MAGNIFICATION AND RELATED FACTORS IN THE ALLEVIATION OF IMPAIRED VISION

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Summary

The technology of magnification has been developed to the level at which modern optical design could permit most visually-handicapped persons a degree of functional independence, particularly in near vision tasks. The more severely disabled patients, however, have been aided only with the higher magnification and supplementary advantages of closed-circuit television (CCTV).

Experimental CCTV magnifiers were constructed for studying the effects of magnification on performance. Reading rate and ability in a hand-eye co-ordination task were quantitatively assessed, and the most severely handicapped patients were found to benefit the most from CCTV. Further, the pattern of improvement in reading performance with practice was determined over several days, using partially-sighted schoolchildren. In addition, the relationship of reading rate with high magnification led to the formulation of a mathematical model expressing the upper limits of performance. Magnification, display-aperture width, and the number of alphanumeric characters displayed influenced the reading rates of visually-handicapped subjects. Recommendations were given for prescribing appropriate angular magnification and display field size.

When the field size is pathologically constricted as occurs in retinitis pigmentosa, inverse magnification creates an expansion of the visible field, allowing detection while attenuating the visual acuity. An experimental binocular search task revealed that extensive adaptation would be essential before selected patients could expect to gain increased detection skill under these unusual conditions of magnification.

Since magnification changes the angular spatial frequency, and little is known about contrast thresholds in low vision, the contrast sensitivity function (C.S.F.) was investigated. In a pilot study, a procedure was devised for relating specific C.S.F. parameters to the optimal magnification required in CCTV reading.

Finally, the experimental deductions are brought together in the conclusion, and suggestions are given for further research.

Key Words

Visually handicapped, Low vision aids, CCTV magnifier, Visual field expander, Contrast sensitivity

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CHAPTER 1

INTRODUCTION

MAGNIFICATION - EXTENDING THE DIMENSIONS OF VISION

1.1 OBJECTIVES OF THE STUDY

The principal objectives of this study were to assess by theory and experiment, the various factors influencing performance in relation to magnification. The closed-circuit television magnifier and the field expander have a complementary range of magnification, which gave scope for a study with wide implications. The dearth of clinical knowledge about these aids suggested experimental designs which could yield a quantitative basis for prescribing.

Thus, the study should deduce the efficiency of closed-circuit television relative to optical aids, using reading and hand-eye co-ordination tests; and a predictor of individual reading rate potential. A mathematical model would be formulated, showing the influence on the reading rate of a continuum of magnification levels. This would lead to a study of the interaction between magnification, viewing distance, and field of view in relation to the reading performance of visually-handicapped subjects.

Patients with constricted fields would be assessed on a search task in utilising the binocular field expander, enabling general conclusions to be drawn about its utility.

Finally, an investigation of contrast sensitivity function might reveal its relationship to magnification, and how optimal magnification could be specified objectively.

1.2 EVOLUTION OF MAGNIFICATION AS AN ADJUNCT TO VISION

The specialised use of magnification, whether in scientific instruments, or in clinically-prescribed aids, is today accepted as commonplace. For a fuller understanding of how this has come about, and particularly of how the visually-handicapped are helped to exploit whatever sight remains, it is necessary to recall the antecedents of modern magnifiers.

The magnified image has been known to mankind since early history. Amongst the earliest evidence are two magnifying lenses of rock crystal, discovered in Crete in 1927, and dating from 1200 B.C. or earlier[1]. Barker[2] has described a crystal lentoid to be found in the Babylonian Gallery of the British Museum, and known as the 'Ninevah lens'. This ancient lens is considered to have been ground by a lapidary and to date from c.900-700 B.C. On the other hand, there appears to be no available evidence that the Greeks and Romans discovered a need for magnification as such. Although they used water-filled glass spheres primarily as burning glasses for kindling fires and cauterising wounds, their magnifying power was probably considered as incidental[1, 3, 4].

The earliest unequivocal account of the refractive ability of a convex form of glass to magnify objects, is generally supposed to have been due to the Arab philosopher, Ibn al Haytham (962-1038 A.D.), more commonly known in the

Western world as Alhazen[1, 3]. His treatise was translated into Latin in the twelfth century, under the title 'Opticae Thesaurus Alhazeni Arabis'. There is one proposition in the book dealing with refraction, in which Alhazen states that when an object and the eye lie at opposite sides of a sphere, then the image will be larger than the object itself[3].

In Europe, two centuries later, Roger Bacon in his 'Opus Majus', written c. 1266, also makes a clear reference to the use of a segment of glass or crystal sphere. When its plane base is laid on a book '.... those that have weak eyes ..... may see the smallest letters sufficiently magnified' [1, 3].

Reference to the use of lenses, manufactured both as simple magnifying glasses and as spectacles, also appears in the thirteenth century. The likelihood is that the craft originated in the glass-making centres either of Northern Italy, the Netherlands, or Southern Germany[4].

A lapse of over three hundred years took place before the next significant event in the development of magnifying aids. The year 1590 has been stated as the date when the telescope was originally invented in Italy[5]. Other authorities have accredited the first telescope to spectacle-makers in Holland in 1608. Hans Jansen, his son Zacharias and Hans Lippershey, of Middelburg, and James Metius of Alkmaar have each been cited as playing some part in its invention[3, 6, 7]. The design comprised a convex objective lens, and a single concave lens as the eyepiece. Bradbury[3] states that the telescope constructed by Lippershey was binocular, which was unusual at that time. Galileo is supposed to have heard of the Dutch novelty, whereupon he proceeded to make his first telescope in 1609, and thereafter spent time on the optical perfection of the instrument. This led to his many celebrated achievements in astronomy, resulting in this particular optical design having become named after Galileo himself, rather than its Dutch originator. Today, the principle is still commonly employed in several low vision aid designs.

The proposition that a convex lens could also be used as the eyepiece of a telescope was conceived by Kepler[3, 7] in his 'Dioptrice' published in 1611. The actual construction of this form of telescope, however, was not undertaken until c. 1615-1630[6,7], when Scheiner, a Jesuit father, first assembled an instrument of this type, which is referred to as a simple astronomical telescope. It had the advantage of providing a larger field of view than the Galilean design, but had the peculiarity of inverting the image. Apparently, Kepler had envisaged the necessity for a third convex lens within the system in order that the image should appear erect, and so be appropriate as a 'terrestrial telescope'. Like the Galilean design, the Keplian telescope is used even now as an alternative design of aid for low vision.

Turning attention to the microscope, the earliest reference to a magnifying glass used as a simple microscope appears in 'Dioptrice et Meteora' by Descartes, and published in 1637. This work includes an illustration of the device, in which a plano-convex lens and a metal concave mirror were arranged for viewing a tiny object.

Early development of the simple microscopic lens was largely due to Leeuwenhoek (1632-1723), a Dutchman, and to his English contemporary Hooke (1635-1703). Leeuwenhoek devised a means of grinding and polishing biconvex lenses of extreme power, yet with excellent resolution[(3,6)]. Hooke, with equal genius, produced tiny globules of molten glass, a proportion of which were found to make suitable lenses[(6)]. Each of these pioneers went on to make a distinguished contribution to the field of microscopy.

A significant problem in dioptrics at that time was presented by the chromatism of simple lenses. In fact, Newton, believing the problem to be insuperable, directed his studies to the reflecting telescope[(5,6)]. Meanwhile, basing their argument on an erroneous belief that the human eye is free of chromatic aberration, Gregory in England (about 1670) followed by Euler in Germany (1747), concluded that an achromatic lens combination was a possibility[(6)]. Indeed, the first achromatic telescope was successfully designed and constructed by the Englishman, Hall in 1733[6, 7, 8]. The objective was made of crown and flint glass. Thereafter, considerable perseverance on the part of Dolland, an English optician, led to his being granted a patent in 1758 for the manufacture of achromatic doublet lenses as objective glasses[6,8].

Together, the aforementioned scientists and craftsmen established the theoretical and practical foundations of optical magnifying systems, largely throughout the Renaissance and Baroque periods. Alongside them were other contributors of distinction, lesser known, who could have been added with justification in a more comprehensive historical narrative. The collective wisdom of these pioneers forged the principles on which are based the modern telescope and microscope. The aids used in clinical practice are simply applications of those principles.

Today, for those members of the population categorised as 'visually-handicapped' - a term fully defined in Chapter 2 - magnification assumes a role of paramount importance to daily living. The plight of the largest proportion of this group is such that they are forced into making an active effort to exercise their residual vision, using appropriate methods of magnification.

During the studies described in this thesis, it was discovered that reading is feasible with up to 1000× magnification of detail. At the other end of the scale, it appeared practicable to increase a restricted field of view by a factor of 3×, with a corresponding magnification of 1/3×.

Either condition could be described as a purposeful application of magnification, causing gross discrepancies between the optically-perceived position and the physically-perceived position of objects in the environment. Nevertheless, sensory-motor co-ordination between the eye, the brain, and the limbs permits the user ultimately to adapt to the unusual retinal image.

In summary, where conditions demand, the human visual system appears to be remarkable in its adaptability: it adjusts to a magnification range with an order of magnitude of several thousand times. This fact is not merely of academic interest: there are genuine practical benefits implied therein for the visually-handicapped.

At this point, a classification is appropriate of those persons referred to as visually-handicapped. Quantitative definitions of blindness and partial sight, such as the statutory definitions listed in Chapter 2, suffer from the weakness that they belie the aptitudes and capabilities of the individual patient; whereas functional classification provides a more realistic gauge of the ability to perform specific tasks. Moreover, a recent study[9] has revealed that official records seriously underestimate the number of visually-handicapped, because many eligible persons do not bother to register.

For these individuals to be helped in making the fullest use of their faculties, a variety of aids have been designed to make information more accessible, especially since the mid-19th century. Tactile and aural aids have become more commonplace during this period, and serve their useful purpose for those unable to use residual vision. These aids are further described in section 5 of Chapter 2.

Many can and do choose to use their residual sight with impunity. For the majority, optical aids supply their need to the most efficient degree. The historical development of these aids is discussed in section 2 of this chapter, and the characteristics of modern optical aids to near vision comprises Chapter 3.

A significant minority - many of whom fit within the statutory classification of blindness - have such gross residual vision that they can perform near vision tasks only with the aid of a closed circuit television (CCTV) magnifier. This novel technique is able to offer degrees of magnification hitherto unattainable, besides other features which enhance the image in a unique manner.

Subsequent chapters are concerned with the several aspects of CCTV magnification. Concerning the technology, discussion is given of the designs of various laboratory instruments, possible future developments, and the criteria in designing the experimental prototype of the present project.

Concerning the utility, the guidelines for prescribing CCTV laid down by earlier workers are discussed in the light of their results. Following on, within the present project novice readers are divided according to their suitability to use CCTV, and argument details the reasons for the division. Description is given of the several experiments undertaken within the project, using CCTV magnification, together with the apparent implications of the results. Another experiment was performed to determine the sensitivity of the eye to gratings with sinusoidal variation of contrast at discrete spatial frequencies (known as the contrast sensitivity function), using subjects with ocular abnormalities. The findings were related to certain CCTV reading parameters.

Numbered amongst the blind are those with a visual handicap of a fundamentally different kind. These patients may have retained normal or near-normal central visual acuity, yet their visual fields can be so limited - 'tunnel vision' - that severe hindrance is caused to their mobility, and capacity to locate objects in the environment. For this group, it has often been proposed that a negative magnification system would be an appropriate aid. Such a device is known as a reversed telescope or field expander. A summary is given of the development of the field expander, along with the rationale of its application. This is followed by a description of the experiment performed by the author to determine its effectiveness in a visual search task.

The field expander is representative of contemporary design and technology in optical appliances for low vision. In section 2 which follows, a summary is presented of the development in design of the early low vision aids.

1.3 EARLY OPTICAL AIDS

The most exhaustive study of small magnifying aids to vision was made by von Rohr, an optical physicist, whose work on the subject was published serially in Germany for several years before the Second World War. Both Ellerbrock[10] and Fonda[11] cite von Rohr as the authoritative historian in the field. The historical review of optical magnifying aids that follows in this section is therefore by way of an abridgment.

First references to the specific use of optical aids for visual defects were made in the seventeenth century. The earliest evidence that a hand telescope was used as an aid for subnormal vision is cited by Ellerbrock[10] as being in 1645 from Kirchner. In 1667, Eschinardi, a Jesuit priest, prescribed spectacles for near vision in the form of a Galilean telescope, for an individual with 6.25 dioptres of myopia. A magnification of 2× was obtained[10, 11].

Eschinardi had foreseen the possibility of focussing the telescope for various distances, by altering the separation between the objective and eyepiece elements. Later, in 1686, Zahn described a mechanism for such a purpose[10].

In 1695, in his classic work 'Dioptrica', Huygens stated the precise rule to be followed when adjusting a telescope to the refractive condition of the eye[10].

The earliest catoptric system was contributed by Dixon in 1786. This consisted of a concave mirror nearer the eye and facing towards the object, with a central 5mm aperture; and opposite the aperture a convex mirror also of about 5mm diameter. The image from the concave mirror was reflected onto the convex mirror and thence into the eye. The convex mirror could be moved along the common optical axis to compensate for refractive errors[11]. The notable effect of this system was its intrinsic freedom from the chromatic aberration found in many lens telescopes of the period.

A small Galilean telescope was produced in 1846 by Steinheil and Seidel, the prototype having a magnification of 2× and a wide field with the minimum of aberrations. However, in production, units were manufactured with lesser magnifications, namely 1.2× and 1.3×, with an emphasis being placed on their exceptionally large corrected field[10].

An achromatic doublet eyepiece was originally introduced for the telescopic spectacles designed by von Rohr. The Zeiss Company began manufacturing this design in 1909, with magnifications of 1.3× and 1.8×. The separation between the objective and the eyepiece remained fixed, in order that the aberrations should be minimised. Supplementary lenses could be slipped over the objective, to correct for near working distances. At the same time, refractive errors could be corrected with supplementary lenses added to the eyepiece[10].

In Britain, during 1927 the firm of Hamblin introduced their original telescopic trial set, with the aim of simplifying the Zeiss set[11].

Meanwhile, in the United States a unique telescope was produced in 1930 by Feinbloom. The unit had a power of 1.8× in the horizontal meridian and 1.3× in the vertical meridian. The purpose of this meridianal disparity was an attempt to provide a spatial projection similar to that perceived normally, so that the unit would be used when walking. Such an optical design must inevitably create an apparent foreshortening or lateral elongation of the image. Ellerbrock[10] states that these units were discontinued after their clinical value had subsequently been assessed as insignificant.

In 1936, Tait and Neil[10] suggested that an ordinary ophthalmic lens be used as the telescopic eyepiece. This was surfaced separately at two positions, for distance and near vision. Mounted in front of the eyepiece lens was a carrier lens, on which were cemented small thin plus lenses acting as objectives. The separation between the eyepiece and the objective carrier lens could be such that the telescopic combination was either afocal or equal to the refractive error. The authors claimed good field properties when the surface curvatures of objective and eyepiece were carefully chosen, although the useful field of view could not match that of the Zeiss telescopic spectacles having equal magnification.

The Stigmat telescopic unit designed by Bennett in 1950[(12)] was innovatory in concept. Instead of providing a distance unit with a near vision cap as usual , this customary technique was reversed. The basic unit was focussed for near vision at 33 cm, and a minus auxiliary lens cap was used to adapt the unit as necessary for occasional distance use. A single eyepiece lens, prescription worked to incorporate any distance correction, was ground from extra dense flint glass, which made chromatic aberration from the objective much less apparent. Another important advance was the plastics aspheric objective, offering a wide field of view, besides a substantial reduction in weight.

All-plastics lenses were developed for the Bier-Fleming telescopic system in 1953, and later were incorporated into the Bier-Hamblin range[(13)]. The Keeler system, for which the A-series charts were designed to determine the required magnification, was introduced in 1956[(14)].

When higher magnifications have been called for in assisting patients, the requirement has been met by employing hand telescopes. These have afforded characteristically large reading distances. Production of units with magnification of 3×, 6× and 8× was initiated by the Zeiss Company in 1911, using a terrestrial telescope design. Because the fields of view rendered by these units were small, rigid stands were supplied so that the devices could be supported while being moved over the lines of print[10]. Today, there is a wide choice of small hand telescopes available as distance aids, often with a near-focussing facility enabling them to be used for reading without any modification.

The suggestion that a contact lens should be used as the eyepiece of a telescopic device, was made independently by Dallos and Dittmer in 1936[10, 15]. The objective lens would be a high plus lens or lenticular, while the contact lens could have various powers. Dallos himself stated that the contact lens telescope was impractical, because the change in perspective while walking was less tolerable than the alternative of poorer visual acuity[15]. Nevertheless, Bettman and McNair[16] achieved a degree of success with the Dallos method. This is more fully reported in Chapter 3, section 3.5.

The telescopic design patented by Feinbloom in 1940 actually incorporated together the objective plus lens and the eyepiece contact lens, which thus became a unified compound optical system. A wider field of view with less peripheral distortion was claimed for the system. Undoubtedly one advantage was that the visual and optical axes always remained virtually coincident, because the entire optical system moved with the eye[10].

Feinbloom, in about 1925, may also have been the first to state the clinical value of specially-designed high-power spectacle lenses. Later, in 1952-53 Lederer actually computed a series of best-form spectacle magnifying lenses[17]. Subsequent computations by Bennett[18] after this basic principle led to the introduction of three Stigmagna spectacle magnifiers, of 3×, 4× and 5× power which were claimed to have less oblique astigmatism. Efforts to reduce the peripheral distortion, especially in the 5× Stigmagna, resulted in the development by Bennett of the Hyperocular lenses[12], made of acrylic plastics material. Their aspheric surfaces brought about an additional correction of aberrations, including distortion.

These lenses, together with other contemporary optical aids for near vision, are described more completely in Chapter 3. Optical aids allow normal ink-print to be read by a significant proportion of those persons categorised as 'visually-handicapped', a term fully defined in Chapter 2.

CHAPTER 2

THE VISUALLY-HANDICAPPED POPULATION

2.1 LEGISLATIVE DEFINITIONS OF BLINDNESS AND PARTIAL SIGHT

The generic term 'visually-handicapped' is used to include those people classified as blind and those others classified as partially-sighted.

A study group of the World Health Organisation found 65 different definitions of blindness alone, in use throughout various countries during 1966[19].

In the United States for example, blindness is defined as 'central visual acuity not exceeding 20/200 (6/60) in the better eye with correction; or central visual acuity greater than 20/200 but accompanied by limitation of the field of vision to 20 degrees'. This is the definition recommended by the Federal Department of Health, Education and Welfare.

In Britain, the statutory definition of blindness according to the Blind Persons Act 1920-1930, and the National Assistance Act 1948, is 'so blind as to be unable to perform any work for which eyesight is essential'.[20] For practical purposes this is interpreted as a corrected visual acuity of 3/60 or worse. Two important points are to be observed:

'(i) the test is not whether the person is unable to pursue his ordinary occupation or any particular occupation, but whether he is too blind to perform <u>any work</u> for which eyesight is essential; and

(ii) only the visual conditions are taken into account and other bodily or mental infirmities are disregarded.'

In addition, when considering a patient for registration of blindness, an ophthalmologist has to bear in mind the degree of visual field loss. A patient with 6/60 or better, for example, could be recommended for registration if the field is markedly constricted, especially in the inferior quadrants; but a person suffering from homonymous or bitemporal hemianopia, but retaining central acuity of 6/18 or better, is not to be regarded as blind.

Also, when considering registration, due regard must be given to whether the visual defect is of recent origin, or of long-standing. When considering schoolchildren, ophthalmologists need to be aware of the factors which may influence local education authorities in their decision over whether special educational facilities should be provided.

In Britain, there is no statutory definition of partial sight in the National Assistance Act, 1948[20]. The Ministry of Health has advised that a person who is not blind within the meaning of the Act of 1948 but who is, nevertheless, substantially and permanently handicapped by defective vision is within the scope of the welfare services provided for the blind by the local authority, with the exception of benefits 'specially enjoyed by the blind' such as Supplementary Benefit or Income Tax concession.

The following criteria are a guide in determining whether a person is eligible for the welfare provisions for the partially-sighted, as well as in recommending for a schoolchild under 16 years of age the appropriate type of school:

'(i) for registration purposes and the provision of welfare services, those with visual acuity;-

(a) 3/60 to 6/60 with full field;

(b) up to 6/24 with moderate contraction of the field, opacities in the media, or aphakia;

(c) 6/18 or even better if there is a gross defect, e.g. hemianopia, or there is marked contraction of the field as in pigmentary degeneration, glaucoma, etc.

(ii) for children whose visual acuity will have a bearing on the appropriate methods of education :-

(a) severe visual disabilities - to be educated in Special Schools by methods involving vision - 3/60 to 6/24 with glasses.

(b) visual impairment - to be educated at ordinary schools by special consideration - better than 6/24 with glasses.

Notes:

(a) infants and young children with congenital anomalies, including visual defects, unless obviously blind, should be classed as partially-sighted.

(b) at age four and over, binocular corrected vision should be the criterion.

(c) all children in (ii) (a) and (b) above should be re-examined every 12 months - or earlier if there is reason to suspect any worsening.

(d) in making recommendations about persons up to and including the age of 16, examining ophthalmologists should bear in mind that - as with blindness - there are other factors which may influence local education authorities in their decision about the special educational treatment to be provided.'

2.2 LIMITATIONS OF THE LEGISLATIVE DEFINITIONS

The foregoing definitions of blindness and partial sight divide subnormal vision into arbitrary categories based on Snellen acuity and visual field loss. Such a division simplifies the issue in question for legislative and insurance purposes.

Nevertheless, there is reason to believe that categorisation should be applied judiciously, particularly where children are concerned. In a follow-up study of 14 infants suspected of being blind at birth, or shortly afterwards, Law[21] found only 3 who had remained totally blind. The 11 others showed distinct signs of improving visual acuity during the developmental years. Law postulated that 80 per cent of babies suspected of being blind at birth eventually prove to have some useful vision. As Barraga[22] points out, this suggestion is borne out by Gesell's theory of continued growth and improvement of the visual processes through experience, despite the physical impairment[23].

Furthermore, simple quantitative definitions disregard the extent to which the individual has become psychologically adjusted to his visual disability, and they cannot indicate the potential capacity for independence of that individual. These subjective factors are important not only to the individual concerned, but also to those who are involved with rehabilitation and a closer understanding of the effects of handicap - the family, social worker and employer on the one hand, and the psychologist, clinician and visual scientist on the other. The experience of professional persons involved with the visually handicapped reveals that in a significant proportion of cases the degree of visual impairment bears no significant relationship to the capacity of the individual to cope with daily tasks.

The outcome of this realisation, advocated in recent times, has been a number of proposals for re-classifying the visually handicapped in terms of functional abilities[24-29].

2.3 FUNCTIONAL DEFINITIONS

Faye[24] advocates the grouping of low vision patients into five classifications according to their degree of functional impairment, their response to visual aids, and their need for special training and education in addition to optical aids. Numerical values for visual acuity, field and required magnification are discounted. By considering function instead of acuity, it is feasible to assign a patient who functions effectively in spite of poor vision to the best group, rather than placing him in the last group because of his poor acuity. The groups range from those patients with vision that does not reduce their ability to function (near-normal vision) in Group I, to those in Group V who still use visual cues for mobility but who have very poor visual acuity and probably a severe field loss. The Group V patients make minimal use of an optical aid and they cannot read continuous text.

Fonda[25] designates four groups, based on a visual acuity assessment of residual vision as follows:

Group I : light perception to 1/200

Group II : 2/200 to 4/200

Group III : 5/200 to 20/300

Group IV : 20/250 to 20/70

Fonda proposes that patients in Group I should be taught braille whenever possible; Group II is a borderline group of cases who should be encouraged to read large print; and Groups III and IV should be assisted with special aids. Those in Group IV can usually cope with normal school regimes as well as various occupations.

Genensky[26] has classified the visually impaired into four qualitative categories according to their sighted ability to read and write, and their ability to manoeuvre safely in an unfamiliar environment with or without guidance. Genensky contends that in the past 'the blind' have been condemned to a life of dependency, whereas the proposed re-classification would, he believes, encourage visually-handicapped people to aspire to their highest ambitions.

In 1972, the Study Group on the Prevention of Blindness convened by the World Health Organisation[19] recommended a total of seven categories of low vision, ranging from normal and near-normal; low vision (moderate and severe); to blindness (moderate, severe and total). The borderline between severe low vision and moderate blindness covered acuities lying between 20/400 (3/60) and 20/500 (1/24). This definition represents a compromise, narrower than the term legal blindness in the U.S.A., and broader than total blindness.

2.4 CONTEMPORARY OPINION ON THE UTILITY OF RESIDUAL VISION

The present concern over making the most efficient use of residual vision became accentuated during World War II, when disabled persons were employed in war plants; and their achievements activated the rehabilitation services and optical aids schemes[27].

Clinical practitioners began reporting their success in restoring visual efficiency to the visually-handicapped during the 1950's[30-32]. Several published papers generalised about the specialised techniques involved in optical treatment, and the various attitudes of mind encountered in visually-handicapped individuals which governed the level of success with their rehabilitation[33-35].

Faye[24] expresses succinctly a common concern, which would be largely removed by a system of functional classification of blindness applied to rehabilitation. Many working people, she considers, would be disturbed if they were formally classified as legally blind. They might feel that if their employers became aware of their handicap, there would be a threat of dismissal on this technicality, rather than of being retained for their work standards.

Cullinan[9], while questioning the present system of registration for the blind and partially-sighted, carried out a national study of visual impairment during 1976-77. The study was based on 15,000 randomly-selected households in England and Wales. With the collaboration of ophthalmologists and family doctors, the hospital and other medical records were examined of all those adults of 16 years and over, who, in complaining of difficulty in seeing to read or to get about, were found on subsequent examination to have a visual acuity of 6/18 or less. This level of visual acuity was suggested as representing 'visual impairment', for epidemiological purposes, by a study group of the World Health Organisation[36]. From the results of the survey, Cullinan[9] made a tentative deduction that 520 persons in 100,000 have an acuity of less than 6/18, within the whole adult home-based population; 80 per cent of this figure are retirement pensioners, almost 50 per cent aged 75 years or more, and about 5 per cent aged 16 to 49 years. Judging from those actually registered as blind in this survey, Cullinan suggests that official registration figures could underestimate by 35 to 40 per cent the total who would seem to qualify in their domestic surroundings. (Official figures of persons registered as blind or partially-sighted in England, as at the 31st March, 1979, are given in Appendix A)[37].

In summary, whereas earlier in the century the visually-handicapped were all considered in one category as 'the blind', educated and instructed by non-sighted methods, it has now become a truism that the use of residual vision causes no harm to the remaining vision. This was officially accepted as fact by British educationalists in 1934[38]. Practical implementation of this recommendation took place following the Education Act of 1944[39]. Separate schools for the partially-sighted were constructed, and the curricula followed the lines of those in schools for normally-sighted children. Access to information began to be concentrated on visual methods. Even a majority of the registrable blind - according to Sorsby[40] some 84 per cent - have sufficient residual vision for sighted methods, within limits, to be used for their instruction.

An earlier survey, in 1968, anticipated this view[41]: this surveyed 2,291 schoolchildren - 1,374 partially-sighted, and 817 blind - in classes and special schools in England and Wales. It was disclosed that only 396 children had 'no vision or perception of light only', while 355 had 2/60 or less. Therefore the logical conclusion is that 67 per cent might well have adequate vision to work with conventional school material if it is augmented with suitable aids. At least one educator would add the rider that a child with a mild dysfunction of vision will function below the expected visual level, if his intelligence quotient (I.Q.) is sub-normal, whereas a child of high intelligence can learn to cope visually with a quite severe visual dysfunction[42].

Controversy arises as to whether partially-sighted children should be taught braille. The contemporary opinion appears to be that while some of these children find reading such an arduous task that they would be unlikely to use printed material for recreation in later life, that fact alone does not justify their being taught braille within the over-burdened curriculum. A committee appointed by the United Kingdom government recommended that such children could use talking-books as an alternative source[43]. It was also considered that braille should be taught only to those children with vision so subnormal that they are unable to read ink-print at present, or are likely to become so later.

Support is given to this recommendation through an experiment by Sykes[44]. Twenty-four blind and 17 partially-sighted students aged 13 to 21 years acted as subjects, whose visual acuities ranged from approximately

1.5/60 to 6/18. Their mean I.Q. was 104, with a range from 90 to 135. They were equipped with distance and near optical aids.

The conclusion was that although the partially-sighted read faster than the blind students, both groups achieved comparable levels of comprehension. Normal-sized print and large print elicited similar reading rates. Visual acuity appeared to be an unreliable guide to reading ability, although better acuity facilitates the reading speed.

Sykes made several recommendations. Emphasis should be placed on the individual appraisal of each student to determine his functional use of vision. Wherever possible, the students who have received adequate near vision correction should be trained in reading normal print instead of large print. Students should also receive active instruction in the utilisation of visual skills, and particularly in overcoming emotional barriers to reading.

Skydsgaard[45] reported a favourable influence on the education and general proficiency of children and adolescents for whom low vision aids had been prescribed: this had stemmed from the major improvement in reading ability. Any patient who is able to type - even those with visual acuity as low as 1/60-2/60 - should generally be taught ink-print at school, rather than braille, according to

Skydsgaard, unless a bad prognosis is imminent. In these latter cases, it might be inadvisable to change from teaching braille in the classroom; but optical aids can still be used for leisure time reading.

No low vision patient, Skydsgaard concluded, should any longer be considered as hopeless until a careful trial with low vision aids has proved ineffective. Print still remains, above all, the primary medium of communication in our society.

2.5 THE DEVELOPMENT OF ALTERNATIVE AIDS FOR THE NON-SIGHTED

The practice of encouraging the visually-handicapped to make maximal use of residual vision has grown within the last 30 to 40 years only [30-35]. Section 2 of Chapter 1 reveals how clinical optical aids have been elaborated, largely during the present century [10, 11, 46]. Prior to the early 1950's the 'blind' were actively discouraged from using their remaining sight.

As a result of this historical emphasis on educating the blind by non-sighted means, the earliest progress was made in developing tactile methods followed by aural aids [47-57]. For the sake of completeness the development of these methods is briefly surveyed here, because they may represent a challenging alternative to ink-print for those with the most severe visual disablement. It is, in fact, within this same category of individuals that the reading of sighted material is often best accomplished with CCTV magnifiers.

2.5.1 Tactile Aids

The history of tactile methods of presenting information began in 1786, when Haüy began developing an embossed type of modified alphabet letters, designed to help the blind read by touch[48]. The only surviving embossed type system is that evolved by Moon, a blind Englishman, circa 1847[49]. Moon Type characters are simplified forms of the normal letters, except for eight unmodified ones. Lines are printed such that one line runs from left to right and the following from right to left, so that return sweeps are unnecessary.

By 1834, a system of reading and musical notation had been worked out by Braille[50]. This was based on a matrix of embossed dots, originally conceived by a French army officer, Barbier, as a method of reading messages in the dark. In the braille matrix, a 'cell' consists of six dots arranged in two columns, each of up to three dots, and the alphabet is designed to fit within this cell. Official acceptance of braille was not confirmed until 1932, when an agreement was reached between the British and the Americans to adopt Standard English Braille as the uniform style. By this time, it had been recognised that sightless persons were able to write as well as read in braille, whereas this was not possible with embossed alphabet type at an economic cost.

Braille writing was first demonstrated with a simple slate and stylus. A section at the top edge of the slate carried six indentations in the braille cell formation, and paper being fed over this section was punched, wherever appropriate, by the stylus. This device, known as the Pocket Frame, is still used throughout the world. While this method has the obvious advantage of simplicity,there has been a manifest need for a mechanical device which would write in an easier, more rapid and accurate manner. The first such braille writing machine was introduced in 1850, in the United States[51].

A succession of devices has followed, founded mostly on the operating principles of the typewriter. Of the instruments available today, perhaps the most notable are the Perkins Brailler, and the Banks Pocket Writer. The Perkins Brailler was designed and developed in 1951 at the Perkins School for the Blind in Massachusetts. In the current models, the carriage carries the styli rather than the paper. The Banks Pocket Writer became available in the late 1920's. It weighs about 700 grams, measures 11.5 cm in width by 18 cm in length, and uses paper tape 12 mm wide, and hence is easily portable[51].

Probably the biggest disadvantage of braille is its bulk: the Bible consists of seventy-four 80-page volumes of braille, and an average novel requires three volumes[52].

A process which reduces the thickness of publications by 45 per cent has been perfected by the Royal National Institute for the Blind, using polyvinylchloride (P.V.C.) dots, deposited onto the surface of thin, strong paper[52]. Unlike normally produced embossed braille, the dots do not deteriorate with use.

By using a recently developed device called the Optacon, Croft[53] writes that the totally blind can now make direct use of ink-print. A miniature solid-state camera, small enough to be hand-held, is placed in contact with the paper, and an image of the print is focussed onto a matrix of 144 photosensitive elements. The matrix of photocells is linked to a corresponding array of stimulators arranged in 24 rows and 6 columns. A tactile reproduction of the image is presented as raised and vibrating pins in the array, about 1 inch wide by 2 inches long, and these are felt with the whole finger-tip. As Croft points out, the virtue of the Optacon is that it can be used on any printed text - e.g. mathematics, or languages with non-European alphabets such as Arabic, Greek or Russian - as well as typescript, computer print-outs and the characters on a visual display unit. Access is also available to material which is too ephemeral to be transcribed, such as telephone directories and magazines. After extensive practice, reading rates of 40-60 words per minute are claimed as being achievable[54].

2.5.2 Aural Aids

The most notable forerunner of the Optacon was the Optophone, invented by d'Albe in 1914[55]. As the name implies, this device produced an audible-tone output. Combinations of six frequencies were emitted, corresponding to the zones occupied by a character, with each letter of the alphabet generating a unique chord tone. A skilled reader could expect to read up to 30 words per minute with the instrument[56].

While the Optophone is now considered obsolete, developments have been progressing in other aural methods. The talking-book disc has been superseded by the cassette tape, which is not only more durable, but also presents a more flexible control of the output. For example, a facility for rapid speech with frequency equalisation allows the recorded voice to be speeded up, in easily assimilated material, while the pitch sounds normal.

Further advancement in aural presentation methods seems to lie in the realm of synthesised speech. One firm has produced a portable calculator with a vocabulary of 24 words, and with the alternative of Arabic, French or German outputs besides English[54].

Elsewhere another approach has been followed in which two different tones are mixed in a code resembling Morse. A laboratory model has been fitted to a standard calculator, and although the workers concerned admit that this solution is less ideal than synthesised speech, at the present time, at least, it is considerably cheaper[53]. Through the use of microprocessor-controlled voice generators, host computers can communicate with the human programmer by means of synthesised speech. The programmer responds with the orthodox means of input, using a keyboard[57]. The technique has still to be developed to the degree where the speech output is constantly interpretable without ambiguities. When that stage has been reached, synthesised speech will possess not only its current advantage of alerting the programmer to an unexpected message, but will also have become a more foolproof competitor with alternative tactile techniques.

Ingenious and practical though all these methods are, in the light of current opinion they should be considered as indispensable only to those persons incapable of functioning as sighted. This applies to approximately 16 per cent of the registrable blind[40].

Given encouragement to make use of their residual sight, the majority of the so-called 'blind' can be trained in the use of optical aids or closed circuit TV magnifiers.

CHAPTER 3

CLINICAL FACTORS IN OPTICAL MAGNIFIERS

3.1 ASSUMPTIONS UNDERLYING THE TERM 'MAGNIFYING POWER'

When considering the magnifying power of an optical low vision aid (L.V.A.) it is customary to make three assumptions:

(i) the eye is emmetropic or corrected, with relaxed accommodation,

(ii) the object of regard is viewed at the focal plane of the lens,

(iii) the image is formed at the conventional 'distance of most distinct vision' of 25 cm.

There exists a long-established supposition that an emmetrope sees an object with maximum clarity at a distance of 25 cm. A clear retinal image will require a 4-dioptre positive lens for the emmetrope with relaxed accommodation, or the presbyope. Hence, at this distance, the retinal image is designated as having unit magnification.

These three assumptions are convenient but not always practical. For example, accommodation may not be relaxed; the magnifying lens may be held nearer to the print than the focal plane, particularly in binocular use; and the distance of distinct vision is arguably too short at 25 cm. Sloan and Habel[58,59] for example, consider a more realistic distance to be 40 cm.

While the conventional assumptions have undeniable disadvantages, the present author recognises that they are nevertheless well-established enough to have become accepted as a convention, and will adopt them where appropriate, in this and subsequent chapters.

3.2 CALCULATION OF THE REQUIRED MAGNIFICATION POWER

A preliminary to the selection of magnifying power must be the determination of an accurate refraction. The resulting spectacle prescription might well augment the focal power of the selected aid, and moreover, any basis for calculation of this power is dependent on the best visual acuity.

Three distinct and empirical methods of calculating the near addition have been devised, due to Kestenbaum[60] Keeler[14] and Sloan and Brown[61]. Each method relies in principle on the resolving power of the eye - either the distance or near acuity - and the close correlation existing between the two acuities in normal eyes[62].

Kestenbaum[60] first conceived of using the constancy of visual angle in the prescribing of high reading additions for low vision patients. He employed the reciprocal value of Snellen acuity (R.V.) as the basis for calculating the value in dioptres required in order to read J.5 print (equivalent to 8-point; or 1M in U.S. terms), e.g. R. V. = 1/ 6/60 = 60/6 $\equiv$ +10D.

Inaccuracy may arise because single letter distance acuity represents a different stimulus from continuous reading text[14, 16]. Furthermore, a discrepancy can occur between distance and near acuity, as a result of opacities in the media and central and paracentral scotomas, dependent on their size, location and density.

Near vision may be better than distance acuity in cases of peripheral opacities of cornea or lens; irregular astigmatism; or pendular nystagmus: in the former conditions because of pupillary constriction, and in the latter because convergence has a limiting effect on the amplitude of the nystagmus. Near vision may be poorer than distance vision where central opacities of cornea or lens are present, or with an incomplete central scotoma, in which single letters can be recognised, although a string of letters cannot be integrated into words[63].

The Kestenbaum method, therefore, represents an arbitrary starting point from which trial-and-error is necessary before a final prescription can be written. As if further to illustrate the empirical nature of the method, Gettes[64] observes that practitioners have advocated reading additions twice the power of that computed from the Kestenbaum formula.

The method originated by Keeler[14] overcomes the discrepancy arising between distance and near acuities, by the obvious method of using near acuity charts only. The so-called A-series charts were designed with a continuous series of print sizes from A1 to A20; each larger text requiring 80 per cent of the visual acuity necessary for the preceding one. At a viewing distance of 25 cm, A1 is equivalent to 6/6 vision; and there are 6 measurable acuity steps between the 6/6 and 6/18 equivalents, 6 steps between 6/18 and 6/60, and 9 steps between 6/60 and 1/60. To improve a given acuity by one A-series step requires a theoretical 1.25× magnification.

Another method - the Sloan-Lighthouse card system used in the U.S.A. - is also exclusively a near vision method[61]. It appears to have been based on an earlier idea of Lebensohn[65]. The Sloan-Lighthouse initial screening card consists of 16 lines of single, non-serif, capital letters calibrated for a working distance of 40 cm. The letters are arranged in descending steps corresponding to distance acuity equivalents, with the letter size in metric notation and M rating listed in the left hand margin. (The designation 1.0M corresponds to a letter whose overall vertical dimension subtends 5 mins. of arc from a distance of one metre). The patient wears a working distance addition for 40 cm if necessary, and reads the smallest capital letters he can see comfortably. The M rating of this print is noted.

The next step involves the patient in reading the cards bearing continuous text. The vertical dimension of the smallest lower-case print subtends a visual angle of 5 minutes of arc at a distance of one metre, and this size is designated as 1.0M. The ability to read 1.0M print at 40 cm corresponds to an acuity of 40/100 (=20/50 or 6/15) in Snellen notation.

The nine reading cards have continuous text in graded 'pica' type, similar to that of a standard manual typewriter, and ranging from 1.0M to 10M in size. The cards represent 1M, 1.5M, 2M, 2.5M, 3M, 4M, 5M, 7M and 10M. Other angular sizes can be obtained by viewing the 3M, 4M, 7M and 10M cards at 20 cm instead of 40 cm, and using a +5D add, to obtain 6M, 8M, 14M and 20M respectively. The sizes from 1M to 20M form approximately equal logarithmic steps, and were adopted after early experience with more finely graded steps.

It is on this reading acuity that the power of the near addition is based. If, for example, the patient reads the 5M print at 40 cm then, in order to be readable, 1M print would need to be held five times closer, at 8 cm. This corresponds to a reading add of 12.5D, assuming no accommodation is exerted.

3.3 TYPES OF OPTICAL LOW VISION AIDS FOR NEAR

Near vision aids designed for low vision can be conveniently divided as follows:-

(1) Spectacle Magnifiers - simple and compound.

(2) Telescopic Magnifiers (Telemicroscopes).

(3) Conventional Hand or Stand Magnifiers.

(4) Projection Magnifiers.

(5) Contact Lenses.

3.3.1 (i) Spectacle Magnifiers : Simple Microscopes

The simplest form of spectacle magnification is produced by prescribing a strong reading addition - a simple microscope - which, in the experience of Fonda[(66)] is numerically the most successful aid for low vision patients. Although strong reading additions are usually prescribed monocularly, it is possible to prescribe binocular additions[(67)]. The patient then gains several practical benefits from the summating effect of binocular vision, such as improved visual acuity; greater depth of focus; and a wider field of vision. Moreover, in many cases a scotoma in the field of one eye is compensated by a functional corresponding area in the other field. There are, in addition, psychological benefits gained from the use of both eyes, and the appearance of conventional spectacles.

Fonda advocates that wherever possible, reading additions should be prescribed binocularly up to 10 dioptres. He adds an empirical rule that for each dioptre of reading addition one prism-dioptre base-in must be incorporated for each eye, or each bifocal segment must be decentred in by one millimetre. With reading additions stronger than 10D, monocular corrections are indicated. Where the worse eye has vision of 1/100 or better, it should be occluded, because its image may interfere with the use of the better eye.

Problems associated with the use of strong positive lenses as reading spectacles can be listed as:-

(i) Lens aberrations, viz. spherical aberration, coma, oblique astigmatism, and curvature of field. Their effect is to limit the useful field of view. Chromatic aberration may have an insignificant effect, since some visually-handicapped patients have a colour deficiency.

(ii) Difficulty in maintaining the required object-to-lens distance. This is most critical with the strongest lens powers, in which the depth of focus is least.

(iii) Uniform illumination on the print is difficult to achieve with a short paper-to-lens distance.

Three best-form glass lenses, designed to minimise aberrations and create the largest field of view were pioneered by Lederer[17]. The magnifying powers were 2.5× 4× and 6×. Subsequent design improvements by Bennett[18] resulted in the Stigmagna range, of 3×, 4× and 5×

magnifications. This range was claimed to have less oblique astigmatism than the Lederer lenses, allowing shallower surface curvatures with larger diameters to be manufactured[56].

Lederer and Stigmagna corrections can incorporate astigmatic corrections. In the opinions of Bier[13] and Fonda[11] however, cylindrical corrections of 2 dioptres and even 4 dioptres are often unwarranted because they produce no visual improvement.

In 1956, Combined Optical Industries Limited introduced their Hyperocular spectacle magnifiers. Designed by Bennett[12] these lenses have the following advantages:-

(i) they were of acrylic plastics, and so lighter, weighing between 8 and 9 grams on average.

(ii) they had aspheric surfaces which further corrected certain aberrations, especially oblique astigmatism and pin-cushion distortion,

(iii) they were in lenticular form, and so could be glazed to larger frames.

The current range of magnification is 4×, 5×, 6× and 8×; with effective apertures of 40, 38, 36 and 34.3 mm respectively. The quoted linear fields of view under normal conditions are 85mm (4×), 65mm (5×), 55mm (6×) and 40 mm (8×). One drawback is that cylinders cannot be prescribed. However, with the recent development of the atoric plastics lens, cylinders of up to 3D can be prescribed within a lens design offering up to 5× magnification with continuous vision over the full field, and a progressive addition.

A simpler but equally ingenious lens form, first employed by Kestenbaum (63), used the established design of the cemented bifocal. For example, the lenses found in linen testers are small and powerful (from +30D to +60D), and can be cemented to a distance or intermediate base lens. An ideal adhesive for the purpose is M-62, an epoxy resin, recommended by Jessen (68) as being almost immovable and remaining crystal clear.

Some patients cannot tolerate high addition bifocals, as the blur encountered in the lower field can hinder mobility. In such cases, jewellers' clip-on loupes provide an optional solution. These clip over the spectacle lens, and because they can be removed easily, are intended for momentary use only, such as the checking of dials or gauges. Dioptric powers from 10D to 32D are available (68).

It is difficult to determine the merits of the various types of lenses. Patients requiring the same retinal image magnification may still differ in tolerance to lens aberrations; thus a lens preferred by one will be rejected in favour of an alternative by another patient. Some less critical patients are unable to distinguish between a simple biconvex lens and an aspheric lens of the same power, according to Sloan(46). She cites this reason for the present lack of agreement about which principal aberrations need to be corrected in order to benefit the majority.

3.3.1 (ii) Spectacle Magnifiers : Compound Microscopes

A divergence of opinion is also apparent among experienced practitioners, on the subject of compound spectacle magnifiers. These units increase the range of higher magnifications beyond that obtainable with single lenses.

Fonda(11) states that the design of wide-angle doublet and triplet units by Bechtold(64) is greatly superior to any similar type of lens. Fonda adds, however that they have no definite advantage over aspheric lenses for magnifications of 12× and less. Bier(13) on the other hand, states that powers in excess of 8× are usually made up as compound systems, which also frequently produce a better image at the lower powers. For any magnification, Bier notes that the clear image field is even larger with the compound lens systems than it is with hyperocular lenses.

In Britain, two rival systems dominate the dispensing of spectacle-mounted compound lenses - the 'Bier-Hamblin' and the 'Keeler L.V.A.' systems.

The Bier-Hamblin system(13) comprises aspheric lens systems made up of all-plastics or combinations of plastics and glass. Introduced in 1954-55 with magnifications of 10×-15×, the kit was extended to 2×-15×, in 1965.

When prescribing, cylinders can be incorporated into all powers except the 15×, in which the effect of strong magnification is such that the cylindrical power can be discounted.

Although the fitting set itself consists only of conventional full-aperture trial lenses, the ordered prescription can be dispensed in bifocal, trifocal or even half-eye form if required.

The Keeler L.V.A.[70] spectacle microscopes span the range from 2× to 20× magnification. The higher powers can be provided with a built-in source of illumination.

The so-called L.V.A. 10 series consists of plastics aspheric spectacle magnifiers from 2× to 8×, in two forms: either in full-aperture form, or with a crescentic area removed from the upper segment and either left clear, or fitted with a distance prescription. In effect this design is a hyperocular upcurve bifocal.

A modification of this idea is used in the L.V.A. 12 series. A reading area is tapped out from below the datum line of the plastics distance lens. An addition is made by edging down a lens from the L.V.A. 10 series, and its edge is lathe-turned to form a screw-thread matching the tapped-out area. Should vision deteriorate, the add can readily be changed for a higher power.

It is worth recalling that in aphakia or high hypermetropia, much of the magnifying power of a positive single lens will be lost in correcting the refractive error. It is in these cases that the higher-powered compound units are especially effective.

The compound lenses of the Keeler L.V.A. system are designed especially to give a flat field, although the viewing distance is extremely close.

To maintain the focus, the 6× and 8× units can be fitted with 'distance posts', viz. a transparent plastics cylinder with open sides. Therewith the reading matter can be held steady and precisely in the correct plane. Yet, for some individuals distance posts can be a hindrance (13). Patients with macular degeneration giving rise to small central scotomata often prefer to scan the print slightly. These individuals find it easier to read by shifting the print to-and-fro within the clear field.

The L.V.A. 9 system uses compound lenses giving 8×, 10×, 12×, 15× and 20×. Such high magnification enforces a close viewing distance, and as the depth of focus is only 2mm, an essential attachment is the distancing annulus provided. The problem of illumination is solved by means of a low-voltage lamp set in the white plastics annulus, which also acts to diffuse the light.

3.3.1 (iii) Rationale for Dispensing L.V.A. Multifocal Units

Low vision aids can be dispensed in half-eye bifocal or trifocal form with advantage. There is no obvious loss of near field, since only the lower half of a lens is used during reading. Multifocal corrections, by extending the range of clear vision, cause the adaptation of the patient to be more rapid. Nevertheless, a patient with a slight distance ametropia may be better suited with a half-eye correction.

The orthodox methods of dispensing employed with conventional spectacles can be applied to L.V.A. techniques. While the reading segment has to be positioned critically for height and centration in order to be most effective, the relative areas of upper and lower segments can be varied according to the demands of the tasks undertaken. For instance, an office worker might require a small upper segment having a small magnification for intermediate vision, combined with a deep near segment for desk use.

In general, although distance and intermediate corrections normally occupy the upper segments, this practice can be altered where an individual's requirements dictate: the segment with highest magnification can be selected for the upper, lower or middle section. Even so, most bifocal and trifocal units carry the distance correction in the upper section, and the reading correction below. Finally, another variation combines a reduced aperture telescope for distance or intermediate vision, within the upper section of a microscope or telemicroscope lens unit.

3.3.2 Telescope Magnifiers (Telemicroscopes)

A telescopic unit designed for low vision use must conform to the same optical criteria as simple or compound spectacle magnifiers: that is, the magnifications and field of view should be adequate, and aberrations minimal.

Although telescopes have a smaller field of view and depth of field compared with spectacle microscope lenses, they do provide a longer viewing distance. This is particularly advantageous for activities such as reading music while playing an instrument, card games, and desk work including typing.

While the asset of allowing a longer viewing distance gives the telemicroscope some protagonists[13, 71, 72], other clinicians have reservations[73, 74]. Fonda[73] believes that most cases are better aided with a high-power bifocal addition. He cites as an example 50 patients who had worn telemicroscope corrections for several years. After a trial period with strong positive lenses, all patients were found to prefer them to the telemicroscope.

Telemicroscope units in L.V.A. systems are designed primarily either for distance or for near use. Those telescopes designed as distance low vision aids have fixed tube lengths, and form too divergent a ray bundle for the average eye to focus at near. The distance telescope demands accommodation for near vision approximating to the dioptric distance of the object of regard, multiplied by the square of the power of the telescope : thus, by using a 2× telescope at 40cm, the accommodation required is $(2^2 \times 2.5)$D = 10D[46]. In practice, a distance telescope is adapted for near or intermediate use by adding extra positive power to the objective, so that the front focal point of the system is coincident with the viewing distance. The total magnification then becomes that of the telescope multiplied by that of the near addition, e.g. 2×(distance telescope)×2.5×(+10 D near cap), giving a total magnification of 5×.

Galilean telescopes designed at the outset for near use have eyepieces with a weaker power than is necessary for distance vision, which improves the image quality. Negative-powered caps are fitted over the objective when these units are used for distance.

3.3.2 (i) The Galilean Telescope

This form of telescope is the oldest and simplest, and with skilful design the most compact. This makes it especially suitable for use as a head-borne aid. Like the spectacle lens magnifiers, this device produces an upright, virtual image. The optical principle of the telescope, however, is rather more complex.

The Galilean telescope is made up of a weaker plus lens anteriorly (the objective), and a strong minus lens nearer the eye (the eyepiece). The two lenses are separated by the difference of their focal lengths, so that their focal planes are coincident. This makes the telescope afocal, since a parallel ray bundle is converged by the objective and then diverged by the eyepiece to become parallel again[75]. The relation between the angle of emergence of the rays and the angle of incidence produces the apparent increase in image size. (See Fig. 3.1).

The magnification produced is dependent on the ratio of the focal lengths of objective and eyepiece, i.e. $M = f_o/f_e$. To illustrate, if the objective is +20D (f_o=5cm) and the eyepiece is -40D (f_e=2.5cm), they are separated by 5-2.5 = 2.5cm; and magnification is 5/2.5=2×. Magnification can also be found from the formula $M=1/(1-dF_o)$, where d is the lens separation in metres and F_o is the dioptric power of the objective.

The field of view depends on;

(i) the distance at which the unit is held from the eye.

(ii) the pupil size of the user, and

(iii) the angular subtense of the entrance and exit

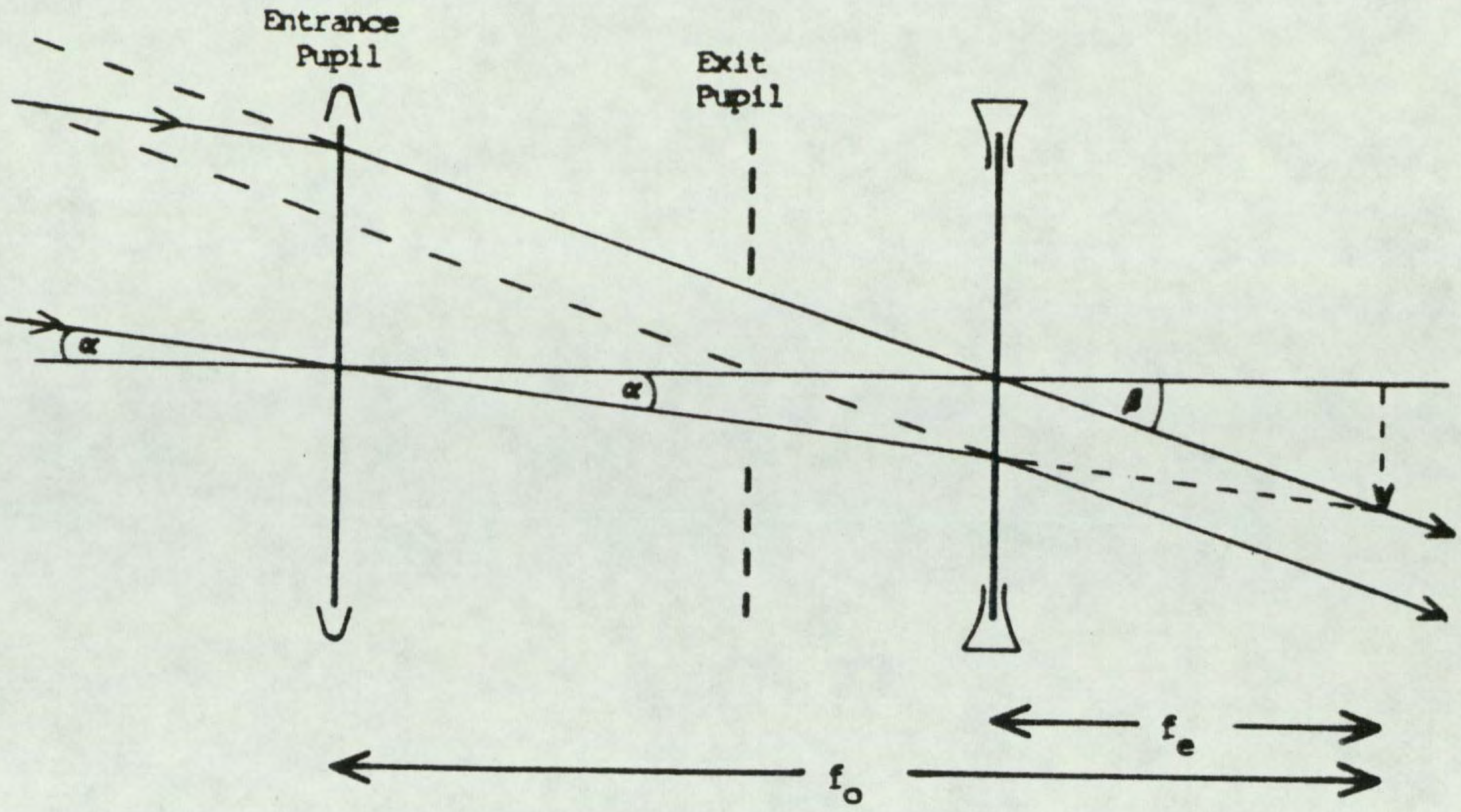

Fig. 3.1 Principle of the Galilean Telescope.

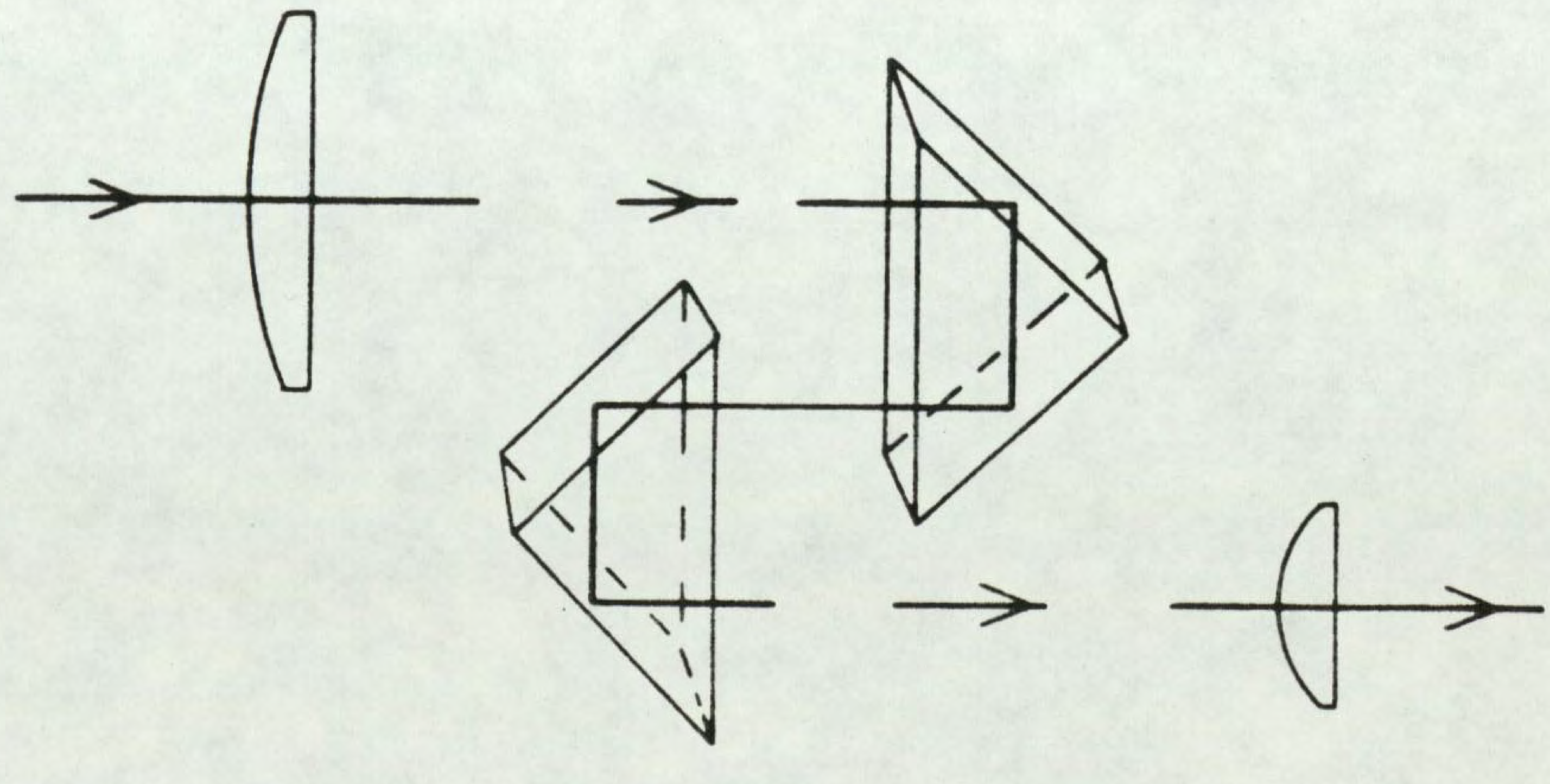

Fig. 3.2 Ray Path in the Roof-Prism Telescope.

pupils of the system at the nodal point of the eye, which are governed in practice by the objective diameter and the separation of the lenses.

Maximum field can be obtained only when the exit pupil of the telescope is at least as large as the pupil of the wearer. The field size as well as the light-gathering power can be increased by enlarging the unit, although in practice this causes a disproportionate increase in weight, leading to probable cosmetic rejection. The image field, angle 2ω, is calculated from the equation[75]

$$\tan\omega = \frac{O}{2(f_o + f_e)}$$

where O is the objective diameter.

Thus, an increase of the magnification demands an increase in the diameter of the objective if the field of view is to remain constant.

A contemporary telemicroscope based on the Galilean design, and having significant optical features was introduced in 1950 by Bennett[12]. This unit - the Stigmat telescopic - is of lightweight construction, having a plastics aspheric objective and flint eyepiece mounted in an aluminium alloy body. The objective diameter of 40mm provides a large field of about 13cm at 33 cm, with aberrations minimised by the aspheric curvature. The extra dense flint eyepiece corrects chromatic aberration.

The magnification is normally 1.75× at 33cm with three additional near caps of +3D, +6D and +9D to provide supplementary magnification, although the reading distance is decreased accordingly. Another option for increasing the magnification is to reduce the eyepiece power.

The distance correction can be incorporated into the single eyepiece lens, instead of requiring an additional cell.

By adding a -3D lens cap, the standard unit can normally be converted to distance use, the exception being when two units are employed binocularly at near and the required angling prevents this.

3.3.2 (ii) Terrestrial and Prismatic Telescopes

One alternative to the Galilean principle is the terrestrial or Keplerian telescope design. Like the astronomical telescope, this has a positive eyepiece, but with an additional third positive lens interposed between it and the objective in order to create an erect image. Higher powers are possible than in the Galilean design, although greater tube lengths are required, which means that spectacle mounts are impracticable. The field of view tends to be small, and also tends to waver when the telescope is hand-held, so that suitable stands have been devised to clamp the instrument for use when reading or typing(11,13). Some terrestrial telescopes incorporate a near-focussing lens barrel, while the less versatile ones can be fitted with a near cap of +6D or above(11, 76).

A more popular optical design used in modern telescopic aids employs a roof prism to erect the image, instead of an intermediate positive lens (see Fig. 3.2). Several manufacturers produce monocular and binocular instruments, of which the miniature monocular is the most cosmetically acceptable, since it can be concealed in a clenched fist. A near-focussing facility is built into many of the roof-prism monoculars.

For the reasons listed in section 3.3.1(i), there is a preference for aiding subnormal vision binocularly, wherever possible. The miniature prismatic binoculars manufactured by Carl Zeiss of Oberkochen, West Germany, and available as 8×20 or 6×20 models, have been especially modified for low vision and microsurgical use by Biessels(77,78). The tube lengths were shortened, from the original of 85mm, down to 55mm, so that mounting within a spectacle frame became possible; and since the weight has been reduced to 35 grams for each monocular, the fitting is not uncomfortable. The objective has been supplemented with a +16D lens, making the combined power of +28D. With the choice of eyepieces, a magnification range of 2× to 12× was obtained.

The optical design of these units is such that binocular use demands the precaution of accurate centration, to avoid horizontal or vertical diplopia. This necessity arises because of the high magnifying power, and the small exit pupils. Fortunately, Biessels outlines a simple method for ensuring the centration[77]. Furthermore, the small exit pupils in comparison with the Galilean telescope can constitute a disadvantage to the young person with average pupils. Conversely, the same attribute is advantageous to the patient with aniridia.

The over-riding advantages offered by this instrument are the high quality of the image, and the longer viewing distance, which is the important factor that allows binocular usage. Galilean systems are feasible in binocular form only up to about 3×, but with viewing distances as short as 12 or 14cm, continuous convergence is impracticable. The modified Zeiss 6× units, however, require an eye-to-object distance of 25cm, which allows comfortable convergence.

As in the case of the Galilean units, a corrective cylinder can be incorporated into the eyepiece of the Zeiss telescope. The fields of view of the two designs are similar, with the 6× Zeiss unit producing a 36mm diameter field, which is superior in optical quality, being clear to the periphery and without chromatism.

3.3.2 (iii) <u>Systems Utilising the Telemicroscope Principle</u>

Complementing the range of compound microscope aids described in section 3.3.1(ii) the most versatile ranges of telemicroscopes are provided by the Keeler and Bier-Hamblin systems.

Keeler units make up a most comprehensive range of near vision telescopic units[70]. The L.V.A. 21 reading telescopes can be used binocularly in 2×, 3×, 4× and 5× magnifications; and the 6×, 8× and 10× used monocularly. For magnifications of 2× to 5×, the viewing distance (i.e. objective to reading surface) is 140mm. This is considerably greater than for a spectacle microscopic unit. In the 8× unit it is 85mm, compared with 32mm for the spectacle lens.

The Keeler L.V.A. 22 set - described as full-field telescopes - has magnifications of 1.6× and 2× available in binocular form, and 3× , 4×, 5×, 6× and 8× used monocularly. Viewing distance varies from 175mm at 2×, down to 65mm at 8×. The useful field of this 8× unit is 28mm compared with 13mm in the L.V.A. 21 8× unit. A minus lens 'quizzer' held up to the objective allows brief periods of distance vision.

A monocular, bi-telescopic unit, L.V.A. 23, has a 2.5× distance unit inset in the upper section of the body lens, which can be selected from powers of 1.6×, 2×, or 3× for near.

The optional method of correcting for distance, intermediate or near employs supplementary caps fitted over the telescope objective. This principle, used in L.V.A. 26, gives a maximum field at each focus and from 2× to 3× magnification.

Telescopes in this system, designed for near vision have 2×, 3×, 4× and 5× magnifications. The objectives and eyepieces are made of crown and flint glass respectively. Alternatively, the distance telescopes of 1.8× and 2× can be fitted with near caps of +4, +6 and +8 and +10D.

3.3.3 Conventional Hand or Stand Magnifiers

The magnifying glass, or loupe is the oldest simplest and most flexible of all aids for the visually handicapped. Sufficient magnification, with minimal aberrations over a wide field, combined with lightness, constitute ideal qualities in these instruments. A variety of modern plastics aspheric magnifiers are available which fulfil these requirements.

3.3.3 (i) Rationale for Prescribing Hand and Stand Magnifiers

There are four main reasons for prescribing a magnifying lens:

(a) A great advantage of the hand loupe is its ready acceptance by the general public, and it is ideal for those patients who are concerned that special spectacles might draw attention to their visual disability.

(b) As an aid for intermittent use, to augment conventional spectacles when reading fine print, like fractions, footnotes, or labels on bottles.

(c) Fonda[11] comments on the relevance of the visual field : a magnifying lens is indicated for patients with fields of 10^{o} or less. A patient with constriction of the visual field gains nothing from the larger field offered by a lens of the same magnifying power in a spectacle mount.

As an illustration, a 20-dioptre biconvex lens of 36mm diameter, mounted in a spectacle frame, has a useful field of view of 45mm at a reading distance of 5cm, and 9mm when used as a hand magnifier held at a distance of 46cm. If a patient has a visual field constricted to 10^{o} - equivalent to 9mm diameter at a reading distance of 5cm - then nothing is lost by using the lens as a hand magnifier at a comfortable reading distance.

(d) Holding print close may be impracticable for patients with arthritic deformity or a hand tremor. Many of these patients find a stand magnifier easier to use, while others are simply set in the habit of supporting the reading matter either on their laps, or else flat on a table.

Notwithstanding these four advantages, the major drawbacks of the loupes compared with spectacle-mounted magnifiers are:

(a) A limited field of view.

(b) With hand magnifiers, the need to use both hands: one to hold the reading material and the other to steady the focus of the lens.

(c) The necessity, with strong hand magnifiers, to hold the lens parallel to the page as well as at the critical distance from it.

In addition to these factors, other characteristics to be borne in mind when prescribing are:-

(a) With a hand-magnifier, distance spectacles should be worn if maximum working distance is to be gained, whilst with a fixed-focus stand magnifier either a near vision correction or accommodative effort is required.

(b) For any lens, magnification remains constant, dependent only upon the separation between lens and object. This allows an individual to select any working distance, whilst observing that the field decreases as the lens-object combination is withdrawn further from the eyes, i.e. the image remains the same size, although the lens diameter subtends a decreasing angle.

(c) With stand magnifiers, when more magnification is required, it is preferable to employ a stronger lens so as to retain a normal working distance, rather than using a stronger near vision correction which enforces a shorter distance[24].

In the common situation in which the patient wears a near correction in addition to using a hand magnifier, the total magnifying power is normally always less than the sum of the two lenses[79]. The one exception occurs when the hand lens is held in contact with the spectacle lens, in which case the total power is a simple summation of their individual powers. This is demonstrated by the well-known formula[80]:

$$F_{sum} = F_{mag} + F_{spec} - c.F_{mag} F_{spec}$$

where F_{sum} is the total dioptric power of the lens system, F_{mag} is the power of the magnifier, F_{spec} is the power of the spectacle lens, and c is the distance between the two lenses expressed in metres.

3.3.3 (ii) Designs of High-Powered Hand and Stand Magnifiers

For the sake of brevity, only those magnifiers with higher powers of magnification (5× and above) will be reviewed. These are, after all, the only aids which could rival CCTV in benefitting the most severely handicapped.

One of the most popular plastics aspheric lenses is available with the option of a hand-mounting, or a fixed-focus stand mount. It has a magnification of 5× (20D) and an aperture of 48mm. A similar but smaller stand model has a higher power at 7× (28D) and an aperture of 36mm.

The same manufacturer produces two pocket magnifiers which are small enough to be concealed in the hand. Both have plastics aspheric lenses arranged co-axially, and apertures of 18mm. One is a double-lens model of 10× power (40D), while the other is an achromatic triple-lens, having 14× power (56D).

Hardly as portable, but still as useful in certain cases are the industrial stand magnifiers. These are mostly designed with a heavy base. A flexible spring arm supporting the lens allows infinite adjustment and the variable focus allows the user to wear a distance instead of a near correction. Bier[13] states that the power range is 2× to 15×, but that few models are self-illuminated.

Of the self-illuminated hand magnifiers, or so-called map readers, the most common have battery-carrying handles, while a few incorporate a mains transformer in the handle. Some have single lenses and others have compound systems. They are all intended to rest flat on a page, or other objects of regard such as needlework, postage stamps, road maps, or in industrial tasks. Magnification and field vary according to the model, but up to 12× can be obtained[13].

3.3.4 Projection Magnifiers

The earliest instruments in this category were of American manufacture, and although obsolete, they established the principles of real-image magnification applied to the partially sighted. In common with CCTV, the function of projection magnifiers is to enlarge the image of reading material, and reproduce it on a flat translucent screen by back-projection.

The outcome of co-operation with a number of interested organisations led the American Optical Company to produce one of the earliest projection magnifiers[81]. An arrangement of three mirrors, with a triplet lens interposed between them, together with a high-intensity projector lamp made up a self-contained, transportable unit. Focussing of the lens was adjusted by means of a knob alongside the screen. A Fresnel acetate sheet, 300mm×114mm served as the screen. Two choices of magnification - 3× and 5× linear - involving object aperture sizes of 92mm×35mm and 60mm×22mm respectively, were engineered by re-arranging the rear-mirror assembly and the projection lens[13].

Another early projection magnifier, the Megascope, produced magnifications of 12.5× and 25× by means of interchangeable optical systems[11,13].

A projection magnifier recently developed at Sheffield Polytechnic has brought renewed interest to the technique[82]. Known as the M.E.V.A. (Miniature Episcope Visual Aid), it uses a modern low-voltage high-intensity projector lamp, rated at 24 volts, 200 watts. Two interchangeable lenses permit magnifications from 8× to 22×. The paper variations within thick books are allowed for in the Mark 3 version by means of automatic focussing.

A fundamental advantage of projection magnifiers, shared with CCTV, is that the total or effective magnification is expressed by the product of linear magnification and relative distance magnification. Moreover, the projection magnifier, unlike current CCTV instruments, reproduces a full-colour image.

The projection method has, however, an inherent disadvantage: image contrast is attenuated, as a result of which the viewing room has to be darkened. Bier[13] regards the image contrast to be inadequate, especially where patients suffer from opacities of the ocular media, or in whom the light-sense is substantially diminished, as in optic atrophy or glaucoma.

3.3.5 Contact Lenses

The fitting of contact lenses can now be regarded as a routine clinical procedure for cases of high myopia, aphakia and keratoconus[83]. Similarly, an irregular deformation of the corneal anterior surface can often be made good with a contact lens in situ, sufficiently to restore useful visual acuity.

There are two contact lens designs with specific near vision applications to the visually-handicapped;

(i) those forming the eyepiece of a contact lens Galilean telescopic aid, and

(ii) those bifocal contact lenses with a very high reading addition.

3.3.5 (i) Contact Lens Telescopes

A high-powered contact lens (of -40D to -50D) forms the eyepiece of the system. The objective is a spectacle lens, normally of +20D to +25D and mounted conventionally in a suitable frame.

The contact lens telescope has two design advantages over the spectacle telescope, viz. a larger field of view, and an improved cosmetic appearance.

The benefits for near vision of the contact lens telescope are only of incidental concern in the reported case histories[84, 85]. This is understandable because the comparatively large field of view is mostly advantageous for distance and intermediate purposes and for gaining mobility. Furthermore, it is impracticable to remove a contact lens as often as one might a pair of reading spectacles.

When a strong near addition is added to the objective, the simple arithmetic rule for magnification can be applied in the same way as for the spectacle telescope, i.e. total magnification at near is the product of the distance telescope magnification and the effective magnification of the near addition.

Patients intolerant of wearing contact lenses are obviously unsuitable as potential users of the contact lens telescope. Otherwise the problems arise from adaptation to the induced spatial distortion and proprioceptive reorganisation.

When a high-powered contact lens shifts on the cornea, an apparent movement of the visual field is caused through the induced change in prismatic effect. The effect is mostly observed during blinking. A scleral lens has less tendency to move around on the cornea, so that it is generally preferred to the corneal lens as the telescopic eyepiece. Indeed, the corneal lens is contra-indicated in the presence of nystagmus. Moreover, patients with poor vision find the larger scleral lens easier to handle.

Similarly, the visual field also appears to move rapidly each time the patient turns his head, and to do so in the opposite direction. For this reason, some patients keep the head still when reading, and move the print instead.

Two other incidental characteristics can disturb patients; although these are more likely to be troublesome in distance vision rather than in near telescopes. The apparent speed of moving objects is increased directly with the degree of magnification. Also, the illusion of magnified objects appearing closer than they really are can be an embarrassment: instead of picking up a pen or a needle-and-thread straightforwardly, a patient can easily make one or more prior misjudgements.

Authors have noted that nystagmus is partially stabilised by the effects of a contact lens telescope(84,85). This stabilisation appears to be the explanation for an improvement in visual acuity beyond what might be expected by magnification alone(86).

Drasdo and Sabell(85) cite the presence of nystagmus as the most significant indication for prescribing a contact lens telescope. High motivation is also a necessary factor.

Bettman and McNair(16) first reported the use of a contact lens telescope as a near aid. The details of treatment for one 50-year old patient are described. Although this man had been able to use his telescopic spectacles successfully, the poor appearance and his total dependence upon them resulted in his application for several jobs to be rejected. He was fitted monocularly with the contact lens telescope, and obtained a distance visual acuity of 20/100 (6/36+) with 1.6×, using a +29D objective; and for near, with a +35D lenticular (giving 2.4×) mounted in another frame he could read Jaeger 1 print at a distance of 13.5cm. He was able to read newsprint at 48 words per minute. With his 1.8× telescopic spectacle and a +8D addition, giving 3.6×, he had only been able to manage Jaeger 2 at 35 words per minute.

Finally, a successful case using modern hydrogyl lens material is described by Weiss[87]. The patient, (whose age and occupation are not stated), was an albino with high myopia and astigmatism, and was fitted monocularly. It is interesting to compare the visual acuities achieved with various appliances: with spectacles 6/60, with a hard corneal lens 6/48, and with a 2.2× telescope 6/24 (but the patient objected to its restricted field and cosmetic appearance). A contact lens telescope using a hard corneal lens was tried, and this also offered visual acuities of 6/24 and Jaeger 7 (with a +5D addition); but even the most stable fitting permitted a wearing time of only up to four hours. After a special -58D soft lens was procured, the stability was further improved and wearing time was increased to eight hours. The patient rejected the idea of a bifocal objective, and preferred to read without the system in place. Doubtless, this was because he was highly myopic (-8D).

Weiss[87] concluded that the soft lens is a superior material for use as a telescope eyepiece, and looks ahead to the telescopic system becoming more clinically feasible with advances in contact lens material.

3.3.5 (ii) Bifocal Contact Lenses

It is practicable to employ, for monocular correction, a bifocal contact lens with a high reading addition. Bier[13] suggests a method of grinding a near segment on the external surface of a scleral lens. The segment should lie at the transition of optic and haptic, and so would be out-of-view during distance vision. For near, the patient will automatically look through the segment, owing to the superior displacement of the lens during infraversion. Magnification of 2× to 20× is possible in the segment. Bier believes the same design principle could be applied to a corneal lens, but in this case 6× would be the practical limit.

The principle of simultaneous focus, first suggested by Jessen[88], can be utilised in a corneal lens. A central near segment on the outside surface, from 2 to 4mm in diameter and so smaller than the pupil, is encircled by the distance portion. When using distance vision the patient learns to suppress the spurious image formed by the near segment. Through practice in his choice of head posture, and with lid control, the patient also learns to stabilise fixation during near vision. Magnifications from 2$\times$ to 20$\times$ are quoted as being feasible.

3.4 CONCLUSION

The choice for the prescriber between an optical aid or CCTV is not always a straightforward one with every patient. While the majority of visually-handicapped persons can utilise optical aids to achieve greater efficiency in general, this does not gainsay that the specific features of CCTV are an occasional advantage to many of the same patients. In other cases, these features are a paramount consideration. The next chapter is largely a discussion of these features, and the considerations in prescribing CCTV.

CHAPTER 4

A SURVEY AND BACKGROUND OF MAGNIFICATION USING CLOSED CIRCUIT TELEVISION

4.1 ADVANTAGES OF THE PRINCIPLE OF CLOSED CIRCUIT TELEVISION MAGNIFICATION

The characteristic common to magnifiers of every kind is the creation of angular magnification. Thereafter, a fundamental difference emerges in the nature of the image. The conventional type of optical magnifier forms a virtual image; whereas the magnifiers designed either as CCTV or optical projection instruments offer a real image, from which follow two distinct advantages - binocular viewing, and the extra angular magnification yielded by the proximity of the eye to the image.

First, binocular viewing of a display screen without excessive convergence is feasible, when the two eyes have comparatively similar acuities in the central field. The use of binocular vision presents several benefits, viz. improved visual acuity[89], a wider field of vision, and the psychological lift to the patient of using both eyes. A magnifying lens of corresponding power could be of such a thickness that the images presented to the two eyes differ in spatial projection, and in the degree of distortion[90]. A spectacle correction, moreover, may require an impracticable amount of base-in prism. For these reasons a patient may prefer to use an optical aid monocularly, even when binocular visual acuity is better than with either eye alone.

The second advantage of real image magnification is that the linear magnification displayed on the screen can be augmented by approaching the eye closer to the screen. Thus, an effective angular magnification is produced, which can be several factors larger than the linear magnification alone. The displayed letters become magnified as a function of the tangent of the angle they subtend at the eye, and the curvature of the screen.

This technique of approaching the screen extends not only the range of magnification, but also the field of view. In practice, by viewing a 60cm CCTV display monitor as close as 12cm, the field of view is increased up to 3-fold in comparison with optical magnifiers of corresponding power (Fig. 4.1), resulting in a substantial gain in the number of letters displayed at a time. This becomes especially relevant at the higher magnifications, because the display field is inversely proportional to the magnification, be it CCTV or optical magnifier. Furthermore, the number of displayed letters is significant because of its influence on the reading performance of the individual, as described in Chapter 7.

Optical projection magnifiers, such as those discussed in section 3.4, Chapter 3, have several disadvantages compared with CCTV. Much of the light reflected from the image is scattered and absorbed within the optics of the instrument, and also within the screen material. The resultant loss of contrast means that the image needs to be viewed in a darkened room. Moreover, the optical

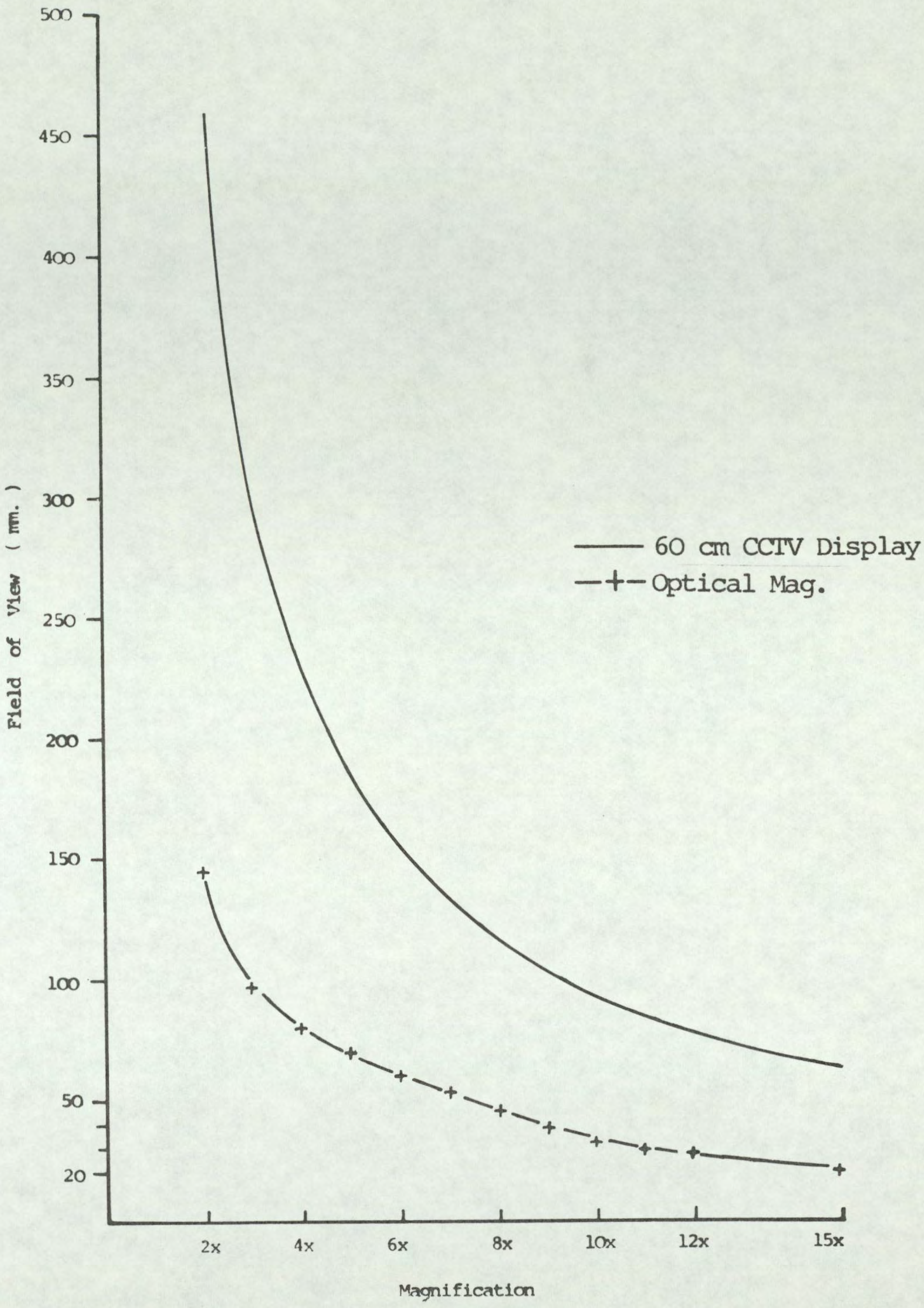

Fig. 4.1 Comparative Fields of View of Best Optical Magnifier Performance (according to Bier[13], Table 3.3) and 60 cm. CCTV Magnifier Viewed at 12 cm.

aberrations present in the higher magnifications limit the usable field of view. The clearance between lens and paper is too slight to permit the user to write and view the result simultaneously. Furthermore, considerable heat is generated by the intense illumination.

With CCTV, on the other hand, subjective brightness of the monitor display is independent of the viewing angle. The contrast can be enhanced electronically to such an extent that the image can easily be viewed with full room lighting.

Furthermore, reversal of the polarity effectively inverts the grey-scale, thereby translating normal print into white on a black background. In this way, the same information can be displayed while the percentage area of light within the field is greatly reduced. Hence the glare caused by light scatter within the eye is minimised, so that better contrast and edge definition of the characters can be expected.

Obviously, those who find the value of contrast reversal most striking are patients with opacities of the media, and especially when accompanied by photophobia. In addition, the control over the brightness of the print is beneficial to those patients with maculopathies. High illumination, with such ocular conditions, has been shown to produce an increase in visual acuity as well as in the ability to read continuous text[91-93]. Genensky et al.[94] reported that over 60 per cent of 81 subjects preferred viewing white print on black. Mehr, Frost and Apple(95) found a similar preference in 30 of their 40 subjects; and a third team in 15 out of 24 subjects using CCTV in their occupations(96), representing proportions of 75% and 63% respectively.

Genensky himself, with no light perception in the left eye, and only 20/750 vision in the right eye, writes that he is compelled to rest his eyes after 15 to 30 minutes viewing a positive image, yet he is able to read and write for hours without a break when he uses contrast reversal.

A feature common to most CCTV systems, and unique among low vision reading aids, is the zoom or variable-focus lens. Several authors have recommended a range of 5-to-1 or greater as the ideal(94,97,98). With such a lens, a large diagram or map section can be viewed as a whole, and then a selected area of it can be magnified progressively. There is none of the time delay associated with the use of interchangeable lenses. Moreover, the maximum extension of linear magnification with CCTV instruments can easily be designed to give over 25×, or even 50×, with an undistorted field. Another advantage of CCTV magnification in comparison with optical aids, is the virtual absence of aberration(74).

An added refinement effectively blanks the signal at the top or bottom of the monitor screen, separately or simultaneously, so creating an elongated 'electronic window' of variable height. This serves to concentrate attention on that line of print actually being read, although the orientation of the reader may be helped by also displaying one line above and below. This feature is analogous to that of a Prentice typoscope on a printed page[13,99].

A CCTV system makes easier those tasks requiring simultaneous reading and writing, such as verification and signing of documents, or completion of forms, as well as editing or marking students' manuscripts. In these circumstances especially, or even in normal writing, high-powered optical aids are a hindrance because the close separation between the lens and paper obstructs the use of a pen. Mehr et al[95] reported that only 25 out of 40 subjects could write legibly with their optical aids, whereas all 40 could do so with CCTV. In brief, CCTV allows a customary eye-to-object working space for the manipulation of pencils, needles and tools[100].

Finally, a notable effect of CCTV, according to a recent study by Goodrich et al.[101], is that it allows the patient a longer duration of reading. This factor did not apparently correlate with the greater viewing distances afforded. Comparing optical aids with CCTV on 42 patients, Goodrich et al. found that although there was no significant difference between the rates of reading, mean durations, on the other hand, were estimated at 34.48 mins. (S.D.±40.83) for optical aid and 105.26 mins. (S.D.±63.66) for CCTV.

The difference between mean durations was statistically highly significant. Some patients reported using their CCTV's for longer than 3 or 4 hours.

These figures were revealed as part of a study of 96 patients, with a mean age of 47.23 years (S.D.±13.56), who had used their CCTV's for periods between 2 and 7 years, with an average of 2 years 9 months. It was reported that CCTV was still being efficiently utilised by 87% of the 96 patients reviewed.

4.2 GENERAL CLASSIFICATION OF PROSPECTIVE CCTV PATIENTS

Amongst the visually handicapped, there is on the one hand a significantly large proportion of patients whose visual efficiency is enhanced to a maximum with optical aids. On the other hand, there is a much smaller proportion - Sorsby reported approximately 16 per cent[40] - whose residual vision is so slight that non-sighted methods, such as are described in section 5, Chapter 2, are the only effective means of gathering information. Neither of these groups would receive any benefit from CCTV magnification.

For the majority of patients who fall outside these two defined areas, the decision has to be made of whether CCTV or optical aid is the most beneficial. Apart from the most obvious factor of comparative visual performance with each aid on relevant tasks, other considerations have to be balanced, such as other physical infirmities and the available monetary resources.

Several interesting points emerged from a mid-1970's study performed by Goodrich et al.[102]. The results were analysed from 26 patients having an age range of 26 to 79 years, and a mean age of 51.9 years. The visual acuities ranged from 10/25 (6/15) to 10/900 (~ counts fingers at 60cm), with a mean of 10/223 (~3/60). Nineteen of the 26 ranked CCTV as their most useful aid in comparison with others, including distance and near spectacles, telescopes, and a variety of other magnifiers.

Furthermore, Goodrich et al. reveal that there is a tendency for patients not to reject the CCTV after a while, as readily as they do optical aids.

In following up 24 of their 26 subjects, Goodrich et al. concluded that all 24 used the CCTV for reading; while correspondence, 'school assignments' (reading, taking notes, memorising drama scripts), and completing printed forms came in descending order of priority. Individual users included stamp and coin collectors, and three people who used the CCTV for doing domestic repairs (including repairing a motor from a clothes drier). The mean daily use of the CCTV was for 2.66 hours, with a range of 30 minutes to 5½ hours per day.

These examples are used to illustrate the flexibility of CCTV, and the reasons that all of the subjects felt that CCTV was so useful an aid in their everyday lives.

Whereas the benefits of CCTV are undeniable, the apparent numbers of people for whom this might rank as an essential aid are debatable. The earliest estimate of the market for CCTV was given by Goldish and Marx[103] whose calculated figure was 30,000 units for the U.S.A. in 1973. This estimate was based upon the figures for total CCTV sales at that time of less than 0.1 per cent of all aids prescribed in low vision clinics. The current figure for potential CCTV users would almost certainly be higher than this.

From analysis of the statistics from four clinical papers, Goodrich et al.[102] suggested that between one in every four or five patients entering low vision clinics could be assisted with a CCTV.

Genensky[104] estimated the proportion of the U.S.A. population with useful residual vision as 0.8 per cent of the total. With a population officially estimated at 215.89 million in April 1977[105] the potential clientèle of the low vision clinics could number about 1.73 million.

Accepting the Goodrich estimate[102], then the number who could benefit from CCTV would be between 350,00 and 400,00 in the U.S.A.

The same criterion can be applied to the statistics of the blind and partially-sighted in England (given in Appendix A). Two provisos need be added: 84 per cent of the registered blind can be counted as functionally sighted;

and, according to the most conservative judgement of Cullinan[9], the more realistic figures are probably some 35 per cent higher than the official estimates. Thus, the low vision clinic population can be deduced as being approximately 185,000, with between 37,000 and 46,000 prospective CCTV patients.

4.3 CHRONOLOGICAL DEVELOPMENT OF CCTV MAGNIFIER SYSTEMS

Closed circuit television was already established in the armoury of industry by 1956, when its potentiality as a low vision aid first appears to have been mentioned. The acknowledged advantages were control of the brightness and contrast of the image, besides ample magnification[90].

The earliest public demonstration of a prototype CCTV magnifier was in January 1958, after two ophthalmologists, Potts and Volk, had collaborated with an engineer, West, in constructing a simple instrument[106]. The impetus for this original idea came about with the realisation that electronic image intensification offers the salient advantage of contrast enhancement compared with optical projection methods.

4.3.1 CCTV Magnifiers for Use by Individual Patients

The prototype of Potts et al. produced a fixed magnification of 10×. It consisted of a vertically-mounted TV camera with a Vidicon tube, and a 3-inch telephoto lens, a 14-inch monitor screen, and a flat reading-stand movable in X- and Y-axes by means of a hand-crank attached to a gear drive.

One disadvantage of the Vidicon image tube, they pointed out, is the tendency for the image to persist, resulting in a smearing of moving details, whenever the viewpoint is shifted. Potts et al. suggest that the Vidicon camera could be replaced with a flying-spot scanner, which would provide an inexpensive and robust option. This idea does not appear to have been pursued successfully by subsequent workers, possibly because of the scant depth-of-field inherent in the method, compared with the good depth-of-field possible with conventional TV cameras.

Experience with their prototype led the innovators to suggest certain technical refinements: namely a rapid return at the end of a line; a motor-driven platform for the reading material; and a foot-switch control. They added that economies could be made by utilising a domestic TV receiver.

The unique quality of CCTV magnification was subsequently overlooked for several years, until Genensky and his colleagues at the Rand Corporation in California became involved afresh in the technology, beginning in 1966[107], after which date they published several papers.

In the construction of their prototype, Genensky et al.[94] incorporated a downward-pointing camera with motor-drive, which allowed a line to be scanned either automatically, or with foot- or hand-operated controls, and also allowed a fast return motion at the end of a line. A separate motor-drive focussed the camera by raising or lowering it through a distance of 27 inches, using a hand-control. The camera mount could be rotated manually about a vertical plane, so allowing an erect image to be displayed whatever the orientation of the reading or writing matter. The camera itself was equipped with a Canon 16.5-95 mm zoom lens, offering an approximate 6:1 range in focal length.

Two symmetrically-placed 9-inch monitors were used, which could be adjusted for height, viewing distance and angle of tilt, again using a hand-controlled motor-drive. Important innovations introduced in this design were contrast reversal and the electronic typoscope.

Complex servomechanisms in the instrument introduced the drawbacks of increased expense and bulkiness. Heavy-duty motors were required in order to overcome the inertia of the components. Following the introduction of a hand-operated X-Y platform, designed by Clewett[108], the need for motors was eliminated, and the cost of the CCTV system was reduced by over 40 per cent[109].

Subsequently, a model was devised having a split platform with a common X-axis, and independent movement of the two halves in the Y-axis. The objective was to assist the CCTV user in the copying of notes onto one half, while viewing the original text on the other half[110].

Another group of workers studied the performance of 17 patients, to ascertain whether an automatic shift of the image - 3 steps per line on average - could reduce patient fatigue[111]. The conclusion was that for some patients automatic scanning was too inflexible . A design was suggested in which hand operation could be used optionally for short, incidental reading and push-button operation for long reading sessions. Ideally, a CCTV system should offer the option of automatic operation, since the dexterity required for manual use is often lacking in those elderly patients who might gain the most from CCTV[112].

While Genensky and his team were pioneering their systems, other workers were making simultaneous and independent contributions. In 1968, Weed[113] described a CCTV in which a hand-held camera was scanned across the printed page. In a later instrument[114], Weed reverted to orthodoxy by fixing the camera downward-facing on a stand, and using an X-Y platform for scanning the page. Magnification changes were made by fitting extension tubes on the fixed focal length lens.

Kuck[115] described in detail, using diagrams, the construction of his CCTV design. This was unusual in that movement both of the camera and the reading platform was possible. The vertically-mounted camera was moved in X- and Y-axes by means of a system of cranks. The reading matter was shifted along the X-axis, by means of a lever controlling the platform, through a news-column width of 2½ inches. The instrument used a 20-inch monitor, and changes in magnification were effected by raising or lowering the camera and refocussing.

Lavieri and Wilson (116) outlined the basic construction of a portable CCTV aid, in which the 5-inch TV receiver and the camera were modified and assembled within a wooden cabinet. The tuner was removed from the receiver, and in its place were fixed the camera-tube and the first five stages of the video amplifier, all mounted within a screening shield. Contrast reversal was a switchable option. The camera lens, projecting through an aperture in the side of the cabinet, focussed on the image of reading matter reflected in an angled mirror mounted on brass rails. With a 105mm lens, a magnification of 9× was obtained. A simple X-Y traversing platform was made from two aluminium plates running in bearings. The total weight of the unit, including the platform, was 30 pounds.

Finally, an ingeniously neat method of automatic line scanning was reported by Feuk (117). In this method, a so-called 'optical-head' was constructed, comprising three concentric tubes mounted on an upward-pointing zoom lens. The outer tube contained a mirror, movable in the line-scanning and line-to-line axes by means of two small d.c. motors. Another mirror reflected the image into the lens, and interposed between the two mirrors, in the central tube, was a rotating Dove prism with a collimating lens. The prism compensated for the tilting of the image when the scanning mirror viewed the beginning or end of a line. A joystick was used for control of the speed of the scanning motors. Also incorporated were adjustable margin locks, operated by microswitches which automatically interrupted the current to the line-scanning motor; and a simple device causing the mirror to return to the first line of the next page, when a page was turned over.

4.3.2 CCTV Magnifier Systems for Schools

Specialised use has been made of a complex CCTV system within a classroom of handicapped pupils. They were either partially sighted, or mentally retarded, or afflicted with both or additional handicaps. The schoolteacher-pupil relationship is reinforced, it is claimed, by this unique method of visual presentation. The pupil is better equipped to comprehend the teacher, because he can see what is being written and explained at the actual moment of writing[118].

Genensky et al.[119] described the layout and function of an ambitious, second-generation interactive classroom television system (I.C.T.S.). This comprised eight so-called 'stations' consisting of independent CCTV systems used by seven individual pupils at their desks, plus the teacher; a ceiling-mounted room-viewing camera; a video tape recorder;

a 19-inch colour TV receiver; and a master control unit. The schoolteacher has several options available when choosing the image to be displayed, and for which the master control unit serves to co-ordinate the video images from all channels. Each station monitor can display material independently from that presented on any other monitor. For example, each station can either display information input

(a) from its own camera;

(b) from the room camera (e.g. a view of the blackboard);

(c) from one of the other pupils' stations; or

(d) from the video tape recorder.

Moreover, where it is advantageous, the teacher can effect a display from any two of the ten sources, either as a horizontally split-image, or as a superimposed full-screen image with or without contrast reversal. Genensky[118] argues in favour of a horizontally-split rather than a vertically-split image on the grounds that writing and reading information is greater in the horizontal direction.

Although a colour TV system was also considered, it was later rejected because of expense, and the opinion that most classroom materials can be seen at least as clearly in black-and-white as in colour, especially since a majority of visually handicapped patients possess defective colour vision.

4.4 INDICATIONS FOR PRESCRIBING CCTV MAGNIFIERS

There is general agreement amongst the authorities in the field, that the major consideration for prescribing CCTV is when optical aids either fail completely to assist the patient[94-97,120], or else cause discomfort after a short spell.

All authorities are also agreed that the patient should be strongly motivated to read, in order to acquire the necessary skill in handling the CCTV apparatus. Mehr, Frost and Apple[95] express more precise criteria: CCTV should enable the patient to read 50 per cent faster and 100 per cent longer than with the best optical correction. If vision is too poor to allow an optical aid to be compared, then CCTV should allow a reading speed of 30 words per minute for 30 consecutive minutes. In either case it is implied that the patient gains adequate comprehension of the text. Genensky[94] states that in his experience, most partially-sighted people who begin by reading about 30 or more words per minute with CCTV, can expect at least to double their reading rate with practice. He adds that this is also likely with those reading as few as 20 words per minute, but it may not be true of persons with relatively high initial reading rates, such as 150 words per minute, because the CCTV system itself presents a limiting factor.

Mehr et al.[95] add that with CCTV the most suitable patients should be able to read 1M (8-point) print or smaller, and be able to write a letter and address an envelope legibly. Moreover, the patient should be able to operate the controls of the device independently, for reading and writing, viz. focussing, magnification change and contrast reversal.

From a total of 75 patients assessed,in clinic, Fonda et al.[120] selected 15 as suitable for benefitting from CCTV. In summarising the characteristics of the selected group, the following points were made:

1) Fourteen of the selected 15 patients had visual acuity of less than 20/320. Seven had corrected visual acuity of less than 5/200, and 2 had visual acuity of 1/200. The fifteenth, with a visual acuity of 20/200, was unwilling to accept a strong reading addition after having gained favourable experience with CCTV.

2) Eight of the selected 15 patients had found optical low vision aids inadequate for reading.

3) CCTV enabled 3 patients to use print instead of braille. For most of the group, the primary benefit came from the greater ease and endurance in reading which CCTV allowed, and not from an increase in reading rate alone. Many patients had been forced to use uncomfortable and fatiguing postures when reading with low-vision spectacles at a distance of 2 inches or less.

4) Young patients adapted more easily to CCTV. Thirteen

of the group of 15 were students under 26 years old.

5) All patients recommended for CCTV were highly motivated for reading. The exception - and the only failure of the selected 15 patients - was a 14 year old boy whose mental retardation prevented an improvement in his reading, despite the visual benefit he gained from CCTV.

In general, the literature contains few observations relating the use of CCTV to particular ocular diseases or anomalies[95,98,121].

Patients whose visual fields are restricted to a central or paracentral area, tend to fixate one word and lose the next in attempting to make normal saccades during normal reading. When using CCTV, by steadily fixating one area of the screen as the print is traversed across it, the need for saccadic movements is minimised. This observation has been confirmed in an unstated number of CCTV users with field defects, including glaucoma, tunnel field, and eccentrically-fixating right hemianopia[95,98].

For those patients in whom cataract was at an advanced stage, Blankenagel and Jaeger[121] stated that they found no improvement in the ability to read with CCTV. This seems surprising, since contrast reversal and a magnification level of 20×-25× were achievable with their system. Furthermore, Turner[98] analysed the data presented by Genensky[94] and concluded that poorer performances with of the group of 15 were students under 26 years old.

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CCTV were presented by patients with cataract, either alone or in association with another ocular disorder. In fairness however, Blankenagel and Jaeger quoted no figure for the number of cases of cataract seen; and while Genensky mentioned 18 cases, he did not quantify the degree of residual vision present in any of them. It seems regrettable that omissions of essential clinical data should have occurred when such potentially valuable conclusions have been drawn.

4.5 CONTRA-INDICATIONS IN PRESCRIBING CCTV MAGNIFIERS

In summarising the contra-indications for CCTV magnifiers with 60 of 75 patients examined, Fonda et al.[120] state that the principal reason was that their vision was too good. For such patients a portable, inexpensive and simple optical aid was as advantageous as CCTV. The level of visual acuity quoted was 'better than 20/400'. At the other extreme, patients with very low vision - acuity of less than 1/200 - were unlikely to benefit from CCTV.

Other clinical contra-indications listed by Fonda et al. were a preference for optical aids, lack of motivation, and poor ability to manipulate the apparatus.

However, amongst the 60 patients whom Fonda et al. considered unsuitable to use CCTV were 11 who, in the opinion of the present author, might be classified as border-line cases.

Five of these patients had extremely short reading distances with optical aids, ranging between 0.6cm and 6.4cm, and their reading speeds on newsprint were substantially similar with CCTV and optical aids. With CCTV, another 4 patients gained a faster rate than with optical aids, and their reading distances were increased from 1.9, 2, 3.8 and 6.4cm to approximately 15, 23, 18 and 25cm respectively. A tenth patient - a 20 year-old albino - could read newsprint quickly and at similar rates (258 and 250 words per minute with CCTV and optical aids respectively). Although his CCTV viewing distance is not stated, it is safe to assume it would have been greater than the 12.7cm used for the optical aid. Nevertheless, in this case CCTV was allegedly impractical because of glare; and yet one would have expected this particular problem would have been eliminated had contrast reversal been used. Finally, a 23 year-old with heredo-degeneration of the macula could read 6-point print with 6× optical aid at 5.1 cm, at a rate of 73 words per minute. Using 6× linear magnification on CCTV, a rate of 62 words per minute was achieved. While this was admittedly slower, less fatigue was apparent, so that reading effort would probably have been sustained for longer. Considering all 11 patients together, it should be added that their results were prejudiced against CCTV performance, since none had had any previous experience with the instrument, whereas the optical aids were familiar to the patients. No doubt, given time and practice, the benefit of CCTV would have become more apparent in each case.

Duration of reading effort was the criterion used by Mehr et al.[95] to indicate whether or not CCTV should be prescribed. Amongst the total of 40 male subjects assessed, they found 28 for whom CCTV was recommended. For these persons the mean duration of reading effort was 14.8 minutes with optical aids, and 48.3 minutes with CCTV, representing a gain in time of over 220 per cent. Of the 12 for whom CCTV was not recommended, the mean reading duration was 19.9 minutes with optical aids, and 35.0 minutes with CCTV, or a gain of slightly over 70 per cent. Subjects in both groups received at least 15 hours practice with CCTV, a trial with the recommended low vision aid; and a near vision spectacle correction where required for CCTV viewing. (Several patients were presbyopic, with ages in the range from 22 to 76 years, and a mean age of 44). There was found to be a 3-to-1 preference amongst the subjects for contrast reversal, and this was listed as one of several contributory factors in the increased duration time for reading. Other factors mentioned were enhancement of contrast; an increased depth-of-field; the improvement in posture afforded by a longer working distance; reduction of aberrations and distortions; binocularity with high magnification; and a reduction in the necessity for saccadic eye movements.

Genensky and his colleagues have been cautious in not attempting to demarcate patients into categories indicated or contra-indicated for CCTV. They tentatively stated[94] that in their experience persons who are obliged to piece words together letter-by-letter may have too slow a potential reading speed with CCTV to warrant its being purchased; and CCTV could also be inappropriate for those unable to view at least 3 or 4 letters at a time. Nonetheless, in order to show that these statements are merely flexible guidelines, Genensky et al. cited an exceptional young patient. His vision was limited to recognising only 2½ characters of typescript, when viewed at 16 inches using 2× linear magnification. Despite this handicap, he could apparently read at a rate of 35 words per minute, after an initial practice session of 5 minutes. What was responsible for the success of this patient, Genensky argued, was his over-riding motivation.

4.6 DISADVANTAGES OF THE CCTV MAGNIFIER

Clinical contra-indications apart, there are a number of intrinsic disadvantages of CCTV which can act to deter the patient. One such is the bulkiness and heaviness of the systems, which limits their portability. A partial solution is found by mounting a system on a trolley with castors. This method was adopted in constructing the heavy 60cm monitor apparatus illustrated in Chapter 8 (Fig. 8.1). In contrast, most optical aids can be carried in the pocket whenever and wherever they are needed.

Again, in the case of optical aids, a patient can be helped to select, and trained to use the most appropriate type and power in two sessions of an hour each, in the opinion of Sloan[97]. She adds that much more practice is normally required to reach maximum proficiency with CCTV. At the Wilmer Low Vision Clinic, Baltimore, all patients using CCTV in addition to optical aids required at least one month of practice before they attained their maximum skill. Moreover, at the rehabilitation centre of the Veterans Administration, in California, Mehr et al.[95] allotted a 15-hour prior training period to each veteran before determining his suitability for CCTV.

The complexity of electro-optical equipment makes it highly expensive relative to optical aids, as well as more likely to become defective. On the latter point there are conflicting reports in the literature. Friedman[112] mentioned that the mechanical complications in the CCTV instruments used by its clients were such that the Massachusetts Commission for the Blind had actually stopped purchasing any further units. On the other hand, in their protracted study of 28 CCTV patients, Mehr et al.[95] reported no breakdowns in the equipment loaned out to them. Sloan[97] revealed that a majority of CCTV magnifiers prescribed by Wilmer Low Vision Clinic 'have been used for several years without any significant maintenance problems'. Nevertheless, a few patients had experienced several failures of the equipment within the first months of use, sufficient to need repair or exchange.

Friedman[112] and Israel[122] indicate an ergonomic problem in present CCTV systems. They consider that the monitor controls of present systems are too often poorly designed and awkwardly placed. Where control knobs are in a single row, Friedman suggests that they should each be of a different shape - triangular, square, circular and rectangular - which would fulfil the recommendation by Israel that they should be located by touch alone, since many users will have insufficient vision to see where the controls are positioned.

Two other problems mentioned by Friedman are insoluble with existing systems. One is the need for frequent refocussing created by the lack of stability and flatness of a thick book. This is brought about through insufficient depth-of-field in the present generation of cameras. The other problem is the residual image left on the screen when the text is traversed, which is an inherent drawback of the Vidicon image tube. The limiting dynamic resolution of the Vidicon tube has been calculated as 10 characters per second[123], or approximately 130 words per minute. Although this characteristic is of more consequence where high magnifications necessitate a continuous movement of the X-Y platform, Friedman considers that the residual image problem is a definite limitation to the ultimate reading rate achievable.

Finally, there are two hazards to health which could conceivably arise from prolonged television viewing: X-radiation and television epilepsy. X-ray emission occurs from a TV receiver because of the high voltages employed. The criterion used to determine whether a TV receiver is safe in this respect is that at normal viewing distances and for long periods (approximately 1000 hours per year) the total body X-radiation dosage is increased by no more than 5 per cent above the natural background dosage received from cosmic and terrestrial radiation[124]. (Normal viewing distance has been defined[125] as any eye-to-screen distance between 4 times and 7 times the height dimension of the screen being viewed). The source of the X-ray emission is the accelerating voltage, which is necessary to generate the electron beam of the cathode-ray tube. This accelerating voltage can be up to 20 kilovolts, and as a general rule is directly proportional to the size of the screen.

According to Genensky et al.[126], the X-ray dosage received at close proximity to the TV monitor may be a factor of about 100 times greater than that at the normal viewing distance, so defined. However Genensky adds the reassuring statement that the X-ray emission of the receiver is very probably too low to cause a problem, but if it were to prove higher than is acceptable it could be reduced to a safe level by fitting 'a small thickness of glass over the present monitor screen'.

In a later publication, Genensky et al.[94] have quoted radiation measurements taken directly on the five accessible surfaces of three identical 19-inch monitors; using a 19-kilovolt accelerating voltage. A firm of nuclear energy consultants found the radiation field to be 0.32 microroentgens per hour. This figure comes well below the quoted criterion of 5 per cent of total background radiation, which is about 10 microroentgens per hour at sea level. On the basis of the tests and calculations, Genensky concludes that a patient does not expose himself to any radiation hazard from monochrome TV receivers operating at 19 kilovolts or less, even if he were to bring his eyes up to the implosion shield for indefinitely long periods.

The other possible health hazard - TV epilepsy - is rare. The incidence of all types of photosensitive epilepsy collectively has been calculated as one in 10,000 of the general population[127]. Studies undertaken by Jeavons and Harding[127] showed that of this number, about 70 per cent are susceptible to the flicker produced by the raster pattern, if this is viewed close enough for the lines to be resolved. Assuming a 625-line system, the critical distance would be 35 cm or less for a patient with an M.A.R. of 6'; and 21cm or less where the M.A.R. is 10', when using a 60cm screen; or half these viewing distances when a 30cm TV screen is used. This type of flicker results from the alternation of the line scanning in the interlaced television frame, and has a frequency of 25 Hz.

A diffuse type of TV flicker also occurs at 50 Hz or 60 Hz, due to the A.C. mains supply respectively in Europe and the U.S.A. Photoconvulsive responses have been shown to occur in 49 per cent of photosensitive epileptics at the 50 Hz frequency and 15 per cent at the 60 Hz frequency.

Summarising the findings, it is evident that the X-radiation from the TV receivers can be safely ignored as a risk to health, even when viewing is at close range for extensive periods. Furthermore, an estimate can be made of the probability that photosensitive epilepsy might be induced unwittingly in a prospective user of CCTV. Even if it were to be assumed that all such users could resolve the raster pattern (and with the visually-handicapped this is improbable), then the incidence could be placed no higher than 1 person in over 14,000. Furthermore, the diffuse TV flicker at 50 Hz might conceivably trigger attacks in 1 person in 20,000.

The foregoing estimates relate to the incidence of epilepsy in the normal population. The presence of central nervous system complications, commoner amongst the visually handicapped, probably equates with a higher incidence of epilepsy. This can usually be treated with medications, such as sodium valproate which does not cause any retardation of the mental processes [128]. Consequently, it can be stated that unless an intractable problem is present, the epileptic child with low vision undergoes no practical risk when using a CCTV magnifier.

4.7 FUTURE DEVELOPMENTS IN VIDEO TECHNOLOGY

In keeping with the general trends in electronic technology, the miniaturisation of components has extended into the video field. The present 'state of the art' is represented by solid state image sensors and flat displays, which considerably reduce the bulk and weight of the camera and display, and so overcome a major objection to the current instruments[129].

4.7.1 Solid-State Cameras

Engineers at Philips Research Laboratories in Surrey have produced a completely solid-state camera which operates as a digital transducer, reproducing a strictly black and white image[123, 130]. The image sensor consists of 64 photodiodes in line, on a single integrated circuit. Complete line scans are loaded into a store, consisting of a semi-conductor random-access memory of 12K bits, and housed in an electronic unit which incorporates other control and processing circuitry,separate from the camera. A television synchronisation pulse waveform is generated, to which data is added sequentially from the store to produce the composite video signal. The polarity of the data signal can be inverted if the contrast reversal mode of display is preferred.

A single horizontal line of data is used for several consecutive display raster lines, the number of which can be preselected, so that control is given to the vertical magnification. By preselecting the width of the store to be displayed, horizontal magnification also can be varied; for example, by setting the control to display the output from only the last 96 line scans instead of the total of 192 in store, the horizontal magnification is immediately doubled. The rate at which the store is sampled is adjusted in order that the entire width of the screen is still used. The composite video signal is modulated so that it can be fed to a conventional television receiver. Using a 20-inch screen, the magnification is variable from 10× to 70× vertically, and 8× to 40× horizontally.

The advantages of the camera used in this design are its relative cheapness, and that it is small enough to be held in the hand. Because it incorporates a lighting unit, the camera can be placed in contact with the surface of the reading material. The lines of print can be scanned faster than with a Vidicon camera, as electronic blurring is not perceptible.

The disadvantage of this unit arises in circumstances where shaded sketches and half-tone photographs need to be magnified. In such cases, the two-step grey scale of the instrument is inadequate for proper reproduction of the image. Moreover, any attempt to simulate an analogue output, with intermediate greys, would at the present time add greatly to the expense.

Future development of image sensor technology, on a large scale, would appear likely to employ the charge coupled device (C.C.D.) sensor[129]. The C.C.D. sensor produces a usable signal-to-noise ratio even at low light levels[131]. One prototype camera, incorporating a C.C.D. sensor, consumed only 3.4 watts of power, and measured 6×6×15cm[132]. The authors considered that the camera size could be halved by using custom-made integrated circuits in place of many of the discrete components actually used. Experimental model[133] and commercial prototype[134] colour C.C.D. cameras have recently been produced.

4.7.2 Flat Displays

As imaging devices, flat-panel displays in the form of thin-film electroluminescent devices and liquid crystal constitute the most novel technology. Both are portable devices with power consumption of about one watt or a few milliwatts respectively; but liquid crystal has the advantage of demanding a lower voltage drive level[135,136].

The merit of the cathode-ray tube however, is its proven capability. On the strength of this, a British electronics designer has recently invested in the mass-production of a pocketable monochrome TV receiver having a 'flat' cathode-ray tube. The tube is capsular, measuring about 10×5×1.9cm, and is formed from two sheets of glass The screen brightness is high, it is claimed, in spite of the limited power consumption[137, 138].

4.7.3 Digitally-Encoded Text Information

Broadcast data-acquisition systems which employ a video display (such as Ceefax, Oracle and Viewdata), have a standard of 48 alphanumeric character spaces in-line on view at any moment. Even when a 24-inch screen is used, the resultant size of the letters may be too small to be clearly resolved by some visually handicapped people.

Recent work in Germany has produced a prototype in which approximately 100 'pages' of broadcast data can be stored on cassette tape[139]. The display can either be in monochrome, or a combination of 6 colours. One line of text is made visible at a time, moving at a selected rate from right to left on the screen. The magnification of the stored text can be chosen in steps between 2× and 16× linearly, corresponding with 24 down to 3 character spaces occupying the screen.

The characters are formed synthetically within a matrix of 7×13 elements, using a character generator, and so there is no requirement for movement of a camera or a traversing platform. Thus, no smearing of the letters takes place, and there are none of the ergonomic problems which can arise in a hard-copy text when attempting to find the next line.

CHAPTER 5

THE EFFECT OF MAGNIFICATION ON VISUAL PERFORMANCE USING EXPERIMENTAL CCTV MAGNIFIERS

5.1 INTRODUCTION : RATIONALE IN THE DESIGN OF AN EXPERIMENTAL CCTV MAGNIFIER

Radical innovation in CCTV technology is limited at present, despite the possibilities for the future outlined briefly in Chapter 4, section 7. Moreover, fresh development is costly, in what is already an expensive technology. With this in mind, it was decided that the most immediate and worthwhile progress would be made by designing an instrument which could be constructed at a lower cost than contemporary commercial models but retaining their most useful features. The principal requirements were a wide range of magnification, contrast-reversal option, and a facility for writing and form-filling.

The apparatus ultimately assembled is illustrated in Fig. 5.1. The video camera and 12-inch (30 cm) domestic TV receiver employed were selected for cheapness and compactness. The double-tiered metal framework, or chassis, was designed so that the display and the working platform were confined one above the other. This attribute was not evident in any of the commercial designs then available. The main advantage anticipated from the configuration was that it would present an ergonomic advantage for writing and other manual tasks, while incidentally occupying less desk space than the commercial models.

A complete account of the design and construction of the experimental prototype CCTV magnifier is given in

Fig. 5.1 The Prototype 30-cm. Display Experimental CCTV Magnifier, showing the X-Y Platform. An Interface Unit is supported on the Display Cabinet.

Appendix B; and a short paper was published outlining the general design approach[140].

5.2 PRELIMINARY ASSESSMENT OF VISUALLY-HANDICAPPED SUBJECTS USING THE EXPERIMENTAL CCTV MAGNIFIER

5.2.1 Subject Selection and Procedure

Patients were referred for assessment from several sources - mainly local eye hospitals; and area branches of the Manpower Services Commission and the Royal National Institute for the Blind, both of which organisations are concerned with vocational rehabilitation.

Clinical history, occupation, age and motivation for using a CCTV magnifier were recorded for each subject.

The experimental apparatus described in the preceding section was used, when assessing the appropriateness of CCTV as a magnifying aid for any patient. The unit was supported on an instrument table, and adjusted for each subject so that the display was at eye level, with a viewing distance of approximately 30 cm.

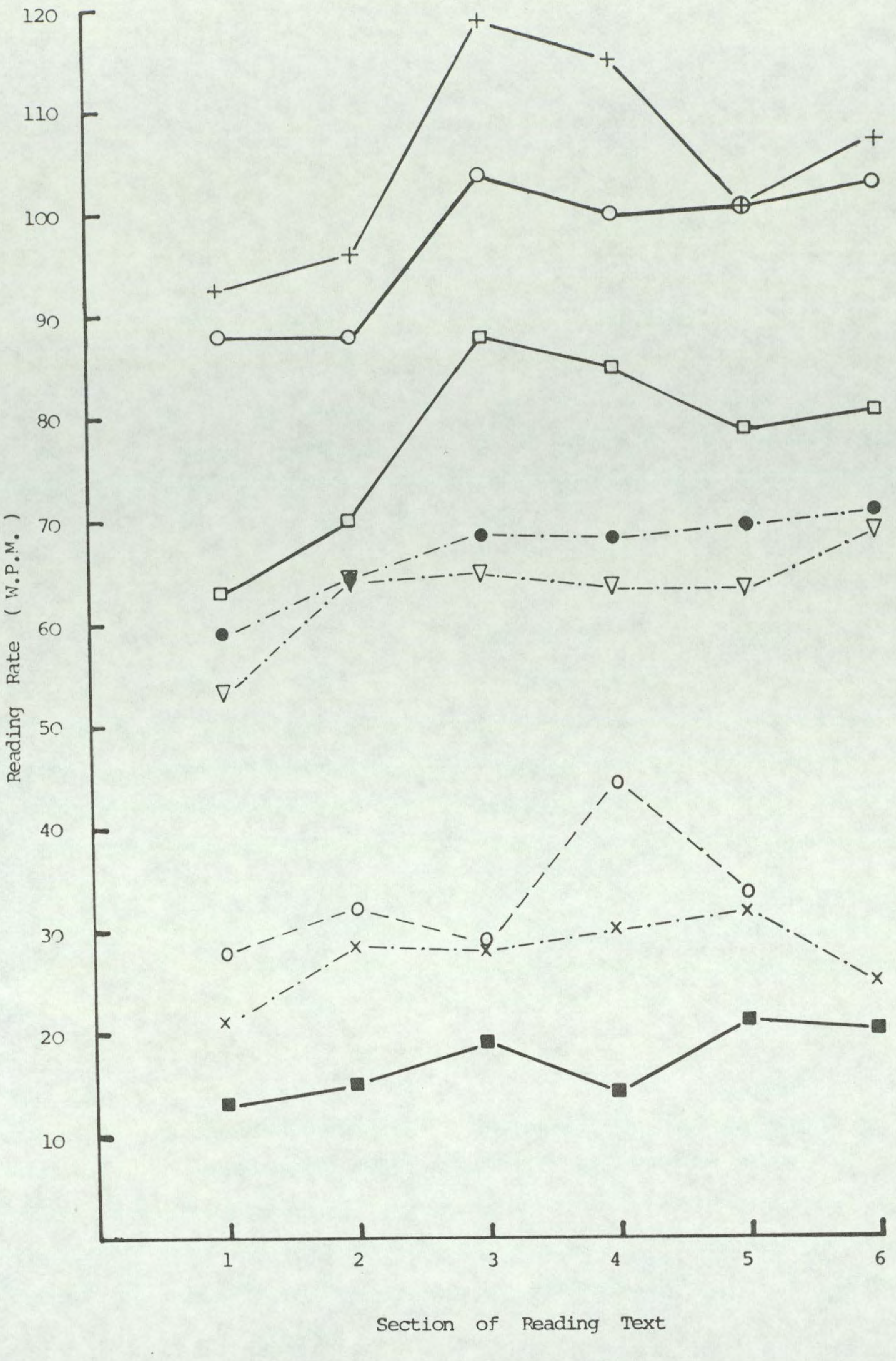
Reading material consisted mainly of specially-prepared typewritten texts, as described in Chapter 7, section 2. An example is reproduced in Appendix D. There were however, 3 schoolchildren subjects for whom large-print books from a popular children's series were used for the assessment.

Linear magnification was set initially so that the subject could adequately read a section of magnified text. The preference for the normal display mode or contrast reversal was next observed. Next, the linear magnification was slowly decreased until words became almost illegible, and then increased to a final point at which the subject remarked that reading was comfortable. This represented the linear magnification as measured.

Attention was then given to the viewing distance. In most cases the subject would feel the need to move slightly closer to the screen than 30cm; or occasionally would sit further back for postural comfort. The viewing distance was measured only whilst the subject was concentrating thoroughly on reading a text - usually beyond half-way through it.

The time spent in reading each text was noted, for calculation of the reading rate. For some subjects, reading was so laborious that time permitted reading only one text. For other subjects, six or even more 200-word texts could be managed consecutively, usually with an increase in the reading rate apparent with practice up to the third or fourth text. The pattern of variability of the reading rate is illustrated in Fig. 5.2.

For the majority of patients, ink-print was also readable using one or other of their customary optical aids. A further test of reading rate with the preferred optical



(Texts a,b,c each 1200 words length)

Subject	Text	Subject	Text
+ 36 IT	a	∇ 48 LT	b
○ 4 MN	a	O 14 JH	c
□ 42 JH	a	× 43 AB	b
● 24 BG	b	■ 30 MF	a

Fig. 5.2 Variability of Individual CCTV Reading Rate with Serially-Presented Text.

aid was undertaken on each such patient, with a different reading text, but of the same pattern, using an adjustable desk-light.

Finally, the distance visual acuity was checked on an internally-illuminated 6-metre Snellen acuity chart in the laboratory. This was also recorded as minimum angle of resolution (M.A.R.) , being the reciprocal of the best acuity attainable binocularly, (where each eye was functional).

5.2.2 Results and Discussion

From the total of patients examined on the experimental CCTV magnifier, adequate records were taken of 32 male and 17 female subjects, in the age range 10-75 years (mean age 38.8; median age 39).

A correction factor of 1.75× was applied to the linear magnification used for the print in the juvenile books read by the 3 schoolchildren. This represented the ratio of the 14-point letter to the typescript letter dimension. The corrected values are recorded in Appendix C.

Detailed results are tabulated in Appendix C. The table is divided into three sections, with each section listing the subjects in order of increasing angular magnification. In columns 5 and 9, reading rates are quoted - with optical L.V.A.'s and CCTV respectively - which apply to only the first text to have been presented, in each case.

Fig. 5.3 illustrates the frequency with which the various powers of angular magnification were selected by the subjects at their initial CCTV reading sessions.

In Appendix C, section I lists 19 subjects who would obtain more overall benefit from CCTV than from optical L.V.A.'s, and for various reasons. Section II gives details of those subjects for whom CCTV could be occasionally useful, although the expense of purchasing a model for individual use might be unjustified. Section III comprises 19 subjects who would derive no regular benefit from CCTV beyond that afforded by a suitable (and cheaper) optical aid.

As might be expected, a large proportion of those for whom CCTV was recommended - 6 out of 19 subjects - read faster with CCTV than with optical aids, and this was the major reason for prescribing. The improvement range lay between one-fifth faster (subject 15CC) and 3½ times faster (subject 14 JH). There were no figures available for the comparative reading rates with optical aids for 4 subjects.

It is also evident that improvement of the rate of reading was by no means the only criterion for prescribing CCTV. Two subjects read with almost equal speed using CCTV or optical aids, and 7 others actually read more slowly with CCTV. Three of these subjects enjoyed a better posture with CCTV: for example subject 16 HB could view at 15 cm from the display, compared with the 5 cm viewing distance with his optical aid. Furthermore, because CCTV

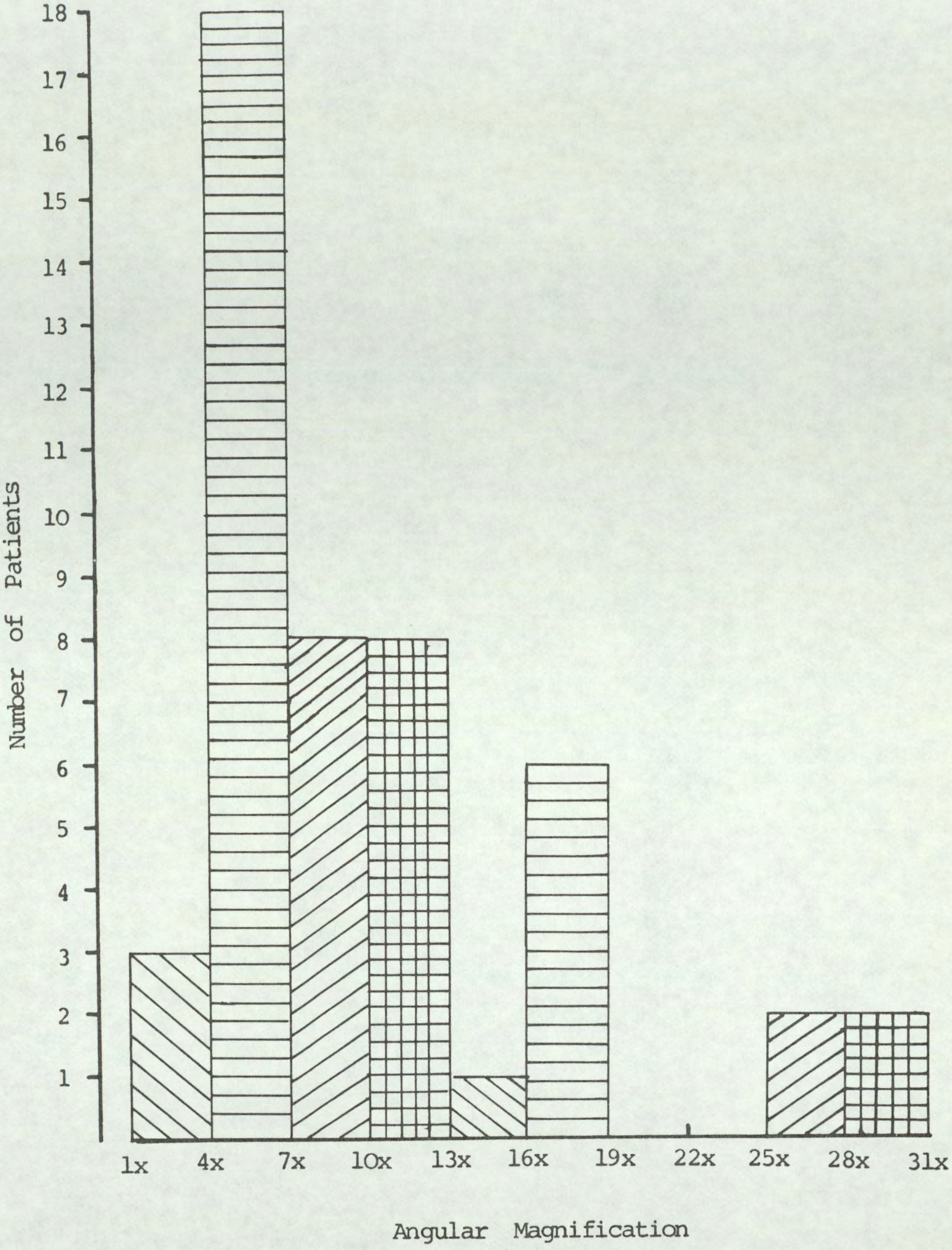


Fig. 5.3 <u>Frequency Histogram of Angular Magnifications Selected by 48 Subjects at their Initial CCTV Reading Sessions.</u>

offered a broader field of view, the rows and columns of accounts ledgers and data sheets were made easier to follow for 3 subjects. For the same reason, a mathematics master could only obtain an overall impression of graphs and diagrams in pupils' exercise books if he used CCTV. A languages teacher was helped by CCTV to distinguish accented letters; she had habitually made several errors while using her optical aid.

Several subjects commented that they found reversed contrast less fatiguing, besides which the use of contrast enhancement caused indistinct carbon or stencilled copies of typescripts to be decipherable when they were not otherwise.

Another convincing reason for prescribing CCTV was when its use caused errors to be reduced or eliminated. Although one subject (9 PC) was 20% slower in reading with CCTV compared with his optical aid, he made no mistakes in reading a 200-word passage of prose with CCTV, whereas with the optical aid he made 11 mistakes in a passage of similar length.

The 11 subjects in section II could each benefit to a limited extent from using CCTV - for instance in studying documents, or by using a less cramped reading posture - yet it was contra-indicated for one or other reason. The primary reason was its expense; but other reasons included a limited motivation in using a CCTV, and the ability to read as quickly with an L.V.A.

Most of the subjects in section III, for whom CCTV was not considered advisable, could read comfortably and more rapidly with their low vision aid (11 subjects); and one subject could read at about an equal rate with either. For 3 others, the motivation to read print was too slight to warrant prescribing CCTV, even though it allowed them a faster reading rate than their L.V.A.'s. The reading rates with L.V.A.'s were not available for the remaining 4 subjects; however, 3 of them were not motivated to read print, and the fourth could manage N.10 print with her L.V.A.

Grouping together all 49 subjects, there was a preference for reversed contrast (white print on a black background) amongst 38 persons, or 78% of the total. This majority figure is on a par with those of previous workers, as mentioned in Chapter 4, section 1[94-97].

5.3 RELATIONSHIP BETWEEN DISTANCE VISUAL ACUITY AND SELECTED ANGULAR MAGNIFICATION

The first hypothesis to be tested was that visual acuity and selected CCTV magnification were directly related. Visual acuity at 6 metres had been recorded for 48 of the subjects assessed on the experimental CCTV magnifier (see section 5.2 and Appendix C). The minimum angle of resolution (M.A.R.) was found to correlate significantly with the angular magnification selected by the subject at the initial CCTV assessment as the most suitable for comfortable reading (Pearson $r = 0.6571$; $p<0.00001$ for one-tailed test).

Accordingly, the linear regression line was drawn for predicting required angular magnification from known values of distance visual acuity; and to this were added the data points from 47 subjects (Fig. 5.4). The point for one subject (30 MF) was omitted since it had an extreme value ($x=60'$, $y=70\times$) whereas 2 other subjects with the same x co-ordinate had corresponding y co-ordinates of 10.3×, which is only slightly greater than two standard errors of the estimate. Omission of this data point appeared justifiable because subject 30MF was an habitual braille reader, relatively unpractised in reading ink-print. By comparison, subjects 10RB and 11EE were both employed as draughtsmen, and were motivated in using their optical aids. A total of only 6 data points (12.5 per cent of the sample) lay outside the boundary of ±1 standard error of the estimate, and three of these came within ±2 standard errors.

The regression equation for predicting the angular magnification (M) required at any visual acuity (x) is:

$M = 2.63 + 0.415x$, where $x>3'$

The value of one standard error of the estimate is ±8.22

It is interesting to note that of the 48 CCTV subjects with distance Snellen acuity recorded in Appendix C, only one - 31GD - selected an angular magnification corresponding precisely with that of the visual acuity, i.e. Kestenbaum's

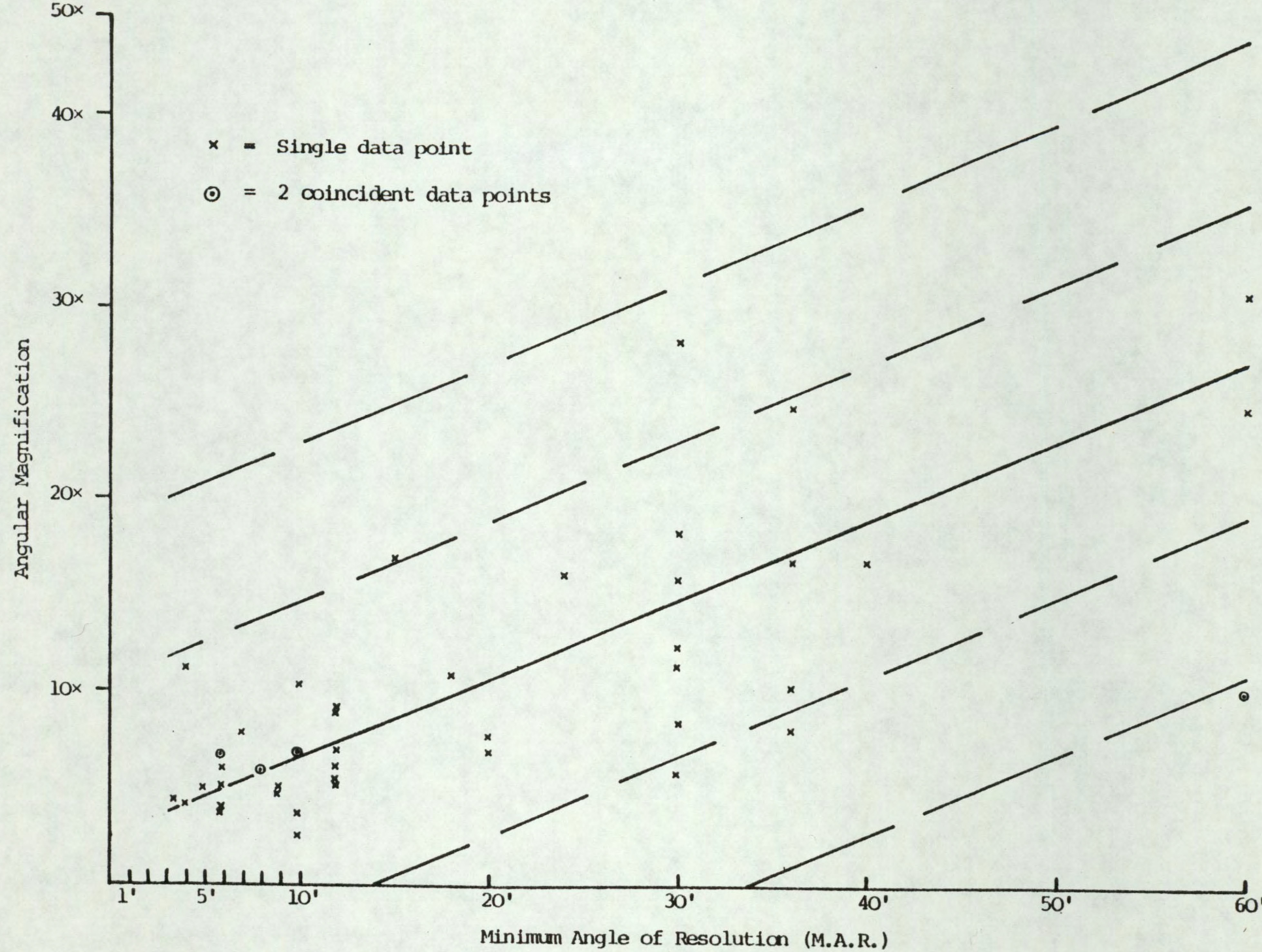


Fig. 5.4 <u>Prediction of Selected Angular Magnification from Distance Visual Acuity (M.A.R.) showing Scatterplot of 47 Subjects.</u>

rule[63] (see section 2, Chapter 3). Four subjects - 10RB, 11EE, 22PM and 43 AB - selected magnifications of less than this empirical level. The remainder, or 90 per cent of the subjects, preferred the angular magnification to be greater.

5.4 THE EFFECT OF CCTV ON EFFICIENCY IN READING

It was postulated that the reading performances may differ significantly between the use of optical aids and CCTV. Using the data contained in Appendix C, the comparative effects of reading with the subject's customary optical magnifier and with the experimental CCTV were deduced statistically. The results of 36 subjects were available to show the reading rates both with optical magnifiers and CCTV.

The subjects were divided into two groups, with those having visual acuity (M.A.R.) of better than 20' of arc separated from the remainder, who with M.A.R.'s equal to or greater than 20' are classifiable as blind in Great Britain. There were 23 subjects in the former group, whose mean M.A.R. was 9' with a range of 3.5' to 18'. In the second group the mean M.A.R. of the 13 subjects was 36', with a range between 20' and 60'.

The Student's t-test for correlated samples[141] was the statistical test employed to determine whether CCTV was a more effective aid to reading than the optical low vision aids (L.V.A.'s). With such a diversity of reading rates amongst subjects, it was necessary to transform the data so as to facilitate comparisons in the form of a statistical test. This was done by expressing the CCTV reading rate as a percentage of the L.V.A. reading rate for every individual.

Taking the 23 individuals whose M.A.R.'s were better than 20', the result of t=0.566 shows that there was no significant difference overall in reading performance with L.V.A.'s and CCTV. Conversely, for those 13 subjects with M.A.R.'s of 20' or worse, the result of t=2.572 ($p<0.05$ for two-tailed test), suggests that CCTV is of more benefit than L.V.A.'s when patients with grossly impaired vision are intent on reading ink-print.

5.5 HAND-EYE CO-ORDINATION USING THE EXPERIMENTAL CCTV

The CCTV magnifier has been claimed to provide benefits for writing as well as reading[94,95]. Certainly, there is a gain in postural comfort over most optical aids. On the other hand, those subjects who were curious to try using the experimental CCTV for writing discovered that considerable diligence was required in hand-eye co-ordination, in order to derive the most benefit from the technique. After a short period of repetitive practice, there was in most cases a rewarding improvement in the quality of the handwriting. Nevertheless, any superiority of CCTV over optical magnifiers in terms of hand-eye co-ordination tasks is probably better assessed quantitatively. An appropriate task for the purpose is the Weston Landolt-C cancelling test.

Weston[142] introduced in 1962 a visual performance task which consisted of a large number of Landolt rings arranged in a matrix, with eight positions for the gaps in the rings being randomly distributed within the matrix (Fig. 5.5). For the assessment of hand-eye efficiency the Weston task is ideal. It is simple to present on the monitor screen, and straightforward to execute since it requires the simplest of hand movements, while demanding visual search and accuracy of hand-eye co-ordination.

The CCTV apparatus made use of the 60cm display constructed for the reading studies described in Chapters 7 and 8 (Fig. 8.1). The screen was masked so as to form a display with dimensions equivalent to those of a 35cm monitor (i.e. 27cm by 21cm). This selection of a mid-screen area meant that the contrast between the ring-targets and the background was closely uniform throughout a large viewing field, which was not the case when the entire display was used on the 30cm monitor. The maximum contrast attainable in the reverse-contrast mode - approximately 70 per cent - was maintained throughout the experiment.

Eleven of the 15 subjects involved in the experiment were adults selected at random from amongst those seen for preliminary assessment with CCTV (see section 5.2.1). The

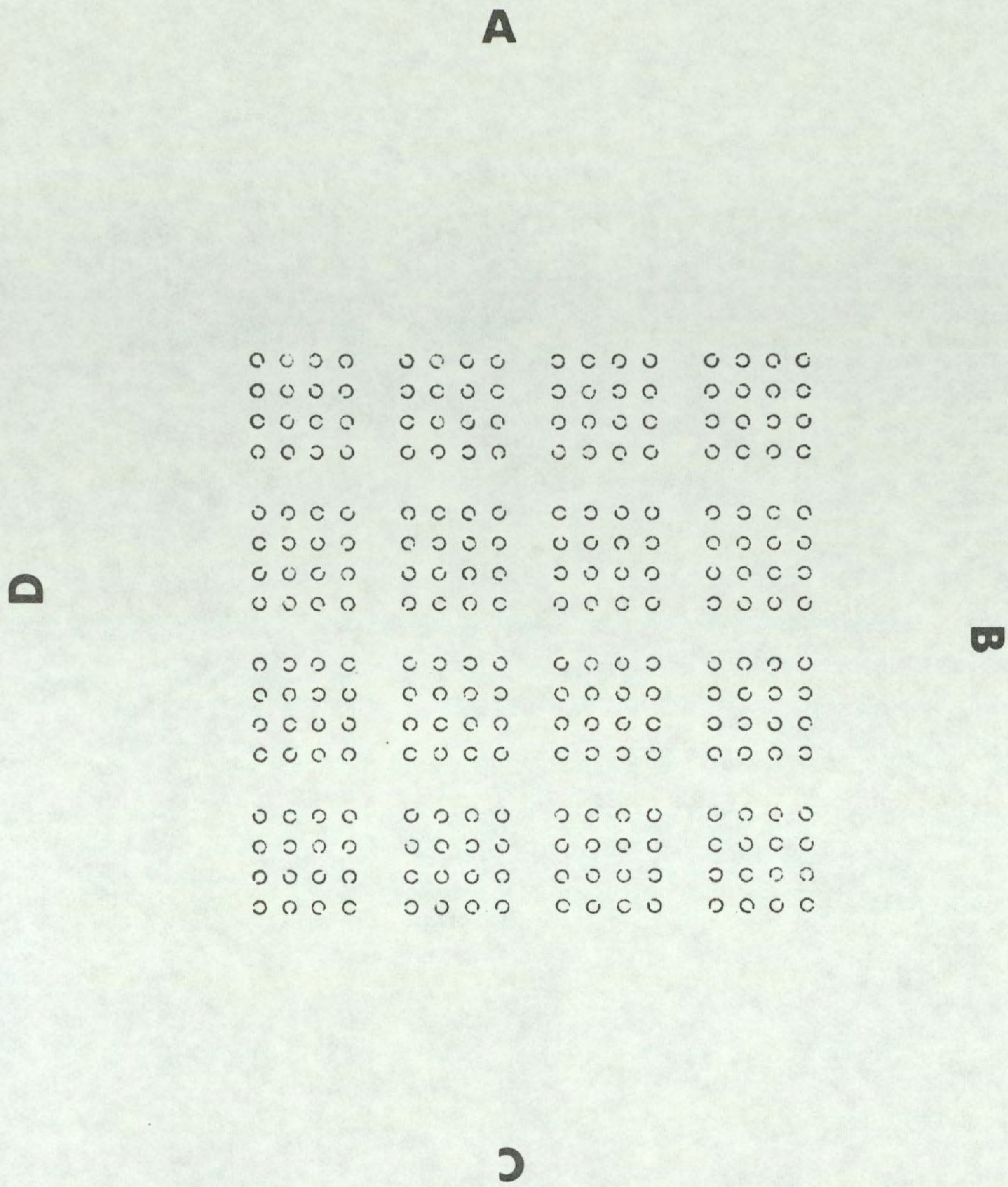


Fig. 5.5 Weston Landolt-C Cancelling Task .

other four were the schoolchildren taking part in the CCTV reading experiment described in Chapter 6. Together they represented a range of age groups, ocular conditions and visual acuities; and all were naive subjects on a hand-eye co-ordination task.

The procedure consisted of first selecting a comfortable viewing distance for the subject, and then advancing the linear magnification of the test material until the subject felt at ease in locating the gaps in the Landolt rings. The matrix was then set with the A side at the top. The subject was instructed to search the diagram as if it were a printer's proof, and to strike out with a pencil all the rings with the gap in the 12 o'clock position. Weston[142] has stated that the average normal-sighted person should complete the test in less than two minutes. However, with the combined effects of unusual presentation conditions and subnormal vision, it was thought fit to allot precisely three minutes for all subjects except one (42JH) who was so painstakingly slow that six minutes had to be allowed.

Each subject's performance was also assessed using his customary optical magnifier, together with the illumination from a shaded desk-light. The time allowed was the same as that for CCTV, namely three or six minutes as appropriate. In order to minimise the effects of bias, half of the group did the performance test using the CCTV first and their L.V.A.'s second, while the other half were instructed vice versa. The results are presented in Table 5.1, which shows the correct number of cancellations out of a possible maximum of 20.

TABLE 5.1

Landolt-C Cancelling Task: Scores with CCTV and optical aids (L.V.A.)

Subject	Age	Sex	Ocular Condition	M.A.R. (mins)	Score on Weston Task	
					with CCTV*	with L.V.A*
2 CW	35	M	Retinitis Pigmentosa/ Myopia	6'	16(I)	15(II)
6 MB	37	M	Optic Atrophy	9'	12(I)	5(II)
8 FE	57	M	Diabetic Retinopathy	6'	7(I)	3(II)
12 MW	16	M	Macular Dystrophy	10'	9(II)	2(I)
16 HB	32	M	R. Maculopathy L. ret. detachment	15'	15(I)	18(II)
27 HM	19	F	Optic Atrophy/Nystagmus	30'	13(II)	7(I)
32 FP	45	F	Post-toxaemia maculopathy	6'	10(II)	14(I)
33 SH	17	F	Macular dystrophy	12'	11(II)	11(I)
35 WG	25	M	Albinism	8'	17(I)	16(II)
36 IT	58	F	Corneal leucoma/myopia	6'	17(II)	12(I)
39 RS	42	M	Primary optic atrophy	10'	18(II)	14(I)
40 RL	15	M	Chorio-retinal degen./ nystagmus	20'	6(I)	6(II)
41 EM	13	F	Aphakia/nystagmus	7'	14(II)	18(II)
42 JH	52	F	L. corneal leucoma/ congenital cataract	20'	17(II)	11(I)
45 JS	48	M	Retinal detachment	18'	10(II)	15(I)

*Order of presentation in parentheses.

Age details: range : 13-58 years
mean : 34.1 years

Visual acuity : range : 6'-30'
(mins of arc) mean : 12.2'

Time allotted for each test = 3 mins, except for subject 42JH who was allowed 6 mins.

Visual acuity did not correlate significantly with scoring ability either with L.V.A.'s ($r=^{-}0.1758$) or CCTV ($r=^{-}0.1132$), which gave good reason to examine scoring ability directly.

The consequence of using CCTV compared with L.V.A.'s for the Weston Landolt-C cancelling task was tested by taking the results in Table 5.1, and applying the Wilcoxon signed-ranks matched pairs test. The result T=22.5 is non-significant at the 0.05 level.

There would seem to be an argument for repeating this experiment, using a selected sample of subjects with previous experience in handling CCTV as well as low vision aids.

5.6 READING AND HAND-EYE CO-ORDINATION : HOW THE TWO SKILLS RELATE UNDER CONDITIONS OF MAGNIFICATION

Using the data from the 15 subjects, reading performances were correlated with hand-eye co-ordination performances. The objective was to determine whether there was any consistent pattern of improvement with CCTV between one task and the other. In order to render the two tasks comparable, individual performances using CCTV were first expressed as percentages of the performances using optical aids, i.e. as relative reading rates (ρ) and relative numbers of correct Landolt-C cancellations (c). The resulting indices of performance using CCTV could then be directly compared for the two tasks, (Table 5.2).

TABLE 5.2

Comparative Performances in Reading and the Landolt-C Cancelling Task

SUBJECT	CCTV : L.V.A. PERFORMANCE INDEX (PERCENT)		$\sqrt{c}$
	READING RATE (ρ)	WESTON 'C' TASK (c)	
2 CW	82	107	10.34
6 MB	127	240	15.49
8 FE	240	233	15.26
12 MW	155	450	21.21
16 HB	75	83	9.11
27 HM	67	186	13.64
32 FP	112	71	8.43
33 SH	56	100	10.00
35 WG	87	106	10.30
36 IT	90	142	11.92
39 RS	84	129	11.36
40 RL	65	100	10.00
41 EM	93	78	8.83
42 JH	122	155	12.45
45 JS	64	67	8.19

The indices were first plotted in a scattergram, which revealed one outlying point (12 MW) to be discussed later. The data were then transformed with respect to the y-axis (Weston 'C' task), by taking the square root values of the indices (Table 5.2). This procedure created a more homogeneous data distribution, suited to the calculation of the linear regression (Fig. 5.6). The Pearson correlation coefficient was $r=0.6224$ ($p=0.006$; one-tailed test).

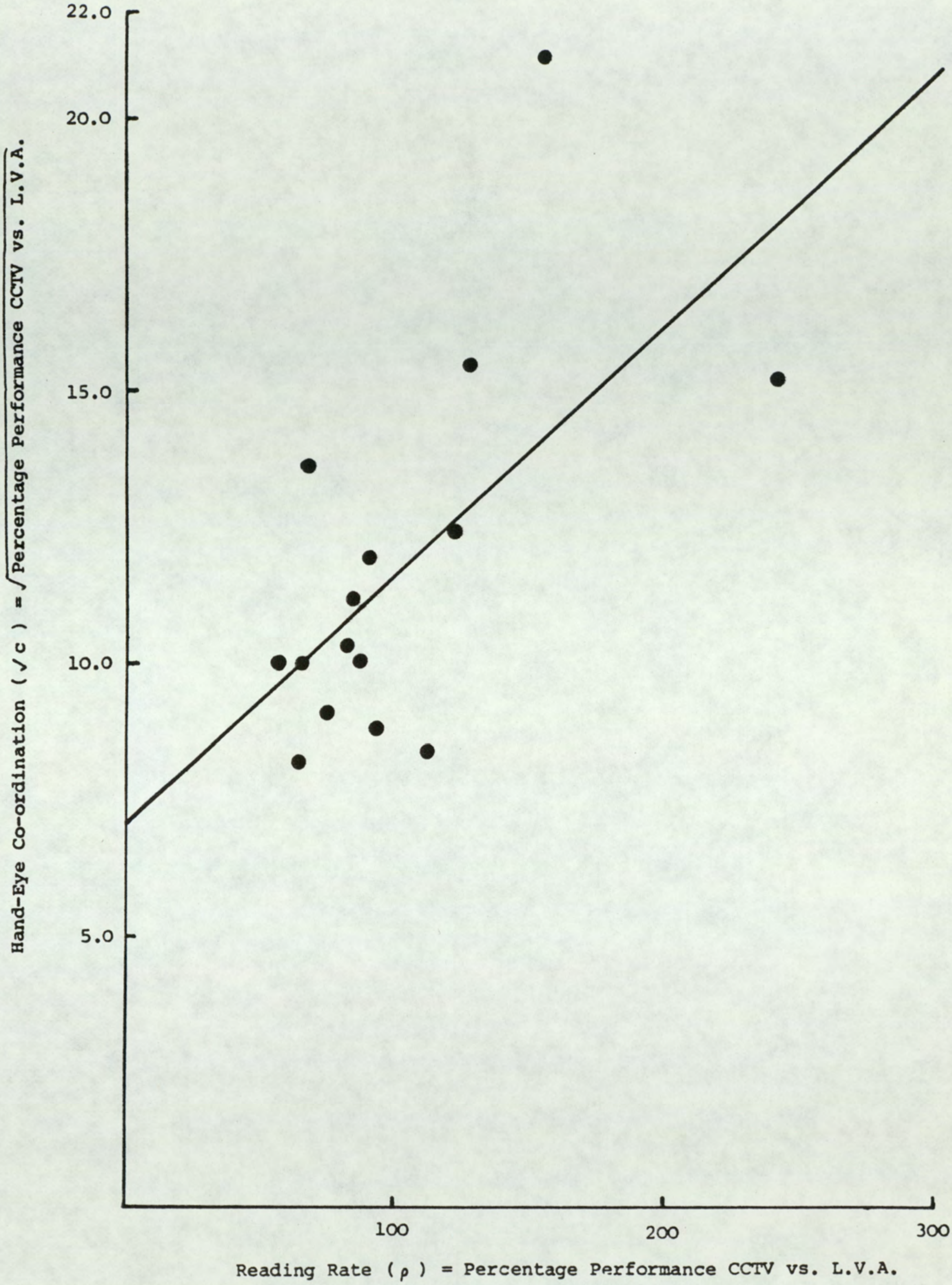


Fig. 5.6 Predictive Regression Lines and Scatterplot of Comparative Performance in CCTV Reading and Landolt-C Cancelling Task.

Fig. 5.6 shows the regression line of y on x for predicting the root of the hand-eye co-ordination task performance index ($\sqrt{c'}$), from the reading rate performance index (ρ).

The function is:

$$\sqrt{c'} = 0.046\rho + 7.11$$

One standard error of the estimate = ±2.72.

The low score for subject 12MW with his optical aid, of only 2 correct cancellations on the hand-eye co-ordination task, was undoubtedly atypical. His score with CCTV of 9 cancellations, being proportionally higher, gave rise to the discrepant point (co-ordinates 155; 450). This might have occurred because the optical aid gave inadequate magnification for the task (at 5× instead of the 10.4× he used with CCTV). Indeed, subject 12MW was rather indecisive at first in differentiating between correct and incorrect gap orientations, and he incorrectly cancelled 7 rings with gaps in the oblique meridians at either side of the correct 12 o'clock position. Furthermore, the rim of the stand magnifier could have obstructed the pencil used for cancellation. Moreover, the extremely high CCTV performance, relative to that of the optical aid on the hand-eye co-ordination task, could to some extent be accounted for by practice, since the optical aid was used prior to CCTV. In fact, when subject 12MW was monitored eleven days later, his scores on this task had increased from the original of 9 to 18 correct cancellations with CCTV, and to 12 with optical aid compared with the original of 2. This represents a more realistic CCTV:L.V.A. performance index of 150% on the hand-eye co-ordination task, compared with the original of 450%.

Using equation (i), the estimated values of the CCTV:L.V.A. performance indices were calculated for the hand-eye co-ordination task. These values, together with the practical experimental results and the percentage errors in the estimates, are presented in Table 5.3.

TABLE 5.3

Estimated vs. Experimental Values of Comparative Performance on the Landolt-C Task

Subject	Estimated CCTV:L.V.A. index on 'c' task (percent age)	Experimental CCTV:L.V.A. index on 'c' task (percent age)	Percent age error in estimate
2 CW	116	107	+ 8.4
6 MB	151	240	-36.7
8 FE	241	233	+ 3.4
16 HB	110	83	+32.5
27 HM	104	186	-44.1
32 FP	140	71	+97.2
33 SH	95	100	- 5.0
35 WG	120	106	+13.2
36 IT	122	142	-14.1
39 RS	117	129	- 9.3
40 RL	102	100	+ 2.0
41 EM	125	78	+60.3
42 JH	147	155	- 5.2
45 JS	102	67	+52.2

Seven subjects - almost half of the sample - performed equally well or better with CCTV compared with L.V.A. on the hand-eye task. Interestingly enough, the converse proved to be the case in reading, for which the L.V,A. proved superior for the same subjects (see Table 5.2). Despite this seemingly inconsistent pattern of performance on one task relative to the other, the correlation between the two was significant.

CHAPTER 6

A STUDY OF THE EFFECT OF PROLONGED PRACTICE ON THE RATE OF READING USING CCTV

6.1 INTRODUCTION

The experiment was designed to investigate the hypothesis that a period of practice elicits an increase in the CCTV reading rate.

Although aspects of reading under normal conditions and with magnification are more fully described in Chapter 7, a brief summary is appropriate. In the normal reading process, the eyes describe a pattern of saccades and fixations whose rhythm depends on the nature of the material, and germane psychological factors in the individual[143-145]. Subjects using CCTV and other forms of magnification need to adapt themselves to an unnatural reading technique, because the normal pattern of reading eye movements is disturbed, the more so as the magnification factor is increased. When using magnifiers of any type for reading, there appear to be two artifacts which limit the assimilation of information.

First, each increment in the linear magnification reduces the number of letters displayed, and thereby restricts the maximum span of recognition. (Taylor[144] states that the average span of recognition is between 1.11 and 1.33 letters of 10-point type in normal reading.) However, over a period of time, the skill is acquired of identifying word patterns, even when single letters within a word are at the recognition threshold, and as this skill is developed it may be found possible to decrease the degree of linear magnification.

The second limiting factor is the rate at which the magnifier 'window' scans the print. This rate governs the intake of word pattern information, whether scanning is manually, as in the case of hand magnifiers, or mechanically when using CCTV. The assessment of patients using CCTV revealed that the physical task of moving the traversing platform while reading from the display screen demands a concentrated effort of sensory-motor co-ordination, more especially on the part of the newcomer. This task appeared to resemble any other which involves co-ordination, in that repeated practice facilitated the skill. The evidence for this observation was that whenever new subjects were reading a series of consecutive passages, their comprehension as well as their reading rates invariably improved with each successive passage up to the third or fourth, as Fig. 5.2 illustrates.

Another factor influencing growth of reading performance is the time devoted to practice. Goodrich et al.[146] concluded from following 'a small number of patients' that peak performance is unlikely to occur until after 15 or 20 days of practice. However, no reference is made to magnification, so it is probably fair to assume that this variable was not controlled. By reducing the linear magnification as they became more adept at recognising whole word patterns, subjects would be presented with a larger span of letters, which in turn leads to faster reading (as described in Chapter 7). This reason could well explain the 20 days needed for some subjects to reach their best performances.

For the present experiment, consideration was given as to whether or not the linear magnification should be kept constant once it had been selected. Doubtless, the skill of acquiring a wider span of apprehension with reduced linear magnification, must be expected to show considerable inter-subject variability, dependent upon the degree of ink-print fluency at the first reading session, as well as the subsequent linguistic ability of the individual. In consequence, it was decided that this complex variable should be controlled: once the appropriate magnification had been determined for each subject, it should remain fixed throughout the whole experiment.

The experiment was designed to investigate how practice over several days affects the CCTV reading rate in partially-sighted schoolchildren. The results were to be correlated in order to deduce a regression equation, from which the maximal reading rate of an individual patient might be predicted.

6.2 SUBJECT SELECTION AND PROCEDURE

The investigations were undertaken at two schools for partially-sighted children. The experimental 30cm display CCTV unit occupied a fixed location within a private study room at each school.

At the first school, there were three subjects, aged 9, 10 and 15 years, and considered by their teachers to have average classroom ability. They were instructed to read on each day serial passages of similar length from popular books for children. These passages amounted to six pages of approximately 90-100 words each, to be read on consecutive days whenever possible, throughout a 22-day period. One of the children - the 9 year old - failed to attend on a majority of days and was therefore omitted from the analysis.

Four children, of ages 13, 15, 16 and 17 years, assessed as having above-average fluency by their teachers, took part at the second school to be involved in the experiment. On each day, these children read one specimen text, of approximately 200-words length, from texts specially prepared for experiments described in Chapters 7 and 8. The time course of this second part of the experiment was 12 days for all but one subject (40 RL), who was absent on the twelfth day. None of the 6 subjects had any reading experience on CCTV whatsoever, prior to this experiment.

At the first reading session, the linear magnification, viewing distance and normal or reversed-contrast display-mode were selected for each subject. These factors were kept constant throughout subsequent days. Spectacles were worn if these were normally used for reading. Wherever possible, the reading rate for each subject was recorded at about the same time of each afternoon of the experimental period.

6.3 RESULTS AND DISCUSSION

The results for the 2 subjects 23CL and 38PS in part one of the experiment are plotted in Fig. 6.1. The mean reading rate on each day of attendance is shown for each subject, together with the standard error of the mean. Figure 6.2 shows for comparison the results for all 6 subjects taking part. No standard errors were recordable for the 4 subjects in part two, because they read only one passage on each day.

All subjects showed an improvement in their reading performance over time. The reading rates for subjects 33SH, 38PS and 40RL show a continued improvement occurring even after one or more days of reading have been missed. (Days of absence are indicated in Figs. 6.1 and 6.2 with a broken line). Subjects 41EM and 12MW appear to have a fluctuating ability from one day to another. A comprehensive table showing reading achievement is given in Appendix E.

The reading rate for each subject on day 1, and the highest rate achieved during the subsequent period of the experiment were noted (Table 6.1).

It is remarkable that 5 of the 6 subjects had reached their reading rate peaks within 11 calendar days after their initial sessions. The sixth subject (38PS), although reaching his best performance on the 13th day, might have achieved this earlier had his practice not been interrupted

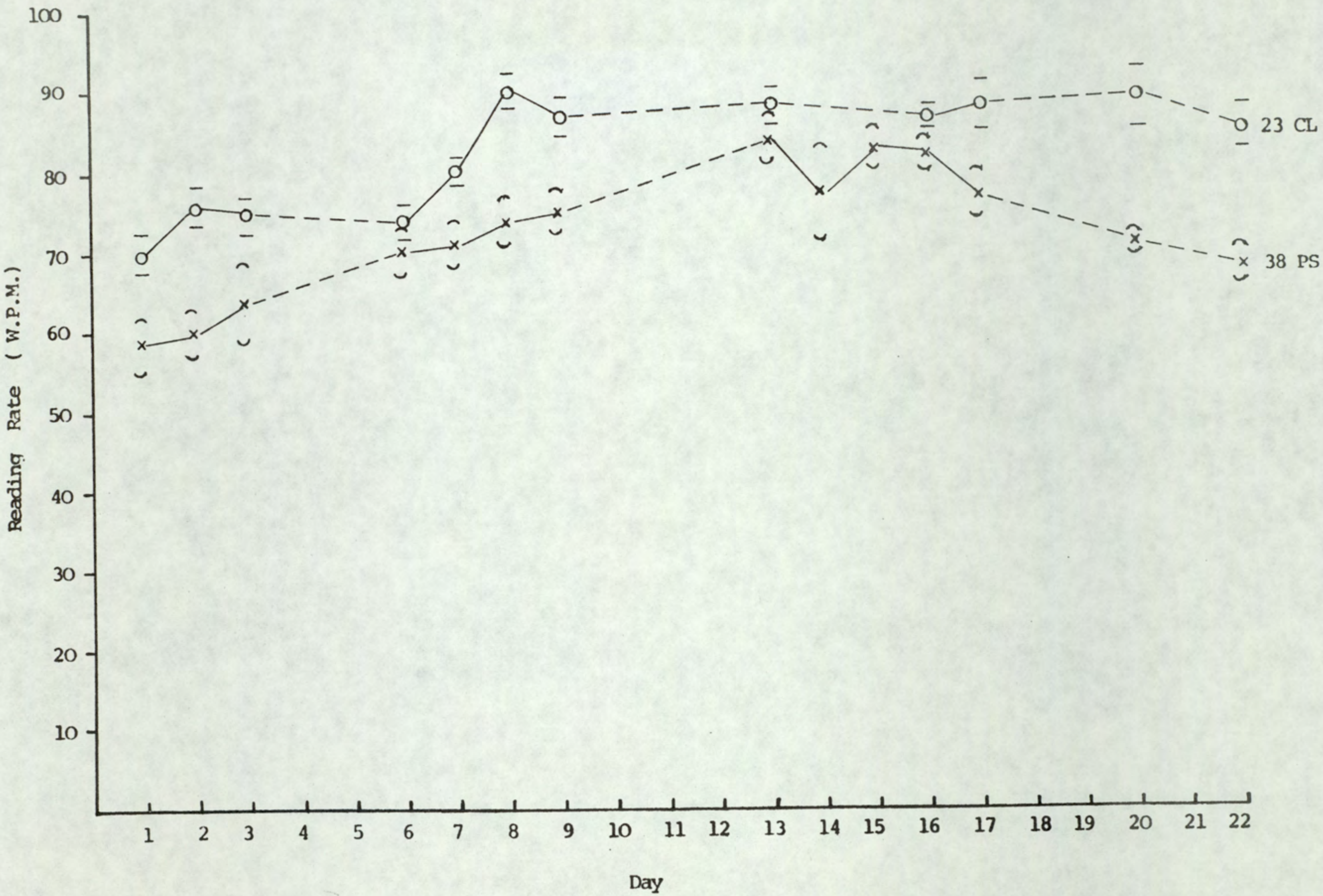


Fig. 6.1 Mean Daily Reading Rates of 2 Schoolchildren Practising CCTV Reading, showing ± 1 Standard Error of the Mean.

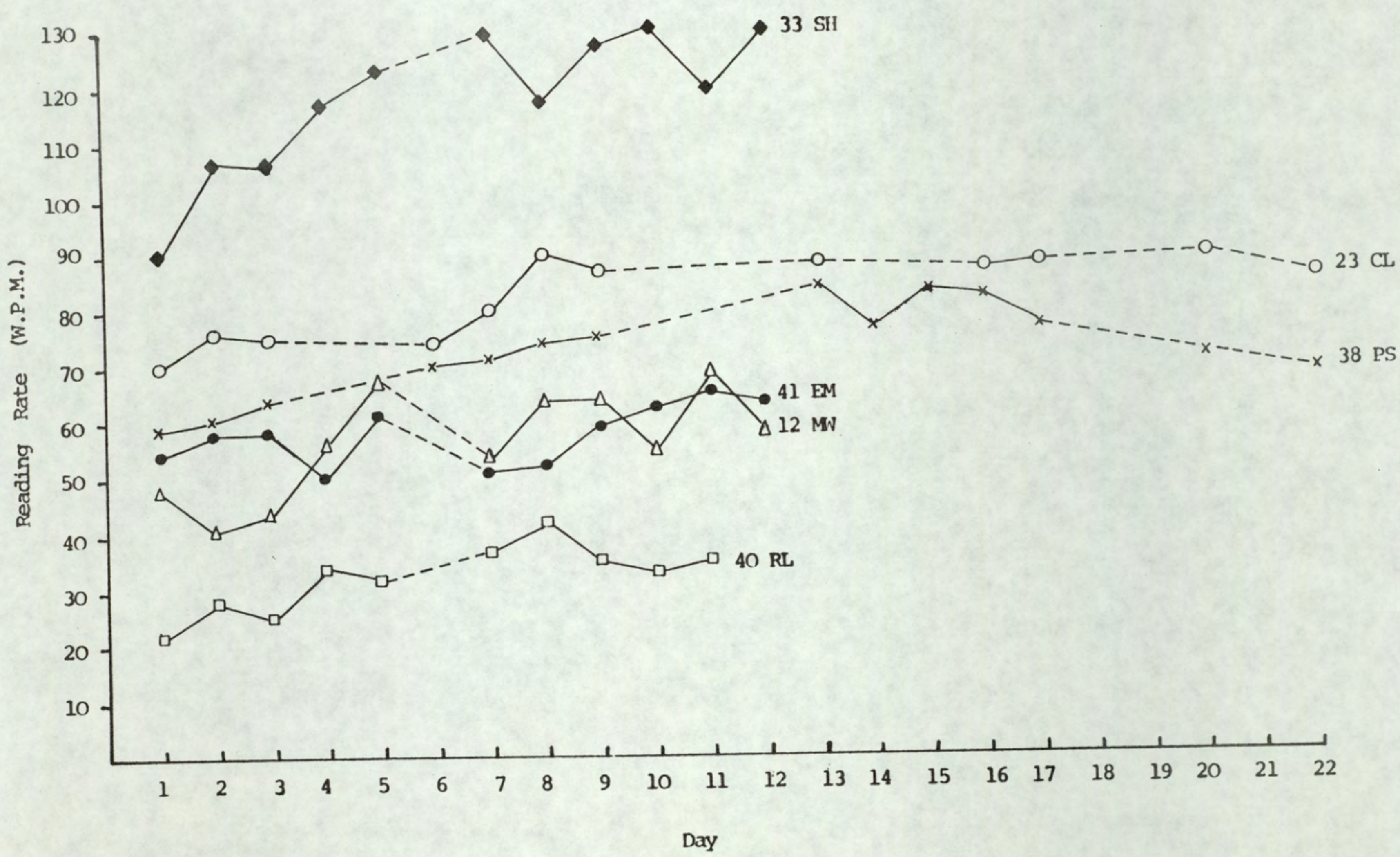


Fig. 6.2 Daily Reading Rates of 6 Schoolchildren Practising CCTV Reading.

between the 9th and 13th days. Moreover, none of the subjects needed more than ten consecutive reading sessions to reach the best performance.

The paired scores of the initial and highest reading rates achieved by each subject were used for computation of the correlation coefficient ($r=0.9683$; $p=0.0002$ for one-tailed test). From the data of Goodrich et al.[146], who studied 12 CCTV readers over 10 days, the corresponding correlation was $r=0.926$.

The regression line was calculated from the six results obtained in the present experiment (Fig. 6.3). This indicates the predicted highest reading rate achievable from the initial rate; plus the limits of two standard errors of the estimate above and below the regression line, which mark the boundaries of the results anticipated from 95 per cent of CCTV users. The points marking the results of the 6 subjects are indicated. The regression line equation is:

$$R' = 1.27R + 7.5$$

where R' is the predicted maximal reading rate, and R is the reading rate at the initial reading session. The figure by which the predicted highest reading rate differs from the actual achievement was expressed as a percentage error for each subject (Table 6.1).

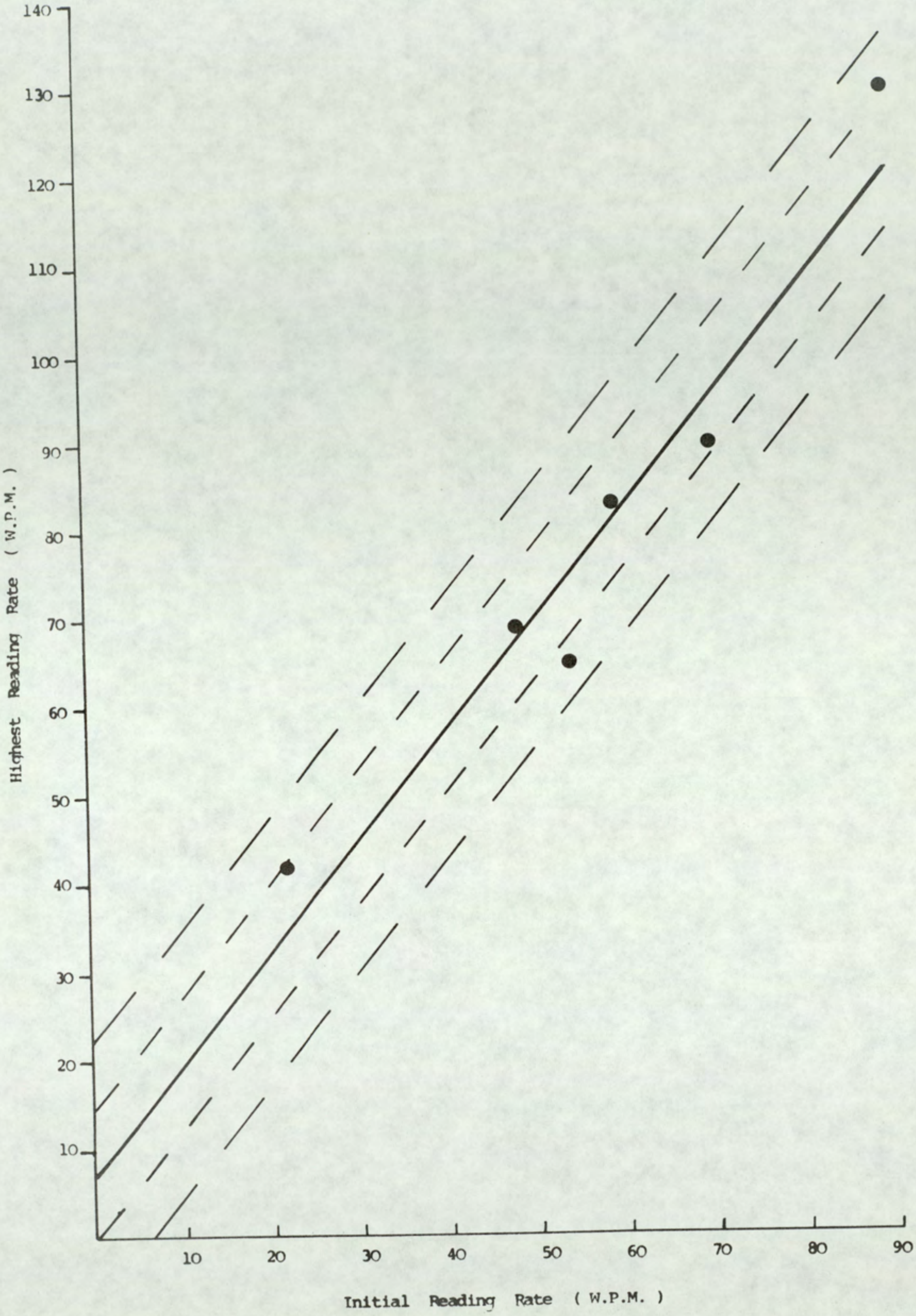


Fig. 6.3 <u>Prediction of Maximal CCTV Reading Rate from Initial CCTV Reading Rate</u> .

TABLE 6.1

RESULTS OF 6 SCHOOLCHILDREN READING WITH CCTV OVER AN EXTENDED PERIOD

Subject	Reading Rate Day 1 (W.P.M.)	Maximum reading rate (W.P.M.)	Calendar Day of maximum reading rate	Daily sessions to maximum reading rate	Predicted rate: actual rate (percent error in estimate)
C.L.	70	90	8	6	+ 6.7
P.S.	59	83	13	8	- 1.0
E.M.	54	65	11	10	+16.7
M.W.	48	69	11	10	- 1.1
S.H.	90	130	10	9	- 6.6
R.L.	22	42	8	7	-15.9

6.4 CONCLUSION

As the facility is developed by the more fluent readers for the recognition of word patterns, so linear magnification can be cautiously reduced, by degrees. Such an adjustment, by lengthening the letter-string, has the effect of increasing the reading rate. Hence, there is a possibility that in the present experiment a 'ceiling effect' occurred which limited the ultimate peak reading rate of each subject, due to the control kept on the linear magnification. The predicted reading rate is probably, therefore, a conservative estimate of what might be achieved by highly-motivated schoolchildren. Nonetheless, this experiment has illustrated that subjects with no prior experience of CCTV reading could still achieve substantial improvement in their performances with practice. Such an improvement is manifest largely as a result of the increasing skill acquired in handling the X-Y reading platform.

CHAPTER 7

THE INFLUENCE OF MAGNIFICATION ON READING PERFORMANCE

7.1 INTRODUCTION

The ultimate limit in magnification employed in reading occurs when a single word or a single letter occupies the entire visual field. While the use of such extreme magnification is unorthodox, there is yet a persuasive reason for believing that efficient assimilation of the information could take place.

The information channel capacity of the eye has been calculated as 240,000 bits[147]. However, if a mere 600 bits of information are presented, using various lettering styles, a normal eye can read at a rate of 260 words per minute (w.p.m.)[148].

Normally, the fovea plays a dominant role during reading[149,150]. This is because receptors and ganglion cells have a one-to-one relationship there,[151, 152] and this concentration of channel capacity gives rise to the superior visual acuity of the foveal region[153-155].

Nevertheless, according to the calculations of Drasdo[156], the parafoveal and peripheral retina contains 88 per cent of the total channel capacity of the eye. This leads to an initial postulation that the peripheral retina could be driven to undertake reading - at least relatively competently - provided the image is large enough for recognition. The hypothesis is upheld when the elements of language redundancy are considered. For example, individual letters and words can often be identified with a fraction of the total visual information presented ('featural redundancy')[157]. Constraints in the spelling of words themselves gives rise to 'orthographic redundancy'[158]. Finally, the whole sentence must conform to the rules of grammar and logic ('syntactic and semantic redundancy')[159,160]. All in all, a figure of 75 per cent has been quoted for the redundancy of literary prose in the English language[161].

However, in normal reading conditions, there occurs a rate of fixation, pauses and saccades as rapid as 3 or 4 per second[143-145]. When the image is magnified, information is assimilated more slowly, partly because the presentation rate is manually controlled.

Efficient reading depends upon contextual support, which in turn depends upon short-term memory. If the rate of assimilation is reduced, the data must be retained longer in short-term memory, causing even slower reading rates.

The peripheral retina may well provide a further limitation due to its slow latency of response[162,163].

The rate of processing of information via the peripheral retina therefore is controlled by several interactive effects. The variability of this rate with magnification was the subject of a two-part experimental study.

In the first part of the experiment, reading material was presented to the whole retina with CCTV, using angular magnifications of up to 1000×. This method entailed the viewing eye being close to the implosion shield of the screen. At this distance, the subtense of the displayed text was more than 140 degrees horizontally, which is referred to as a full-field image, and constitutes 98 per cent of the channel capacity in a normal eye[164]. Such a technique thereby eliminates the 'window effect' constraint on reading caused by the aperture border, which in optical magnifiers corresponds with the exit pupil, limiting the field of view. Optical magnifiers having the same power often vary in their extent of field, dependent upon their design. Thus, the experimental technique avoided such confounding effects.

The significance of increasing the linear magnification - that of the displayed image alone - is to decrease the number of letters displayed with an inverse proportionality. This is apparent from Fig. 4.1, Chapter 4. In the second part of the experiment, the number of letters seen simultaneously was varied while their size was kept constant. The objective was to isolate the specific effect of magnification, by comparison of the results from both parts of the experiment.

7.2 SELECTION OF THE READING MATERIAL

For the appraisal of reading rates, Tinker[149] recommended that texts should be about 100 to 150 words long. For greater accuracy, particularly since a wide range of reading rates against magnification was anticipated, it was considered that all texts should be of about 200 words. Thirty-five texts of easy narrative prose were selected from magazine and newspaper articles of general interest. These were edited by substituting short synonyms for long words; words for numerals; and complete texts were shortened if necessary - all to fit the constraint of a nominal 200-word length.

The factors with most influence on the legibility of type are its size, stroke thickness, style of typeface, and spacing[165]. When the print can be magnified, as in this experiment, the type size itself is immaterial. A medium-bold sans-serif typeface apparently elicits the best reading performance from adults and children with various ocular defects[166,167]. Moreover, an early study [168] showed that when white print is viewed against a black background, sans-serif print suffers less blurring from irradiation (the halation effect of a bright object stimulus contrasted against a dark background).

I.B.M. 'Artisan' was selected as the best style fulfilling the typeface criteria, and further, was readily obtainable with an electric typewriter. Unfortunately, a typewriter offers little control over the inter-letter spacing. However, it was considered that the largest span of letters within a given space would aid recognition of the whole word pattern. Accordingly, a 12-pitch spacing (12 letters per inch) was selected, rather than the alternative 10-pitch. For the same reason, lower-case rather than upper-case typeface was selected to produce more familiar and distinctive word patterns[165,169,170].

The number of character spaces was chosen to simulate that of the average paper-back book, i.e. approximately 60 per line of type, avoiding the hyphenation of words wherever possible. Each text was typed on a single sheet of white bond A4 paper, using double spacing, and an average of 20-22 lines in total.

A specimen reading text is reproduced in Appendix D.

7.3 METHOD

Four postgraduate students with normal visual acuity acted as subjects. Thus, a degree of control was exerted over the variables of intelligence, fluency and capacity of short-term memory. The subject's preferred eye viewed the display screen centrally, and the other was occluded.

In studies using a variable span of the letter-string, previous workers had concluded that the reading rate asymptotes maximally with a display of 25-30 letters per line[150, 171]. Hence, for the present experiment the maximum display size was selected as 32 letters.

Throughout the experiment, magnification was defined in relation to 12-pitch typescript, in which 12 letters occupy 25mm line width. Obviously, where the typeface parameters differ from this, then more or less letters are displayed for a given magnification. For example, there are, on average, about 18 letters of 8-point newsprint, and 24 of 5-point print in a 25 mm line.

Reversed contrast was used to create enhanced white character forms and reduce overall glare. The mean luminances of the characters and background were 80 and 4.5 candelas/sq. metre respectively, measured at mid-screen: this represented a contrast of 94 per cent.

An X-Y platform (described in Appendix B) was used for scanning the texts. The subject therefore had control over the rate and direction of motion of the reading material.

For the first part of the experiment, texts were read at each of nine discrete levels of magnification, forming a geometric progression between 6× and 1000×. The 30 cm experimental CCTV magnifier, (described in Appendix B) was used for reading at all magnifications except 1000×, for which the 60 cm display was used, as described in Chapter 8.

Each reading was vocalised to aid monitoring, and three questions were asked afterwards to check comprehension. A break of several minutes was given between readings. The order of presentation of each magnification condition was randomised amongst the subjects, so as to balance practice and fatigue effects.

Using an established electro-oculographic technique[172], for one of the subjects, the reading eye movements were recorded on one channel of a pen recorder at six levels of magnification (Fig. 7.1). Ideally, the eye movements for all 4 subjects would have been analysed, but this was prevented by lack of available time, and was not a primary aim of the experiment. The second channel of the pen recorder produced a synchronous signal of the line-traverse of the X-Y platform, which was engineered as follows.

A 10-turn linear potentiometer (10 K-ohm) was connected with a D.C. power supply (set to output an arbitrary 3 volts) and in series with a 50 K-ohm linear potentiometer. A rubber pulley-wheel was fitted onto the spindle of the 10 K-ohm potentiometer so as to make a friction contact with the underside of the X-Y platform. This acted to transduce the line movement, from a mechanical state to a change in the electrical potential which served to power the pen recorder. The 50 K-ohm potentiometer functioned as a sensitivity control. It was pre-set prior to the experiment,

Fig. 7.1 Recording Reading Eye Movements with CCTV Magnification.

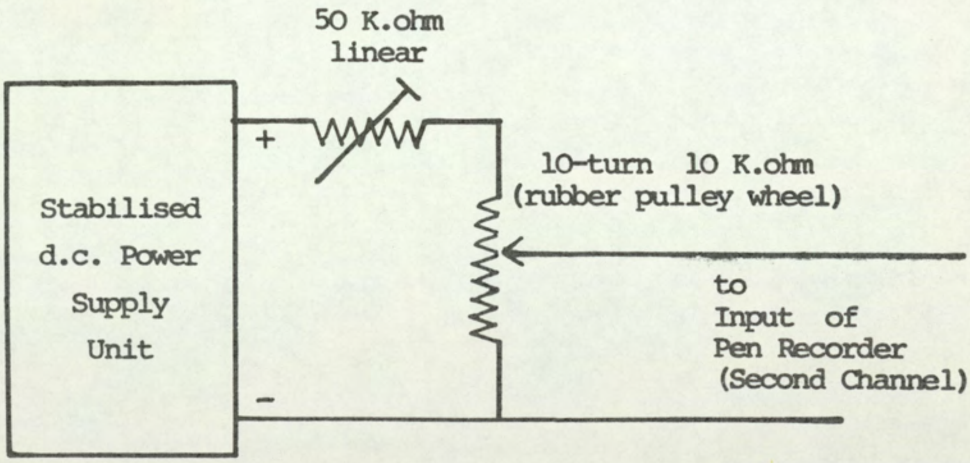


Fig. 7.2 Electrical Circuit Diagram of X-Y Platform Movement Transducer.

so that a complete line traverse was signified by a full-scale deflection of the pen recorder. The electrical circuit is illustrated in Fig. 7.2.

The second part of the experiment was a CCTV simulation of normal reading, using text subtending an appropriate angle at the fovea and parafovea.

For efficient normal reading, Paterson and Tinker[173] found that 12-point print had the greatest flexibility of line widths and inter-line spacings. If an average reading distance of 40 cm is assumed, then a CCTV display of 32 letters width, with each symmetrical letter (e.g. 'O') 7 mm diameter, when viewed at 128 cm, provides a stimulus with angular dimensions corresponding to the normal reading situation. A forehead rest enabled the subject to maintain this viewing distance.

To produce a variable length of the letter-string, opaque masks with apertures having 16, 8, 4, 2 and 1 character spaces were placed in front of the display.

The subjects were those who took part in the first part of the experiment.

7.4 RESULTS AND DISCUSSION

The results are shown in Tables 7.1, 7.2 and 7.3. The reading rates of the four subjects were averaged and plotted to produce a model (Fig. 7.3). The best fit curves were determined by computation. The continuous curve, representing reading rates under the conditions of magnification, takes the form:

$$R = 5.15\ m^3 - 82.7\ m + 131$$

where R is the reading rate in words per minute, and m = log (angular magnification/6).

TABLE 7.1

Results with Magnified Image

Viewing Distance (Eye-Display) (cm)	Linear Mag. (on Display)	Angular Mag.	Letters Visible per Line in Display	Letter Subtense at Centre Display	Mean Reading Rate (W.P.M.)	Standard Error of Mean
14.6	3.5×	6×	32	3^o	131	9.6
14.6	7×	12×	16	6^o	100	11.4
3.5	3.5×	25×	32	12^o	89	8.8
3.5	7×	50×	16	24^o	65	5.7
3.5	14×	100×	8	46^o	42	3.0
3.5	28×	200×	4	81^o	20	2.9
3.5	56×	400×	2	120^o	15	2.3
3.5	70×	500×	1	140^o	9	1.1
2.5	100×	1000×	<1	155^o	3	0.5

The broken-line curve in Fig. 7.3 reveals that the fovea processes the word input more efficiently than the peripheral retina at all letter spans. Absolute

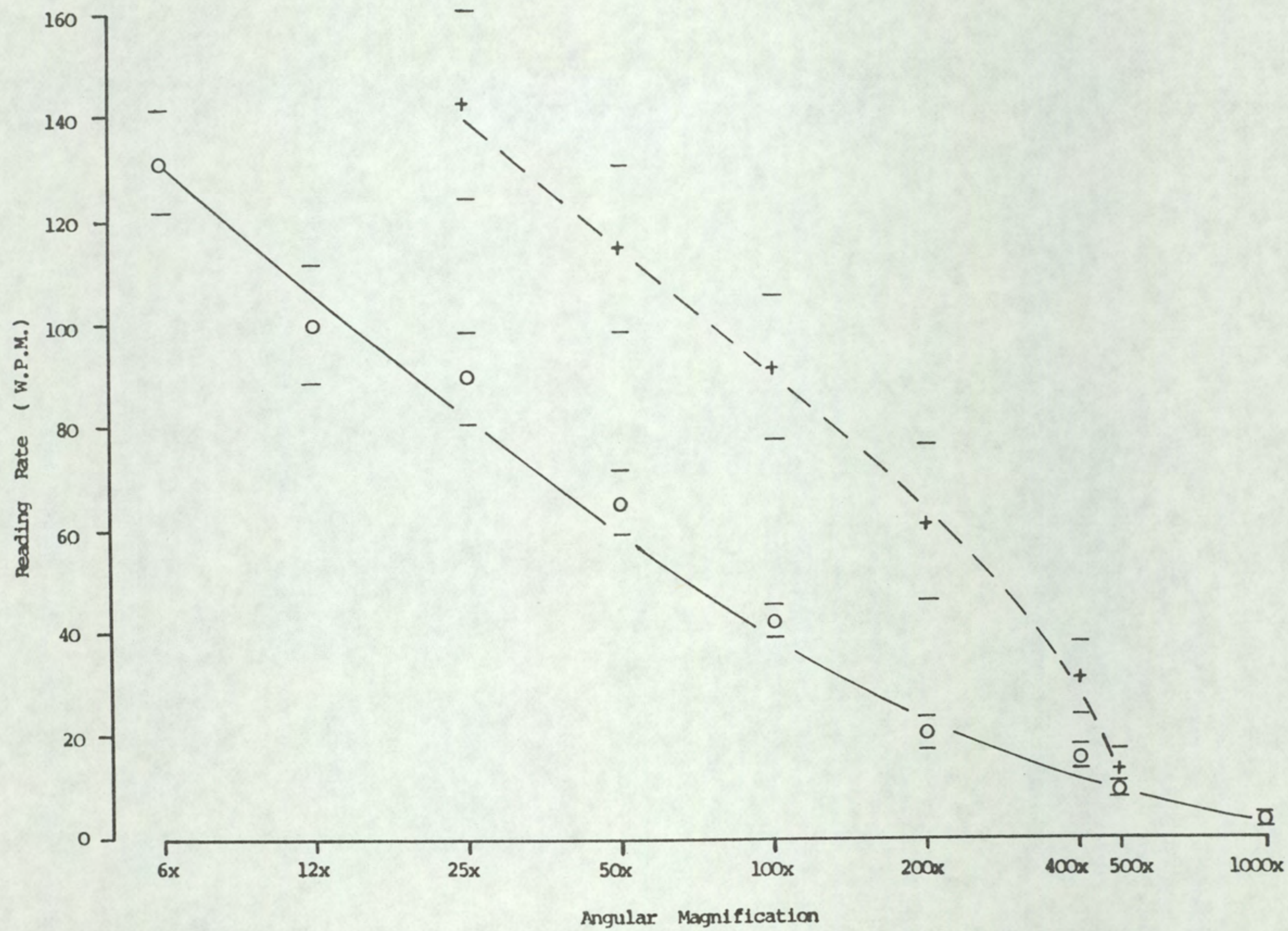


Fig. 7.3 Mean CCTV Reading Performance of 4 Normal Subjects under Magnified (o) and Non-magnified (+) Conditions showing ± 1 Standard Error of the Mean.

reading rate drops markedly as the number of character spaces falls from 2 to 1. A slowing down of the manual scanning occurs because only the single letter shape - not the syllable or word - supplies the featural information. Moreover, the presentation of one letter is the least efficient means of loading short term memory, and regressions to recheck preceding words were more frequent.

TABLE 7.2

Results of Simulated Normal Readings

Aperture Size (Letters)	Mean Reading Rate (W.P.M.)	Standard Error of Mean
32	142	18.0
16	114	16.2
8	91	14.4
4	61	15.2
2	31	7.0
1	13	3.5

The proportional difference in reading rates between foveal and full-field retinal processing is most marked at 4 letters (Fig. 7.4). This is the span of recognition of the fovea itself under these experimental conditions and so represents the optimal information input[174]. Displays of 1 and 2 letters are notably lacking in information, which hinders central processing. As a result,

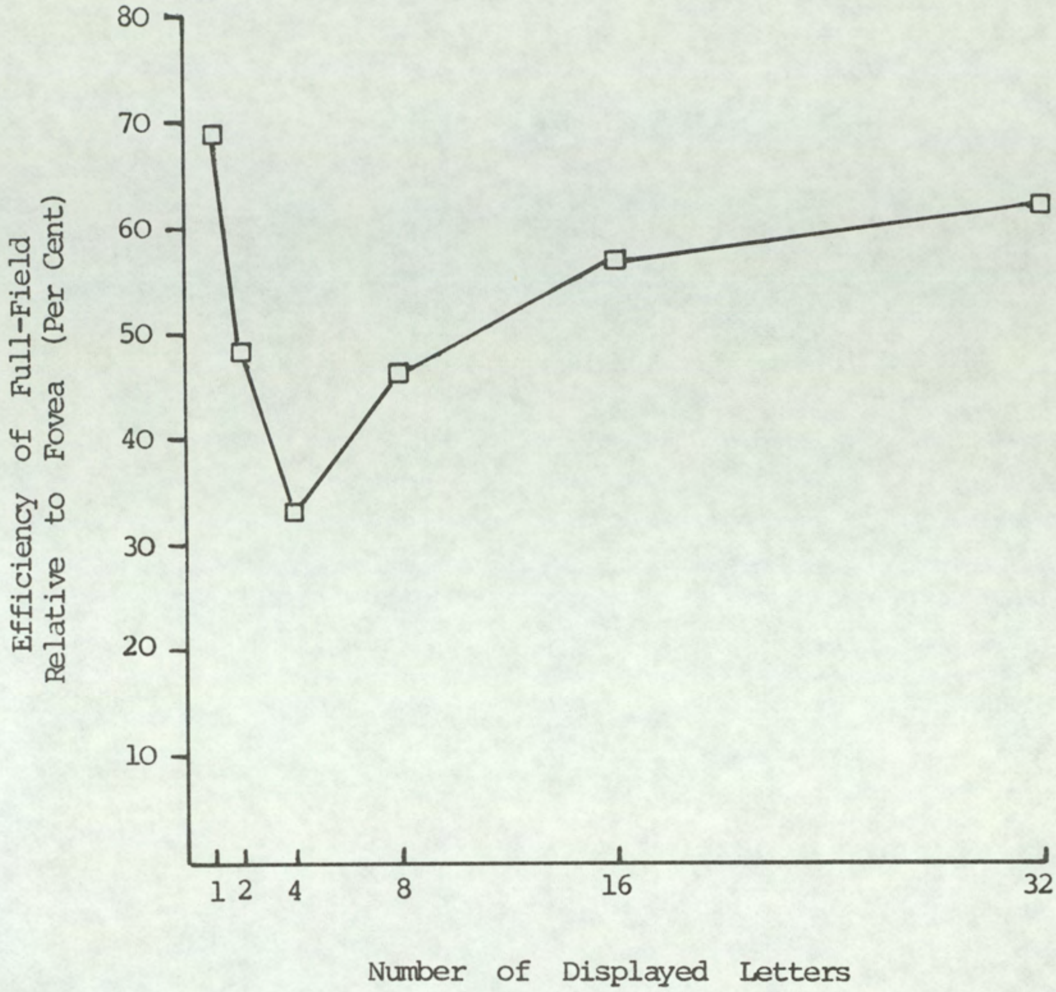


Fig. 7.4 <u>Reading Rate Differential between Foveal and Full-field Images</u>.

the relative difference in the reading rate between normal and full-field images is minimal.

As the number of letters is increased beyond 4, magnification is decreased and the depressive effect which peripheral viewing has on reading appears to decrease exponentially. This may be because the letter size in the full-field condition tends to approximate more towards that of the foveal condition. It seems more likely, however, that the span of recognition is the deciding factor: in both normal and magnified image reading, the larger the letter-string displayed, the faster the reading rate ($r = 0.9705$; $p = 0.0002$ with magnified image). Even when single letters within words are not discernible, if the pattern of the word as a whole is recognisable this presents valuable information[170, 175, 176].

From the results of the eye movement charts (Fig. 7.5), it appears that increasing magnification is accompanied by an exponential increase in the number of saccades in each line of print (Fig. 7.6), with a corresponding exponential decrease in the average span of recognition, i.e. the number of letters processed in each fixation.

This phenomenon may be explained as a change in recognition strategy. The more letters that are presented, the quicker the assimilation of the word pattern, and fewer fixations become necessary in each line. Conversely, as the size of the letters is increased, letter recognition

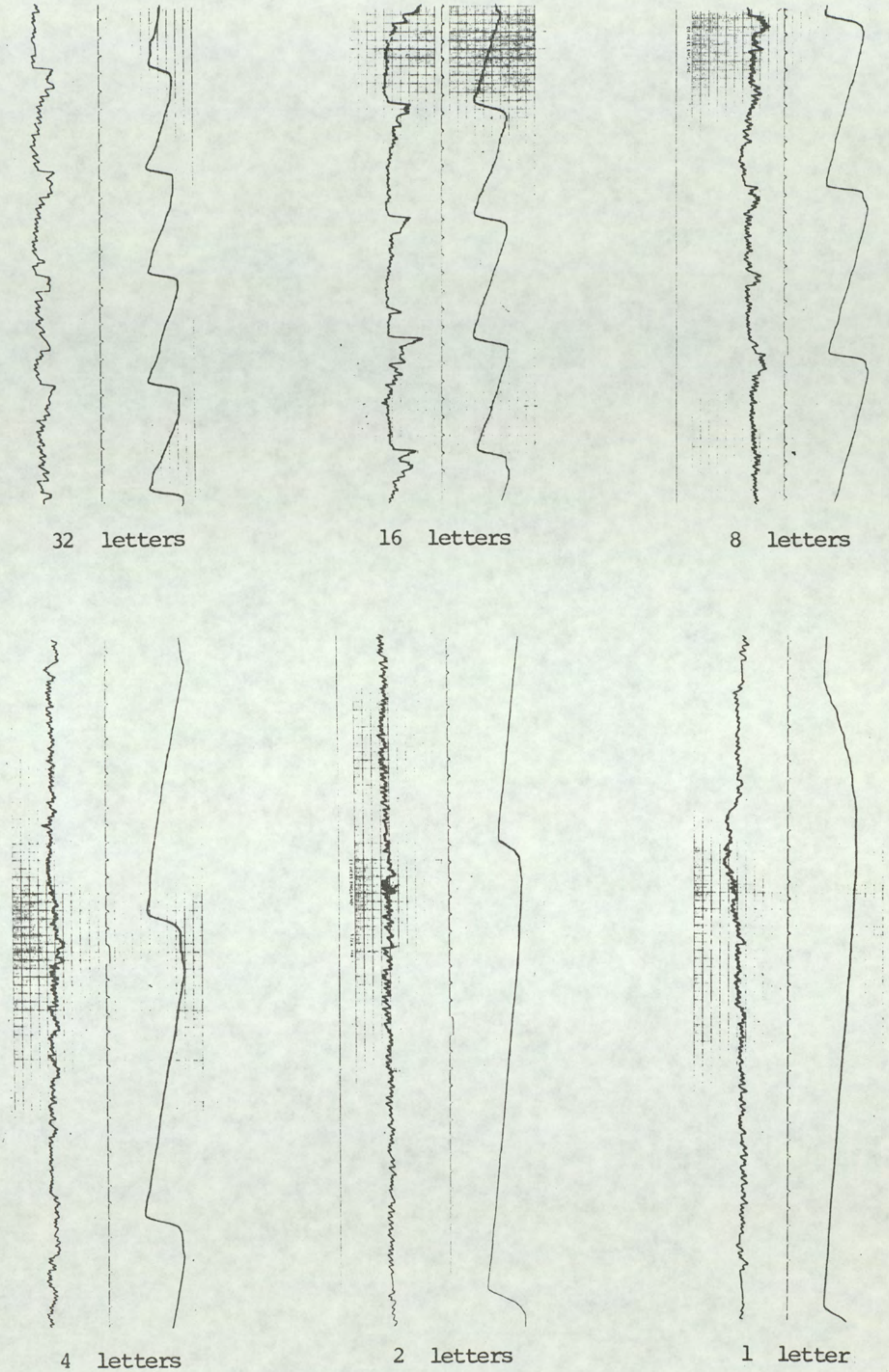


Fig. 7.5 Facsimile of Sections of Reading Eye Movement Recordings.
(Paper speed = 2.5 mm/sec.)

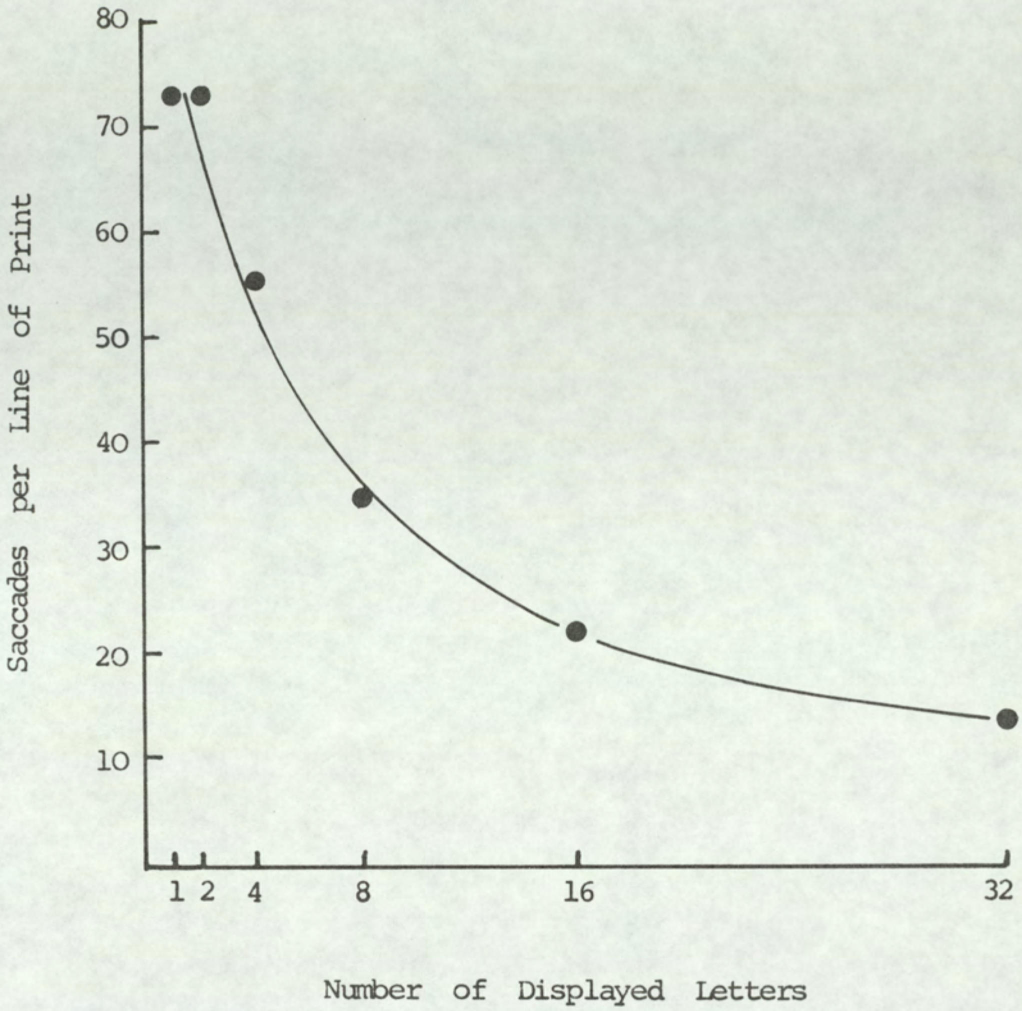


Fig. 7.6 Function of Number of Saccades with Size of Letter-String.

requires a saccadic search throughout the display field. Letters with similar shapes - 'i' and 'l', 'm' and 'n' for example - are confusable under these conditions. Moreover, especially at higher levels of magnification, the movement of the displayed text appears rapid, and tracking of this moving stimulus should be expected to initiate many opto-kinetic saccades. Evidence for this is that the large majority of saccades have an angular extent beyond the normal figure of 3^{o} [177] (see Table 7.3).

TABLE 7.3

Results from Eye-Movement Charts

Angular Mag.	No. of Letters Displayed	Range of Saccades (Degs)	Mean Saccade Length (Degs) & Std. Error	Variance in Saccade Length	Mean Span of Recognition (Letters/ Fixation) & Std. Error	Mean Rate of Fixation/ Sec. & Std. Error
25×	32	3 -50	19.0±1.0	95.5	3.88±0.23	3.02±0.13
50×	16	3 -56	12.8±0.7	81.2	2.61±0.08	4.19±0.14
100×	8	5.5-45	16.0±0.5	39.4	1.81±0.05	4.20±0.07
200×	4	5.5-39	13.0±0.4	37.5	0.97±0.03	4.17±0.07
400×	2	5.5-33.5	15.3±0.5	35.5	0.75±0.02	3.16±0.01
500×	1	5.5-31	14.9±0.4	26.8	0.77±0.04	3.19±0.07

The rate of fixation shows no apparent correlation with the number of letters displayed. The highly significant correlation between the degree of dispersion of the saccade dimensions (represented by the variance) and the number of letters displayed ($r=0.9523$; $p<0.0015$) reveals that the greatest variance occurs as the number of letters displayed is increased (or magnification is decreased). From inspection of the pen charts, it was apparent that saccades larger than average in dimension tend to proliferate under these conditions (Fig. 7.5). These saccades are directed at covering in each fixation a wide span of letters when such is present.

Since the reading rate data were collected from normal functioning eyes, the derived model represents an envelope of maximum attainment for the visually-handicapped. Fig. 7.7 illustrates this point by showing the reading rates of 36 subjects at their preliminary CCTV assessments. The results, which are taken from Appendix C, involve a magnification range of 5.9× to 70×. Furthermore, the subjects in this study, being university graduates and therefore experienced readers, could be expected to read at the average rate or better, by applying the rules of redundancy in language intelligently and automatically.

Nevertheless, it was evident that comprehension was most disrupted in both experimental conditions in which only a few letter spaces were displayed, especially when extreme magnification was used. Words were pieced together subvocally, often with regressions to recheck letters and words. Smith(157) has stated that when 1, 2 or 4 letters are presented, twice as many basic pattern features or

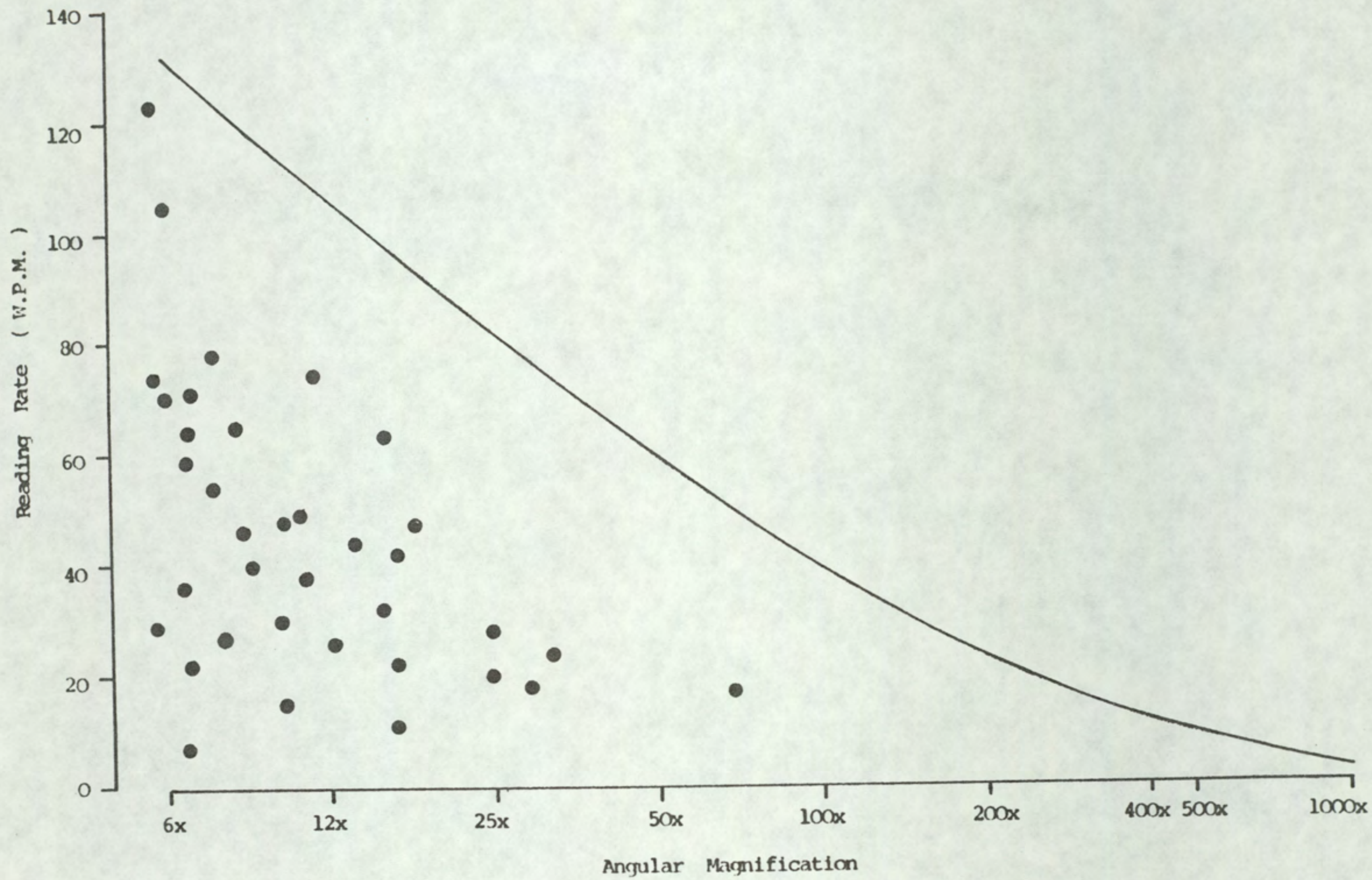


Fig. 7.7 <u>CCTV Reading Performance of 36 Visually-Handicapped Subjects at their Selected Angular Magnifications, showing 'Envelope' of Fig. 7.3</u> .

'morphemes' are required to identify a given group of words. Inevitably, this depreciated the reading rate, and caused difficulty in retaining the maximal comprehension required for assessment purposes [149].

It did not appear essential, however, that 4 or 5 words at a time - 16 or 32 letter spaces - should be assimilated into short-term memory in order to achieve fullest comprehension, as Smith [157] also stated. Three out of four subjects retained full comprehension with displays of 2 and 4 letters, even under the difficult condition of reading with extreme magnification. Yet it is doubtful if total comprehension could be maintained for periods much longer than those required for this experiment.

7.5 CONCLUSION

Because the fovea has a density of neuronal connections in the cerebral cortex several times greater than that of the peripheral retina [178,179], the use of a full-field image may mean that central processing limits fluency in reading. As the dimension of the image was increased, the detrimental effect on the reading rate and the generation of opto-kinetic saccades support the suggestion by various workers [180, 181] that the peripheral retina is more sensitive to motion perception than to other forms of visual discrimination, and has a slower response time [162,163].

When angular magnification beyond about 300× is necessary for an individual to recognise letter forms, the resulting reading rate may prove unacceptably slow for narrative prose. Kolers[182] stated that normal reading cannot proceed by a serial scanning of single letters. Nevertheless, the conclusion from this experiment is that reading of short items with adequate comprehension remains feasible even up to 1000× magnification. This point is of interest in the light of developments in cortical visual implants for the totally blind[183].

Central processing may well constitute the limiting factor to reading at ultra-high magnifications, and in this range the deduced mathematical model probably represents the actual performance of the majority of visually-handicapped patients.

CHAPTER 8

INTERACTIVE EFFECTS OF MAGNIFICATION AND FIELD SIZE ON THE READING PERFORMANCE OF VISUALLY IMPAIRED SUBJECTS

8.1 INTRODUCTION

The previous chapter considered how changes in magnification constrain the reading rate. One effect of each increase in linear magnification is to limit the information available for processing, by reducing the number of letter spaces within the boundary of the TV display field. This suggests a reason why the majority of CCTV users in the United States prefer large monitor screens, according to the claim of the manufacturers(94). Moreover, the experience of the present author with experimental subjects reveals additional clues about the usual course taken in selecting a suitable magnification.

The present author has found that when the occasional word is imperceptible most subjects, including non-presbyopes, are reluctant to draw closer to the screen in order to realise the approach magnification so produced. Instead, it has seemed that patients generally discover an appropriate angular magnification haphazardly, with frequent re-adjustment of linear magnification predominating over variation in viewing distance. At the same time, they soon become aware of the reciprocal relationship between the linear magnification and the number of letters displayed; and they intuitively understand the detrimental effect on reading performance which results when only a few letters instead of whole words are presented in the display 'window'(150). Normally, the examiner has continually to encourage the technique of approach magnification, with its advantage of a maximal letter span, rather than the alternative option of frequent re-adjustment of the linear magnification. An important incidental advantage of using minimal linear magnification is that the depth of field is larger, so that the reading matter remains in focus for a longer period.

For any given linear magnification, large screens provide a longer letter span, which allows the processing of word cue information to function at a higher level, as described in Chapter 7. Hence, patients untutored in the technique of approach magnification tend to prefer larger screens to smaller ones. A further point is that larger screen sizes demand less movement of the X-Y platform in traversing a line of print. It is thus made easier to follow rows and columns on a page.

Nevertheless, there are some intrinsic drawbacks to using the larger-sized monitors. They are more cumbersome and are therefore less portable; more expensive; and the screen flicker is more apparent. Thus, the best interests of patients would be served if it were possible to recommend, on a scientific basis, a CCTV screen size matched with a viewing distance to suit the individual.

Consequently, in view of the conflicting arguments in favour either of large screens or the alternative of approach magnification technique, it was considered that a study should be made of the inter-relationship of the field size and magnification with the reading rate.

Field size controls the length of the letter-string displayed and, as shown in Chapter 7, this factor is allied with magnification in affecting reading performance. With this relationship in mind, the question arises as to whether the optimal screen size/magnification ratio can be determined for any individual.

When magnification itself is considered, it should be possible to establish the letter subtense which is optimal for any one individual. This letter subtense would be such as to induce the most rapid reading rate, as the letters would be small enough to require the least number of fixations per line, with the minimum of movement of the traversing platform.

Two experiments were undertaken: the first to elucidate the relationship between field size and magnification, (described as experiment I); and the second to determine the optimal letter subtense and its relationship with certain other variables which might affect the reading performance of the individual (experiment II).

8.2.1 Apparatus and Method; Experiment I

The apparatus consisted of a 24-inch (60 cm) monitor mounted on a tubular stand. A forehead rest, mounted on the stand, was so arranged that the eye level of the subject, when seated, was at 19 cm from the mid-point of the screen. Placed directly below the monitor was a CCTV camera module and traversing platform (as described in Chapter 5, Section 1). Fig. 8.1 illustrates the arrangement of the apparatus.

Five levels of magnification and five angular field spans were selected. The magnifications produced letter subtenses ranging from 3^{o} to 15^{o} at the mid-point of the screen, and correspond with angular magnifications of 6.5× up to 33×. These magnifications cover a broad range of those required for various acuities. The former magnification was chosen because it falls within the modal, or most commonly used group of CCTV angular magnifications of 4× to 7× (see Fig. 5.3). Furthermore, according to Kestenbaum's rule,[60] 6.5× is the theoretical magnification required by a patient with an acuity between 2/60 and 3/60, and 33× by an individual with an acuity of 'counts fingers' at 0.5 metre.

With regard to the field, a horizontal span of 100^{o} was considered to be a practicable upper limit, and corresponded to the angular extent of the 24-inch (60 cm) screen viewed from 19 cm. The other field spans of 85^{o}, 70^{o}, 50^{o} and 25^{o} were formed by using masks, while the 19 cm viewing distance was maintained throughout the series. The smallest field (25^{o}) corresponds to a 60 cm screen viewed from 1 metre, which in practical terms is equivalent to a screen placed aside the far edge of an office desk.

Fig. 8.1 <u>60 cm. CCTV Apparatus for Assessment of Effect of Magnification and Field on Reading.</u>

Six partially-sighted persons acted as subjects in the experiment, and were chosen on the merit of their reading skill in preliminary screening tests. Binocular vision was used where this was possible. Clinical details are presented in Table 8.1.

TABLE 8.1

Details of Subjects Involved in Magnification/Field Experiment (I)

Subject	Male/ Female	Age	Ocular Condition	Snellen V.A.	Best M.A.R. (mins of arc)
22 PM	F	49	Retinitis pigmentosa	R) 1/60 L) 1/36+1	30'
32 FP	F	45	Toxaemic Retinopathy	R) 6/36 L) 6/60+1	6'
35 WG	M	25	Albinism; saw-tooth nystagmus	R) 6/60+1 L) 6/60+1	8'
36 IT	F	58	R. prosthesis; L. corneal opacity	R) N.P.L. L) 6/36	6'
39 RS	M	42	Primary optic atrophy	R) 1/60 L) 6/60	10'
42 JH	F	52	R. prosthesis; L. corneal opacity	R) N.P.L. L) 3/60	20'

8.2.2 Apparatus and Method: Experiment II

The 12-inch (30 cm) monitor was separated from the camera/traversing platform module and placed in line with it, on a laboratory bench. A forehead rest was secured to the upper tier of the module. This monitor was used for smaller letter subtenses, while for those from 3° to 15° the results were added from the 70° field (60 cm monitor) used in experiment I. Additional results using the 70° field size were obtained for larger subtenses of 18° to 26°. More specific details are listed in Table 8.2.

TABLE 8.2

Details of Letter Subtenses Produced for Experiment II

Letter Subtense	Letter Height (mm)	Viewing Distance (cm)	Monitor Display size
30'	5	57	30 cm
45'	5	38	30 cm
1°	5	29	30 cm
$1^{\circ}30'$	10	38	30 cm
$1^{\circ}45'$	10	33	30 cm
2°	10	29	30 cm
3°	10	19	60cm(70°field)
6°	20	19	60cm(70°field)
9°	30	19	60cm(70°field)
12°	40	19	60cm(70°field)
15°	51	19	60cm(70°field)
18°	61	19	60cm(70°field)
21°	72	19	60cm(70°field)
24°	82	19	60cm(70°field)
26°	90	19	60cm(70°field)

8.3 PROCEDURE

Subjects were required to read the typewritten narrative texts described in Chapter 7, and three questions were asked at the end of each reading to check comprehension. In experiments I and II the presentation of magnification was randomised, as also was the presentation of field sizes in experiment I: the objective of this procedure was to minimise the effects of learning and fatigue. A reversed-contrast display was standardised, so as to create the minimal glare.

From experiment I, the reading results were processed in four ways. The reading rate performance for each subject was plotted against:

(i) magnification at 5 field sizes

(ii) field size at 5 magnifications

(iii) the number of letters displayed on the screen (which is limited by the field size as magnification is increased).

Finally,(iv) analysis of variance (A.O.V.) was performed in order to determine the significance levels of the effects of field size and magnification on the reading rate.

The A.O.V. procedure followed that outlined by Ferguson[141] for two-factor experiments with repeated measurements.

From experiment II, the results were plotted graphically so as to reveal the optimal letter subtense.

8.4.1 Results and Discussion (Experiment I)

(i) As Fig. 8.2 (a) and (b) reveals, at all field sizes the reading rate declines exponentially with increasing letter size. The results illustrated (for subjects 35 WG and 39 RS) are typical of all 6 subjects. It was apparent from examination of these graphical results that within the three field sizes 100°, 85° and 70°, the data points on the 6 subjects tended to cluster together, and more especially at the smaller letter subtenses of 3°, 6° and 9°. This tendency was confirmed when the results for all six subjects were averaged, and plotted, together with standard errors of the mean, for the 100°, 70°, 50° and 25° fields (Fig. 8.3). It is shown that although the mean reading rate for the 70° field is generally slower than that for the larger field, it lies within the standard error of the 100° field, except at the 15° letter size, where it falls just outside the limit of the standard error. The same is not true of the 50° and 25° fields, where the mean results show an independence from the standard error of larger field sizes.

(ii) Using subject 35 WG as an example, Fig. 8.4 illustrates how the reading rate appears to increase exponentially with increments in field size, and to asymptote when the field subtends 70°. This observation is true at

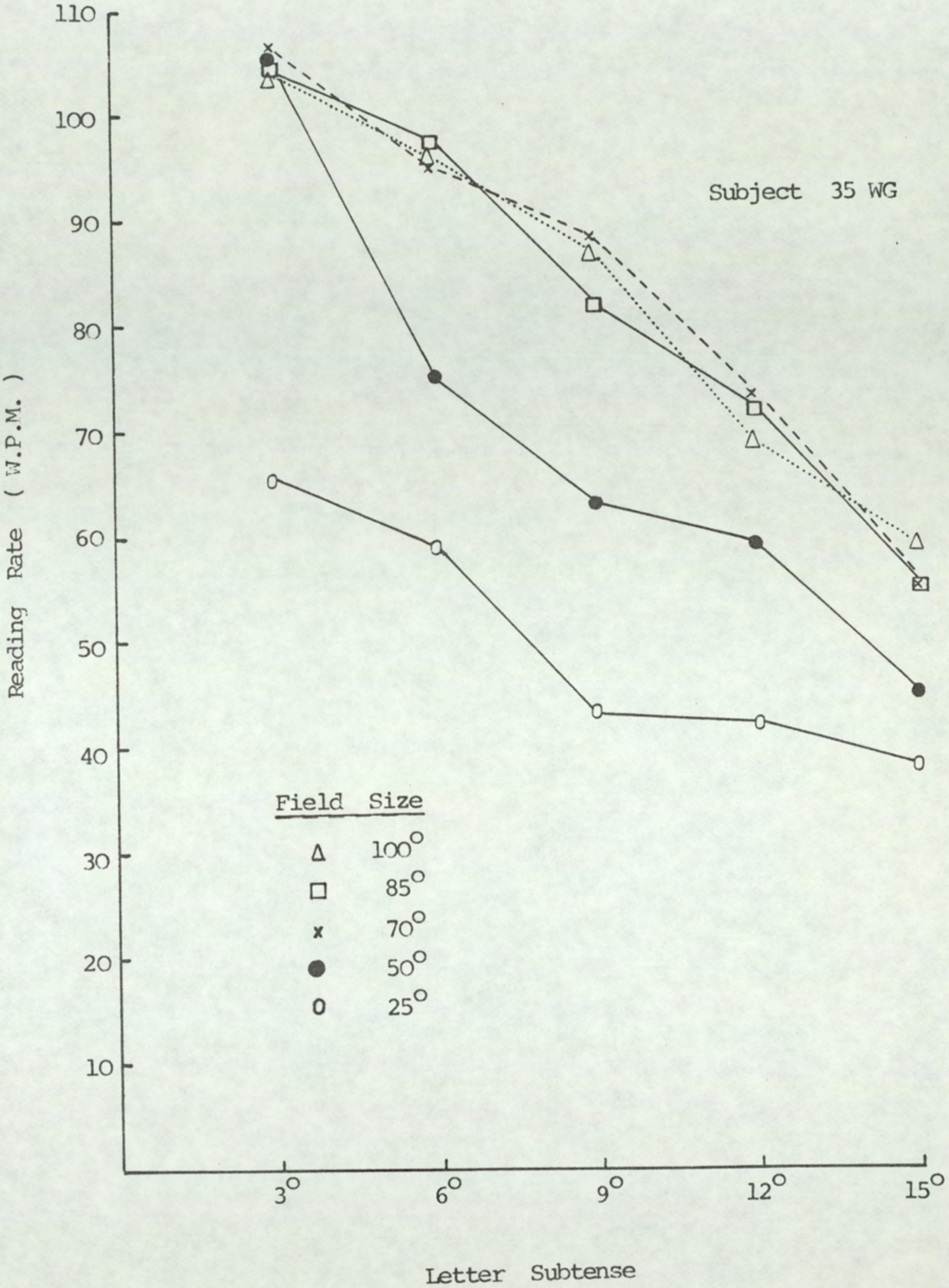


Fig. 8.2 a Effect of Letter Subtense on CCTV Reading Rate.

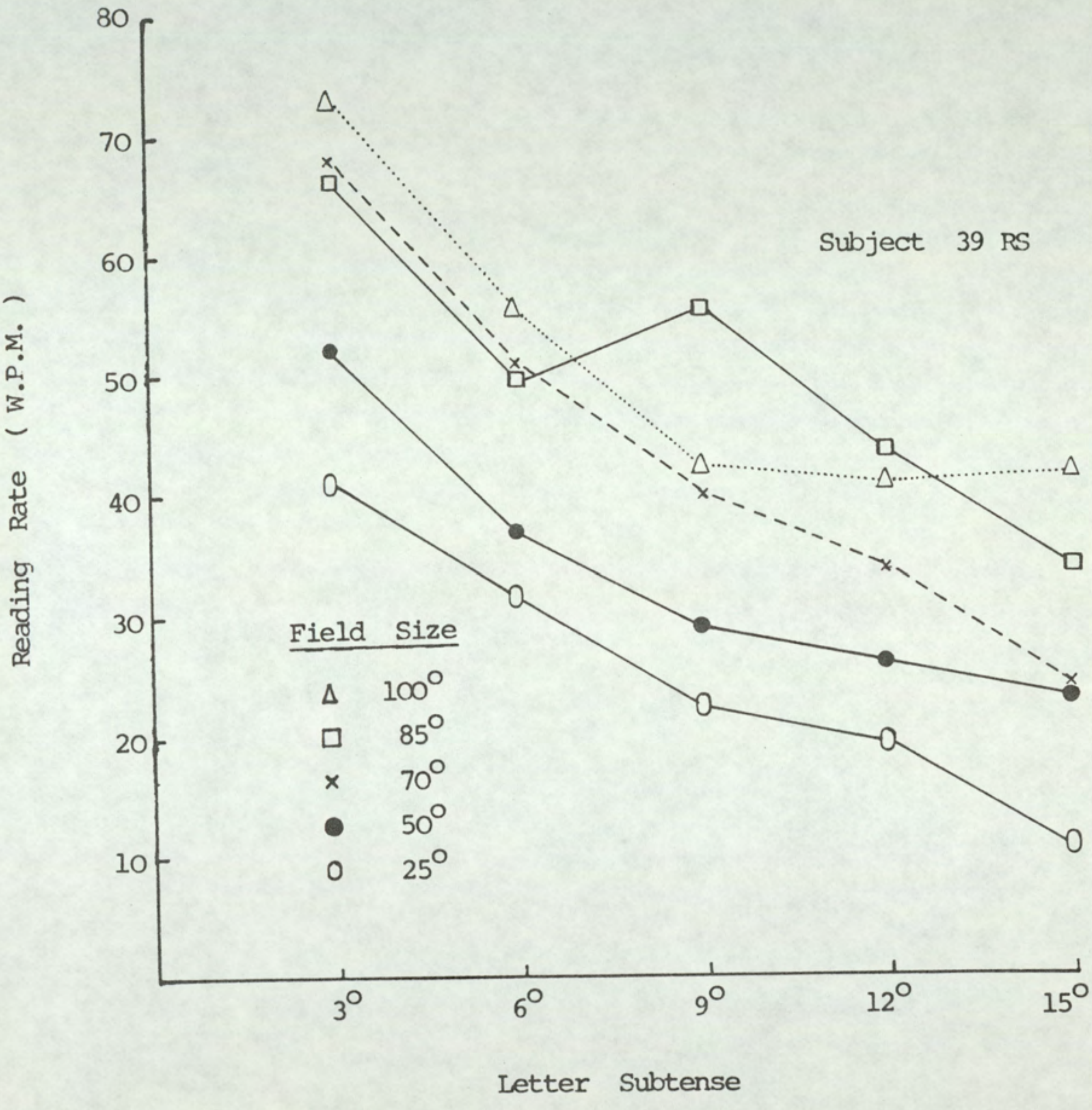


Fig. 8.2 b Effect of Letter Subtense on CCTV Reading Rate.

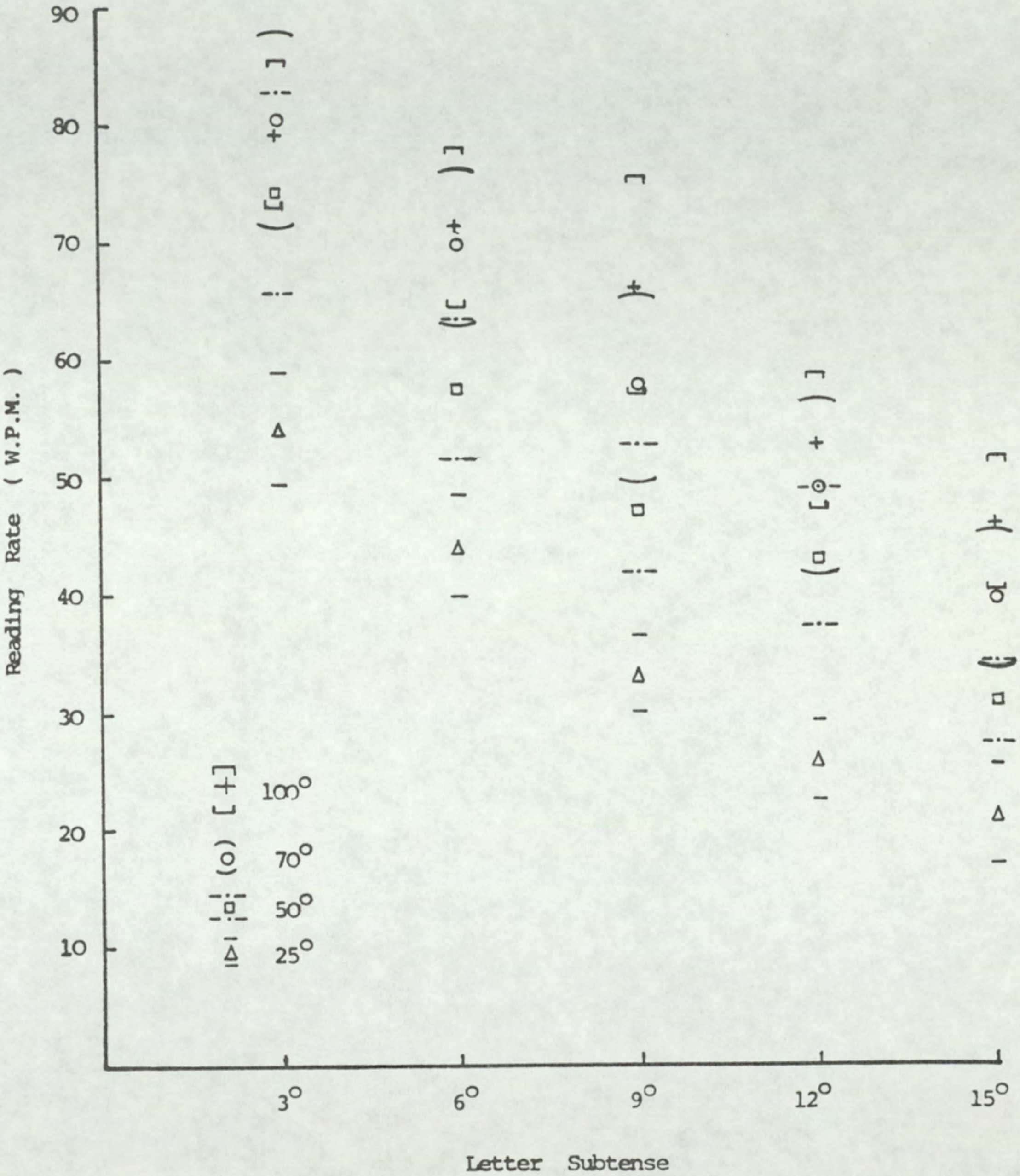


Fig. 8.3 Effect of Letter Subtense on CCTV Reading Rate, showing Mean and Standard Error of 6 Results.

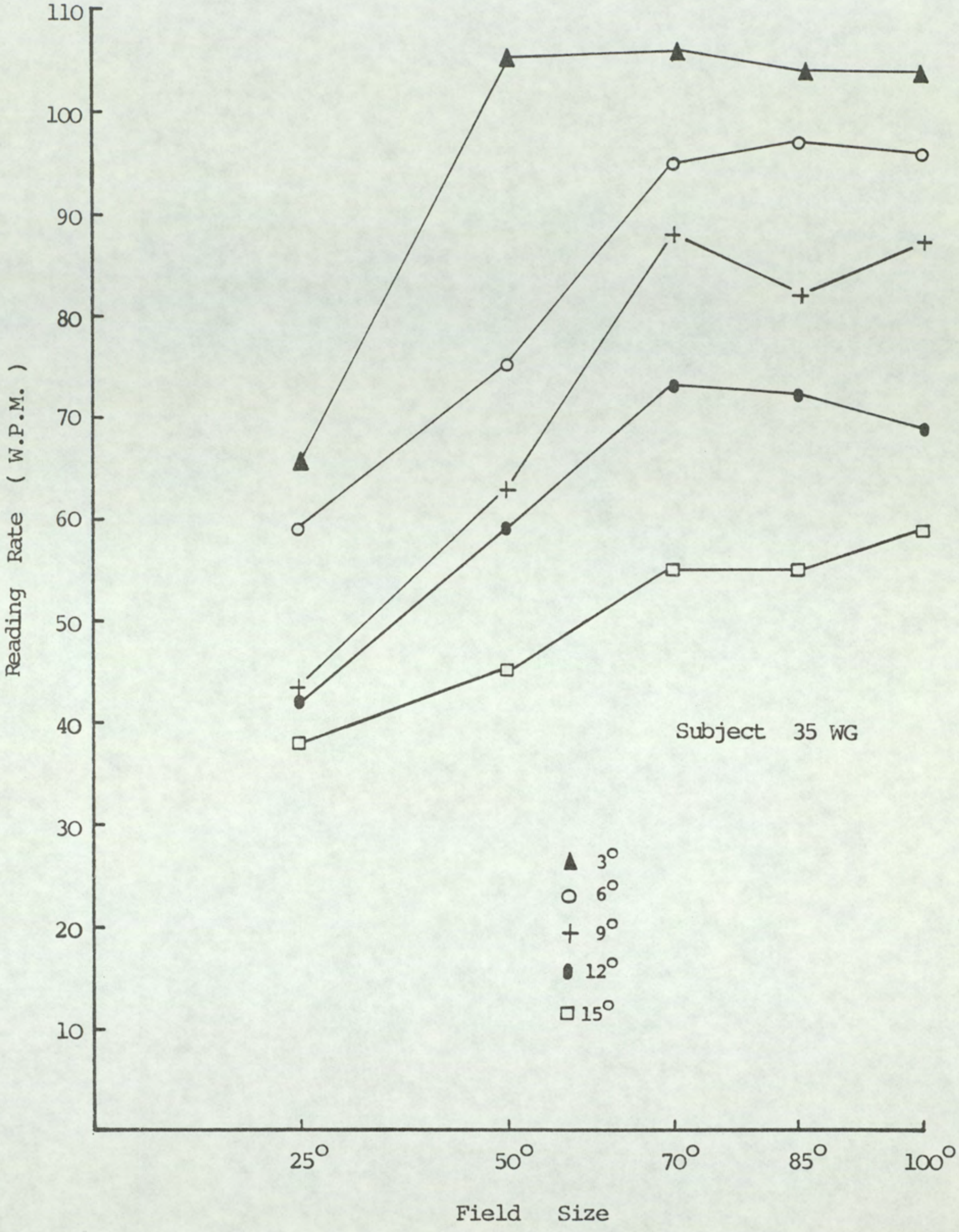


Fig. 8.4 <u>Effect of Field Angular Width on Reading Rate for Various Letter Subtenses.</u>

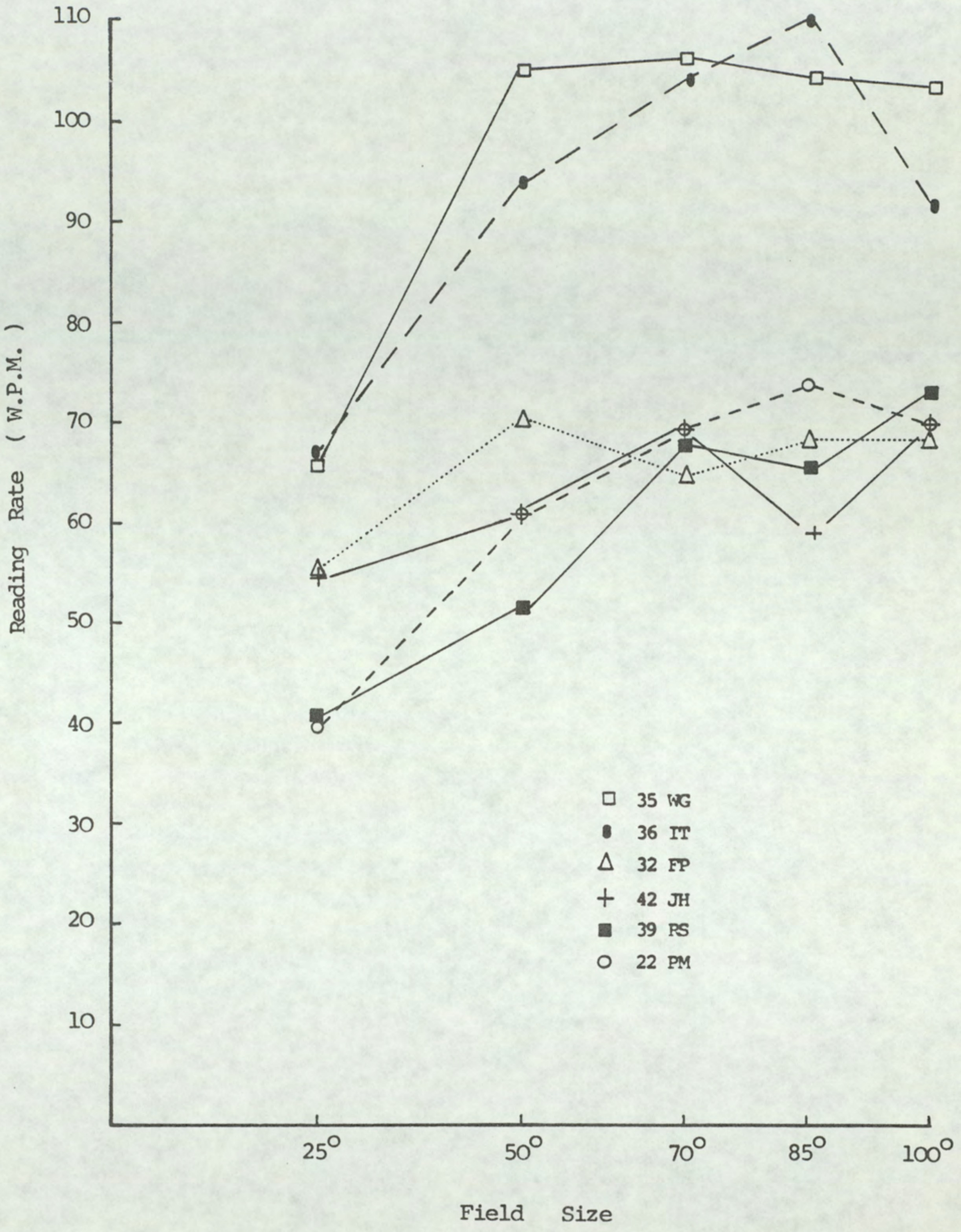


Fig. 8.5 Effect of Field Angular Width on Reading Rate at 3° Letter Subtense, for 6 Subjects.

each magnification. The trend applied to all subjects, within the limits of experimental error, and at each of the 5 letter magnifications. Fig. 8.5 illustrates this point by presenting the results of each subject, using for the sake of clarity only the 3^{o} letter size.

(iii) Because the field size is finite, when the magnification is varied so the number of letters displayed within the horizontal extent of the field varies inversely. This number of letters - as was pointed out in Chapter 7 - has an important influence on the maximal rate of reading which can be achieved. Fig. 8.6 (a) and (b) illustrates the mode of change in the reading rate as the number of displayed letters is varied. The curves have been computed by the method of least squares to be the best fit to the data points. The equations for the curves of individual subjects are:

	Variance about the fit
22 PM : $R = 2.84i - 0.034i^2 + 12.65$	31.05
32 FP : $R = 3.73i - 0.067i^2 + 28.77$	165.33
35 WG : $R = 4.65i - 0.074i^2 + 39.19$	86.18
36 IT : $R = 5.13i - 0.081i^2 + 24.46$	71.38
39 RS : $R = 2.86i - 0.036i^2 + 15.32$	34.46
42 JH : $R = 2.94i - 0.052i^2 + 32.45$	63.08

where R is the reading rate and i is the number of letters displayed in the letter-string.

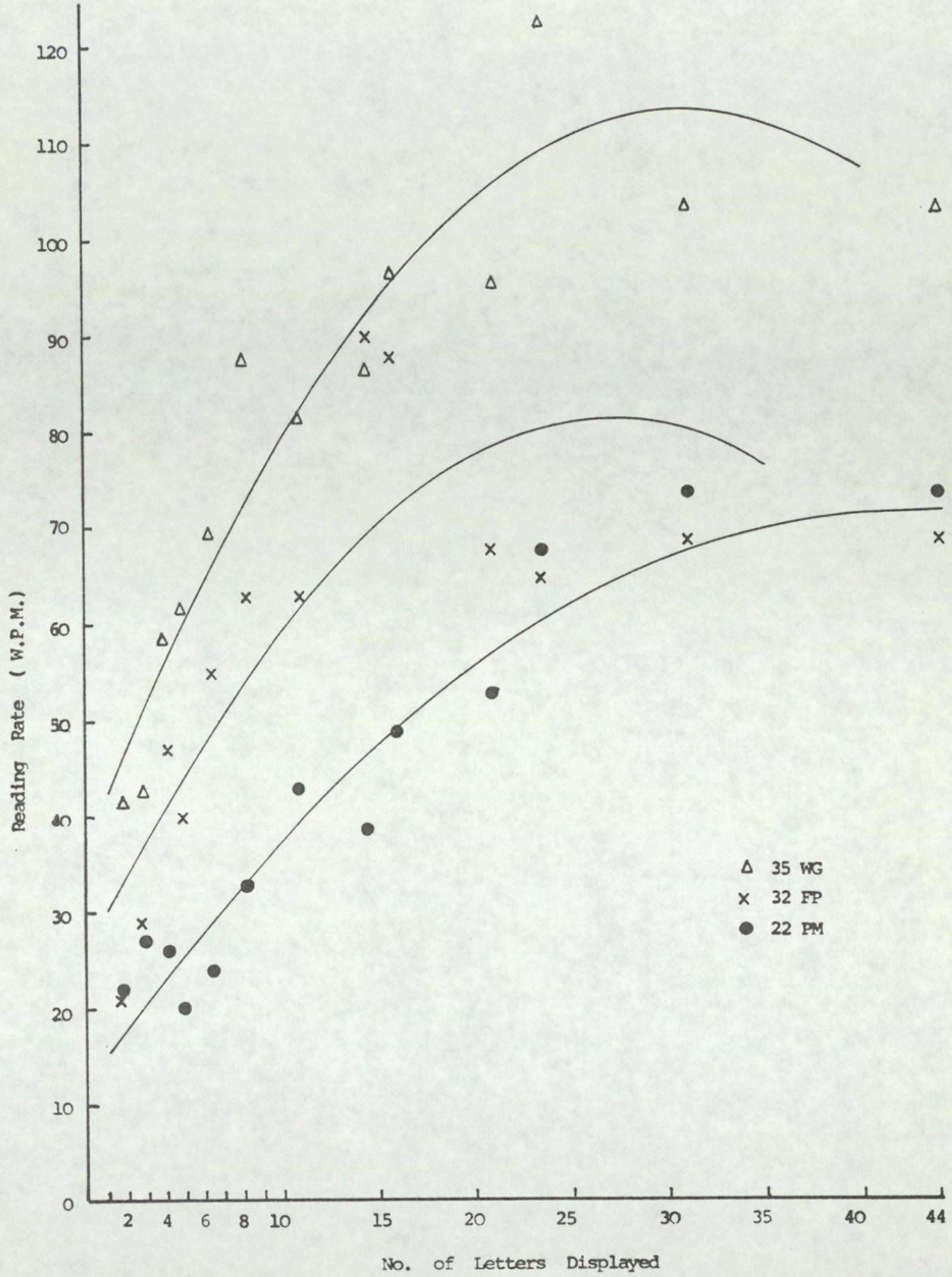


Fig. 8.6 a <u>Effect of Number of Displayed Letters on Individual Reading Rate.</u>

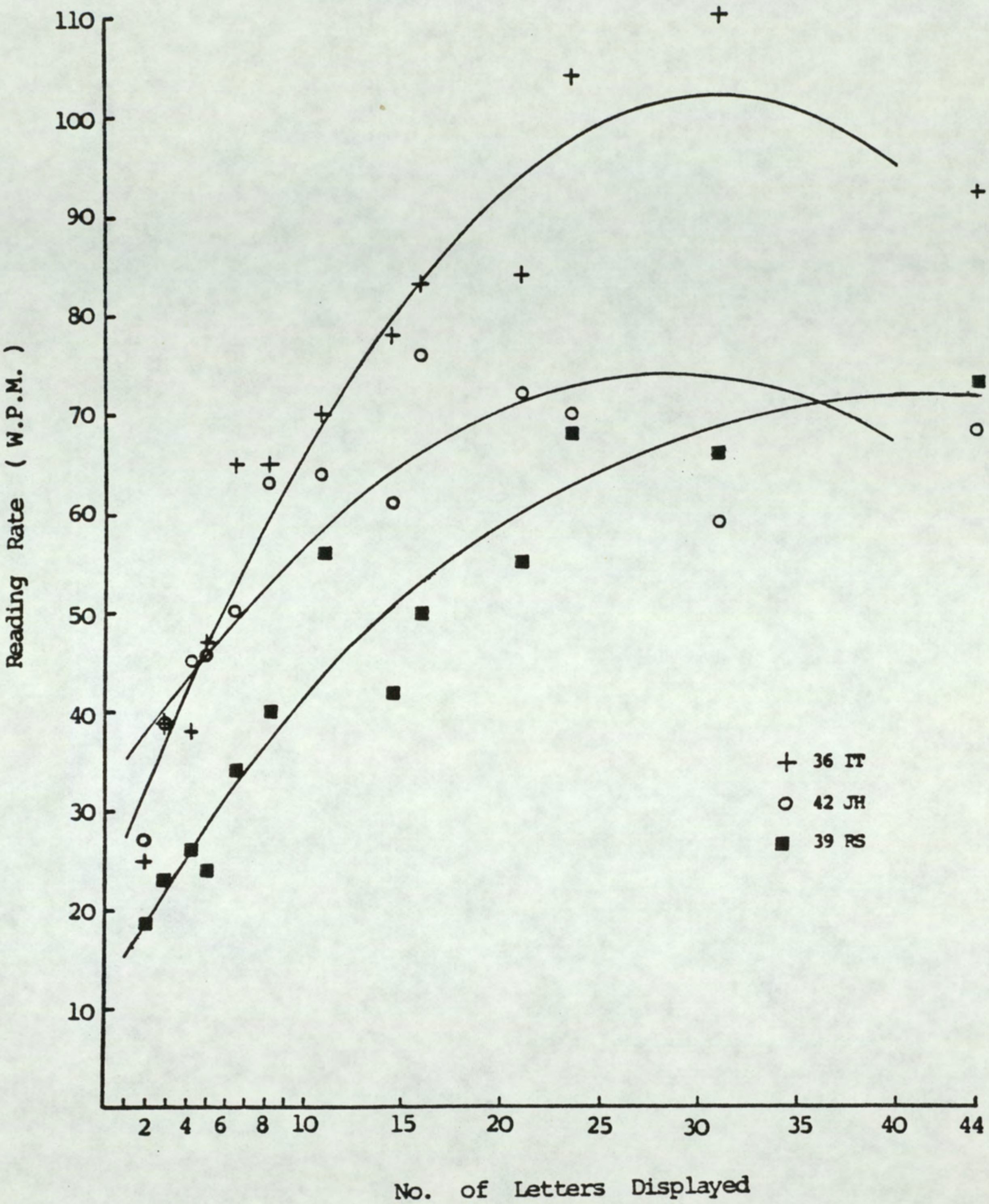


Fig. 8.6 b <u>Effect of Number of Displayed Letters on Individual Reading Rate.</u>

From examination of the curves, it is evident that where the slope becomes less steep (as reading performance begins to saturate) is the region of clinical significance. Little is to be gained from recommending a display of the precise number of letters corresponding with the peak.

On the contrary, when the number of displayed letters is judiciously reduced by increasing linear magnification, the reading rate declines marginally, while the increase in angular magnification can approach two-fold when viewing distances of 20 cm or less are employed. The further implication is that if the choice is to keep linear magnification constant, then the display size can be reduced.

Moreover, it is clear that the variance within data is considerable close to the peak. This can be explained by fluctuations in subject performance. Hence, the probability can arise that the reading rate may be maximal despite a reduction in the number of displayed letters.

In conclusion, this author proposes two alternative methods as a guide for deciding when a suitable number of letters has been displayed. The first presumes that point to have been reached, when an increase of one displayed letter causes an increment in the reading rate of no more than one word per minute. The second method selects that number of letters at which an addition of one letter increases the reading rate by no more than one per cent. Both methods employ the equation fitting each curve. The one-word per minute increment method is determined from the slope of the curve by simple differential calculus; while the one per cent method relies upon the calculation of the ratios of reading rates corresponding with adjacent numbers of displayed letters. The results for each subject using both criteria are;

TABLE 8.3

Number of Letter Spaces Necessary for Efficient Reading

Subject	1-w.p.m. Increment	1% Increment
22 PM	28	32
32 FP	21	22
35 WG	25	24
36 IT	25	25
39 RS	21	27
42 JH	19	21
	Mean = 23.17	25.17

There is an argument for employing the mean of these two discrepant mean values - 24 letter spaces in round terms - as a starting point to be used universally for patients at their initial CCTV reading assessment.

Coincidentally, one of the 6 experimental subjects, 35 WG, needed 24 letters to reach a maximal reading rate. At first sight, it seems paradoxical that this subject's reading rate was faster than that of subject 22 PM who, despite much worse visual acuity, appeared to require a longer letter-string for maximum efficiency. It might be expected that the longest letter-strings would be required by those with adequate visual capacity for processing the peripheral retinal information, i.e. the normally-sighted or those with relatively minor visual impairment. However, assuming adequate horizontal visual fields for the subjects, it may be the case that the slower readers are forced by their poorer acuities into making maximal use of peripheral retinal information. Moreover, the lower visual acuity of the peripheral retina means that even quite severe visual disturbances cause proportionally less perturbation of the information there, than at the fovea.

In this context, it is of note that subject 22 PM reached her fastest reading rate with a letter display of 28-32 letters, yet she had the worst acuity of all. This was 1/36+1 in the better eye (equivalent to a minimum angle of resolution of 30') and individual letters at the edges of a 30-letter-string would be at threshold values of resolution, subtending as they did 2.3^{o} of arc overall. However, during the reading task the individual letter information is consolidated by the word pattern and the context.

(iv) The analysis of variance using the results of the 6 partially-sighted subjects showed that the field size and the magnification independently have effects on reading, which are statistically highly significant, even with only 6 subjects.

The F-ratios were:

for field size : $F = 56.72$ ($p < 0.001$)

for magnification: $F = 51.23$ ($p < 0.001$)

The interaction of the two factors was found to be non-significant ($F = 0.987$) over the entire 25 combinations. This lack of significance could be attributed to the wide range of reading rates amongst the subjects.

8.4.2 Results and Discussion (Experiment II)

The optimal letter subtense for each of 9 subjects was found by interpolation of the graphical results (Figs. 8.7 (a), (b) and (c); Table 8.4).

TABLE 8.4

Optimal Letter Subtense and its Relationship to M.A.R. and Angular Magnification

Subject	M.A.R. at 6m	Optimal Letter Subtense (O.L.S.)	Ratio of OLS/MAR	Equivalent Angular Mag. of O.L.S.	Angular Mag. at Initial Reading (I.A.M.)	Ratio of OLS/IAM
32 FP	6'	3°	6×	6.6×	3.6×	1.83×
36 IT	6'	3°	6×	6.6×	6×	1.10×
35 WG	8'	2° 30'	3.8×	5.5×	5.9×	0.93×
39 RS	10'	1° 30'	1.8×	3.3×	6.9×	0.48×
44 ET	12'	4°	4×	8.7×	8.9×	0.98×
42 JH	20'	5°	3×	10.9×	7.8×	1.40×
48 LT	24'	9°	4.5×	19.6×	16.2×	1.21×
22 PM	30'	3° 30'	1.4×	7.6×	5.9×	1.29×
24 BG	30'	5°	2×	10.9×	8.6×	1.27×

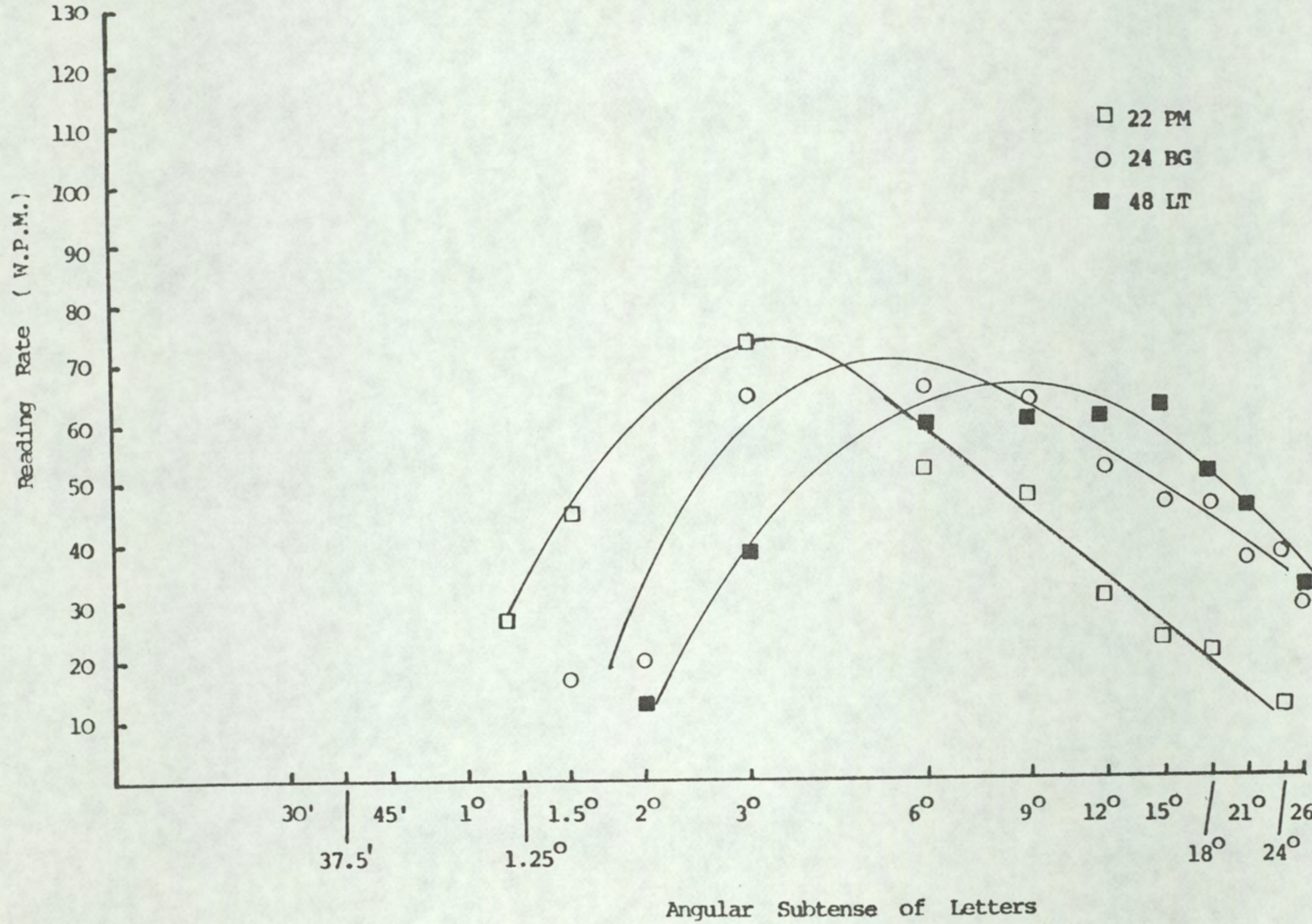


Fig. 8.7 a Individual Reading Rate Results Plotted for Determining Optimal Letter Subtense.

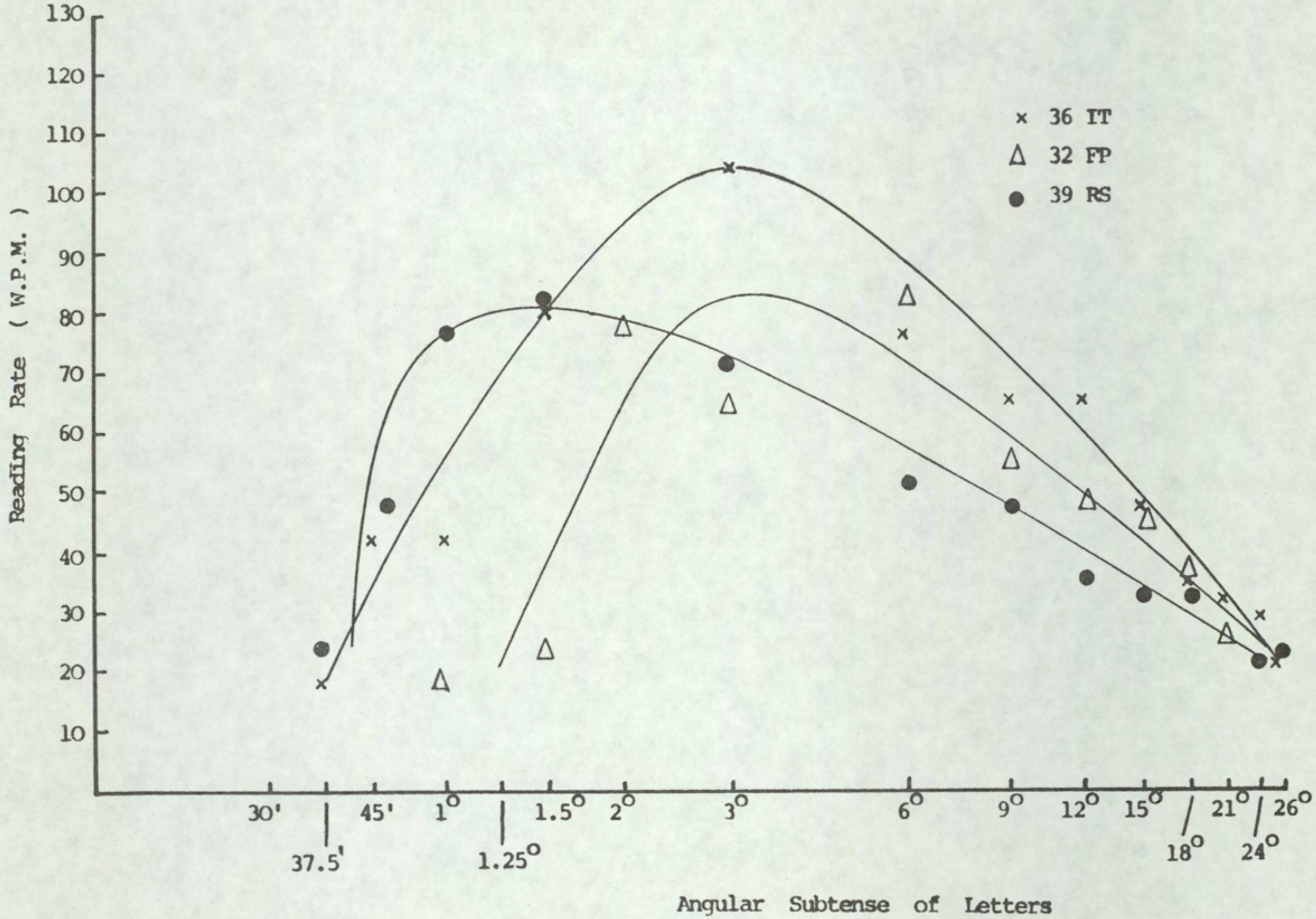


Fig. 8.7 b <u>Individual Reading Rate Results Plotted for Determining Optimal Letter Subtense.</u>

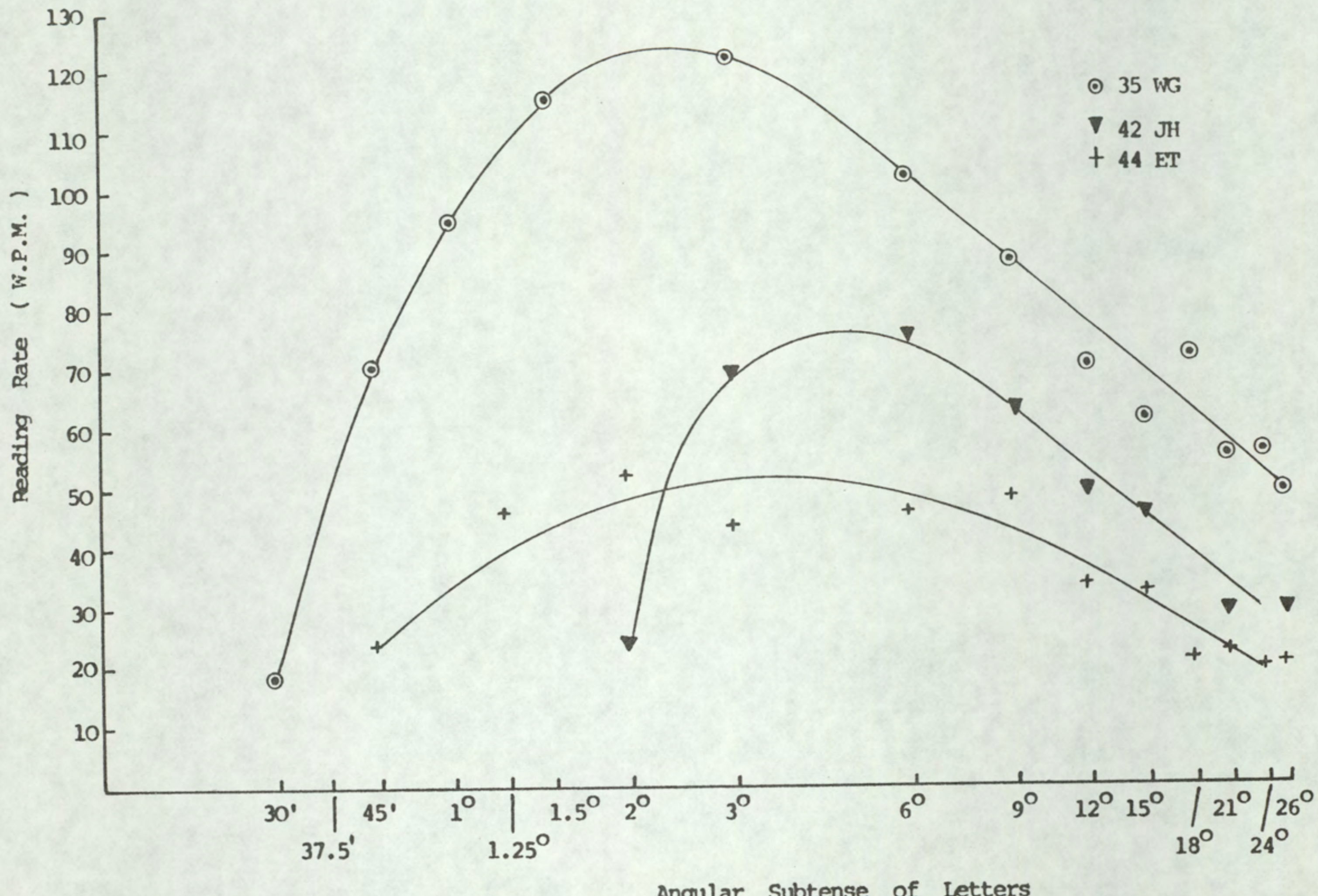


Fig. 8.7 c Individual Reading Rate Results Plotted for Determining Optimal Letter Subtense.

The Pearson correlation coefficient relating the visual acuities (expressed as M.A.R. at 6 metres) and the optimal letter subtenses is significant. When taking into account the first 7 subjects listed in Table 8.4, $r = 0.8705$ ($p < 0.01$ for two-tailed test) and this degree of correlation seems a reasonable expectation. If all 9 subjects are considered, however, the correlation becomes non-significant at $r = 0.5679$ ($p < 0.12$ for two-tailed test). Table 8.4 reveals that the subjects 22 PM and 24 BG do not conform to the general trend set by their fellow subjects, namely that as the distance M.A.R. becomes worse, so the optimal letter subtense and the angular magnification tend to increase.

Although this discrepancy in the two results is surprising, it is probably accounted for in part by the disparity between the distance Snellen acuity and the word acuity at near (see Chapter 3, Section 2).

Another explanatory factor might be subject error; and the likelihood that subjects 22 PM and 24 BG were reluctant to attempt reading Snellen letters of which they were uncertain, with the result that their distance M.A.R.'s have been underestimated. In support of this notion, whereas angular magnification correlates highly significantly with M.A.R. in 48 subjects (see Chapter 5, Section 3), and also significantly for the first 7 subjects in Table 8.4 ($r = 0.8567$; $p=0.01$ for two-tailed test), when subjects 22 PM and 24 BG are added to the seven the correlation coefficient falls to r=0.4535, which is non-significant. There is further evidence that in these two cases the recorded distance M.A.R. could be responsible for producing misleading results, when the relationship between different factors is examined. For example, when optimal letter subtense and angular magnification are correlated, the difference between the coefficients using 7 or 9 pairs of data is negligible, being r=0.8924 for 7 and r=0.8877 for 9 subjects (p =0.0006 for two-tailed test).

Despite the optimal letter subtense being larger than the distance Snellen acuity for every subject, the variation in the ratios of their angular sizes shows little consistent trend. When the present data is surveyed, the optimal letter subtense is between 1.4× and 6× larger than the M.A.R. (See Table 8.4). This explains the low correlation between these two variables (r=0.5679) referred to previously. This lack of consistency can be explained by the fact that, ultimately, the judgement of optimal letter subtense relies upon a subjective criterion. To illustrate, between two individuals with similar acuities one might be confident reading print several times smaller than that required by the other (comparing subjects 39 RS and 44 ET; and 22 PM and 24 BG).

At their initial reading sessions with CCTV, 3 subjects (36 IT, 35 WG, and 44 ET) selected angular magnifications which were very similar to that of the optimal letter subtense. Only one subject (39 RS) had selected an angular magnification larger than optimal, i.e. greater by a factor of just over two. It is interesting to note that at his initial CCTV session subject 39 RS used angular magnification of 6.9× and the reading rate was 64 w.p.m.; whereas with the optimal letter subtense of 3.3× ,(and consequently a longer letter-string display), he managed 81 w.p.m..

Somewhat surprisingly, the angular magnification selected by the remaining 5 subjects was smaller than optimal, ranging from 1.21× to 1.83× less, with a mean value of 1.40× less. One explanation of this phenomenon is that because the number of data points in the region of the curve peaks is insufficient to ensure absolute accuracy, the true dimension of the optimal letter subtense in these five cases may have been less than that value found by interpolation. Moreover, when optimal letter subtense was being investigated, a longer time was spent in taking results than during the initial reading session. These subjects may conceivably have become more fatigued during the longer session, resulting in a decline in their performance, and thus in their ability to read the smaller letter sizes. Conversely, an equally plausible explanation is that these subjects, at their initial CCTV reading sessions, selected angular magnifications which were less than optimal, probably as a result of inexperience with the technique. The factor by which their angular magnifications was less than optimal is listed in Table 8.4.

Had each individual approached closer to the display screen by that particular factor, then resolution of the words would have increased, errors might have been reduced, and reading performance generally improved.

8.5 CONCLUSION

The reading rate was found to decline exponentially as a function peculiar to the individual when the magnification is increased.

Reading performance with a display field subtending approximately 70° was only negligibly slower than that with a larger field.

Using the results from 6 partially sighted subjects, analysis of variance showed that the field size and the magnification have independent effects on reading which were statistically significant. Although the interaction of the two factors was found to be non-significant when the 6 subjects were considered en bloc, it is nonetheless obvious that this interaction governs the number of letters displayed, which in turn was found to have a radical effect on the reading performance of each individual if the results were scrutinised independently.

In addition, it was found that the reading rates reached asymptotic values for the visually-handicapped subjects when an average of 24 letters in line were displayed.

Taken together, these results suggest that a 12-inch (30 cm) monitor, having a display with a 24 cm horizontal dimension, should be viewed at 17 cm or nearer, if maximum efficiency is to be attained. When 24 letters of 12-pitch typescript are displayed, mid-screen angular magnification at this distance would be 7×. If one makes the assumption that 12 cm is the minimal viewing distance that could be maintained, using near vision spectacles with prismatic correction if necessary to maintain any binocular vision, then the angular magnification of the same typescript becomes over 10×. To take a practical example, one of the subjects (27 HM) who attended for preliminary assessment with the experimental CCTV, and listed in Appendix C, had binocular vision. She was content to use a viewing distance of 13 cm, and achieved angular magnification of 11.5× thereby. As a student of languages, she was aided by the wide field afforded by this technique, since it enabled her to see within the display an entire multi-syllable word, and this was particularly valuable when reading German.

The optimal letter subtense of magnified print was found for each of 9 visually-handicapped subjects from inspection of the graphical results. The optimal letter size was always larger than might have been anticipated from the distance Snellen acuity of each subject, yet the degree of correlation between these two measures of resolution was only moderate.

A similar diversity was found amongst subjects in the relationship between optimal letter subtense and the angular magnification selected at the initial CCTV reading session. Three subjects selected angular magnifications similar to the optimal. Another subject overstepped the optimal magnification by 108 per cent. While his viewing distance could have remained at the 29 cm he had originally selected, he might have been persuaded to reduce the linear magnification, and thereby extended the letter-string from 15 to 31 letter spaces.

Five subjects selected angular magnifications averaging 27 per cent smaller than the optimal. This discrepancy could have been avoided had they approached nearer the display screen. If the linear magnification in each case were to remain constant, subjects 32 FP and 42 JH needed to reduce the viewing distance to 21cm, from their respective selected distances of 38 cm and 29 cm; subjects 22 PM and 24 BG would have needed a 15 cm distance instead of 19 cm; and 48 LT a decrease from 17 cm to 14 cm. In most, if not all of these five cases it may have been necessary to prescribe a special near correction, if the optimal reading performance were to be attained.

These results point to the necessity for the examiner to impress upon the patient the importance of deliberation for assessing the best viewing condition. The first step is to adjust the linear magnification so that the display has a letter-string of 24 character spaces. Once that has been set, there is tentative evidence for stating that the patient should view as close to the screen as he can comfortably bear, wearing near vision glasses where necessary, and that this distance could well be nearer than that chosen without guidance. On the other hand, some individuals will be able to read equally well at these short distances when the linear magnification is reduced from its initial 24-letter setting. The reduction in magnification should be continuous until a level is reached at which reading performance begins to decline. The magnification should then be increased cautiously to restore the best performance, and notice taken of the angular magnification at this point; this represents the optimal letter subtense for that patient. By comparison of the initial angular magnification using 24 letter spaces, and the angular magnification corresponding with the optimal letter subtense, examiner and patient are aware of the maximal viewing distance afforded when a standard 24 letter spaces are displayed.

While the foregoing methods have led to some novel conclusions, the author would not attempt to state the quoted results as universal values. However, bearing in mind that 6 subjects with 5 ocular conditions took part in experiment I, the clearly consistent pattern of the curves for all subjects on each of the independent variables investigated, reinforces the conclusions. Furthermore, the deductions from the family of 9 curves in experiment II have produced a definite guideline for the initial setting of angular magnfication. Considered as a whole, the principles of the techniques as described are applicable to any prospective CCTV patient, if they are used with discrimination.

CHAPTER 9

THE HANDICAP OF SEVERELY CONSTRICTED VISUAL FIELDS

9.1 INTRODUCTION: IMPLICATIONS OF FIELD CONSTRICTION RELATED TO IMAGING FROM INVERSE MAGNIFICATION

The guidelines for classifying blindness and partial sight include reference to constriction of the visual fields (see section 2.1, Chapter 2). This is reasonable because severe handicap, in the form of restricted mobility, can be a consequence of gross field defects, even when central acuity remains good. Moreover, in methods of assessment of visual efficiency, considerable importance is attached to the angular dimensions of the visual field[184-186].

Considered in terms of solid angles, a 20^{o} diameter field is equivalent to about 2 per cent of the normal binocular field. In theory, target searching would involve such a patient in making 48 sampling fixations to cover the entire normal field, assuming these were organised into a perfectly systematic coverage. In practice, it is unlikely that such efficiency could be achieved, and inevitably many more fixations would be spent in scanning the area[187]. This is the explanation for 'tunnel vision' patients experiencing problems in orientation and in locating mislaid articles: they have to sample the environment continuously to consolidate an impression within short-term memory. The situations giving rise to these problems, and their frequency, are discussed in section 3 of this chapter, which analyses the response of patients to a questionnaire.

In order to counter the effects of peripheral field loss, several optical innovations have been designed with the common objective of providing an image of the non-sighted area within the sighted area. Trials have included mirror systems, 15-dioptre glass prisms, and flexible plastics Fresnel prisms adhered to conventional spectacle lenses[188-190].

A more popular remedial measure, advocated by Bronstein in 1960[191], and later by Holm[192] and others subsequently [187,193], is based on the principle of minifying the image by using inverse magnification. This involves the use of a reversed Galilean telescope, or field expander. In this method, the high acuity of the fovea is utilised to receive the information from a compressed visual field. In effect, within the foveal region the balance of information intake is displaced, with the shift being from the high spatial frequencies that are normally resolvable, to the lower frequencies.

In ocular diseases where the fields are constricted but foveal acuity remains good - as in retinitis pigmentosa, or less commonly in glaucoma - it has been theorised that such field expanders should provide an advantage. Because the field expander increases the sampling field directly as the square of the factor of minification, the visual search time should be markedly shorter. It is also apparent that visual acuity is depressed, theoretically by the same factor as the minification itself.

In practice however, this depression is somewhat greater, partly as a result of the diffusion of light and aberrations within the device, but also because of changes within the central pupillary area of the crystalline lens. Posterior sub-capsular cataract is a frequent complication of retinitis pigmentosa[194-196].

Kennedy et al.[197] reported that the use of a 5× field expander resulted in a mean decrease in Snellen acuity of 7.6 times in ten patients with retinitis pigmentosa. Even three control subjects with normal acuities showed a mean decrease of 6.9 times.

9.2 BASES FOR THE DESIGN OF THE FIELD EXPANDER

While it is expedient to think of the field expander as a reversed Galilean telescope, in reality this is an over-simplification. In fact, when a conventional telescope is used in reverse, the visible field is quite limited, because the entrance pupil of the system - the negative-powered objective - has a smaller diameter than is practicable. On the other hand, a field expander can be specially designed with a 180 degree field, although this inevitably produces the barrel distortion characteristics of a 'fish-eye' camera lens. Other aberrations, which pass unnoticed in the compressed image, become magnified when the design is reversed, and so render it unsuited for use as a magnifying telescope.

Any type of low vision aid is acceptable to the individual only when it fulfils his visual expectations, and equally, is aesthetically agreeable. The field expanders in which a contact lens acts as the eyepiece have a cosmetic advantage, but only contribute a meagre gain to the field. Neither can they be easily displaced in order to see an image of customary size, resulting in a decline in visual acuity and accurate spatial projection.

The spectacle telescope design suggested by Holm[(192)] supplies a workable expansion of the field, but, being a full aperture lens, it has the same disadvantage as the contact lens design in that distance visual acuity is reduced. Moreover, the Holm device is obtrusive, constructed as it is of a +20D spectacle lens and two Goldmann high minus contact lenses hinged to the front of the frame.

Ciuffreda[(193, 198)] has advocated the use of monocular and binocular designs of a bioptic type, using commercial 'door-spy' devices. When one of these is fixed at the upper or lower perimeter of a carrier spectacle lens, the patient is presented with an immediate choice of either an expanded field, or a normal-sized image with maximal visual acuity. While the bioptic design is a practicable one, door-spy devices used in this way are cosmetically objectionable, and it is interesting to observe that Ciuffreda[(199)] appeared to have abandoned the spectacle-mounted principle in favour of a hand-held monocular device, during his later experiments.

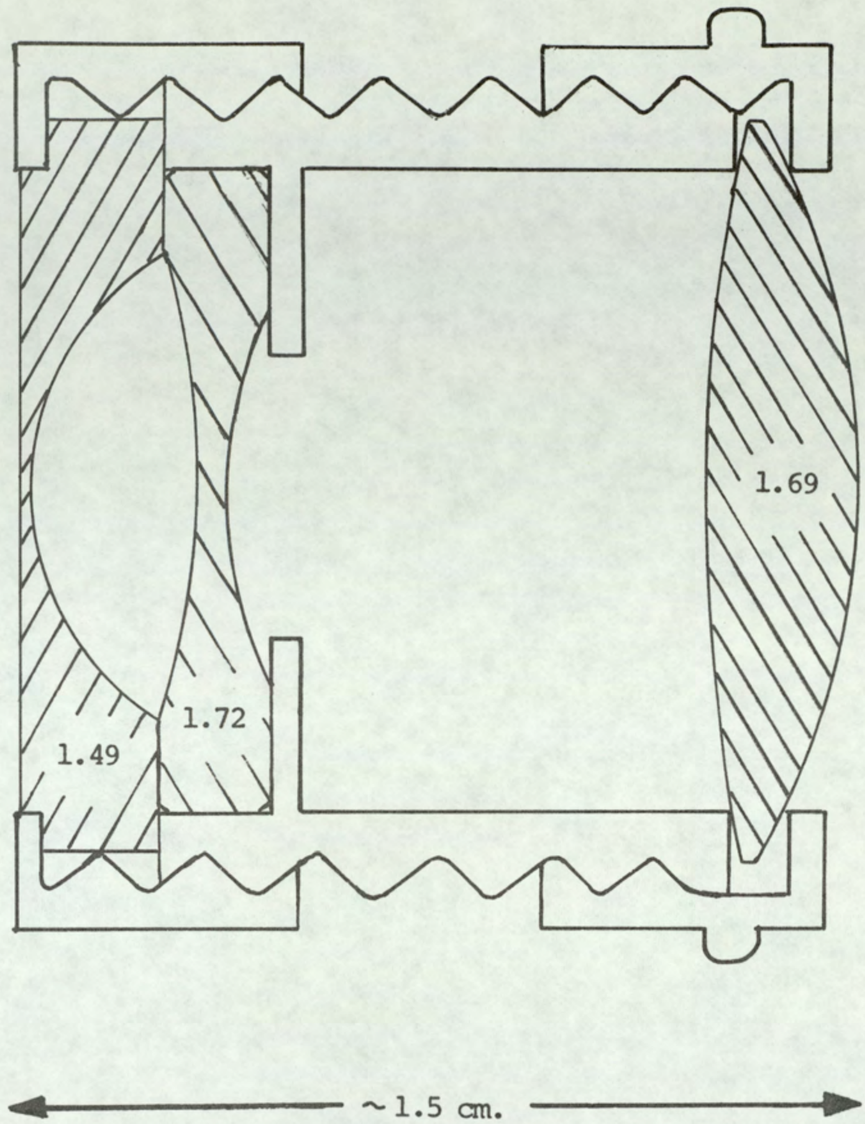


Fig. 9.1 Diagrammatic Section of Three-Element Field Expander showing Refractive Indices. (after Drasdo[201]).

While considering the Galilean principle afresh, Drasdo(187) postulated that patients would more readily accept a spectacle-mounted field expander which was miniaturised as much as possible, on obvious aesthetic grounds. This would have the incidental advantages of allowing more freedom for placement of the unit within the carrier lens in a bioptic design, as well as reducing the physical hazard should the patient suffer a fall. The design of the improved miniature field expander unit is shown in diagrammatic section in Fig. 9.1.

The bioptic design has the advantage that it induces successive sampling through the expanded field and directly through the spectacle lens thereby enabling the patient to retain the advantage of his normal visual acuity(187). If the carrier lens is tinted, this could inhibit further degeneration of the rod receptors, which Berson(200) has considered to be aggravated by the action of light.

9.3 SURVEY OF RETINITIS PIGMENTOSA PATIENTS USING A QUESTIONNAIRE METHOD

With the full co-operation of the Midlands branch of the British Retinitis Pigmentosa Society, a two-page questionnaire was sent to 64 patients with this disease, during May-June 1977. The questionnaire format was largely based on one designed and used by Drasdo and Murray(201), with slight modifications.

There were 48 respondents, only one of whom - a juvenile patient - failed to give adequate answers to the more detailed questions in section II. The age group ranged between the tenth and seventieth decade. Copies of five completed questionnaires are included in Appendix F.

The questionnaire was phrased so as to elicit the maximum information from patients about the physical problems of copying day-to-day with their complaint. A majority of the questions were concerned with the mobility of the individual, both indoors and outdoors. Others related to the task of visual search, either statically, or in conjunction with mobility, for example when looking before crossing the road.

Where there was light traffic, 29% of the respondents replied that they could cross the road with slight difficulty, but another 29% could barely manage. Thirty-six per cent claimed to have no difficulty, but 6% could not manage at all. On a busy road, the number who could not manage to cross rose to 38%, and only 10% claimed no difficulty; while some degree of difficulty was experienced by another 39%, and 13% felt they could barely manage. Ten people (21%) blamed their low vision for their having had a road accident or narrowly escaping one. Two others (4%) felt particularly nervous of traffic.

Another common occurrence in which the restricted-field patient is at risk, is in colliding with people or obstacles, or in misplacing the step while walking, sometimes falling as a result. Even in familiar surroundings 47% replied that mishaps of this kind occur between 1 and 3 times a week, 23% between 4 and 6 times a week, and a further 13% more than 6 times a week. Only 17% (8 individuals) claimed not to suffer from this problem.

When the environment is unfamiliar, the number to whom these mishaps occur oftener than 6 times each week rises, not unexpectedly, to 42%. Twenty-nine per cent experience such minor accidents between once and 3 times a week, and 13% between 4 and 6 times a week. Again, 16% apparently are not so impeded, but then half of this percentage admitted that they are normally accompanied in unfamiliar surroundings.

The commonest sort of collision is with other people, whether on the pavement, in shopping precincts, in the theatre, or in other public places. A total of 40% singled out this experience. Several patients mentioned that they tend to avoid crowds whenever possible. When they are surrounded by people, 42 patients (88%) experienced difficulties, which varied from a feeling of claustrophobia to nervous strain in company, and vertigo when avoiding collisions with others, of which 2 complained (4%). One person even had bouts of vertigo when walking downhill, and another when turning to walk away from a shop window. The simple act of changing direction whilst walking induced vertigo in 9 (19%) respondents, one of whom was also susceptible to these attacks when dancing. Two other common problems are a difficulty in recognising familiar faces (19% mentioned this), and 13% had a feeling of awkwardness through not noticing the proffered handshake, cigarette, or other article. Another social embarrassment, indicated by 3 people (6%), was a tendency to stumble unawares into small children and dogs. Two persons (4%) remarked on the strain felt in walking alongside others. One woman, was concerned not to miss someone trying to catch her attention in company; another stated how difficult it was to look directly at people at close range.

With regard to accidents with stationary obstacles, 23% of the 48 respondents had suffered these, 2 of them (4%) severely enough to need hospital treatment. Street furniture such as lamp-posts, grocers' advertising banners, and scaffolding, besides carelessly parked cars and bicycles and the overhanging branches of trees were each mentioned as causes of hazardous experiences. Perhaps not surprisingly, the frameless glass doors at the entrances to department stores constitute a hazard also: two people had bumped into them heavily. Nonetheless, the activity of walking, in itself presents no complications to the majority (58%). The remaining 42% experience symptoms such as a loss of balance, or uncertainty in finding their bearings when they change direction either in the street or in a store.

Tripping and falling, without serious consequences, was experienced by 4 people (8%). More serious falls included two people who fell into road works, and one who stumbled over the edge of a platform onto the railway line. A thirteen year-old boy on a cross-country run was unfortunate enough to fall into a canal; and two other individuals, while walking along a river-bank, had suffered narrow excapes from a similar experience. One man only just avoided dropping into a six-foot deep inspection pit at work, and another came close to falling over a fifty-foot railway embankment. A total of 42 people (88%) affirmed that they had encountered hazardous experiences which were caused specifically by their vision. Of these 42 people, the most recurrent accident appeared to be falling downstairs, which happened to 7 respondents (15%).

In answer to the question 'Can you walk up and down unfamiliar stairs alone?', 36 people (75%) considered that they could cope but with slight difficulty, 5 (10%) found the task only just manageable, but 6 (13%) apparently had no difficulty whatsoever.

One woman recalled how she had missed her footing in attempting to step onto a bus platform at the same instant that the bus driver started off unwittingly. Doubtless because of such risks, 40% of respondents did not use public transport when alone, while 41% used it between once and 3 times a week. Six per cent replied that they use public transport between 4 and 6 times a week, and 13% oftener than 6 times a week.

When confronted with the daily round of shopping, 38% managed with no difficulty, and 33% with little difficulty in a small shop. Only 10% felt they could not manage at all. Naturally, a large store is more stressful, with 17% conceding that this was too difficult and 23% stating that it was barely manageable. A further 33% found store shopping a little difficult, but to 27% it presented no problem. Only 10% never attempted shopping alone, whereas a further 10% did so more than 8 times a week and 27% between 5 and 8 times a week. The majority (53%) could make shop purchases unaccompanied between once and 4 times each week.

One patient commented that she was aware of having to adjust to a change in the lighting conditions when entering shops. The adaptation process generated in the normal eye by a change in the ambient light is diminished in retinitis pigmentosa, with the result that many complain of acute sensitivity to the environmental lighting conditions. In fact 31% of respondents raised this matter spontaneously in their answers. Bright sunlight - indoors as well as outdoors - was troublesome to 15%. Dimly-lit surroundings were disconcerting to 15% respondents, one of whom wrote of feeling particularly vulnerable while walking through a subway at night.

Finally, domestic or vocational tasks were stated as presenting difficulties in 79% of the replies. Thirteen per cent were prone to knock over the glassware, especially when it was placed on a white tablecloth or draining board;

and another 6% break and chip the crockery when washing up. Three women (6%) found that ironing was problematic. Two people had difficulty in writing straight on unlined paper; and one man, with sight in the left eye only, was inclined to lose fixation of the pen tip when he was writing.

Probably a more universal everyday task for active people is locating a misplaced article. A visual search task such as this, is inevitably more tedious for tunnel vision patients. Sixty-two per cent acknowledged some difficulty in spotting a mislaid object at table level, and 13% had no difficulty, while 6% found this impossible to manage. When the object was at floor level, a successful search within reasonable time was admitted to be impossible for 17% of respondents. Slight difficulty was encountered by 52% and only 2% could claim to have no difficulty. The group of individuals who felt they were only just capable of managing visual search tasks like this rose from 19% for a table level search, to 29% for a floor level search task.

In considering section I of the questionnaire, answers to the seven questions were graded, so that an index of performance could be determined for each individual. The levels of difficulty experienced by the respondents were graded into four, with a score of 1 indicating 'cannot manage', and 4 indicating 'manage without any difficulty'. Questions 2(b) and 3(a) and (b) were concerned with the skill of visual search by itself, and the answers were weighted so that a whole number, from 1 to 4, was assigned to the score. As to the tasks mentioned in the remaining four questions, visual search could be assisted by ancillary clues and other senses. For example, regular proprioceptive impulses assist in the action of climbing stairs; the sense of hearing is involved when crossing a road; and in a small shop an assistant is often nearby to help the handicapped customer. The answers, therefore, to questions 1, 2(a) and 4(a) and (b), were awarded half of the full score; in which respect the answers were weighted in a different manner from that employed by the designers of the original questionnaire.[201] Thus, the possible aggregate score for any individual experiencing the least handicap was 5×4 = 20, and for anyone unable to manage any of the seven tasks, the least score was 5.

A percentage index of performance (P) was then determined for each respondent as follows:-

$$P = \frac{\text{aggregate score of difficulty} - 5}{\text{aggregate maximum possible score} - 5} \times 100$$

$$\text{i.e. } P = \frac{\text{aggregate score of difficulty} - 5}{15} \times 100$$

Within the respondent sample of 48 patients, the distribution of performance indices in the tasks is shown in Fig. 9.2.

Forty-two respondents completed a visual acuity self-assessment at home. This was a high contrast photocopy of Snellen optotypes designed to be used at 3 metres wherever

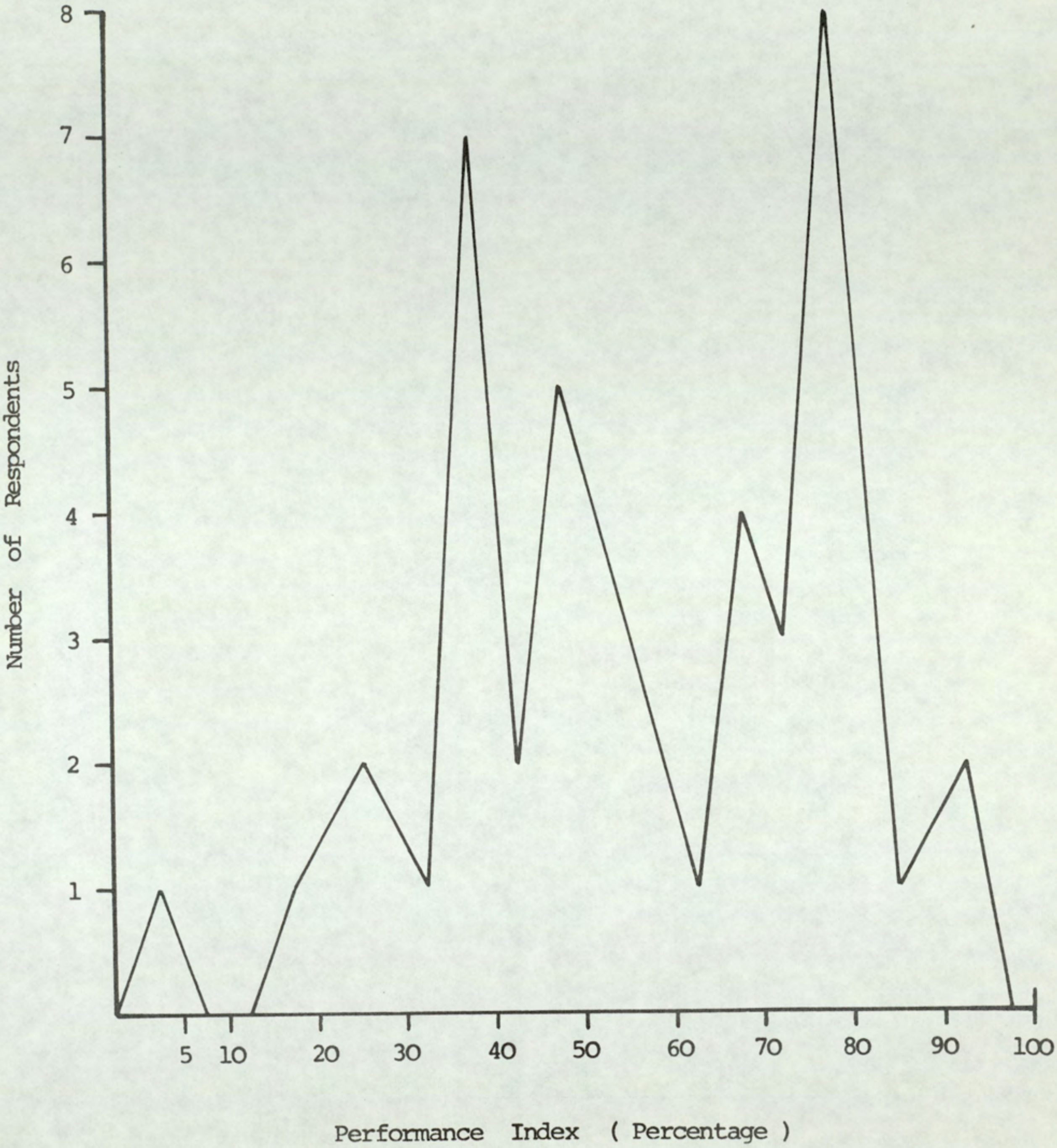


Fig. 9.2 Frequency Polygon showing Distribution of Performance Indices amongst 48 Questionnaire Respondents.

possible; but if distance vision was inadequate the patient was instructed to wear his reading glasses and use the same chart at 25cm. Patients were instructed to use good lighting, and to mark the smallest line which could just be read comfortably. The distribution of the visual acuities in the respondent sample is illustrated in Table 9.1.

Finally, the 42 visual acuities within the respondent sample were correlated with the performance indices of the same individuals. The Spearman rank correlation coefficient was calculated, using the formula appropriate to this case, in which several tied scores occur[202]. The value of the correlation coefficient was r_s = 0.2335 which is significant only at the 0.1 level.

9.4 EXPERIMENT IN CO-ORDINATED VISUAL SEARCH AND PROPRIOCEPTIVE ABILITY USING THE FIELD EXPANDER

9.4.1 Introduction

Kennedy et al.[197] discovered that the field expander actually impeded the mobility of 8 subjects out of 10 who used it while walking. The procedure employed a monocular 5× field expander, hand-held before the better eye. The visual acuity range lay between 11/7.5 (~6/4) and 6/160 (~2/60), with the former subject having a visual field of 10° and the latter of 25°. Taking all 8 patients into account, the fields varied in extent between 8° and 85°.

TABLE 9.1

Distribution of Visual Acuity Occurring in 42 Questionnaire Respondents with Retinitis Pigmentosa

	Best Visual Acuity (M.A.R. in mins of arc) (Binocularly or Better Eye)											
	1'	1.5'-2'	3'	3.5'-4'	5'-6'	8'	12'	16'-20'	24'	36'	40'	48'
Numbers of Respondents	4	5	5	10	4	2	4	3	1	2	1	1

Generally, there was a difficulty in using the device in crowds of people or near moving objects. The authors blamed the distortion of perspective and size constancy for the tendency of tunnel vision subjects and normal-sighted controls to bump into objects when they were using the device. Kennedy et al.[197] stated that the field expander was most beneficial to patients in situations where they could remain stationary and scan an area, rather than move about looking for objects. Adaptation to the device was remarkably variable, taking from less than one day up to 21 days.

9.4.2 Experimental Rationale and Hypothesis

In the present study, the replies to the questionnaire show that mobility presents the greatest hazards confronting patients with retinitis pigmentosa. However, in view of the results of Kennedy et al. - that mobility was impaired by the field expander - it was considered unwise to attempt a controlled study of mobility using a binocular device because of the inter-subject variability in adaptation. This view was reinforced by the circumstances, which allowed for only a limited number of suitable patients and limited available time.

The questionnaire replies revealed the additional fact that visual search is a demanding task for the tunnel vision patient. Because visual search requires no simultaneous ambulatory adaptation, it allows a more easily-regulated procedure for quantitative assessment.

However, other workers found that the difference in visual search time between the use of a monocular field expander or unaided binocular vision was insignificant[201]. The next logical experiment, it appeared, would be a comparative study of binocular search performance with and without use of a field expander. The binocular field expander enhances stereopsis remarkably compared with a monocular unit, so that it seemed advantageous to devise an experiment to show simultaneously a simple proprioceptive ability.

The hypothesis to be tested was that the effect of the binocular field expander is to decrease significantly the time necessary for accurate search.

For the experiment, the use of multiple targets was rejected, because practice causes an exponential decrease in the time required for their detection[203, 204]. This variable would have confounded the analysis of results, so instead a single target was chosen. Circular target stimuli were selected because other workers had found that these were generally the most easily detectable shape[205].

9.4.3 Subject Selection

Seven subjects with peripherally constricted visual fields were initially selected from the questionnaire respondents. Each subject had normal or near-normal visual acuity in each eye, and binocular vision. Subsequent visual field plotting revealed that 2 subjects had a central area of vision, but differed from the others in having a concentric annulus of peripheral vision, separated from the central sighted area by a scotomatous ring. These 2 subjects were excluded from the analysis, as they did not represent ideal cases for the purposes of the experiment.

9.4.4 Apparatus

A back projection screen was constructed from opalescent acrylic plastics material. This consisted of a sheet 100cm in length by 70cm in height, and 3mm in thickness, curved under tension to a radius of 60cm, and supported at each end by an upright angle iron. The screen was mounted on a firm plywood base 95cm in length by 30cm in width, with the concave face of the screen towards the subjects.

Two Kodak 'Carousel' automatic 35mm slide projectors were operated in tandem by the subject himself, using a device described later. Two slides were projected simultaneously, side-by-side, so that each occupied half of the screen field.

Preceding the experiment itself, 6 colour slides were projected to demonstrate to each subject the rationale in using a field expander for tunnel vision cases. These photographs were created with an ultra-wide-angle lens providing a 180° field of view, and simulating the minification and spatial distortion of the field expander. Two or three black circles (from 'Letraset' self-adhesive lettering) were superimposed onto some of these slides at points of interest. The size of each circle was comparable with the sampling area of the typical restricted field present in advanced cases of retinitis pigmentosa.

Following the 6 demonstration colour slides, 28 monochrome 'target' slides were fitted in random sequence throughout the subsequent fifty-six spaces. Wherever a target slide was arranged in one magazine, the corresponding space of the other showed a uniform black field. All the monochrome sides, both target and blank, were produced on photo-lithographic film so as to achieve the highest contrast, and matching of both halves of the background. Each target slide consisted of a uniform black background on which a white disc was located at random. In the centre of the white disc was a sans-serif, upper-case black letter whose contrast with the disc equalled that of the background. The letters used were of confusable forms, e.g. A, H, N; D, O, G; E, F, P; V, U; and T, Y, X.

The contrast ratio of the target was 66%, using the formula $C = (L_t - L_b)/L_t$, where C is contrast, L_t is the target luminance, and L_b is the luminance of the background screen. Luminance measurements were taken using a Spectra Mini-Spot silicon cell photometer.

For the purpose of advancing the sequence of search target slides, an electrical circuit was devised in which a photosensitive resistor (ORP 12) was connected via a 25-volt stabilised power supply to two relays of 185-ohm resistance. One relay was used to produce a synchronous change of slides in the two projectors, while the other relay simultaneously activated the event-marker on a pen-recorder. The circuit is shown in Fig. 9.3. The

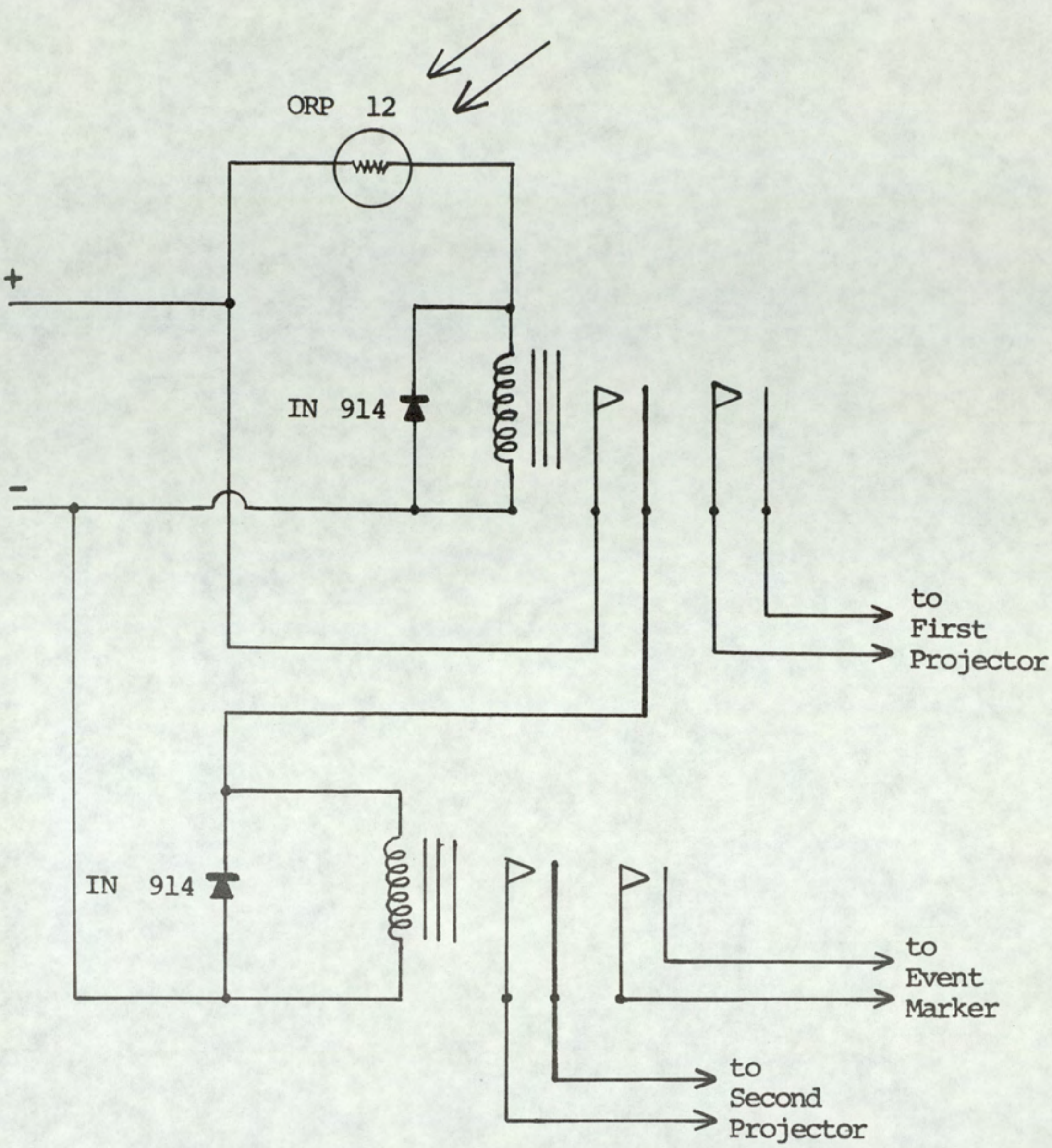


Fig. 9.3 <u>Circuit Diagram of Electrical Apparatus Used in Visual Search Task.</u>

photosensitive resistor was rigidly fixed at the end of a 25cm length of matt black plastics rod. This formed a 'wand' which the subject was instructed to hold in the dominant hand.

Two matched field expander units, designed by Drasdo[201] were used, having magnification factors of 0.33× (Fig. 9.1). For the present experiment, each field expander unit was fitted into a specially-designed acrylic mount of 38mm diameter (Fig. 9.4). The mounts could be finely adjusted for tilt, with thumb screws. Hence, when both mounts were placed in a trial frame, binocularity was achievable by vertical and lateral adjustment of the field expander optic axes (Fig. 9.5). It was essential that the device be worn before alignment of the axes could be attempted. In order to do this, the subject was required to view a lamp at one metre with one eye, while a Maddox rod was placed before the other, alternately in the horizontal and vertical orientations. The thumb screws were adjusted until the two images were coincident, after which the Maddox rod was removed and the subject was asked to verify that a single percept was present.

9.4.5 Procedure

First, Snellen visual acuity was recorded binocularly at 6 metres, for each subject. Then the subject was seated in front of the visual search apparatus, such that the mid-screen position corresponded with the primary position of

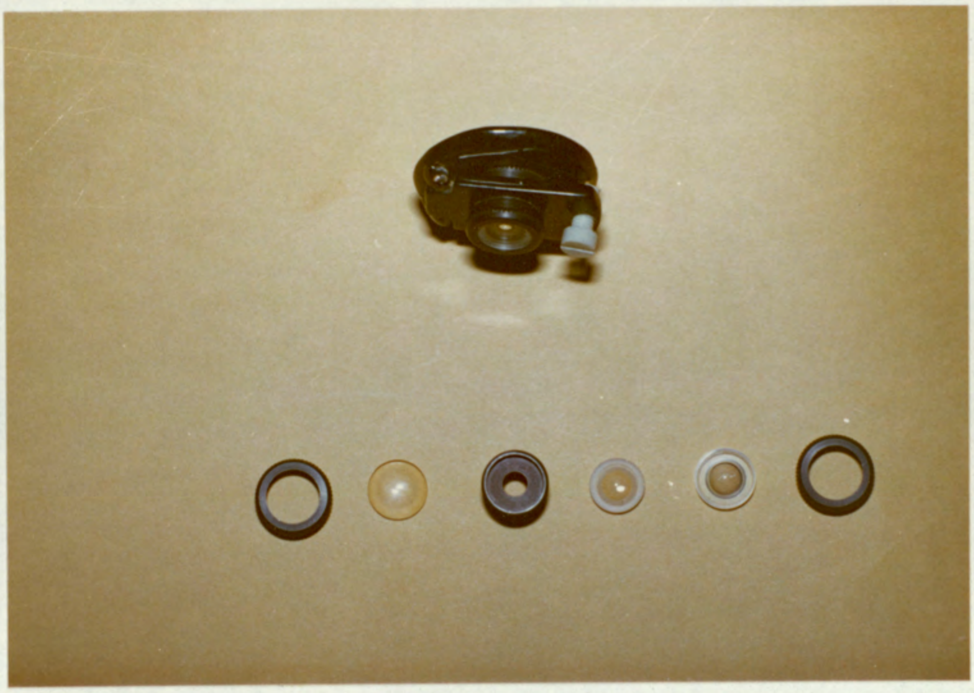


Fig. 9.4 Component Elements of Field Expander, with Complete Unit fitted to Trial-Frame Mount.

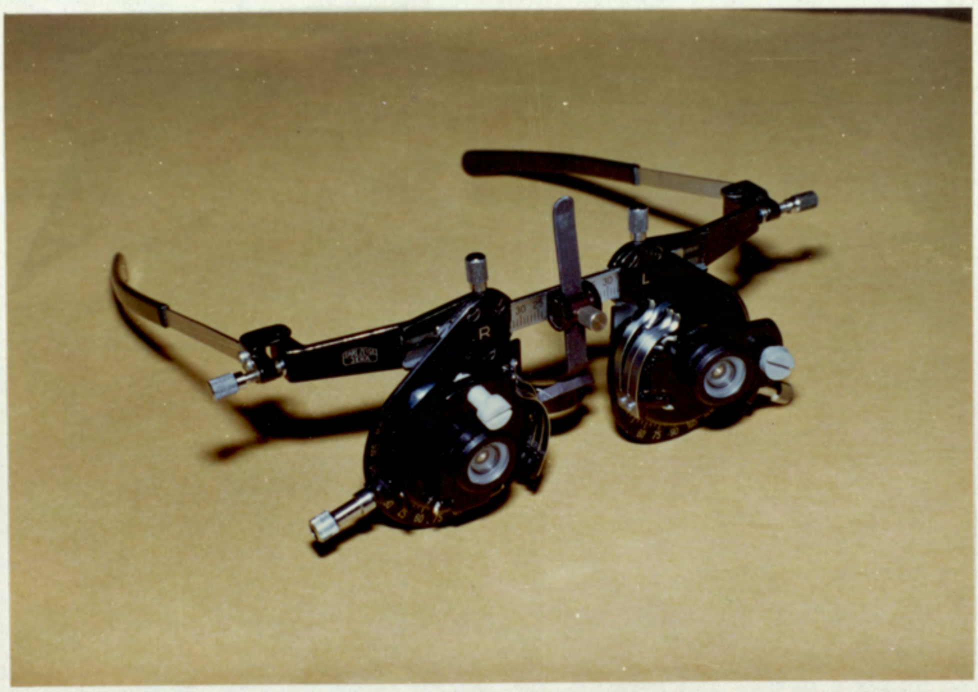


Fig. 9.5 Experimental Binocular Field Expander fitted to Trial-Frame.

fixation. At this distance the utilised screen field subtended a visual angle of 90° laterally and 67° vertically. At the centre of the field, a target disc subtended 2° 18' overall, while the letter within subtended 1° 24'. This letter size was necessary because some subjects had Snellen acuity of worse than 6/6. Moreover, the field expander diminished the linear subtense by a factor of three. Hence, the overall size of the target letter was approximately sixteen times larger than that recognised by an eye with normal acuity.

The preliminary demonstration colour slides were shown first to the subject, followed by a short break. Next, as a practice run, two target slides were projected in turn. The subject was instructed to locate the first target disc on the screen, state the letter within it, and to touch the target with the photosensitive resistor, whereupon the next target slide would appear, and the slide change was recorded by the event marker. The procedure was repeated with the second demonstration slide, and then a dark blue field appeared while the subject rested before beginning the experiment. Fig. 9.6 illustrates the apparatus in use.

The experiment was divided into four equal parts in an A-B-B-A design. There were 28 target discs in each sequence, and a blank field between sequences. This procedure involved repeating each of the two slide sequences.

Two of the subjects - BF and LS - used the field expander for the first and last sequences, and their unaided vision (or distance spectacles when they were normally worn) for

Fig. 9.6 Visual Search Task Apparatus in Use.

the two intermediate sequences. This order was reversed for the other three subjects. Each sequence was timed from the beginning with the event marker. The time taken to locate each target in the sequence was thus recorded.

Finally, the visual fields of the two eyes were plotted, using the Goldmann perimeter with a 3/330 white target, which had a contrast of 72% (using the formula stated earlier). The field plots are reproduced in Appendix G.

9.4.5. Results

The performance times for completing the search task with and without the field expander are shown in Table 9.2.

TABLE 9.2

Time Taken to Complete Visual Search Task

Subject	Search Time (secs)			
	With Field Expander		Without Field Expander	
	Run I	Run II	Run I	Run II
A.H.	91	74	80	84
B.F.	204	179	90	75
G.P.	151	114	152	128
J.B.	115	94	91	88
L.S.	98	96	92	93

Results of the first run, with and without use of the field expander, and of the second run, were first analysed separately. Using the "Student's t" test for correlated samples[141], there was found to be no statistically significant difference in performance between the use or non-use of the binocular field expander, either in the first or second experimental runs ($t = 1.453$ for first run; $t = 0.814$ for second run).

Interestingly, practice revealed a statistically significant effect when the field expander was worn ($t = 3.586$; $0.01 > p < 0.025$), but a non-significant effect without its use ($t = 1.407$), as shown by analysis of runs I and II. Both runs were averaged, and the resulting mean is presented in Table 9.3.

Next, the percentage of information channel capacity within the restricted field of each eye was determined, using a method devised by Drasdo and Peaston[164]. This was done by using a transparency equal in size to the Goldmann perimeter chart, and marked as a graticule to denote the distribution of channel capacity within the whole field. The percentage of the residual channel capacity of the two eyes was recorded in Table 9.3.

TABLE 9.3

Details of 5 Subjects Performing the Field Expander Visual Search Task

	SUBJECTS (AGE)				
	A.H. (37)	B.F. (48)	G.P. (40)	J.B. (47)	L.S. (49)
Binocular visual acuity (M.A.R. = mins. of arc)	1.1'	1.5'	1.5'	1.5'	2'
Questionnaire Performance Score (percent age)	60	73	60	80	67
Mean search time (secs): with field expander	82.5	191.5	132.5	104.5	97
Mean search time (secs): without field expander	82	82.5	140	89.5	92.5
Percent age channel capacity. R.eye/L.eye (Mean)	58:57 (57.5)	33:32 (32.5)	36:39 (37.5)	47:43 (45)	51:57 (54)

9.4.7 Discussion

While a larger subject sample would have been desirable, certain facts are clearly apparent from the results. The t-test results and the tables 9.2 and 9.3 show that the value of a binocular field expander in assisting the subjects in efficient visual search is limited.

Practice on the experimental search task proved effective in reducing the time necessary for successful completion, in every case. This being so, in comparing the times taken to complete the search task in run II, it is notable that subjects A.H. and G.P. spent 12 and 11 per cent less time respectively, when wearing the field expander, compared with unaided vision (see Table 9.2).

Several parameters within the sample were correlated with performance with and without the field expander, using the Pearson correlation coefficient, and the majority were found to be non-significant. Non-minified binocular visual acuities and mean search times correlate at $r=0.0607$ and $r = 0.1199$ with and without the field expander respectively. Questionnaire performance scores have a non-significant correlation with mean search times: there is an expected negative correlation without use of the field expander ($r = {}^{-}0.4555$), but the results produce a falsely positive correlation when the field expander is worn ($r = 0.2651$).

Although mean search time without the field expander correlates non-significantly with channel capacity ($r = {}^{-}0.3590$), when the binocular field expander is worn the coefficient becomes $r = {}^{-}0.9116$ which is significant at $p < 0.015$.

9.5 CONCLUSION

The experiment and the questionnaire responses together, reveal several interesting points. On the one hand, there is a non-significant correlation of visual acuity with search performance (as ranked by 42 questionnaire replies). In simple detection tasks, such as those listed in the questionnaire, this is not an unexpected result. On the other hand, from the experiment, the relationship between residual channel capacity and search time when the field expander is worn is significant, although not so without it. This reveals that channel capacity is a necessary parameter to be included in assessment of detection performance; but furthermore it might appear to show that those patients with higher channel capacities benefit the most from using field expanders. Because only a limited number of experimental subjects was used, such a possibility cannot be completely verified, yet it is nevertheless apparent from Table 9.3 that the pattern of search time with the field expander is not consistent with individual channel capacity.

Moreover, even if the two most positive experimental results, for subjects A.H. and G.P., are considered alone, it is questionable whether improvements in visual search efficiency of as little as 11 and 12 per cent would justify the occasional use of a binocular field expander.

The outcome of these results shows the desirability of designing a longitudinal study, to determine benefits gained from wearing a binocular field expander after practice, while also using a much larger subject sample. If these conditions could be met, the ambiguities might be resolved, and at the same time the tentative deductions which have arisen from the results might be affirmed.

CHAPTER 10

THE RELATIONSHIP OF THE CONTRAST SENSITIVITY FUNCTION TO MAGNIFICATION IN THE VISUALLY HANDICAPPED

10.1 INTRODUCTION

Whether the magnification is orthodox or inverse, contrast - either of luminance or of hue - between the object of regard and its background is necessary for detection and recognition. Quantitative assessments of contrast thresholds have tended to be most common in terms of luminance, probably because these experiments have the advantage of being simpler to design and probably cause less inter-subject variability amongst normals.

The traditional Snellen optotypes, which provide a measurement of the smallest object recognisable, have a contrast of the order of 90 per cent. Visibility, or 'ease of seeing', however, is not linearly related to Snellen visual acuity. Indeed, as a result of experiment on normal subjects, Hill[206] defines the precise exponential relationship of these two factors.

Valuable though the Snellen acuity may be as an assessment technique, it reveals nothing of the capacity of the eye to distinguish slight changes of lower contrast in larger targets. Some patients can present with a visual acuity of 6/6, while paradoxically suffering from a generalised disturbance of vision which they describe as 'mistiness'. Such a state is caused when the contrast sensitivity of the ocular system is affected by the degenerative processes associated with ageing or disease[207,208].

Contrast sensitivity was thus considered to be particularly suitable as an assessment technique for low vision subjects in relation to the visibility of magnified images.

Schade[209], and later Campbell and Green[210] first introduced a method involving grating patterns with a sinusoidal waveform to assess the effect of contrast on visibility, using the normal eye. Their technique of presenting the gratings on an oscilloscope or television screen is now well-established in the laboratory, and has also become a recognised method in the assessment of ocular and neurological defects[211-212].

The method records threshold contrast of the gratings as a function of their spatial frequency. Normally, the reciprocal of the contrast threshold (i.e. contrast sensitivity) is plotted graphically, and the resulting curve is referred to as the 'contrast sensitivity function' (C.S.F.), or spatial modulation transfer function (M.T.F.).

In normal-sighted individuals, contrast sensitivity reaches a peak in the region of 3-5 cycles/degree, with a decline either side this value, more rapid in the low frequencies. At the high frequency end, if the slope of the decline is extrapolated, the point at which it intersects the abscissa generally lies between 40 and 50 cycles/degree[207,210]. Since the abscissa is equivalent to approximately 100 per cent contrast, this point denotes the visual acuity.

10.2 EXPERIMENTAL RATIONALE AND HYPOTHESIS

Contrast sensitivity function represents visual capability more completely than visual acuity alone, however, so that it seemed probable that the C.S.F. could be used to predict factors of CCTV reading performance. In particular, it was postulated that a linear correlation might exist between the optimal letter subtense and a specific C.S.F. parameter.

In a pilot C.S.F. experiment involving an albino subject with lateral saw-tooth nystagmus (35 WG) the contrast sensitivity was found to be markedly higher when the gratings were re-orientated from the vertical into a horizontal direction. However, another experimental subject (39 RS) had a vertical pendular nystagmus, which countermanded the use of a horizontal grating throughout the entire experiment. Clearly the most satisfactory answer to the problem seemed to be to standardise, which was done by rotating the cathode-ray tube of the oscilloscope until the gratings sloped in a 45° meridian.

Although decreased sensitivity to oblique gratings has been noted in earlier studies, the effect was only apparent at the higher spatial frequencies resolved by normal eyes. In fact, the upper limit selected for the present experiment using visually-handicapped subjects was 5 cycles/degree. One group of workers produced results showing no substantial effects on contrast detection threshold due to orientation of the gratings, when the spatial frequency was about 5 cycles/degree or less[213].

A similar observation has since been reported by other teams[214, 215].

One method for determining C.S.F. requires that the viewing distance from eye to display screen remains fixed, while the number of grating bars is varied so as to achieve several spatial frequencies. The converse technique, which was adopted for the present experiment, was to display a fixed number of cycles, and to alter the viewing distance. This latter technique was chosen to elicit the highest contrast sensitivity from every subject, judging from the various arguments of previous workers[216-221]. These arguments have been based upon two variables, namely the number of cycles in the target grating, and the target width. Furthermore, in using visually-handicapped subjects it was necessary to employ a target subtense sufficiently large to stimulate the peripheral retina.

Recent evidence has indicated the importance of considering the number of cycles displayed,[216-219] especially when sensitivity is determined at low spatial frequencies, i.e. up to 3 cycles/degree[218]. According to the evidence of Hoekstra et al.[217], the number of bars in the grating and the target mean luminance have interactive effects on the contrast threshold. If the grating is produced on an oscilloscope, in the manner of Campbell and Green[210], and the z-modulation is fully attenuated so that no grating is visible, a background luminance remains on the cathode-ray tube. Within the range of available contrast settings, the gratings had optimal appearance when this background luminance was fixed at 8 candelas/sq. metre. Interpolation from the graphical results of Hoekstra et al.[217] shows that at this luminance the C.S.F. becomes maximal and asymptotic when the display has about 5 cycles.

For the present experiment, however, 12 cycles were chosen to be displayed, for the following reasons:-

(a) Viewing distances could be kept to manageable lengths (the maximum distance used was 191 cm at 5 cycles/degree).

(b) The peripheral retina had to be stimulated in order that the target should be visible to partially-sighted subjects. Even with an oscilloscope display of only 8 cm diameter, this was feasible with 12 cycles, because the smallest overall subtense of the target was 2.4° when the grating spatial frequency was 5 cycles/degree.

(c) Notwithstanding (b), more than 12 cycles would have necessitated an impractically short viewing distance at the lower limit of 0.2 cycles/degree. As it was, 7 cm was found to be the shortest distance manageable.

(d) The resolution range of the oscilloscope is limited, such that whereas the grating appeared satisfactory at 12 cycles, any large increase might have caused a deterioration in resolution.

In addition to these points, the results from other teams of investigators lend support to the technique of presenting a fixed grating pattern and moving the subject to and from the display[214,220,221]. The peripheral retina, they have concluded, appears to possess a contrast sensitivity similar to that of the fovea, provided the target width is adjusted so that the grating stimulates an equal number of receptive fields[214], with the corollary that the cortical magnification factor remains constant[220]. The resulting C.S.F. is maximal, and represents the total visual channel capacity.

The area immediately surrounding the target display has also been found to be important for achieving the maximal response[222]. To elicit the highest contrast sensitivity to intermediate spatial frequencies, the target should have a homogeneous surround, with a luminance equal to the mean luminance of the grating.

Briefly reviewing the literature on binocular versus monocular thresholds, Legge[223] recounts the opinion that neural interaction, rather than probability summation alone, is responsible for the increased contrast sensitivity given by binocular viewing. Hence, for the present assessment, it was decided that subjects should undertake the procedure using both eyes, assuming each eye was functional.

10.3 APPARATUS

The apparatus was assembled on an instrument table, and consisted of a Telequipment D61a oscilloscope with a P.1 green phosphor, and a control box. The fascia-mask was removed from the oscilloscope, leaving the whole face of the cathode-ray tube as an 8cm diameter circular target for display. The cathode-ray tube was reorientated through 45°, so as to present a sloping grating, for reasons referred to in the Introduction (Figs. 10.1; 10.2).

Fixed to surround the oscilloscope screen was a rectangular sheet of pale green cardboard, measuring about 60cm in length and 45cm in height. This was illuminated obliquely, as uniformly as possible, with a shaded opal 60-watt tungsten lamp in an adjustable fitting, to give a mean luminance of 5 candelas/sq. metre.

The oscilloscope was connected to a pattern generator having two potentiometers, one for controlling the periodicity of the displayed grating, and the other for adjusting the grating contrast level (i.e. the z-modulation). Both potentiometers were of the rotary 10-turn type, having annular graduated scales. Mean luminance of the grating was adjusted initially with a knob on the oscilloscope itself.

10.4 PROCEDURE

The initial requirement was to plot a calibration curve, from which the contrast scale settings of the potentiometer could be translated from arbitrary numbers into percentage

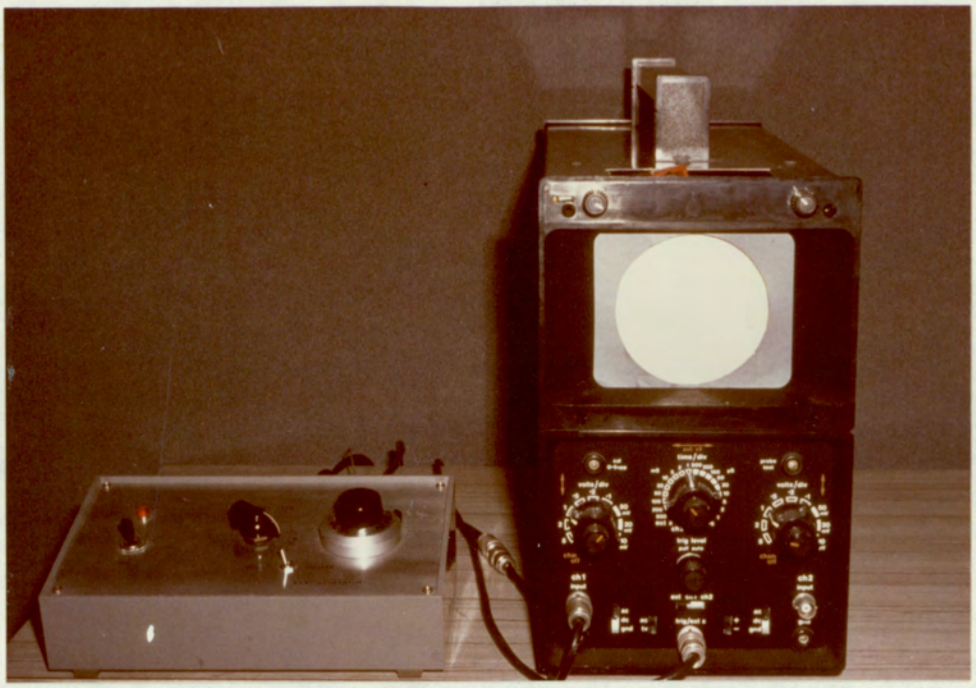


Fig. 10.1 Oscilloscope and Control-box used in Determining Contrast Sensitivity Function.

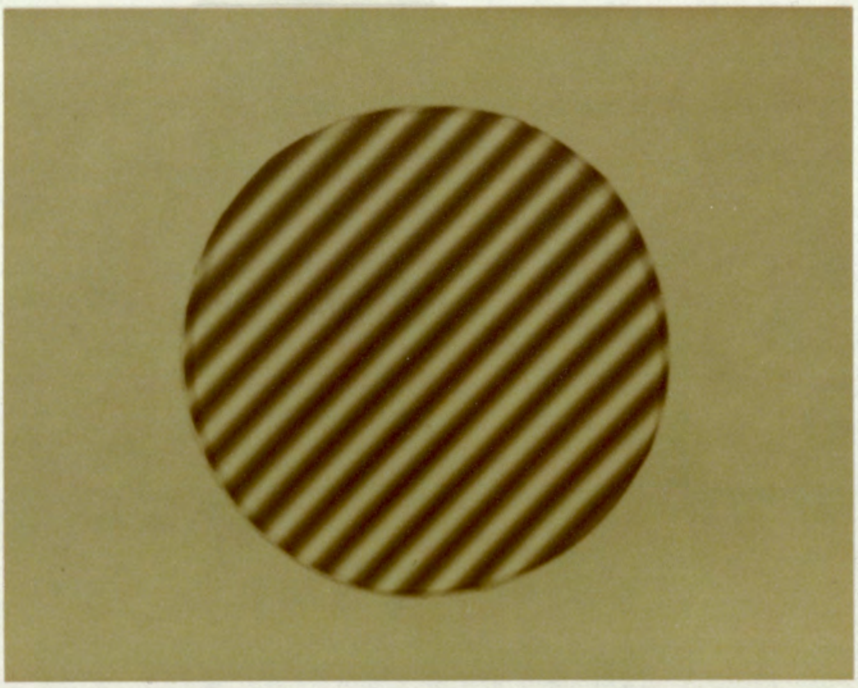


Fig. 10.2 Appearance of Grating Display.

values of contrast. In order that this calibration curve should be applicable for the contrast sensitivity readings of all the subjects in the experiment, it was necessary to standardise the display conditions.

With the contrast potentiometer of the oscilloscope setting at zero contrast, the mean luminance was adjusted until the reading at the centre of the display was 8 candelas per square metre (cd/m^2). This level appeared to give the most satisfactory relative width of the grating bars, as well as a workable range of contrast. The number of cycles on the target display was adjusted to 12. Luminances of dark and light bars of the grating were measured with a 'Spectra Mini-Spot' photometer at ten potentiometer settings. The contrast, C, was calculated for each setting using the formula (220)

$$C = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} ,$$

where L_{max} is the luminance of a light bar, and L_{min} of a dark bar. The calibration curve was then produced by plotting the contrast levels corresponding with the potentiometer settings.

With this preliminary completed, the C.S.F.'s were determined for 8 visually-handicapped subjects, and 5 normally-sighted controls (post-graduate students). The grating display was positioned at eye-level to the seated subject. For assessment of the contrast threshold, the method of limits was used: an ascending run was followed by a descending run, and the procedure was repeated once. The subject was required to state when the grating was 'just visible' or 'just invisible', and the mean was taken of the four threshold results. The precaution was observed of instructing the subject to scan the whole target in order to minimise image fading caused by adaptation, and the Troxler effect.

The sequence of viewing distances was arranged to reduce to a minimum the neuronal adaptation within the visual system, which would otherwise occur when gratings of neighbouring frequency are presented consecutively[224]. Where required, distance or near spectacles were worn by the subject, dependent on the viewing distance.

10.5 RESULTS AND DISCUSSION

Sensitivity to contrast is denoted by the reciprocal of the mean threshold, at each of the selected spatial frequencies which were detectable to the subject. In plotting the C.S.F., the custom adopted by previous workers was followed of measuring contrast sensitivity on the ordinate in logarithmic values. Normally, in a C.S.F., spatial frequency (expressed in cycles per degree) is employed as the unit of measurement on the abscissa. When the relevance of the results was considered, however, there was reason to adopt an unconventional method of representing the abscissa, as will be explained.

Spatial interval (or wavelength) - being the distance between grating cycles expressed in degrees per cycle (deg./cycle) - is the inverse of spatial frequency.

In rendering detail visible to the eye, magnification has an effect comparable to increasing the predominant spatial interval by an extent equal to the magnification factor. Therefore, the C.S.F. results and magnification were made compatible by expressing the abscissa in terms of spatial interval. The C.S.F. was plotted for each of the 8 visually-handicapped subjects, and the curves are shown in Figs. 10.3 and 10.4. Specific parameters have been abstracted and presented in Table 10.2. The averaged results of the 5 normal subjects are presented in Table 10.1; and the C.S.F. indicated with a broken line in Fig. 10.3.

The minimum spatial interval that could be perceived by any of the visually handicapped subjects was 0.2 deg/cycle. Some of the subjects were unable to detect this fine a grating.

Figs. 10.3 and 10.4 reveal that contrast sensitivity reaches either a peak or an asymptote, which represent individual saturation levels. The corresponding spatial interval, it can be argued, is proportional to the magnification necessary for discrimination of fine detail.

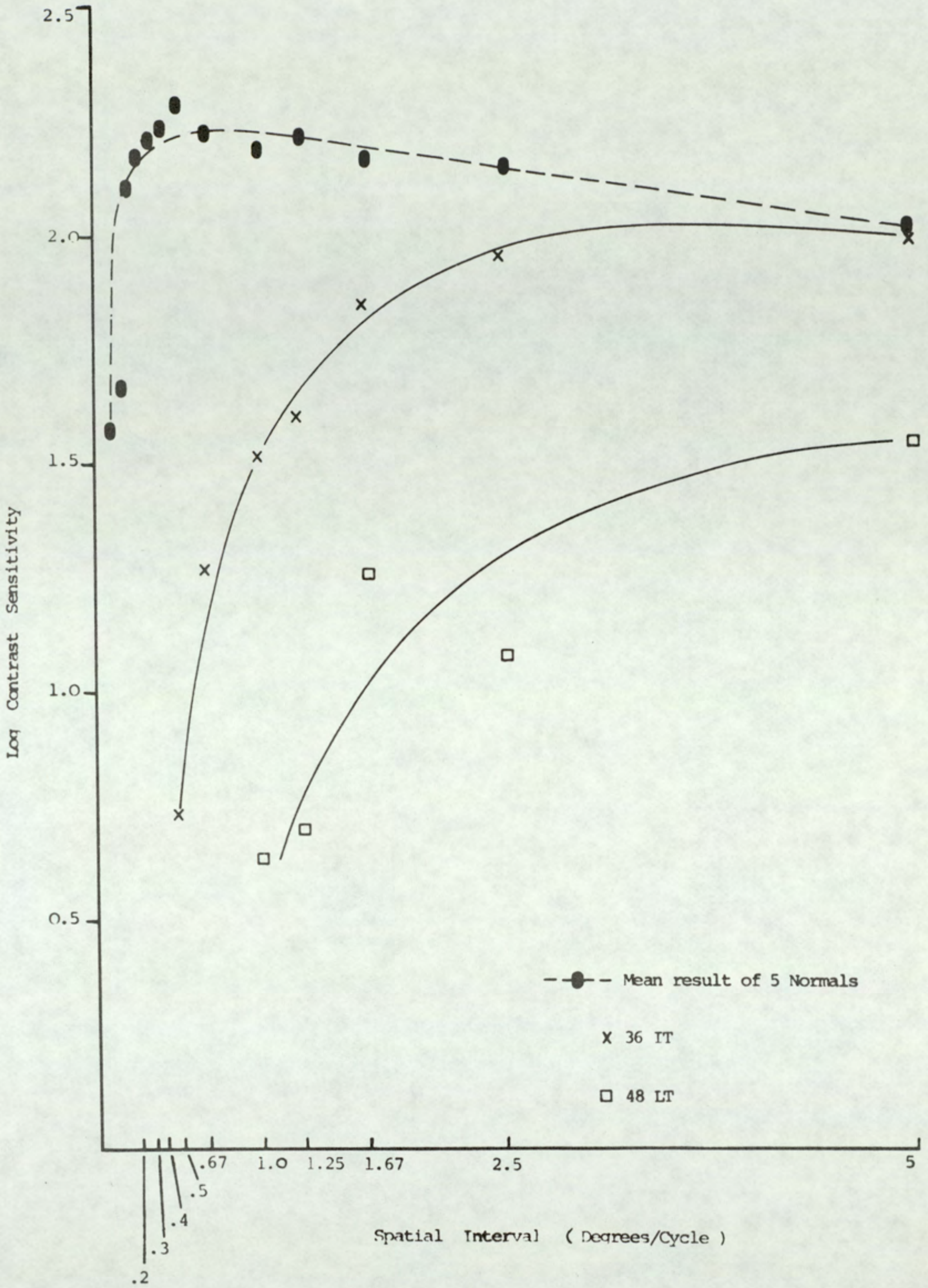


Fig. 10.3 Contrast Sensitivity Functions (C.S.F.) of 2 Visually-Handicapped Subjects and Mean C.S.F. of 5 Normals.

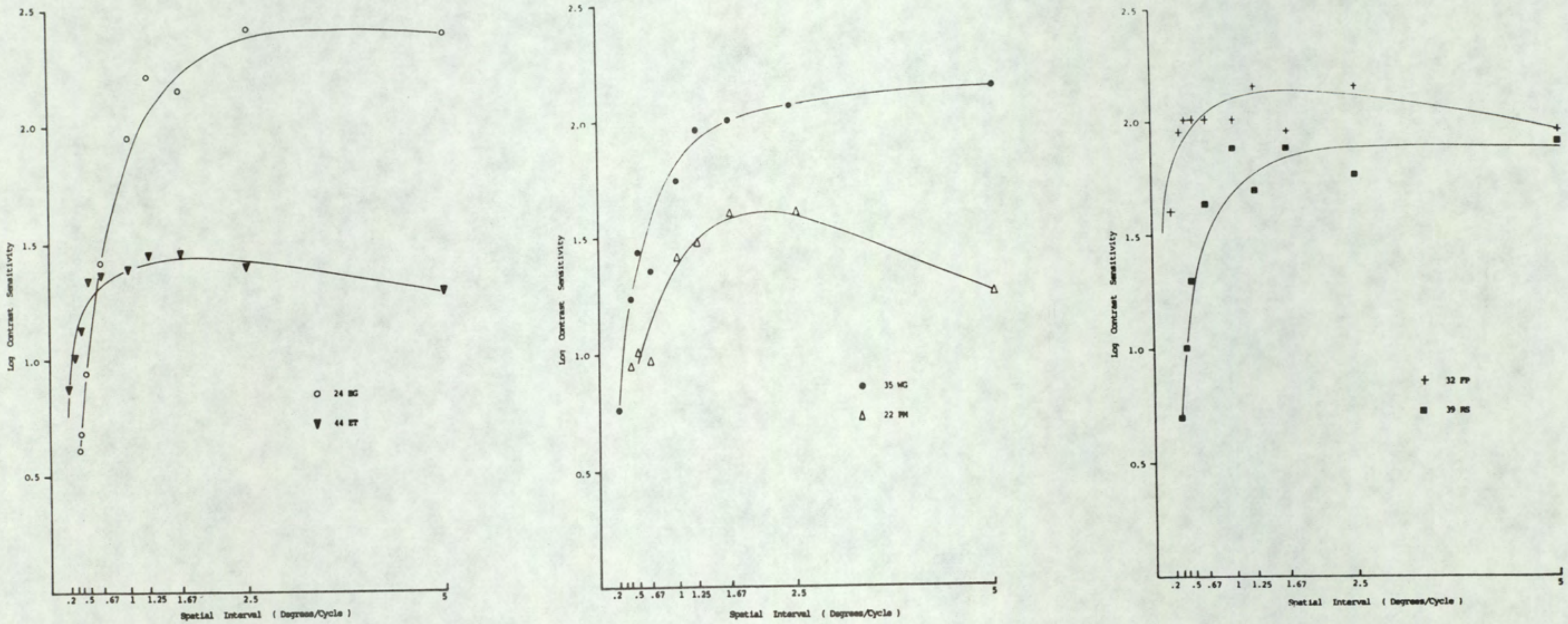


Fig. 10.4 Contrast Sensitivity Functions of 6 Visually-Handicapped Subjects.

TABLE 10.1

Contrast Sensitivity Results Averaged From 5 Normally-Sighted Subjects

VIEWG. DIST. (CM.)	SPATIAL INTERVAL (DEG./CYCLE)	CONTRAST THRESHOLD (t)	CONTRAST SENSITIVITY (=1/t)	LOG. CONTRAST SENSITIVITY
7	5.00	.00945	105.88	2.0248
15	2.50	.00701	142.59	2.1541
23	1.67	.00674	148.35	2.1713
30	1.25	.00610	164.02	2.2149
38	1.00	.00641	155.96	2.1930
57	0.67	.00594	168.31	2.2261
76	0.50	.00514	194.67	2.2893
95	0.40	.00580	172.43	2.2366
115	0.33	.00619	161.66	2.2086
134	0.29	.00671	149.11	2.1735
153	0.25	.00675	148.18	2.1708
172	0.22	.00743	134.65	2.1292
191	0.20	.00785	127.38	2.1051
286	0.13	.02134	46.87	1.6709
382	0.10	.02627	38.07	1.5806
572	0.07	.06811	14.68	1.1668

In practice this level of magnification is higher than that which produces the most efficient rate - a magnification defined in section 1, Chapter 8, as the 'optimal letter subtense'. This specific letter size may be related as much to the supportive function of word pattern as it is to the individual letters within the word. Furthermore, since the faculty of word recognition shows an inter-subject variability[149], so too, could the factor by which the peak of the C.S.F. exceeds that spatial interval corresponding with the optimal letter subtense. Accordingly, a parameter of the C.S.F. could be selected empirically, which corresponds as closely as possible with the majority of optimal letter subtense values.

Two arguments for selection are applicable here. Either a parameter specific to the curve for each individual could be the criterion, in which case both the selected contrast level and the corresponding spatial frequency will be variable amongst individuals; or a fixed contrast level can be taken, with only the threshold spatial frequency being the considered variable.

Adopting the former criterion, several points of the C.S.F. curve were selected. Values of the spatial intervals corresponding with the individual saturation level of contrast sensitivity (determined by inspection of the C.S.F.), and at 6 lower levels are given in Table 10.2. The column headed '$\delta y/\delta x = 1$' shows the spatial interval corresponding with the 45° slope on each curve. The last column shows the threshold spatial interval at a fixed contrast level (log contrast 1.4). Inspection of the resulting data shows that the distribution of points comes closest to homogeneity at the criterion of spatial interval corresponding with 0.6 log unit contrast below saturation (Table 10.2).

TABLE 10.2

Details of C.S.F. Results on 8 Visually-Handicapped Subjects

Subject	Age/ Sex	Ocular Condition	M.A.R. (secs. of arc)	Optimal Letter Subtense	Spatial Interval (deg./cycle) at points on C.S.F. below Contrast Sensitivity Saturation Level							
					Zero below saturation	0.1 log unit below	0.25 log unit below	0.4 log unit below	0.5 log unit below	0.6 log unit below	$\frac{\delta y}{\delta x}=1$	SI at log contrast Sensty.1.4
22PM	49 F	Retinitis Pigmentosa	30'	7.6×	2.00	1.29	0.93	0.74	0.63	1.09	1.19	1.00
24BG	31 M	Choroidal Coloboma	30'	10.9×	2.86	1.94	1.46	1.17	1.03	0.94	1.60	0.66
32FP	45 F	Toxaemic Retinopathy	6'	6.6×	1.57	0.69	0.34	0.20	0.17	0.14	0.57	0.14
35WG	25 M	Albinism	8'	5.5×	4.29	1.91	1.09	0.77	0.69	0.59	1.09	0.54
36IT	58 F	Corneal Leucoma/ Myopia	6'	6.6×	3.14	2.14	1.54	1.20	1.00	0.90	1.54	0.89
39RS	42 M	Primary Optic Atrophy	10'	3.3×	2.57	1.34	0.89	0.67	0.57	0.50	1.09	0.59
44ET	58 M	Chronic Simple Glaucoma	12'	8.7×	1.71	0.69	0.40	0.29	0.27	0.26	0.66	1.14
48LT	35 M	Congenital Cataracts	24'	19.6×	4.71	3.43	2.49	1.96	1.71	1.54	2.06	3.03

At this same level of contrast, the C.S.F. for the normally-sighted equates with a spatial interval of 0.1 degrees/cycle.

These figures provide a basis for the calculation of an 'equivalent' or 'predicted' magnification. Thus, the predicted magnification is that factor by which the value for each subject exceeds the value for the normal, namely 0.1 degrees/cycle. These values, and the corresponding optimal letter subtenses, shown in Table 10.3, were plotted in a scattergram (Fig. 10.5).

TABLE 10.3

Predicted Magnification cf. Optimal Letter Subtense

Subject	Spatial Interval at 0.6 log unit below saturation	Predicted Mag.	Optimal Letter Subtense
22 PM	1.09	10.9×	7.6×
24 BG	0.94	9.4×	10.9×
32 FP	0.14	1.4×	6.6×
35 WG	0.59	5.9×	5.5×
36 IT	0.90	9.0×	6.6×
39 RS	0.50	5.0×	3.3×
44 ET	0.26	2.6×	8.7×
48 LT	1.54	15.4×	19.6×

In a recent paper, Brown[225] chose to correlate contrast sensitivity results with CCTV reading rates. Ten patients with media opacities and 7 with senile macular degeneration took part in the study. The age range was 67 to 87 years (mean 73.9 years). The contrast sensitivity was recorded using an oscilloscope display, and Arden gratings. In the oscilloscope method, the contrast threshold was recorded using a switch-attenuator having

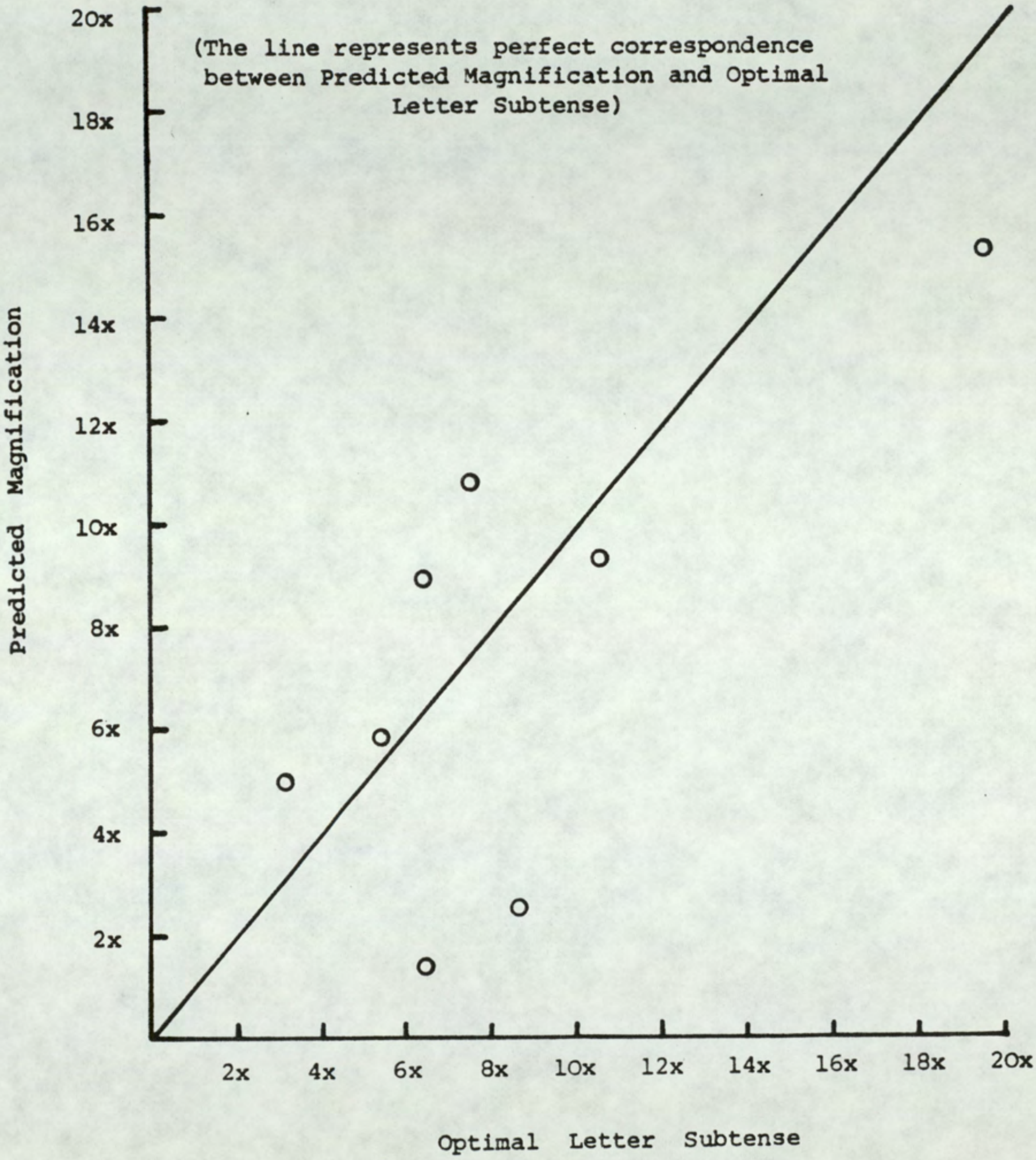


Fig. 10.5 <u>Predicted Magnification Compared with Optimal Letter Subtense</u>.

0.5 decibel steps; and the value of log sensitivity at 4 spatial frequencies was noted.

By combining the two groups of 17 patients, and using the CCTV in reversed contrast at a level of 66 per cent contrast, the resultant reading rate was correlated with contrast sensitivity. The highest correlation was claimed with the score on Arden plate 2 ($r = {}^{-}0.77$). However, on the oscilloscope, a grating frequency of 0.8 cycles/degree produced the highest correlation between contrast sensitivity and reading rate ($r = 0.43$). The latter value is non-significant, and compares with that of $r = 0.2640$ taking log contrast sensitivity at the same spatial frequency for the 8 subjects involved in the present study.

This low correlation is hardly surprising, since neither Brown nor the present author claim to have controlled the linguistic ability of the subject sample. In fact, in view of the wide inter-subject variability in reading skill, probably a more favourable predictor of attainable reading rate is initial reading rate, as is described in Chapter 6.

10.6 CONCLUSION

In discussing appropriate magnification, a comparison should be borne in mind between the selected angular magnification - that which was chosen freely by the subject, on the basis of comfortable reading, without constraint - and the optimal letter subtense, which elicited the more efficient reading rate.

Prediction of selected angular magnification has been discussed in section 3, Chapter 5. However, in the opinion of the author, the more important factor is optimal letter subtense. The interesting point is that distance visual acuity correlates non-significantly with this factor ($r = 0.5540$; $p = 0.17$).

Hence, the need is argued for a method of assessing the optimal magnification other than one based upon distance acuity. Because 'visibility', so-called, is implicit within contrast sensitivity, the C.S.F. offers one such alternative. Furthermore, the present results encourage the continuance of experiment, to establish quantitative relationships between C.S.F. and magnification.

CHAPTER 11

CONCLUSION

The utilisation of closed circuit television magnification can render ink-print readable to an even greater percentage of the visually-handicapped than was hitherto feasible. The evidence from Chapter 5 is that persons classifiable as blind in Britain - those with a visual acuity of 3/60 or worse - read more efficiently with CCTV, even without experience from practice, than they do with their habitual optical aids. For a subject sample with a mean visual acuity of ~ 3/36, CCTV was also slightly more beneficial than optical aids in a hand-eye co-ordination task. There is probably a case for stating that in general, those with the worst visual handicaps would gain the most from CCTV on such tasks for two reasons. First, because there is a similar finding with reading ability, and secondly the correlation between comparative ability with CCTV and optical aids on the two skills accounts for over 40 per cent of the variation in performance between one skill and the other. Training over a period of 10 days or longer elicited a significant improvement in the rate of CCTV reading.

Three predictive regression equations have been obtained, which together provide an original quantitative basis for deciding on the suitability of the CCTV magnifier for the individual patient. From one equation, it is possible to estimate within limits the angular magnification required for CCTV reading when the visual acuity is known. Using another equation, when the comparative performance between CCTV and optical aids is known, in relation to the task either of reading or hand-eye co-ordination, then it is possible to predict the comparative performance on the other task. A third regression estimate has been deduced which allows the maximum attainable reading rate to be predicted within limits, when the reading rate at the first CCTV reading session is known.

Whatever the degree of CCTV magnification, there was a steady rate of fixation varying between 3 and 4 fixations per second, and throughout a similarity in the saccade dimensions. Such constancy of eye movement behaviour caused the span of recognition to decline in an inverse proportion to the increase in magnification. This steadily decreasing span of recognition is cited as one factor responsible for the exponential decay in the reading rate as magnification is increased. Other factors involved are suggested as being the slow latency of peripheral retina and the inefficient loading of short-term memory when very few letters are displayed.

Reading rate was also influenced exponentially by field size, which in conjunction with magnification limits the number of characters presented as information at any instant. The minimal field angle which appears to permit the visually-handicapped reader the most efficient performance is 70^{o}. On average, 24 alphanumeric characters is the minimal number required to elicit the fastest reading from each patient. If these figures are considered as parameters, then the suggestion is made that in reading with CCTV, only the viewing distance need be varied to create the appropriate angular magnification for many individuals.

Conversely, when inverse magnification is used to assist patients with contracted fields, due to disease processes, the improvement in the assimilation of information which was theorised to occur with a binocular field expander, was discovered by experiment not to take place consistently. Two subjects out of five gained only moderately from the use of the device in a simple visual search task. Statistically, it emerged that practice in performing such tasks using this aid could well permit selected patients eventually to benefit from its use.

The inverse magnification of the field expander furnishes a wider effective area for detection than would normally be apparent, at the sacrifice of recognition (Fig. 11.1a and b). On the other hand, orthodox magnification renders the higher spatial frequencies within the viewed object more perceptible, thereby allowing recognition. There can be no single discrete level of magnification at which detection merges into recognition: rather, there is a wide range of transition. Doubtless partly for this reason, the angular magnifications selected by subjects for CCTV reading bore a less exact relationship with visual acuity than might have been anticipated from empirically-based calculations,

(a) Every viewing task has an appropriate optimal magnification. Fig. (a) can be considered as unit magnification. The field is relatively large, and faces can be counted but not recognised.

(b) Magnification of 3× allows recognition of individual faces, but the field area is 1/9th of that in (a). Alternatively if (b) is considered as a typical constricted field, then (a) represents the effect of a 3× field expander.

(c) Magnification of 30× reveals the detail of the half-tone dot matrix, but the dominant high frequencies detract from recognition of the face to the normal eye. Better recognition can be achieved by viewing the image through a diffusing screen, such as fine gauze.

Fig. 11.1 <u>The effect of orthodox and inverse magnification on the perceived image</u>.

such as those referred to in section 2, Chapter 3. It could be that empirical methods are unreliable where the coarsest visual acuities are involved, since, for example, conventional Snellen assessment is also imprecise at these levels. The majority of the magnifications selected were greater than such rules of thumb would have indicated.

In fact, it is feasible to advance the degree of magnification beyond the optimal level. In reading, the consequence would be a shortened letter-string, which was demonstrated in Chapter 7 to cause a slower reading rate. Furthermore, the point can be reached at which an emphasis on the high spatial frequencies masks those fundamental frequencies essential to subjective recognition of the whole (Fig. 11.1b and c).

This relationship between magnification and spatial frequency was investigated objectively, by experiment. Individual contrast sensitivity functions were plotted using sine wave gratings. Evidence was produced to suggest that the spatial interval just perceptible at some parameter of brightness contrast below maximum sensitivity might be linearly related to the optimal letter subtense on the CCTV display, i.e. the character size eliciting the most efficient reading rate. Further supportive data would supply more specific deductions. Thus, a method has been proposed for setting the initial magnification objectively, and at the optimal level for the patient.

Prospective further work, it is suggested, should include an extension of the contrast sensitivity experiment to gain a clearer understanding of the relationship between the contrast sensitivity function and the factors involved in CCTV reading.

The present results from the experiment in practice with CCTV reading over the course of several weeks were encouraging. Ideally, they should be consolidated by examining different age groups. In addition, the effect of reductions in the linear magnification should be determined, as subjects become more adroit in the recognition of word patterns.

Similarly, a training effect was found to occur while using the binocular field expander in visual search. This could form a longitudinal study but because suitable subjects are scarce, any statistical inferences are thereby limited.

The introduction of CCTV magnifiers into schools makes still more apparent the dilemma surrounding the methods of educating visually-handicapped children. For the most severely handicapped patients, with the alternative choice between non-sighted methods (tactile and aural) or high magnification on CCTV, little is known about the relative efficiency of each option. This could be an area worthy of study, with the intention of classifying the characteristics of individuals, so that the most suitable method can, in future, be scientifically recommended for the individual.

When the technological developments are considered, several appear forthcoming. Miniaturisation in the video field is likely to generate a portable self-contained CCTV unit: at first, perhaps small enough to fit inside an attaché case; possibly, in time, allowing a head-mounted flat display. A matrix of light-emitting diodes might well constitute a suitable display for this purpose. Such a device might be fitted into goggles, and designed for viewing at 20-25 mm from the pupil. If a high-powered Fresnel lenticular surface was superimposed on this device, it should be feasible to minimise the diameter of the blur circles and optically compress the wide-angle of the display within a smaller viewing angle. The finding in the present study that reading can be accomplished with magnifications of 100× and more, despite blurred images, lends encouragement to this idea.

The extra capability that colour affords ought not to be overlooked. Within the engineering industries - the drawing-office and the work-bench - and within recreational activities such as stamp and coin-collecting, and needlework, colour is frequently an essential component for perception. Colour television magnifiers, particularly if they were miniaturised to become easily portable, forseeably represent the ultimate technological development in magnification for the visually-handicapped.

APPENDICES

APPENDIX A

Register of Blind and Partially-Sighted Persons (England),

Year Ending 31st March 1979 : Department of Health and Social Security.

Age Group (years)	No. of Blind/ %age of total	Partially-Sighted/ %age of total
0 - 4	285 (<0.5%)	159 (<0.5%)
5 - 15	1801 (2%)	2262 (5%)
16 - 64	24382 (23%)	12847 (26%)
65 - 74	19224 (18%)	8255 (17%)
75+	59578 (57%)	25698 (52%)
Total =	105,270	49,221

New Cases Registered during Year Ending 31st March 1979.

Age Group (years)	No. of Blind/ %age of total	Partially-Sighted %age of total
0 - 4	92 (<0.8%)	64 (<0.8%)
5 - 15	124 (1%)	211 (3%)
16 - 64	1825 (15%)	1355 (17%)
65 - 74	2347 (19%)	1699 (21.5%)
75+	7690 (64%)	4562 (58%)
Total =	12,078	7,891

Registered Blind with Additional Handicap, as at 31st March 1979.

Mentally ill 935
Mentally ill + other handicap 262
Mentally handicapped 2095
Mentally handicapped + other handicap 841
Physically handicapped 12525
Physically handicapped + other handicap ... 1429
Deaf with speech 1647
Deaf without speech 298
Hard of hearing 3770

APPENDIX B

A DETAILED RATIONALE OF THE DESIGN AND CONSTRUCTION OF THE EXPERIMENTAL CCTV MAGNIFIER

One major objective in designing the experimental prototype CCTV magnifier was that it could be constructed and copied at an economic cost in comparison with the commercially available units. Moreover, there was still a need to retain those characteristics found in such units; namely, a wide range of magnification, and the option of contrast reversal, added to which the arrangement of the working surface and display screen should be ergonomically satisfactory for writing.

A compact design was achieved by using a 12-inch (30 cm) domestic television receiver as the display monitor. Minor additions and modifications were incorporated into the circuitry of the first model, for boosting the video amplification and switching the polarity to provide contrast reversal when required. The camera ultimately selected - the Eumig VC 551 - was chosen on the grounds of cost, which was approximately 60 per cent of that of a favourable competitor - the Philips LDH 25 - although the latter was slightly more compact and had better intrinsic resolution.

The variable focal length of the zoom lens in the Eumig VC 551 camera, with a 3-1 range, was less than ideal for the intended purpose. A more extensive magnification range was necessary if the instrument were to benefit many of the patients defined as registrably blind. In an endeavour to increase the magnification range, several lens forms were tried, with the result that plastics aspheric lenses were found to create the least aberration and loss of picture resolution. Two such lens designs in particular were ideal, namely those with 12-dioptre and 20-dioptre powers; and by interposing one or the other in front of the zoom lens a continuum of linear magnification from 5× to 28× became available. This practically matched the 6-1 zoom range of the commercial models.

Nevertheless, the use of these aspheric magnifying lenses meant that a constraint was set by having introduced into the optical system two discrete principal foci. For the image to keep in focus, when switching from one lens to the other, it was necessary to shift the lenses into two working loci approximately 6 cm apart. The smaller depth of field of the higher-powered magnifier lens posed the problem of maintaining sharp focus on thick books; and that necessitated engineering a progressively variable movement of the lenses, rather than two spot locations.

An additional limitation was encountered in the designing of the instrument, because the supplier had advised against the use of the camera with the lens pointing downwards. The reason for this precaution was that, in time, fragments of hot cathode flake off and fall onto the photosensitive face of the Vidicon tube, where they permanently damage the antimony trisulphide coating. Thus the preferred design configuration would place the camera in a horizontal mode.

The result of these requirements was a model which entailed first the construction of a metal supporting framework, or chassis, from Dexion 'Speedframe'. This consists of mild steel, 1.6 mm in thickness, formed into 25 mm square section. The constructed framework was two-tiered, with the lower tier acting as a baseboard for the traversing platform, and the upper tier supporting a concave platform of 0.8 mm thickness tin-plated steel, covered with matt-black polyvinylchloride. The picture monitor could be angled on this platform. The camera was mounted horizontally on a sub-frame underneath the upper tier. Having the working surface directly below the monitor screen in this way, proved the most advantageous solution to the ergonomic problem set by the task of writing, while using CCTV.

The provision for a continuous focussing range was made in the first place by moving the magnifying lenses relative to a stationary camera. The two lenses were fastened side-by-side onto a quadrant-shaped carrier of 4 mm thickness perspex, which could be slid along a vertical steel rod and stay fixed at any point with a spring-clip device. The result proved unsatisfactory for two reasons: the TV image wavered each time the magnifiers were adjusted, besides which the vertical rod caused an obstruction to thick books.

The next arrangement was more satisfactory, and was decided upon as the final solution. With this method, focussing was operated by shifting the camera and the lens turret together as one. This lens turret design offered more stability, since it could only be rotated to bring the high- or low-power magnifier into line with the camera lens, and no separate vertical shift was possible.

Viewed from the front, the camera was mounted broadside downwards, and close to the front and left-hand edges of a steel 'cradle', movable between the upper and lower tiers of the chassis. The camera lens was almost directly above the mid-centre of the baseboard; and adjacent to the lens at an angle of 45° was a plane rear-silvered mirror of dimensions 55 mm × 68 mm. The lens turret was attached to the cradle by a spindle, allowing it to be rotated in the horizontal plane so as to bring either lens into alignment below the mirror. Hence, the mirror reflected a magnified, but laterally-inverted image into the camera lens. A correctly orientated display was produced by reversing the connecting leads to the line scan of the receiver.

Raising and lowering of the camera and the supplementary optics for focussing was achieved by moving the camera cradle within the extension limits of a double pantograph, with one half rivetted to each end of the cradle. The uppermost members of each pantograph were rigidly fixed to the outer edges of the upper tier of the chassis. This design ensured that the camera held a horizontal aspect while the focussing shift took place in the strictly-vertical plane. Simple damping of the pantograph-cradle movement and counterbalancing of the camera was provided by two 13 cm length coil-springs, with the free ends fastened to each pantograph and the fixed ends fastened to the upright members of the chassis. Further damping, rigidity and ease of focussing were engineered with an additional mechanism: a 1 cm diameter mild-steel rod was mounted horizontally, free to turn, midway between the upright struts at the rear of the chassis frame. A metal collar was secured with a cotter-pin to each projecting end. A lever, about 35 cm in length was welded to each of the two collars, slotted into a pin at each end of the cradle and extended forwards a further 9 cm so as to permit finger-grip control of the complete camera-lift mechanism with either hand. Thus the camera could be focussed in any position through its vertical shift, and remained fixed, without backlash. Construction of the cradle, pantographs and operating levers was carried out using 1.6 mm thickness mild steel. Fig. B.1 illustrates this construction.

In a subsequent model, the pantograph was eliminated in order to simplify the mechanism. Instead, the camera cradle was supported by a parallel pair of levers at each end (Fig. B.2). Compared with the pantograph design, this method had the theoretical disadvantage of causing a drift of the vertical plane through the lens axis when the camera cradle is raised or lowered for focussing. In effect, this amounts to a displacement of 1.7 mm in the Y-axis, which corresponds approximately to the height of one line of 5-point type. By designing the maximal displacement to occur

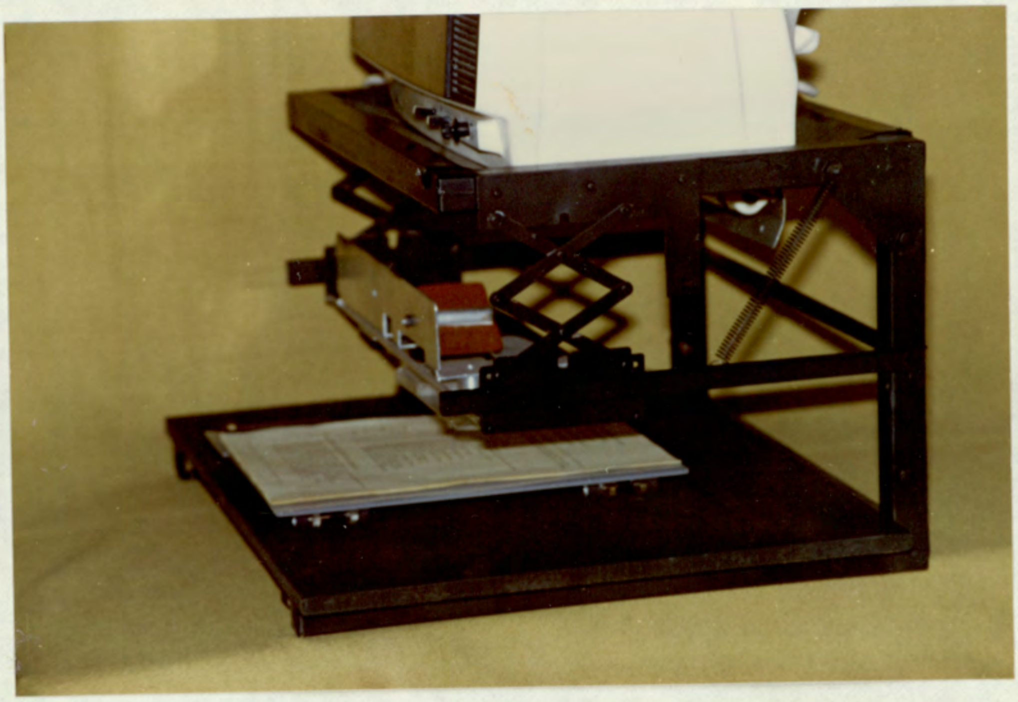


Fig. B.1 Prototype CCTV Magnifier, showing chassis and pantograph focussing mechanism.

Fig. B.2 Parallel-lever focussing mechanism of improved Experimental CCTV Magnifier.

mid-way in the focussing range, in the plane of the pivotting steel cross-rod, the two principal focussing positions became vertically coincident for practical purposes.

Also, in the second model an alternative approach was brought to the electronic circuitry. A video amplifier boost and contrast reversal option were connected together with a stabilised D.C. power supply and ultra-high frequency modulator to form a self-contained interface unit, which was designed to operate with any unmodified TV camera and receiver. This was in fact operationally successful. However, where the design of the CCTV magnifier incorporates a mirror (as does the experimental prototype instrument), then it would be necessary to reverse the connections to the line-scan coil of the camera rather than the receiver, if the additional advantage of normal broadcast reception were to be enjoyed.

The lighting on the prototype consisted of two 60-watt tubular filament lamps, 22cm long, shielded in a cylindrical aluminium reflector. This was rivetted to the rear of the underside of the monitor platform, and angled to cast maximum diffuse light onto the baseboard, directly below the camera lens system. For the second model the lighting was provided by a single 60-watt opal lamp, and angled in a circular reflector, and clamped to the horizontal rod spanning the frame uprights. Despite its simplicity, this appeared to be as effective as the tubular filament lamps.

The baseboard originally consisted of 12 mm thickness chipboard, with a depth of 42 cm matching that of the frame, and at a length of 55 cm some 5 cm longer than the chassis frame. A simple X-Y platform was constructed from 3 mm acrylic sheet, slightly larger than an A4 sheet at 30 cm by 24 cm, with a rigid strip fixed to one long edge. Rubber model wheels of 17 mm diameter were fastened at each corner on the underside of the platform. During reading, line-to-line movement (Y-axis) was achieved by sliding the reading material up against the strip and away from the reader; whilst line traversal (X-axis) simply involved rolling the platform along the baseboard. The disadvantage in using this basic X-Y platform was that after a while it would run out of line, causing the displayed print to tilt upwards or downwards, and so requiring repeated adjustment.

This disadvantage was overcome in the platform designed for the second model (Fig. B.3) In this construction, the baseboard was made thinner than previously by using 9 mm thickness 3-ply timber. Aluminium channelling was selected to make up two linear ball-races, 23 cm apart, attached to the baseboard and extending its entire length. Each channel was designed to contain 32-34 ball bearings, which were guarded from overspilling by a strip of rigid wire, fastened inside one upper edge using adhesive. To prevent the momentum in each ball-race building up to a point at which the force could dislodge this guard-wire, the bearings were divided into 4 equal-sized nested groups separated by plastic blocks about 2-3 cm long. Polyacetyl plastic ball bearings, 6 mm diameter, were used in the channels, because they have a lower coefficient of friction and are quieter in operation than steel bearings.

Polyvinylchloride extrusion strip with flanged edges was used for runners, equal in width to the ball races they surmounted. This method provided a free-running line-traverse or X-axis movement. Line-to-line movement in the Y-axis required greater friction. This was arranged by fixing onto the X-axis strip two smaller lengths of the same extrusion material, 45.5 cm apart, flanged edges uppermost, and running perpendicular to the X-axis. These Y-axis strips provided sliding grooves for two strips of aluminium channelling adhered to the underside of a 6 mm thick 3-ply platform, measuring 49 cm by 30 cm. Through a careful choice of channelling and plastics extrusion strip, the one could slide freely along the other, without undue play being observed in either axis, even with high magnifications, at which it might have been most noticeable.

Finally, the baseboard and bare metal parts were finished with matt black paint, and the upper surface of the traversing platform was covered with plain green fabric and edged with white enamel to contrast with the baseboard.

Both the prototype and the second model could be used for writing tasks as well as reading; but typing was not accomplished so readily because of distortion of the typescript image. Since a significantly large number of

Fig. B.3 Experimental CCTV Magnifier used in Reversed-contrast mode, showing improved X-Y Platform .

Fig. B.4 Experimental CCTV Model with simple Focussing/Tilt Mechanism designed for Typing.

visually-handicapped individuals have been trained in typing, consideration was given to the design of a third model to be constructed specifically for this purpose. At the same time, experiment was made with further mechanical simplification.

Although the frame construction was a replica of the earlier models, a simplified method was contrived for the camera focussing shift. The cradle supporting the camera, mirror and magnifier turret was suspended on a U-shaped lever made of 6 mm diameter mild steel. The sides of the lever were locked into metal collars at each end of the free-turning horizontal rod at the back of the frame. Damping was provided by adjusting the pressure of brackets on the collars, and counterbalancing was produced as before, using coil-springs. Unlike the two previous designs, no device was used to keep the camera shift constantly perpendicular to the desk surface: instead the camera tilted through an arc during the focussing shift. Nevertheless, a clear overall display, without noticeable distortion and with sufficient contrast, was obtained by using the smallest aperture of the camera to create adequate depth of field.

To produce an undistorted image, the typescript characters should be perpendicular to the optic axis of the camera. This was engineered quite simply, by adding an angling bracket to the left side of the camera cradle. The bracket had two locating notches designed to engage with the left side of the focussing lever, and the cradle was spring-loaded to force the bracket to stay engaged. Thus the camera could be either in the normal horizontal mode, or tilted through 45° for viewing the typewriter platen.

Using this model shown in Fig. B.4, a small portable typewriter could be operated satisfactorily with up to about 20× magnification of the typescript.

APPENDIX C

I. Subjects for whom CCTV is recommended magnifier * Normal (N) or Reversed Contrast (R-C) preferred

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL LVA	READG. RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C *	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
1 M.D.	47 M	Retinitis Pigmentosa	2.7× hand mag.	102	5× N	34	3.7×	98	R) 5/60 L) 6/60	10'	Schoolmaster	Facilitates marking of exercise books, especially when checking graphs and diagrams.
2 C.W.	35 M	Retinitis Pigmentosa/ Myopia	Reads unaided at 14cm	98	5× R-C	31	4×	80	R) 6/12 L) 6/12	2'	Clerical Officer	Better posture ; can see faint lines on proformas, and can write more easily than unaided, despite CCTV reading rate being slower
3 E.B.	55 F	Glaucoma/ Myopia	3× wide-angle telescope	59	6× R-C	37	4.1×	49	R) 6/24 L) C.F.	4'	Senior Clerical Officer	Work entails accounting (present LVA gives restricted field) and reading handwritten letters. Finds R-C less fatiguing
4 M.N.	50 M	Bilateral Congenital Cataract/ Aphakia	Soft Contact Lenses R=L=11.OD	?	7× R-C	38	4.6×	97	R) 4/36 L) 4/36	9'	Psychiatric Social Worker	CCTV less fatiguing for his work (involves reading confidential, medical docs. etc)
5 G.L.	38 M	Disciform Maculopathy/ Myopia	NIL. Reads newsprint unaided at 50 mm	105	5.5× R-C	28	4.9×	64	R) 1/60 L) 5/24	5'	Auditor (Local District Council)	Enhances poor photo-copies of accounts and estimates, letters etc.

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL LVA	READG. RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
6 M.B.	37 M	Optic Atrophy	Keeler 4× Binoc. telescope	41	5× R-C	25	5×	52	R) 4/36 L) 2/60 diff.	9'	Accountancy	Contrast enhancement aids reading. Extra field advantageous for book keeping
7 A.G.	39 M	Vascular Retinopathy/ Dense Bilateral Cataract	NIL	?	5.5× R-C	27	5.1×	75	R) 3/60 L) 6/36	6'	Sales Promotion	Aids his analysis of data sheets, and preparation of information for dealers
8 F.E.	57 M	Diabetic Retinopathy	3× wide-angle telescope	15	6.7× R-C	25	6.7×	36	R) 6/36 L) H.M.	6'	Haulage Contractor	Reversed contrast aids reading; increased postural comfort.
9 P.C.	39 M	R.Prosthesis L.Aphakia	Keeler 4× bioptic telescope	87	7× R-C	25	7×	71	R) - L) 5/60	12'	Computer Systems Designer	He made 11 errors in LVA reading and 0 errors in CCTV reading Also can read poor quality stencil copy with CCTV but not with LVA. CCTV necessary for work.
10 R.B.	45 M	Post-Operative Bitemporal Hemianopia	7× stand mag.	10	14× N	34	10.3×	30	R) 1/60 L) NPL	60'	Draughtsman	Numerals on technical drawings easily readable, and handwriting readable faster than with LVA
11 E.E.	59 M	Diabetic Retinopathy	8× telescope	~8	14× R-C	34	10.3×	8	R) 1/60 L) NPL	60'	Draughtsman	Can read technical drawings, blue-prints and instruction cards accurately.

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL LVA	READG. RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
12 M.W.	16 M	Macular Dystrophy	5× stand mag.	31	7.5× R-C	18	10.4×	48	R) 3/60 L) 3/36 +1	10'	Schoolchild	Reads faster with CCTV; better posture; photophobia less with reversed contrast
13 D.R.	54 F	Retinitis Pigmentosa	5× binocular microscope	52	15× R-C	27	14×	44	?	?	Housewife	Keen reader; finds CCTV useful for writing; husband and son prepared to construct CCTV
14 J.H.	38 F	Retinitis Pigmentosa/ Myopia	8× microscope	9	9× R-C	14	16×	32	R) 1/60 L) 2/60	30'	Teacher (Languages)	CCTV enables her to mark exercise books easily
15 C.C.	11 F	Post-Hydrocephalic Optic Atrophy	5× stand mag.	18	10× R-C	15	17×	22	R) 1½/60 L) 1½/60	40'	Schoolchild	Can read with less fatigue and better posture with CCTV than with LVA
16 H.B.	32 M	R.Maculopathy L.Retinal Detachment	10× Keeler microscope	56	10× R-C	15	17×	42	R) 4/60 L) P.L.	15'	Salesman (Packaging Company)	Cannot adapt to close posture (5cm) with LVA and finds CCTV more comfortable.
17 K.M.	46 M	Vascular Retinopathy	NIL Has not read print for 3 years	-	22× R-C	22	25×	20	R) 1/36 L) P.L.	36'	Inspector - motor car manufacturing	CCTV aids checking technical drawings, and flaws in components; but optical aids have not assisted.

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL LVA	READG. RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
18 R.H.	24 M	Diabetic Retinopathy	Keeler 15× Self-illuminated loupe	9	25× R-C	22	28.4×	18	R) 2/60 L) P.L.	30'	Clerical Officer	Reads faster with CCTV; posture improved
19 C.D.	37 M	Retinitis Pigmentosa	8× loupe	?	15× R-C	12	31×	24	R) H.M. L) 1/60	60'	Social Worker	Cannot read phone directory with LVA, which is useful for brief periods. With CCTV, he can locate phone no. in 30 secs.

II. Subjects for whom CCTV is of limited use

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL LVA	READG RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
20 B.C.	51 M	Diabetic Retinopathy	2.5× hand mag.	43	6× R-C	35	4.3×	35	R) 2/36 +1 L) 6/18 pt.	3.5'	Foundry Consultant	R-C of CCTV is beneficial, but reads faster with LVA.
21 C.C.	71 M	Bilateral Corneal Leucoma	6× short-focus telescope	?	8× N	34	5.9×	29	R) 6/60 +1 L) 6/60	8'	Retired	Used to be keen reader, but has not read ink print for 5 years. CCTV too expensive.
22 P.M.	49 F	Retinitis Pigmentosa	Plastics Lentic (L) +30D at 4cm	55	4.5× N	19	5.9×	74	R) 1/60 L) 1/36 +1	30'	Housewife	Used to be fluent reader; finds improved posture with CCTV, but expense deters.
23 C.L.	10 F	Aphakia/ R. Retinal Detachment/ Nystagmus	Plastics Lentics at 4cm	84	7.5× R-C	31	6.1×	70	R) 5/60 L) 5/60	12'	Schoolchild	Reads faster with spectacles, but with cramped posture. CCTV gives greater working distance, but too expensive.
24 B.G.	31 M	Choroidal Coloboma	10× loupe	42	6.5× R-C	19	8.6×	65	R) 2/60 L) N.P.L.	30'	Piano Tuner	Reasonably satisfied with slower reading rate of LVA
25 A.L.	56 F	Retinitis Pigmentosa	7× stand mag.	7	7× N	19	9.2×	40	R) C.F. L) 5/60	12'	Housewife	Would like to read some ink print, but has not read print for 7 years but CCTV expense deters. Can read braille satisfactorily.

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL LVA	READG RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
26 J.G.	61 M	Congenital Cataract	10× microscope	8	12× N	29	10.4×	15	R) N.P.L. L) 1/36	36'	Social Worker	Clumsy in operating CCTV; but could benefit for studying documents.
27 H.M.	19 F	Optic Atrophy/ Nystagmus	8× Agfa Lupe	111	6× R-C	13	11.5×	74	R) 2/60 L) 1/60	30'	Student (Modern Languages)	Despite faster reading with LVA, wider field with CCTV aids ascertaining whole word in German; accented letters are easier to check with extra CCTV mag.
28 A.S.	75 M	Choroidal Atrophy	NIL	?	19× R-C	28	17×	11	R) 1/60 L) 1/36	36'	Retired	Would like CCTV for reading personal mail, looking at circuit diagrams, etc. (Amateur radio enthusiast).
29 E.F.	28 F	Bilateral Corneal Leucoma	NIL (reads newsprint unaided at 4cm with good comprehension)	-	28× R-C	38	18.4×	47	R) 2/60 L) P.L.	30'	Telephonist	Would find CCTV occasionally useful, but not necessary for job, and not keen reader.
30 M.F.	16 M	Primary Optic Atrophy	Braille Reader	-	28× N	10	70×	17	R) 1/60 L) H.M.	60'	Schoolboy	Would find CCTV useful, but would need extended practice to operate successfully.

III Subjects for whom CCTV is unsuitable

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL LVA	READG RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
31 G.D.	28 M	Macular Dystrophy (Stargardt's Disease)	NIL (reads unaided)	150	5× R-C	50	2.5×	100	R) 6/60 L) 6/60	10'	Physio-therapist	Reads faster unaided with good posture.
32 F.P.	45 F	Maculopathy (Post-toxaemia of pregnancy)	N/V Rx R=L=+5D	82	5.5× R-C	38	3.6×	92	R) 6/36 L) 6/60 +1	6'	Housewife	Not motivated for reading.
33 S.H.	17 F	Macular Dystrophy	Keeler 5× telescope	160	5.5× R-C	27	5.1×	90	R) 3/36 L) 3/36	12'	Schoolchild	Reads faster with LVA
34 S.J.	21 F	Bilateral Congenital Cataract	6× microscope	?	6.5× N	30	5.4×	73	R) 5/60 L) 2/60	12'	Audio-typist	Not motivated for reading; can read and type braille satisfactorily.
35 W.G.	25 M	Albinism	4× telescope	141	4.5× R-C	19	5.9×	123	R) 6/60 +1 L) 6/60 +1	8'	Engineering Workshop Technician	Reads faster with LVA
36 I.T.	58 F	Corneal Leucoma/ Myopia	NIL (reads unaided at 16 cm)	117	7× N	29	6×	105	R) N.P.L. L) 6/36	6'	Housewife	Reads faster with LVA.
37 D.L.	33 M	Diabetic Retinopathy/ Retinal Detachment/ Cataracts	3× microscope	?	9× R-C	33	6.8×	7	R) N.P.L. L) 6/36	6'	Carpenter	Not motivated for reading. Prognosis poor: braille instruction advisable.

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL L.V.A.	READG RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
38 P.S.	15 M	R. Prosthesis L. Cataract	NIL (reads, unaided at 10cm)	123	6× R-C	22	6.8×	59	R) - L) 6/60	10'	Schoolchild	Reads faster unaided.
39 R.S.	42 M	Primary Optic Atrophy	6× telescope	76	8× N	29	6.9×	64	R) 1/60 L) 6/60	10'	Social Worker	Reads faster with LVA.
40 R.L.	15 M	Chorio-Retinal Degeneration	Plastics Full-field Bifocals at 10cm	34	7× R-C	25	7×	22	R) 3/60 L) 3/60	20'	Schoolchild	Reads faster with spectacles
41 E.M.	13 F	Aphakia/ Nystagmus	Plastics Lentics at 4cm	58	7.5× N	24	7.8×	54	R) 3/36 L) 3/24 +1	7'	Schoolchild	Reads faster with spectacles
42 J.H.	52 F	L.Corneal Leucoma and Congenital Cataract	12× loupe	64	9× R-C	29	7.8×	78	R) N.P.L. L) 3/60	20'	Housewife	Not motivated for reading
43 A.B.	39 F	Uveitis	8× Short-focus telescope	?	8.5× R-C	26	8.2×	27	R) 1/36 L) 1/36	36'	General Medical Practitioner	Can read N.10 with difficulty with LVA.
44 E.T.	58 M	Chronic Simple Glaucoma	7× Stigmagna	77	10× R-C	28	8.9×	46	R) N.P.L. L) 5/60	12'	Typing Instructor to Blind Students.	Reads faster with LVA.

SUBJECT	AGE/ SEX	OCULAR CONDITION	PRESENT OPTICAL L.V.A.	READG RATE WITH L.V.A. (WPM)	CCTV LINEAR MAG. N/R-C*	CCTV MEAN VIEWG DIST. (cm)	CCTV ANGULAR MAG.	INITIAL READING RATE WITH CCTV (WPM)	SNELLEN VISUAL ACUITY	MAR	OCCUPATION	COMMENTS
45 J.S.	48 M	Retinal Detachment	8× Watchmakers loupe	77	7.5× R-C	17	11×	49	R)P.L. L)2/36	18'	Electrician	Reads faster with LVA, no use for CCTV in job.
46 J.L.	33 M	Diabetic Retinopathy/ Aphakia/ Glaucoma	6× telescope	40	12.5× R-C	28	11.2×	38	R)6/24 L)N.P.L.	4'	Trainee Computer Programmer	Reads equally as fast with LVA
47 I.H.	46 F	Microphthalmos/ Aphakia	Keeler 20× microscope	?	11× R-C	22	12.5×	26	R)2/60 L)2/60	30'	Physio-therapist	Not motivated for reading.
48 L.T.	35 M	Congenital Cataracts	Keeler 15× self-illuminated microscope	73	11× R-C	17	16.2×	63	R)H.M. L)2/60 +1	24'	Labourer	Reads faster with LVA; not motivated for reading.
49 T.B.	51 M	R. Corneal Leucoma/ L. Prosthesis	12× loupe	8	28× R-C	28	25×	28	R)1/60 L)-	60'	Telephonist	Satisfactory braille reader; not sufficiently motivated to read ink print.

APPENDIX D

DOLPHINS (I) Reader's Digest

205w

Dolphins have large and complex brains, a good part being associated with the hearing system. In the case of an eight-foot-long Pacific Bottlenose, the brain weighs about three and a half pounds, compared to the three-pound brain of a man. Some scientists place the dolphin's intelligence between that of a dog and that of a chimpanzee.

While myth portrays dolphins as cheerful creatures, they are also sensitive and temperamental. Companionship is important. They move in packs in the open sea and solitary confinement in captivity often leads to sulking and loss of appetite. When angry, they beat the water with their tails or snap their jaws. Their smooth, hairless skin feels like a wet inner tube, and is highly sensitive to touch. I found that dolphins enjoy being patted, and frequently pat one another with their flippers. They communicate by a variety of grunts, squeals, clicks and whistles. One of these sounds is a distress call, used to warn of impending danger; another is a bark of anger.

The dolphin breathes air like a land mammal. What looks like a blowhole on top of its head covers two inside nostrils which permit air to pass but expel any water that enters accidentally.

APPENDIX E

CCTV READING ACHIEVEMENT BY 6 SCHOOLCHILDREN

Subject/ Age	Ocular Condition	Linear Mag.	Angular Mag.		Day													
					1	2	3	6	7	8	9	13	14	15	16	17	20	22
23CL 10½	Congenital cataract/ aphakia nystagmus	7.8×	6.3×	Mean reading rate (w.p.m.)	70	76	75	74	80	90	87	88	-	-	87	88	89	85
				Standard Error	2.5	2.6	2.6	1.9	1.7	2.3	2.4	2.3	-	-	1.6	2.9	3.5	2.8
38PS 15	R.prosthesis + L. cataract	8.6×	9.8×	Mean reading rate (w.p.m.)	59	60	64	70	71	74	75	83	77	83	82	77	71	68
				Standard Error	3.3	3.0	4.9	3.3	2.8	3.0	2.5	2.7	5.9	2.6	2.3	3.0	1.6	2.2

Subject/ Age	Ocular Condition	Linear Mag.	Angular Mag.		Day											
					1	2	3	4	5	6	7	8	9	10	11	12
12MW 15½	Macular Dystrophy	7.5 ×	10.4 ×	Mean reading rate	48	41	44	57	68	-	56	64	64	56	69	58.5
33SH 17	Macular Dystrophy	5.1 ×	5.5 ×	Mean reading rate	90	107	106	117	123	-	129	117	127	130	119	129.5
40RL 15	Chorio-retinal degeneration	7 ×	7 ×	Mean reading rate	22	28	25	34	32	-	37	42	35	33	35	-
41EM 13	Aphakia/ Nystagmus	7.5 ×	7.8 ×	Mean reading rate	54	58	58	50	61	-	51	52	59	62	65	63

APPENDIX F

EVALUATION OF VISUAL FIELD EXPANDER

Assessment of everyday difficulties

This questionnaire is designed to enable us to determine where and when your visual impairment causes you most inconvenience.

NAME Subject A.H.

ADDRESS ______________________

____

Section 1

Please answer as carefully as you can the questions below according to the extent of their difficulty as follows:-

1 - Cannot manage
2 - Just manage
3 - Manage with difficulty
4 - Manage without any difficulty

Please ring the appropriate number.

NOTE IF A FRIEND OR RELATIVE HELPS YOU ANSWER THE QUESTIONS PLEASE TICK THIS BOX [ ]

1. Can you walk up and down unfamiliar stairs alone? 1 2 (3) 4

2. Can you purchase an item alone -

(a) in a small shop? 1 2 3 (4)

(b) in a large store? 1 2 (3) 4

3. Can you search for, and locate, a small article e.g. coin or key -

(a) at table level? 1 2 (3) 4

(b) at floor level? 1 (2) 3 4

4. Can you cross a road on which traffic is -

(a) relatively quiet? 1 2 (3) 4

(b) very busy? 1 (2) 3 4

Section II Please answer the following questions by ringing the appropriate answer and making brief further observations.

1. Are you able to use public transport alone? **[YES]** NO

If 'Yes' how often do you use public transport?
- 1 - 3 times per week
- 4 - 6 times per week
- **[more than 6 times per week]**

2. How often do you make purchases in a shop or store when unaccompanied?
- Never
- **[1 - 4 times per week]**
- 5 - 8 times per week
- More than 8 times per week

3. In <u>familiar</u> surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- More than 6 times per week
- **[4 - 6 times per week]**
- 1 - 3 times per week

4. In <u>un</u>familiar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- **[More than 6 times per week]**
- 4 - 6 times per week
- 1 - 3 times per week
- Never in unfamiliar environment unaccompanied

5. When walking, do you experience difficulties such as loss of balance when suddenly changing direction? YES **[NO]**

If 'Yes' please give examples:-

6. Do you experience problems when surrounded by people? **[YES]** NO

If 'Yes' please give examples:-

Difficulty in seeing people who walk across the front of me. Walking into people, particularly on crowded streets.

7. Have you had any very hazardous experiences due to your vision? **[YES]** NO

If 'Yes' please give examples:-

Walked into a bus. Fell down a flight of steps in a darkened street.

8. Do you have difficulty with any domestic, or vocational task? YES **[NO]**

If 'Yes' please give examples:-

9. Do you have any further comments:-

EVALUATION OF VISUAL FIELD EXPANDER

Assessment of everyday difficulties

This questionnaire is designed to enable us to determine where and when your visual impairment causes you most inconvenience.

NAME Subject B.F.

ADDRESS ______________________

____

Section 1 Please answer as carefully as you can the questions below according to the extent of their difficulty as follows:-

1 - Cannot manage
2 - Just manage
3 - Manage with difficulty
4 - Manage without any difficulty

Please ring the appropriate number.

NOTE IF A FRIEND OR RELATIVE HELPS YOU ANSWER THE QUESTIONS PLEASE TICK THIS BOX [ ]

1. Can you walk up and down unfamiliar stairs alone? 1 2 (3) 4

2. Can you purchase an item alone -

(a) in a small shop? 1 2 3 (4)

(b) in a large store? 1 2 (3) 4

3. Can you search for, and locate, a small article e.g. coin or key -

(a) at table level? 1 2 (3) 4

(b) at floor level? 1 2 (3) 4

4. Can you cross a road on which traffic is -

(a) relatively quiet? 1 2 3 (4)

(b) very busy? 1 2 (3) 4

Section II Please answer the following questions by ringing the appropriate answer and making brief further observations.

1. Are you able to use public transport alone? **[YES]** NO

If 'Yes' how often do you use public transport?
- 1 - 3 times per week
- 4 - 6 times per week
- **[more than 6 times per wee]**

2. How often do you make purchases in a shop or store when unaccompanied?
- Never
- 1 - 4 times per week
- **[5 - 8 times per week]**
- More than 8 times per wee

3. In familiar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- More than 6 times per wee
- **[4 - 6 times per week]**
- 1 - 3 times per week

4. In unfamiliar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- More than 6 times per wee
- 4 - 6 times per week
- **[1 - 3 times per week]**
- Never in unfamiliar environment unaccompanied

5. When walking, do you experience difficulties such as loss of balance when suddenly changing direction? YES **[NO]**

If 'Yes' please give examples:-

6. Do you experience problems when surrounded by people? **[YES]** NO

If 'Yes' please give examples:- Difficulty in moving about where other people are moving, either indoors or outdoors.

7. Have you had any very hazardous experiences due to your vision? YES **[NO]**

If 'Yes' please give examples:-

8. Do you have difficulty with any domestic, or vocational task? **[YES]** NO

If 'Yes' please give examples:- Writing in straight lines on notepaper; digging garden in straight line; decorating - especially painting light colours; playing draughts or other games involving objects.

9. Do you have any further comments:- Difficulty in performing tasks in poor light conditions.

EVALUATION OF VISUAL FIELD EXPANDER

Assessment of everyday difficulties

This questionnaire is designed to enable us to determine where and when your visual impairment causes you most inconvenience.

NAME Subject G.P.

ADDRESS

Section 1 Please answer as carefully as you can the questions below according to the extent of their difficulty as follows:-

1 - Cannot manage
2 - Just manage
3 - Manage with difficulty
4 - Manage without any difficulty

Please ring the appropriate number.

NOTE IF A FRIEND OR RELATIVE HELPS YOU ANSWER THE QUESTIONS PLEASE TICK THIS BOX ☐

1. Can you walk up and down unfamiliar stairs alone? 1 2 (3) 4

2. Can you purchase an item alone -

(a) in a small shop? 1 2 (3) 4

(b) in a large store? 1 2 (3) 4

3. Can you search for, and locate, a small article e.g. coin or key -

(a) at table level? 1 2 (3) 4

(b) at floor level? 1 (2) 3 4

4. Can you cross a road on which traffic is -

(a) relatively quiet? 1 2 (3) 4

(b) very busy? 1 2 (3) 4

Section II Please answer the following questions by ringing the appropriate answer and making brief further observations.

1. Are you able to use public transport alone? **[YES]** NO

If 'Yes' how often do you use public transport?
- 1 - 3 times per week
- 4 - 6 times per week
- more than 6 times per wee

Public transport rarely used.

2. How often do you make purchases in a shop or store when unaccompanied?
- Never
- 1 - 4 times per week
- **[5 - 8 times per week]**
- More than 8 times per wee

3. In familiar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- More than 6 times per wee
- 4 - 6 times per week
- **[1 - 3 times per week]**

When not concentrating.

4. In unfamiliar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- More than 6 times per wee
- 4 - 6 times per week
- 1 - 3 times per week
- Never in unfamiliar environment unaccompanied

But less often than the examples given.

5. When walking, do you experience difficulties such as loss of balance when suddenly changing direction? YES **[NO]**

If 'Yes' please give examples:-

6. Do you experience problems when surrounded by people? **[YES]** NO

If 'Yes' please give examples:-

Colliding with people walking across my path at close range, e.g. theatre, crowded shopping areas, etc.

7. Have you had any very hazardous experiences due to your vision? **[YES]** NO

If 'Yes' please give examples:- Bruised and cut forehead owing to walking into raised back-door of traveller car; also into low tree branches. When quickly bending to retrieve items from floor level, narroly avoided injury to the eye from protruding adjacent obstacles.

8. Do you have difficulty with any domestic, or vocational task? **[YES]** NO

If 'Yes' please give examples:-

A general difficulty in relocating implements that have been put down during the course of a task.

9. Do you have any further comments:- Greatest difficulty in coping with people at very close range or locating them on entering a room.

EVALUATION OF VISUAL FIELD EXPANDER

Assessment of everyday difficulties

This questionnaire is designed to enable us to determine where and when your visual impairment causes you most inconvenience.

NAME Subject J.B.

ADDRESS

Section 1 Please answer as carefully as you can the questions below according to the extent of their difficulty as follows:-

1 - Cannot manage
2 - Just manage
3 - Manage with difficulty
4 - Manage without any difficulty

Please ring the appropriate number.

NOTE IF A FRIEND OR RELATIVE HELPS YOU ANSWER THE QUESTIONS PLEASE TICK THIS BOX ☐

1. Can you walk up and down unfamiliar stairs alone? 1 2 (3) 4

2. Can you purchase an item alone -

   (a) in a small shop? 1 2 3 (4)

   (b) in a large store? 1 2 (3) 4

3. Can you search for, and locate, a small article e.g. coin or key -

   (a) at table level? 1 2 3 (4)

   (b) at floor level? 1 2 (3) 4

4. Can you cross a road on which traffic is -

   (a) relatively quiet? 1 2 3 (4)

   (b) very busy? 1 2 (3) 4

Section II Please answer the following questions by ringing the appropriate answer and making brief further observations.

1. Are you able to use public transport alone? **[YES]** NO

If 'Yes' how often do you use public transport?
- **[1 - 3 times per ~~week~~ month]**
- 4 - 6 times per week
- more than 6 times per wee

2. How often do you make purchases in a shop or store when unaccompanied?
- Never
- 1 - 4 times per week
- 5 - 8 times per week
- **[More than 8 times per wee]**

3. In familiar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- More than 6 times per wee
- **[4 - 6 times per week]**
- 1 - 3 times per week

4. In unfamiliar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- **[More than 6 times per wee]**
- 4 - 6 times per week
- 1 - 3 times per week
- Never in unfamiliar environment unaccompanied

5. When walking, do you experience difficulties such as loss of balance when suddenly changing direction? YES **[NO]**

If 'Yes' please give examples:-

6. Do you experience problems when surrounded by people? **[YES]** NO

If 'Yes' please give examples:-

Cannot see people or children to the side of me or under my feet.

7. Have you had any very hazardous experiences due to your vision? **[YES]** NO

If 'Yes' please give examples:-

Car backed into me while crossing road.

8. Do you have difficulty with any domestic, or vocational task? YES **[NO]**

If 'Yes' please give examples:-

9. Do you have any further comments:- Difficulty in adjusting to light conditions mainly when entering shops, and evening conditions.

EVALUATION OF VISUAL FIELD EXPANDER

Assessment of everyday difficulties

This questionnaire is designed to enable us to determine where and when your visual impairment causes you most inconvenience.

NAME Subject L.S.

ADDRESS

Section 1 Please answer as carefully as you can the questions below according to the extent of their difficulty as follows:-

1 - Cannot manage
2 - Just manage
3 - Manage with difficulty
4 - Manage without any difficulty

Please ring the appropriate number.

NOTE IF A FRIEND OR RELATIVE HELPS YOU ANSWER THE QUESTIONS PLEASE TICK THIS BOX ☐

1. Can you walk up and down unfamiliar stairs alone? 1 2 (3) 4

2. Can you purchase an item alone -

   (a) in a small shop? 1 2 (3) 4

   (b) in a large store? 1 2 3 (4)

3. Can you search for, and locate, a small article e.g. coin or key -

   (a) at table level? 1 2 (3) 4

   (b) at floor level? 1 (2) 3 4

4. Can you cross a road on which traffic is -

   (a) relatively quiet? 1 2 (3) 4

   (b) very busy? 1 2 (3) 4

Section II Please answer the following questions by ringing the appropriate answer and making brief further observations.

1. Are you able to use public transport alone? **[YES]** NO

If 'Yes' how often do you use public transport?
- 1 - 3 times per week
- 4 - 6 times per week
- **[more than 6 times per wee]**

2. How often do you make purchases in a shop or store when unaccompanied?
- Never
- 1 - 4 times per week
- 5 - 8 times per week
- **[More than 8 times per wee]**

3. In familiar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- **[More than 6 times per wee]**
- 4 - 6 times per week
- 1 - 3 times per week

4. In unfamiliar surroundings does your vision cause you to collide with obstacles or fall? **[YES]** NO
- More than 6 times per wee
- 4 - 6 times per week
- 1 - 3 times per week
- **[Never in unfamiliar environment unaccompanied]**

5. When walking, do you experience difficulties such as loss of balance when suddenly changing direction? YES **[NO]**

If 'Yes' please give examples:-

6. Do you experience problems when surrounded by people? **[YES]** NO

If 'Yes' please give examples:-

When people walk in front of me, or when they come from the side. Also when anyone is walking with me I find it is very trying on my nerves.

7. Have you had any very hazardous experiences due to your vision? **[YES]** NO

If 'Yes' please give examples:-

(1) The steps of subways.
(2) When cars have their headlights on, I find I cannot see their blinker lights.

8. Do you have difficulty with any domestic, or vocational task? **[YES]** NO

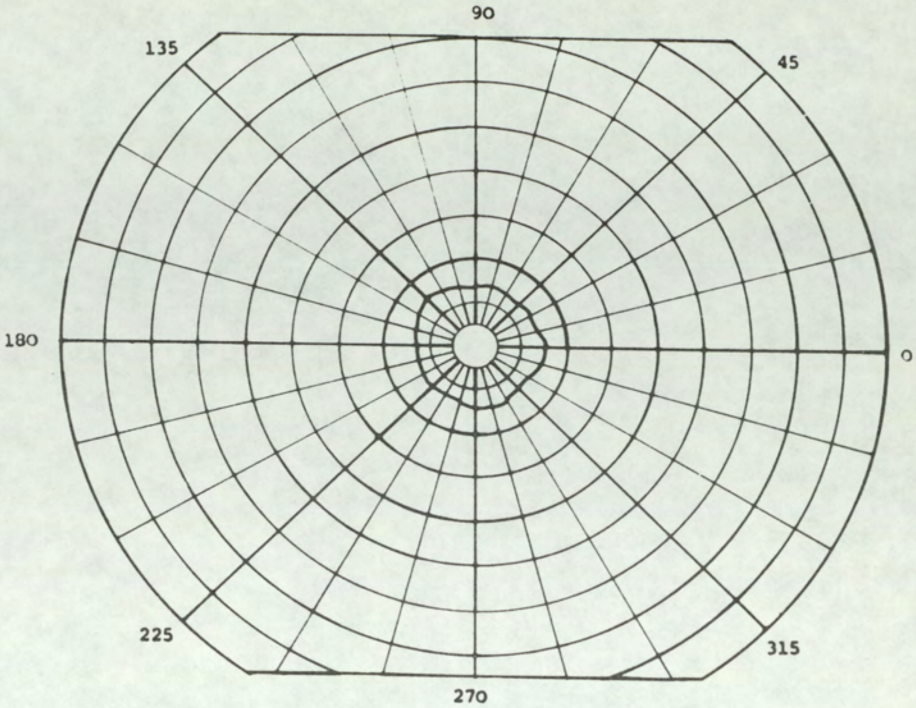
If 'Yes' please give examples:-

The only difficulty I have is in shaving. I find I am relying on touch more than seeing.

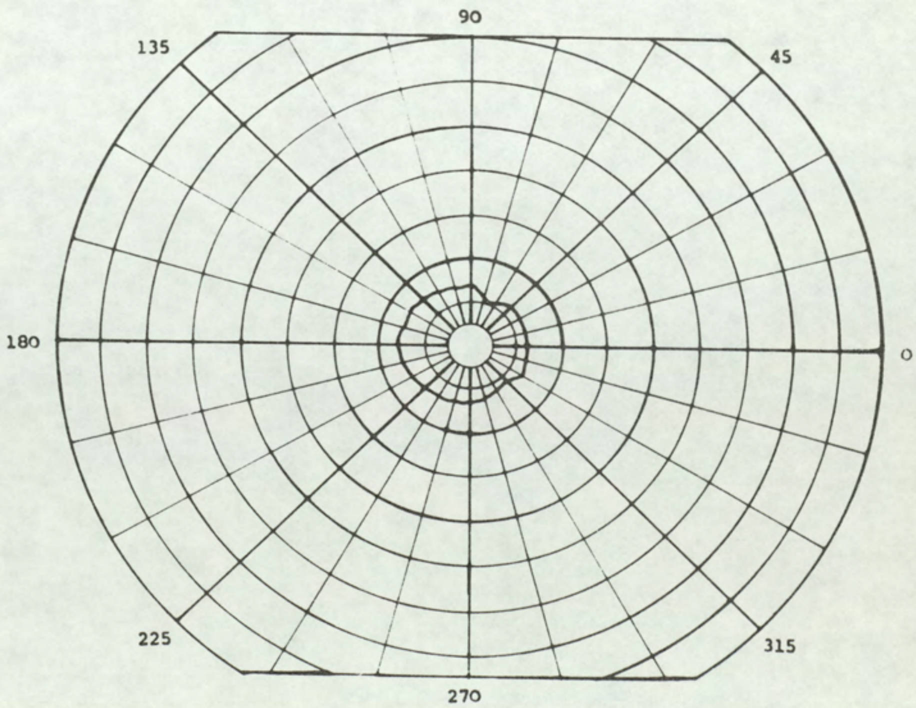
9. Do you have any further comments:-

APPENDIX G

Subject A.H.

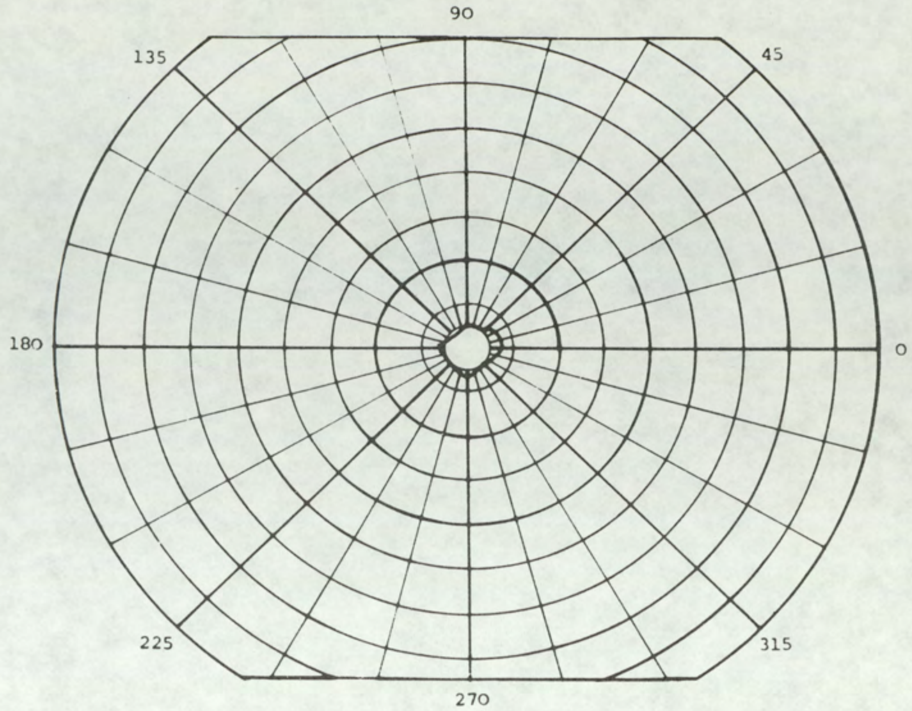


Right Eye

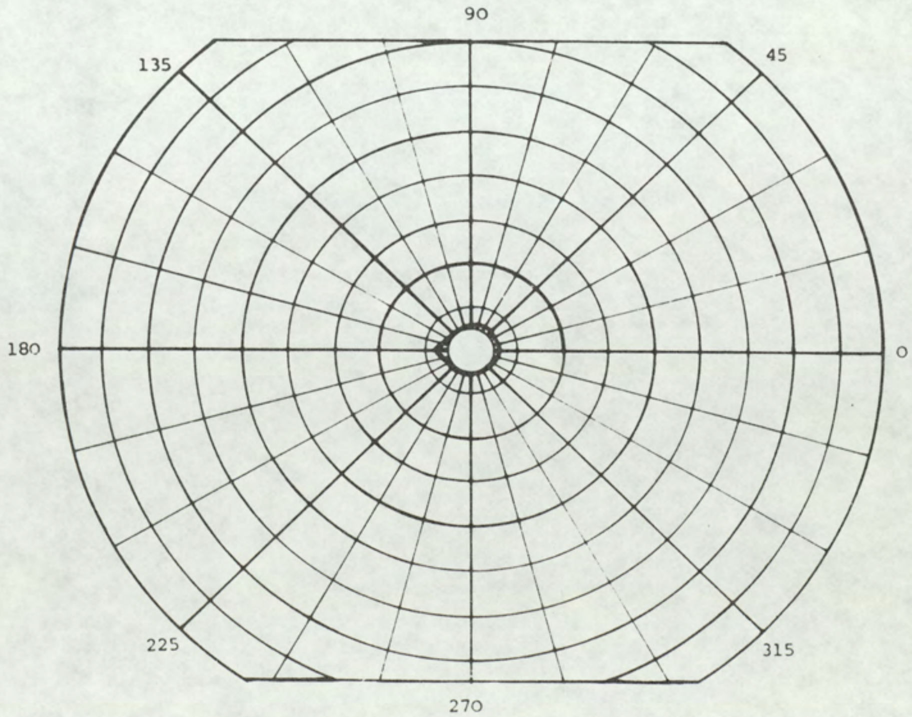


Left Eye

Subject B.F.

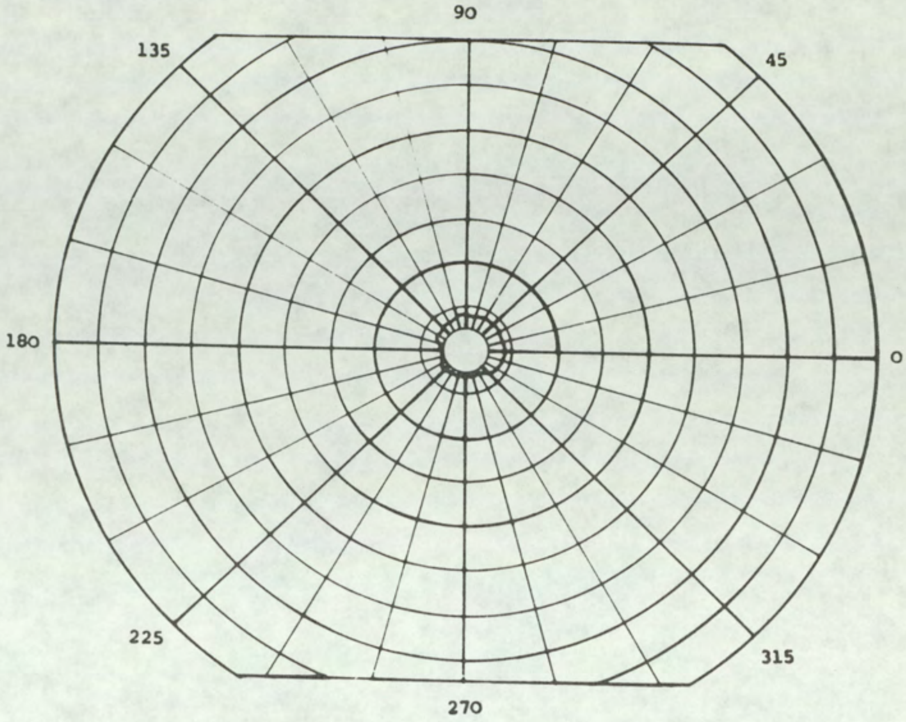


Right Eye

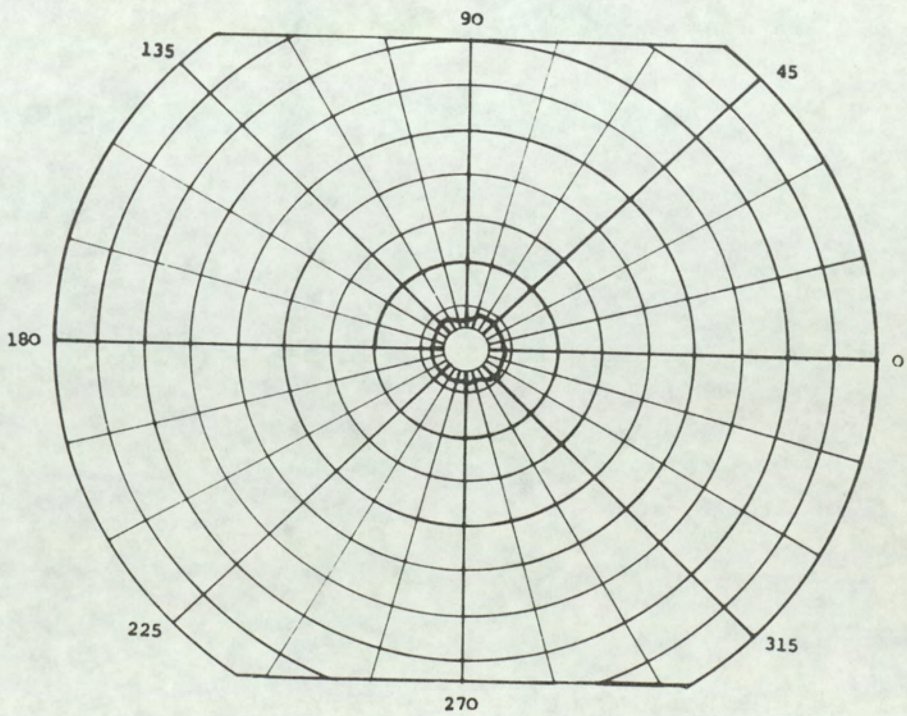


Left Eye

Subject G.P.

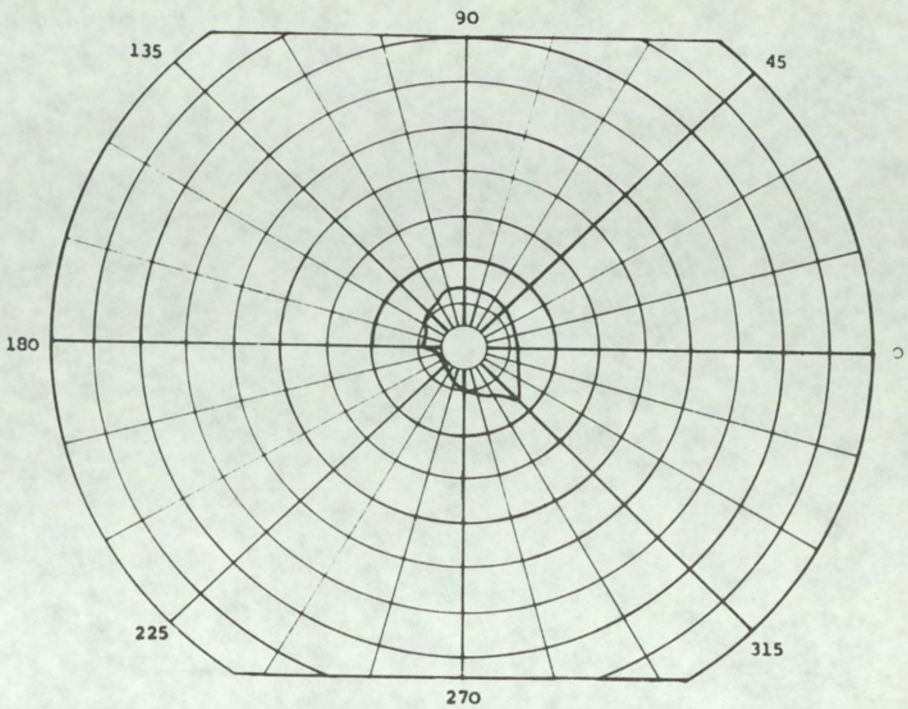


Right Eye

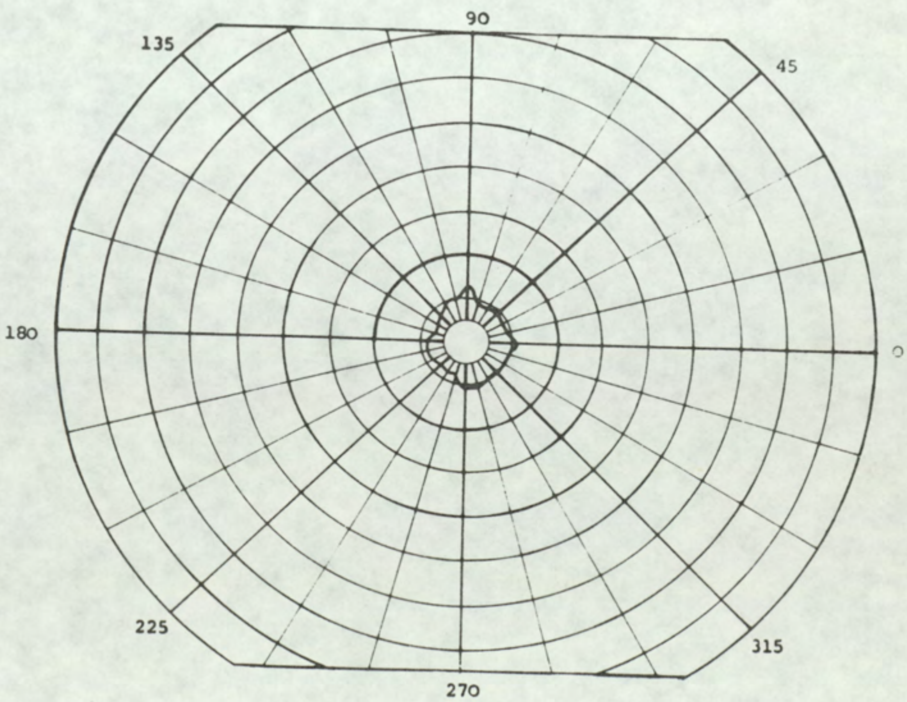


Left Eye

Subject J.B.

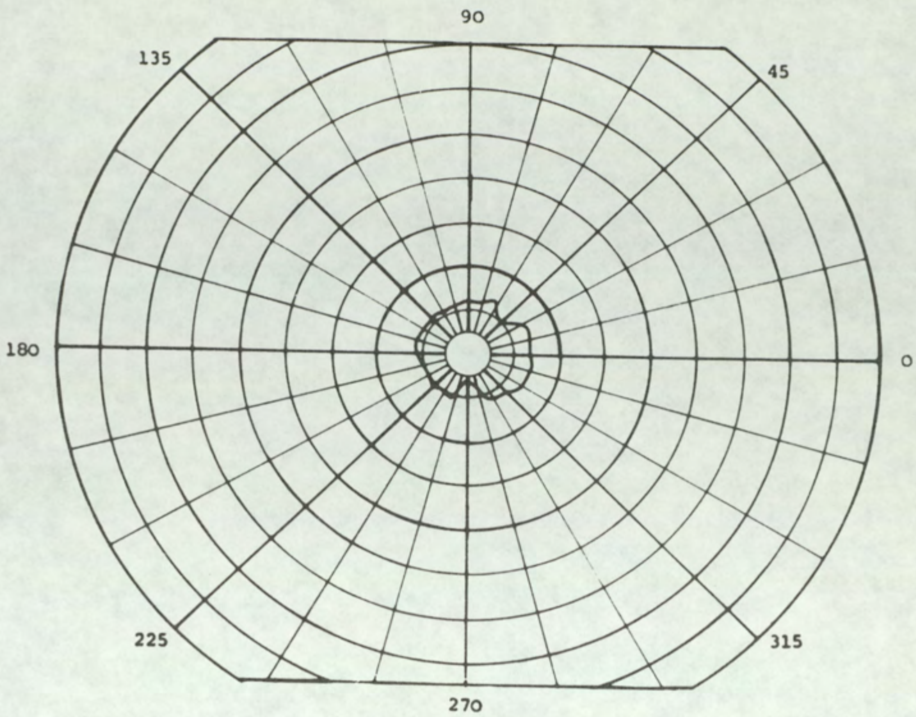


Right Eye

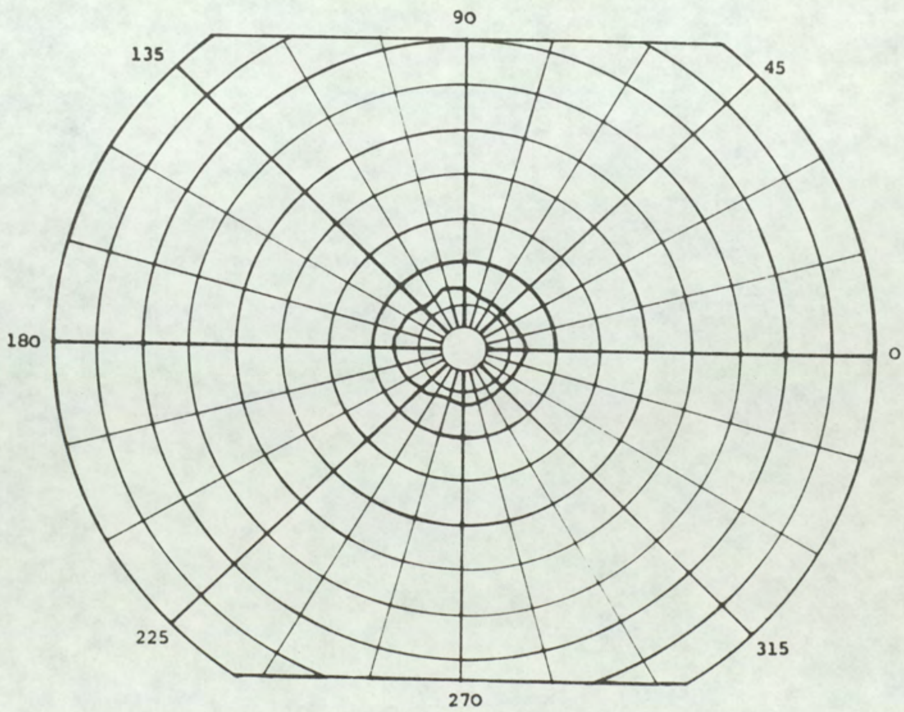


Left Eye

Subject L.S.



Right Eye



 Left Eye

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