, while a very high level of illumination may increase visual function for a short task, that same level may result in decreased performance because of eyestrain or glare discomfort if used for hours at a time.

Blackwell's, 1981⁴ system does not take into account the fact that many practical tasks with a motor component depend less on (il)luminance than purely visual tasks (Hentschel, 1971⁹⁷; Lindner, 1977⁹⁸). Moreover, Blackwell's relative contrast sensitivity function leads to the belief that the visual performance of a normal subject increases asymptotically with increasing task luminance. In reality an excess of illumination beyond a certain high level may actually produce a deterioration of performance by glare, fatigue phenomena and dioptric factors. In addition, the system does not appreciate that for any visual task, for any individual, there is a range of illumination levels that will allow optimal performance.

The indirect method based on visibility levels is even more artificial than that based on the contrast sensitivity function because the scale of suprathreshold visibility is arbitrary even when threshold contrast has been actually measured for the same scene by means of a visibility-meter. On the other hand, drawbacks of the subjective assessment of preferred (il)luminance levels are that the subject's choice is not always the same as the experimentally determined level for optimal vision (Sloot-Smits et al, 1967⁹⁹) and, moreover, that the results depend on previous adaptation and on adaptation time.

Luckiesh and Moss (1936)¹⁵ found that the visibility of specific tasks (not described) for the considerably partially sighted improved more than for normally sighted with increasing illuminance. The same authors observed for 73 partially sighted children that an increase of the visibility level from 18-point type to 24-point type can be reached for the partially sighted with a 25 percent higher illuminance value than for normally sighted.

Luckiesh and Eastman demonstrated that for achieving an improved (unqualified) visibility 4 persons with a visual acuity of 0,5 needed an illuminance of 300 lux, whereas persons having a visual acuity of 0,25 needed 730 lux. For recognizing 7-point type persons with a visual acuity of 1,0 needed 20 lux, persons with a visual acuity of 0,5 needed 200 lux and persons with a visual acuity of 0,25 needed 1 200 lux.

3.7.4 Preferred lighting levels

An early paper dealing with preferred (il)luminance levels for the partially sighted is that of

Sloot-Smiths et al, 1967⁹⁹. For children with lesions of the refractive media, 7 of the 8 aphakic children asked for more light, which can probably be explained by the small post-cataract opening, compared with the normal pupil. Two of the three children with aniridia asked for less light, the third for more, probably because of opacities due to a central cataract which was also present. The children with fundus lesions, those with optic nerve atrophy and with achromatopsia asked for a dim light, even when the condition was accompanied by some cataractous opacities. Two of the 3 ocular and 3 of the 5 generalized albinos asked for more light, as long as this did not shine directly into their eyes.

Steiner, 1969¹⁰⁰ recorded that individuals with myopia, esophoria and optic atrophy preferred illumination higher than IES-NA, 1959¹⁰¹ standards (30 footcandles, about 322 lux), while subjects with congenital cataract and chorioretinitis preferred levels lower than IES standards. Lehon, 1976¹⁰² compared visually impaired adults (acuity 0,1 or less) with fully sighted adults (1,0 or better). Subjects were instructed to select their own preferred illuminance for an oral reading task. Lehon found that the impaired group selected a median illuminance of 1 802 lux whereas the normals chose a median of 1 038 lux. However, the range of light levels selected by the impaired group was larger than that of the normal group. The fully sighted subjects selected illuminances ranging from 323 to 5 918 lux whereas the reduced vision group selected illuminances ranging from 161 to 8 070 lux.

Zhokov et al, 1976¹⁰³ found that patients with high myopia required 500 to 1 000 lux for short-distance tasks (Landolt rings), while patients with opacities of the cornea, cataract and atrophy of the optic nerve required 100 to 500 lux. Examining 16 patients Lie, 1977³⁹ noted a big difference in the preferred illuminance level between the patients in each group of disease.

Julian, 1983¹⁰⁴ stated that subjects with macular defects or lens opacities experienced improvement of visibility with increasing lighting of various visual tasks (telephone dial, clock, facial detail, picture on a wall), while restricted field subjects did not perceive improvements.

Southall, 1984¹⁰⁵ stated that the partially sighted often choose luminances higher than those corresponding to best performance.

Barca et al, 1986¹⁰⁶ showed that (healed) disease of the anterior segment decreases the preferred illuminance level, while diabetes (without any ocular involvement) increases that level.

Lindner et al, 1987¹⁰⁷ examined the subjective lighting requirements for reading by 75 patients with cataract and 50 patients with glaucoma of different causes. The patients with cataract felt comfortable at illuminances between 600 and 1 050 lux, and those with glaucoma at values between 600 and 750 lux. After lens extraction the lighting requirements of patients with aphakia were less. For relaxation lighting (living-room in the evening) patients with cataract selected values ranging to 200 lux, patients with glaucoma values ranging to 1 000 lux.

3.8 Summary

We could summarize the whole of this section by stating that the range of the individual (il)luminance levels corresponding to best vision is, for every parameter of vision, much wider among a population of partially sighted persons than among a normal population. Moreover, the pathological distribution is always bimodal as we always find, on the one hand light lovers, in whom vision becomes better at levels which normally give no further improvement, and on the other light haters, who see better at low illuminances and for whom ordinary lighting levels are uncomfortable and even disabling. As there are more light lovers than light haters and, as many partially sighted persons must read and work in their own shadow, the mean optimal (il)luminance level will be higher for the partially sighted as a group than for the normals.

We must add that, because of varied responses to increased illumination in different patients with age-related macular degeneration, Lovie-Kitchin has advocated that test luminance or illuminance should be a variable in the assessment of the visual performance of each patient. If an internally-illuminated acuity chart with variable illumination is not available, the illuminance of an externally-illuminated distance or near chart can be varied by placing a

light source at different distances from the chart. Lovie-Kitchin et al, 1983¹⁰⁸ suggested that the simplest initial assessment of illuminance response would be to assess reading performance, firstly under dull room illumination (5 to 20 lux), then under brighter room illumination (100 to 300 lux) and then at high illumination levels (1,500 to 5,000 lux) by placing a reading lamp, in the last case, at short distances from the test material (approximately 200 mm or closer). This assessment of illuminance response could be applied to any low vision patient.

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4. DARK AND LIGHT ADAPTATION

4.1 Dark adaptation

Adaptation refers to a gradual change in the subject's light sensitivity subsequent to an instantaneous modification of the retinal illuminance.

The most studied aspect of adaptation is dark adaptation, which is the gradual sensitivity increase (inverse of threshold decrease) that follows the rapid transition from an exposure to a highly lit scene to complete darkness. When the luminance of the scene is sufficiently high and the observer's field includes a retinal area containing both rods and cones, the dark adaptation curve (representing the change in log-sensitivity as a function of time) is biphasic and it is possible to distinguish first the photopic segment followed later by the scotopic segment and both present an asymptotic course. The dark adaptation curve can be determined clinically by means of adaptometers, among which the Goldmann-Weekers is well known. The inter-individual variations in sensitivity mean that, even in standardized conditions, there is a spread of about one decimal log unit in the normal sensitivities for each period of dark adaptation.

The initial phase of dark adaptation (called *Sofortadaptation* by German authors) is studied clinically by measuring recovery time (for example, for a given visual acuity) after adaptation of the macular region to a strong light (test of Bailliar, and different kinds of photostress tests, often erroneously considered as glare tests). Central serous retinitis is the retinal disease in which prolongation of the recovery time has been most often described.

The principal types of abnormal dark adaptation are absence of the photopic segment or scotopic segment, subnormal amplitude of one or both segments, slowing of one or both segments, and delay of the initial phase.

4.1.1 *Achromatopia*

Achromatopsia is characterized by the absence of the normal photopic segment. This is often replaced by an abortive and faster first segment, which has been attributed by Sloan & Feiock, 1972¹ to so-called "photopic rods" (cones with rhodopsin), while the scotopic segment begins earlier and is faster due to the absence of the inhibition normally exerted by the photopic system.

Absence of the scotopic segment is typical for congenital night blindness, but there exist atypical cases (Oguchi's disease) in which a very delayed and slowed scotopic segment is evident.

4.1.2 *Avitaminosis*

According to earlier papers, dark adaptation is defective in the patent cases of avitaminosis A, but there is no evident relationship between threshold and carotenemia. Both photopic and scotopic segments are elevated in case of abnormal night vision (see Hecht & Mandelbaum, 1939²).

4.1.3 *Cataract*

Opacities of the media, such as cataract do not greatly alter the dark adaptation curve when this is determined by means of a big target (Feldman, 1936³; Jayle et al, 1950⁴).

4.1.4 *Cone degeneration*

The most typical change in the dark adaptation curve in progressive cone degeneration is an elevated cone plateau; however there are cases with normal curves or with elevated scotopic segments (Sloan & Brown, 1962⁵; Krill et al, 1973⁶; François et al, 1974⁷).

4.1.5 Retinal detachment

Retinal detachment alters both segments of the dark adaptation curve (Jayle et al, 1950⁸). This is more altered in actual detachments than in healed ones (François & Verriest, 1962⁹).

4.1.6 Diabetic retinopathy

Both segments of the dark adaptation curve can be elevated or slowed in diabetic retinopathy and in other vascular diseases of the retina (see François & Verriest, 1956)¹⁰. Gliem & Schulze, 1975¹¹ and Frost-Larsen et al, 1980¹² established, by means of the Zeiss Jena Nyktometer, a progressively impaired initial dark adaptation in relation to increasing degrees of diabetic retinopathy. This is also the case in macular oedema, which is a frequent complication of diabetic retinopathy (see Glaser et al, 1977¹³). Dark adaptation of diabetics is even more abnormal when the injection of insulin causes hypoglycaemia (McFarland et al., 1941¹⁴).

4.1.7 Glaucoma

There are many papers from the 1920s and 1930s era describing defective dark adaptation in glaucoma. Jayle et al, 1950¹⁵ summarized these older papers and found that their dark adaptation curves were more abnormal in primary glaucoma than in secondary glaucoma. Ourgaud & Etienne, 1961¹⁶ examined 205 cases of glaucoma and found a more elevated final threshold in open angle glaucoma and in secondary glaucoma than in the other kinds of ocular hypertension.

4.1.8 Juvenile macular degeneration

François et al, 1962¹⁷ showed that the dark adaptation curve is normal or subnormal in juvenile macular degeneration (unless there is association with a peripheral chorioretinal degeneration of the retinitis pigmentosa group).

4.1.9 Age-related macular degeneration

Dark adaptation can be abnormal in age-related macular degeneration, as already stated by Jayle et al, 1950¹⁸. François et al, 1956¹⁹ found as typical features slowing of the curve and a large central scotoma in scotopic conditions. Brown and Lovie-Kitchin, 1983²⁰ found that, while there was some variability, results fell approximately into two groups. Some of the patients showed near-normal dark adaptation results compared with age-matched controls, while others showed a slowed adaptation, but eventually reaching approximately normal sensitivities. Brown et al, 1986²¹ found decreases in sensitivity for both scotopic and photopic segments, an increased time constant for recovery of rod function and a sensitivity loss that was greatest in the macular area but extended over a relatively large retinal area. The initial phase of dark adaptation is often delayed in this disease (see Chilaris, 1962²², Glaser et al, 1977¹³).

4.1.10 High myopia

Dark adaptation is slightly abnormal in high myopia as shown e.g. by Jayle et al, 1950²³.

4.1.11 Optic atrophy

Defective dark adaptation has been stated in optic atrophy but is of secondary importance in the clinical picture (see Jayle et al, 1950²³. As studied by means of the photostress test, the initial phase of dark adaptation is normal in optic nerve disease (Glaser et al., 1977¹³).

4.1.12 Retinitis pigmentosa

Mandelbaum, 1941²⁴, Jayle et al, 1950²³, François et al, 1956¹⁹ and François & Verriest, 1962¹⁰ showed that dark adaptation curves can be encountered in retinitis pigmentosa which ranged from normal to a high monophasic type. The scotopic segment is generally more affected than the photopic