EFFECTS OF SEVERAL COLOURED INTERVENTIONS ON READING PERFORMANCE IN AGE-RELATED MACULAR DEGENERATION (ARMD)

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Thesis summary

A literature review revealed that very little work has been conducted to investigate the possible benefits of coloured interventions on reading performance in low vision due to ARMD, under conditions that are similar to the real world reading environment. Further studies on the use of colour, as a rehabilitative intervention in low vision would therefore be useful. A series of objective, subject based, age-similar controlled experiments were used to address the primary aims.

Trends in some of the ARMD data suggested better reading performance with blue or green illuminance but there were also some individuals who performed better with yellow, or with illuminance of reduced intensity. Statistically, better reading in general occurred with a specialised yellow photochromic lens and also a clear lens than with a fixed tint lens or a neutral density filter. No reading advantage was gained from using the coloured screen facility of a video-magnifier.

Some subjects with low vision were found to have co-existent binocular vision anomalies, which may have caused reading difficulties similar to those produced by ARMD. Some individuals with ARMD benefited from the use of increased local illuminance produced by either a standard tungsten or compact fluorescent lamp. No reading improvement occurred with a daylight simulation tungsten lamp. The Intuitive Colorimeter® can be used to detect and map out colour vision discrimination deficiency in ARMD and the Humphrey 630 Visual Field Analyser can be used to analyse the biocular visual field in subjects with ARMD.

Some experiments highlighted a positive effect of a blue intervention in reading with ARMD. This could indicate a possible magnocellular pathway effect resulting in more efficient eye movements and better word localisation. Also the peripheral retina of normal observers has been shown to be sensitive to blue light, and it may be advantageous for people using para- and peri-macular areas, as in ARMD, to read with a blue intervention. These two theoretical constructs could be linked since the peripheral retina and the magnocellular pathway are inter-related.

Key words low vision, colour, illuminance, colorimetry, lamps, video-magnifier, magnocellular pathway

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Introduction

The purpose of this research was to determine whether one or more forms of coloured intervention could be used to enhance reading performance for people with age-related macular degeneration (ARMD). This thesis describes a series of consecutive studies that have examined the use of several coloured interventions in this context.

The World Health Organisation estimated in 1997 that about eight million people are blind or severely visually disabled due to ARMD. The most common cause of permanent visual loss in the UK is ARMD. The exact number of people with this condition in the UK is unknown, but it is thought to be in the hundreds of thousands. The disease aetiology is not fully understood but the ophthalmoscopic appearance is characterised by pigment migration, drusen, and in some cases haemorrhage and exudate. Sarks and Sarks (1989) defined ARMD as:

> 'An eccentrically located atrophic or exudative process capable of lowering visual acuity if it spreads into fixation as well as excessive numbers or softening and confluence of drusen that predispose to these complications'.

With advancing years, visual breakdown products are less effectively handled by the pigment epithelium. Sarks (1976) has described the condition as:

> 'A general degeneration of the retina affecting the retinal pigment epithelium, Bruch's membrane and the choriocapillaries. Bruch's membrane separates, and the pigment epithelium and underlying choroid become thicker and less permeable to the passage of metabolites. Greater hydraulic force is required to transport material across the pigment epithelium, which may, in turn lead to its detachment, or accumulation of debris between it and the underlying Bruch's membrane. This debris is often visible on ophthalmoscopy as drusen. Subsequently, two processes may develop; atrophy resulting in dry (non-exudative or non-neovascular) ARMD, or neo-vascular growth into the sub-pigment epithelial and, ultimately, the sub-retinal space. Fluid then accumulates, the retina becomes detached locally, and haemorrhage with subsequent scarring follows

resulting in wet (exudative or neovascular) ARMD.'

Both processes result in a chronic visual disability, which is not correctable by conventional spectacles or contact lenses. Visual acuity (VA) is reduced and central visual field, colour discrimination, dark and light adaptation, and contrast sensitivity (CS) are all affected. Individuals with this condition often complain of difficulty in performing activities of daily living such as reading, especially small, poor quality text found in newspapers and telephone directories, watching TV, and recognising faces of friends and relatives.

Central visual field loss has been shown to have particularly deleterious effects on reading since it is the macular area of the retina that is used for reading (Faye, 1984; Legge *et al.*, 1985).

In short, degenerated retina forms a macular scotoma, which can be absolute or relative, unilateral or bilateral, and often results in an acquired reading dysfunction as a direct result of ocular disease.

Most people assume that it is important to read in 'good light'. But Wilkins (1993) asked:

> 'What constitutes good light? It is widely assumed that text should have a luminance of about 50 cdm^{-2} (candelas per square metre) for optimum performance. It is also assumed that the best illuminant chromaticity is close to that of daylight, but for many individuals, especially those with ocular disease, white light may not be the optimum or most comfortable colour of light.'

The Chartered Institution of Building Services Engineers (CIBSE) Code for Interior Lighting (1994) advised an illuminance of 100 to 300 lux in lounge areas of residential dwellings with the 'addition of local lighting for the elderly when performing reading and other visually difficult tasks'. No recommendations are provided for private dwellings or for people with low vision.

Clinicians, researchers (Sloan, 1969; Sloan *et al.*, 1973; Zhokhov *et al.*, 1976; Silver *et al*,

1978; Lagrow, 1986; Collins, 1987; Eldred, 1992) and commercial organisations have claimed that some people with low vision experience improved visual function when using local lighting with high illuminance. Similar claims have also been made for certain coloured interventions (Chapter 1-Background and Research Rationale).

Individuals, who have been prescribed one coloured intervention in particular namely tinted spectacle lenses, have claimed improved visual function. Similar claims have been made by clinicians who prescribe these lenses and by workers involved in their rehabilitation. Many of these claims have been based on un-quantified clinical intuition and anecdotal reports; there is very little published objective evidence to substantiate claims for improved visual function (Chapter 1-Background and Research Rationale). Therefore, practitioners who attempt to prescribe this type of tinted lens have to rely on the manufacturers' guidelines and subjective responses of the user to determine if there is any improvement in visual function.

Working as a clinician in this field, the lack of published objective and independent research has made the recommendation of specific types of high illuminance local lighting and coloured interventions, especially tinted lenses, very difficult. A formal study in this area is necessary in order to investigate this mode of rehabilitation, using a scientifically robust outcome measure and rigorous analyses to determine any success. This is particularly important at the present time, as fund holders are asking many health care workers to question their procedures with the emphasis being placed on using only evidence-based treatment.

In the field of low vision rehabilitation, high illuminance local lighting is currently available as luminaires with either tungsten incandescent or compact fluorescent lamps. Coloured interventions are available in the following formats:

- Fixed surface tinted, plastic and glass spectacle lenses in plano or prescription form.
- Specialist plastic and glass photochromic tinted spectacle lenses in plano or prescription form.

- Plastic clip-ons and 'behind the lens' inserts in plano form.
- Polycarbonate, fixed, solid tinted, wrap-round overshields in plano form.
- Coloured text or coloured screen backgrounds on video-magnifiers.

Tinted spectacle lenses are often expensive, especially in the photochromic form. Fixed tint, wrap-round overshields although comparatively less expensive, personal experience has indicated that people do not readily accept them on grounds of poor cosmesis. Overshields will be referred to only briefly in this work.

Video-magnifiers (also known as closed circuit television or CCTV systems) are sometimes of benefit to people with low vision related reading problems, and are considered by many low vision practitioners to be the gold-standard in terms of magnification provision and reading rehabilitation. Some video-magnifiers allow text to be presented in various colours, usually black-on-grey, and white (reversed contrast), red, yellow, green and blue on a black background. Some video-magnifiers allow black text to be presented on a coloured background. This colour capability considerably increases the cost of the video-magnifier compared to a standard unit by approximately five times.

Presently it is not known whether the cost of tinted spectacle lenses or a video-magnifier with a coloured text/background facility can be justified to the purchaser (an individual with ARMD or a third-party supplier such as a government funded employment agency) in terms of improved reading performance.

Other types of coloured intervention are available, but a literature search (Chapter 1-Background and Research Rationale) indicated that these are not currently used in low vision rehabilitation:

- Plastic coloured sheets (often called gels) available commercially and used to vary the colour of theatrical stage lighting.

- Plastic coloured overlays (Intuitive Coloured Overlays®) placed directly on the printed page (appendix 2) used in the treatment of people with non-ocular disease related reading difficulties and migraine.
- Fixed, surface, Precision Tinted® plastic lenses as determined by the Intuitive Colorimeter® (appendix 3) also used with people who have non-ocular disease related reading difficulties and migraine.

Intuitive Coloured Overlays® and the Intuitive Colorimeter® were developed by Wilkins (Wilkins and Neary, 1992; Wilkins *et al.,* 1994) to assist healthy children and adults with learning difficulties (especially reading), photosensitivity and migraine.

It would be useful to know whether these other forms of coloured intervention can be used to enhance reading performance in ARMD and perhaps provide a less expensive rehabilitation alternative to those currently used, i.e. photochromic tinted spectacle lenses and colour text/background video-magnifiers.

It may well be that there is no coloured intervention that improves reading in ARMD when the results are averaged across a group of subjects, but that the optimum colour varies with each individual, i.e. the best colour may be idiosyncratic and specific. The use of coloured overlays on normally sighted subjects with specific reading dysfunction, not due to overt ocular disease, has proved to be idiosyncratic and specific (Jeanes *et al.*, 1997). There are no studies described in the literature that have investigated this phenomenon in a low vision population.

The primary purpose of this work was to investigate the effects of several coloured interventions, using techniques novel to the field of low vision, on reading performance with ARMD. Techniques are clinical, objective and designed to determine whether there are any group averaged or individual subject improvements in reading performance.

This research will attempt to make an original and significant contribution to the literature, by assessing whether subjects with ARMD require individually prescribed coloured interventions and not solely rely on general statements based on averaged data.

The primary aim of this study was to investigate the following coloured interventions:

- Coloured gel filters.
- Intuitive Coloured Overlays®.
- Tinted spectacle lenses, both plastic fixed tint and glass photochromic.
- Coloured video-magnifier screen backgrounds.

The secondary aim of this thesis was to investigate:

- Effects of local lighting produced by various types of luminaire on reading performance.
- Use of the Intuitive Colorimeter® as a colour vision analyser.

Two technical notes are also described:

- Use of the Humphrey Visual Field Analyser to map out biocular scotomas in ARMD
- Use of Wilkins Rate of Reading Test® (WRRT) and the Bailey-Lovie near word reading acuity card in low vision reading research.

Logistical restrictions meant the following interventions were not investigated:

- Plastic clip-ons and 'behind the lens' inserts in plano form.
- Polycarbonate, fixed, solid tinted, plano, wrap-round overshields.
- Coloured text on a black video-magnifier screen.

In short, the main question this thesis has attempted to address is: Can one or more types of coloured intervention improve reading performance in ARMD?

Brief discussions are provided at the end of each study but more detail is provided in Chapter

5-Overall Discussion. Tables with subject details have been embedded in the text. However, in order not to break up the text ANOVA tables are presented at the end of each experiment. Raw data and Chi squared analyses tables can be found in appendix 1.

The thesis is presented with the following structure:

Chapter 1-Background and Research Rationale

By way of a literature review this chapter has provided the background to the study. Previous work on luminance and colour in low vision is described, along with studies that have reported specifically on the use of tinted spectacle lenses for enhancement of visual function in low vision. The research rationale behind this thesis is presented at the end of this chapter. Brief reference is also made to salient studies from the literature in the introduction to each experiment.

Chapter 2-Pilot Experiments

Two pilot experiments are described, including methodology, results, analyses, discussion and conclusions:

- Experiment 1 was designed to determine whether individuals with low vision also have a coexistent binocular vision (BV) anomaly; if present, these could be partly responsible for reading difficulties. The use of subjects with ARMD and also a coexisting BV anomaly for subsequent experiments in this series would almost certainly have confounded the results. It was considered necessary to exclude this type of subject.
- Experiment 2 was conducted as a pilot in order to be able to refine the designs of subsequent experiments. It involved an evaluation of the effect of local illuminance, varied in colour and intensity (not normalised for total light transmission [TLT]), on reading performance for young and senior normals (YN and SN) and an ARMD group. Practical limitations are discussed, tentative conclusions made and further testing suggested.

Chapter 3-Primary Experiments

This chapter describes the primary experiments that make up the main part of this thesis, and includes methodology, results, discussion and conclusions for each experiment:

- Experiment 3 investigated the effects of coloured local illuminance produced by gel filters (with approximately equal TLT) on reading performance for YN, SN and ARMD groups.
- Experiment 4 investigated the effects of eleven coloured plastic overlays (mainly Intuitive Overlays® with approximately equal TLT) on reading performance for YN, SN and ARMD groups.
- Experiment 5 investigated the effects of four spectacle-mounted coloured filters [Corning Photochromic Filter (CPF) 450, neutral density (ND), clear and a fixed surface tinted plano lens generated by the Intuitive Colorimeter®], on reading performance for SN and ARMD groups.
- Experiment 6 investigated the effects of text presented on various coloured screen backgrounds produced by a video-magnifier on reading performance for an ARMD group.

Chapter 4-Secondary Experiments

Two secondary experiments with methodology, discussion and conclusions for each are outlined along with two technical notes:

- Experiment 7 compared the effects of three luminaires on reading performance in YN, SN and ARMD groups.
- Experiment 8 investigated the use of the Intuitive Colorimeter® as a colour vision analyser for SN and ARMD groups.
- Technical note 1 - the use of the Humphrey 630 Visual Field Analyser to determine the extent and depth of biocular scotoma in an ARMD group.
- Technical note 2 - use of the WRRT and the Bailey-Lovie near word reading acuity card for reading performance analysis in low vision.

Chapter 5-Overall Discussion

The study as a whole is discussed, with previous research being linked to findings from this series of experiments and theoretical constructs put forward to explain the results obtained.

Chapter 6-Overall Conclusions

Conclusions for each experiment are discussed and general conclusions are put forward.

Chapter 7-Practical Implications

Practical implications are suggested for further research, future experimental designs and for low vision clinical assessments and rehabilitation.

Glossary and Abbreviations

References

List of references.

Appendices

1. Raw data and Chi squared analyses.
2. Intuitive Coloured Overlays®.
3. Intuitive Colorimeter®.
4. British Ability Scales.
5. Daylight simulation tungsten incandescent lamps.
6. List of random words used as test print for experiment 2.
7. List of words from five different Bailey-Lovie near word reading acuity card.
8. Score sheets for WRRT.
9. Supporting published work.

Chapter 1-Background and Research Rationale

A literature search was conducted to obtain previous publications on the use of colour as a rehabilitative intervention in low vision. This chapter is a critical review of previous work and is divided into studies that have investigated the use of colour and luminance, and those that describe the use of tinted spectacle lenses.

COLOUR, LUMINANCE AND LOW VISION: A REVIEW

Introduction

There have been many studies that have attempted to illustrate the effects of illuminance and colour on visual function for people with low vision. Most have concentrated on illuminance while only a few have dealt with the effects of colour. In this review attention is focussed on the effects of these parameters on low vision reading (Eperjesi *et al.*, 1995).

The effects of (il)luminance on reading in low vision

Weston (1945) highlighted how the performance of a simple visual task, for normally sighted observers, is influenced by the size of its details, and illuminance. The performance of a visual task improves as the size of the test object is increased. The performance of the task is improved by about 135% when the size of the object is three minutes instead of one minute and that the improvement is nearly 200% when the size is increased to 10 minutes.

Conversely if the size of the object is kept small (one minute) and the illuminance is increased 10 times, only a 30% improvement in performance is achieved. This data was obtained from a

normal population but can also be applied to those with low vision in that although low levels of illuminance are undesirable, a large detail size (produced by magnification where necessary) or by using large print books, provides a much more potent aid to visibility.

Some people with low vision, however, are unable (for physical reasons) or unwilling (for psychological reasons) to use magnifiers and sometimes it is not possible to have large print such as in a standard newspaper, cooking instructions or correspondence. Large print also has cost and logistical implications. In these situations, appropriate local lighting may provide some improvement in performance.

The ability to recognise detail in a task depends not merely upon its angular subtense, but also upon its contrast, either of luminance (brightness), colour or both, between the essential parts of the task and its immediate background. If the size of the detail is kept constant and the contrast reduced, the detail becomes more difficult to see. Large objects are relatively easy to detect at quite low contrast, whereas high contrast is always needed for the detection of small detail.

Luminance contrast (Michelson) is normally expressed by the equation:

$$\text{Contrast} = \frac{L_{max} - L_{min}}{L_{max} + L_{min}}$$

Lmax and Lmin refer to the luminances of either the detail or its background, depending on which is the brighter. In other words, when different objects receive the same illumination, they will be seen more easily by luminance contrast if their reflection factors are very different. A grey object may reflect 0.2 or 20% of the light of all wavelengths that it receives, if this is placed on white background, which may have a reflection factor of 0.8, or 80%, the contrast between the two objects would be 0.75 or 75%. If the grey object is placed on a black background (reflection factor 0.15 or 15%, the contrast between the two objects would be

considered to be low (0.25 or 25%).

Weston (1945) compared the effect of enhancing the contrast with increasing illuminance of a small detail task. He found even under a very low level of illuminance (50 lux), when poor contrast of the detail (0.28) is improved (0.97), i.e. the relative difference of brightness between the detail and its background is increased nearly three times, the gain in visual performance is 130%. Conversely, if the contrast remains poor but the illuminance is increased ten times, the gain in performance is only 20 to 30%. Although providing an adequate level of illuminance for the satisfactory performance of difficult visual tasks is usually essential, improving the contrast of the task detail with its immediate background can have a far more significant effect. Unfortunately, improving the contrast of near objects, especially print is only achievable using video-magnifiers, and these are not readily available.

One of the earliest studies investigating the effects of luminance was conducted by Sloan (1969) who assessed the change VA with luminance, and its variation with retinal location over a wide range of photopic intensities. Subjects had lesions in the optic pathway, strabismic amblyopia or macular disease. Foveal measurements were made at 7.4 m and all other measurements at 5 m. For parafoveal VA measurements, the subject fixed a small point of light located at the desired distance laterally to the test target which was a Sloan distance VA chart. Background luminance ranged from 0.03 to 1000 cdm^{-2}, provided by two photoflood lamps and measured with a MacBeth illuminometer. Luminance was varied by placing ND filters in front of the test eye. All measurements were made with the natural pupil.

For subjects with ARMD, a plot of VA versus log luminance intensity showed a shift to higher intensities and a reduction in the maximum possible VA that could be achieved when compared to normal subjects. These findings were attributed to the use of parafoveal or paramacular regions of the retina. The eccentric viewing area was associated with a reduced rate of change of VA with log luminance similar to that observed in the normal paracentral retina. Sloan suggested that these subjects required very high intensity luminance to attain best

VA. Although this study did not involve a near reading task, it has been included in this review to demonstrate effects of high intensity reading lamps in low vision.

In a second study involving subjects with macular disease, Sloan *et al.* (1973) suggested that these individuals might need levels of background luminance above 318 cdm^{-2} for near reading tasks. Forty subjects were tested using Sloan capital letters and Sloan M cards at near, with a room luminance of 31 cdm^{-2} and with a luminance of 1114 to 1273 cdm^{-2}, formed by a high intensity lamp 7.5 cm from the test material.

It was suggested that weaker low vision magnifiers could be used in conjunction with high luminance and that better levels of near VA could be obtained than with normal luminance and a stronger aid. This is of benefit as lower power magnifiers provide a greater field of view and less peripheral distortion. However, some subjects commented that letters appeared to fade after a few minutes of observation. The investigators also noted that the determination of near VA variance with luminance provided a more precise measure of their relationship than a distance test, since at near a 'greater number of letters are available in large sizes and it is easier to obtain an evenly illuminated test area'.

Shirshikov *et al.* (1974) determined the optimal illumination intensity for visual work performed by 102 subjects with low vision due to a variety of ocular conditions. VA ranged from 6/120 to 6/600. For carrying out 'visual work' there was a large range of optimal illuminance levels from 20 to 800 lux. Subjects with achromatopsia, juvenile macular degeneration, and cataract (10% of the study group) required low levels of illumination, 20 to 150 lux.

Silver *et al.* (1978) found that reading acuity was considerably enhanced when lighting was improved for subjects with a variety of eye diseases including ARMD. Clinic and home reading performance was compared; lighting with a median value of 1188 lux produced

optimum clinic reading performance. However, normal home conditions were found to have a median illuminance value of only 177 lux. The median home optima illuminance value was 1675 lux. When subjects who could read N5 before intervention were excluded, a median illuminance value of 1738 lux was found to give the optimum performance. Over 90% of all subjects showed some improvement in reading acuity or distance VA with increased lighting.

Hartmann *et al.* (1980) [cited in Lindner *et al.*, (1989)] studied the dependence of VA on incident and transmitted light for various ocular disorders. A clear disease-specific dependence (no details provided) was seen in the 380 to 1000 lux illuminance range, i.e. VA increased with luminance in this range. Interestingly, the study by Lindner *et al.* (1989) indicated that normal sighted young subjects had a statistically significantly subjective higher lighting need for easy and difficult near vision tasks than older subjects.

Gill and Silver (1982) tested the illuminance of nine types of commercial luminaires with tungsten incandescent lamps using a light-meter. Nominal wattage was either 60 or 100W. Most of the luminaires gave similar performance. However, the 60W Thorn Decorspot 80 Diffused (an 'architectural-type spotlight') produced the highest illuminance of 3800 lux at 40 cm when mounted in an Anglepoise luminaire, nearly four times the next closest lamp. The researchers recommended this as an alternative to conventional lamps when increased power would be required to produce an equivalent illuminance, or when a conventional lamp, even when moved closer to the reading material, still did not produce adequate illuminance.

Krischer and Meissen (1983) compared the effects of blurred and dimmed (with ND filters) conditions on reading speed for normal compared to partially sighted subjects with central scotomas, peripheral field defects and normal visual fields. They proposed that the dimmed light condition would simulate a foveal dysfunction whereas the blurred condition would simulate a media dysfunction. The researchers used a technique that involved single sentence text drifting across a TV monitor. Both simulated impairments reduced the reading speed of

the normal subjects but the dimmed conditions produced a slower rate.

Partially sighted subjects with central scotoma had a lower reading speed than those with peripheral field loss and normal fields. There were some similarities in the reading speed versus VA relationship for the partially sighted subjects with central scotoma and the normal subjects who read under dimmed light. They concluded that reading with a blurred image in normal bright light (68 to 100 cdm^{-2}) inhibited reading much less than reading with a dim light; if the image is only blurred, the fovea and parafovea are still used. The authors postulated that for the partially sighted, reading speed depends on VA and the type of eye defect. The poorer the VA the larger the necessary magnification and therefore the more peripheral is the retina onto which the image falls. The more peripheral the retina the poorer the retinal sensitivity and the probability that reading speed will be reduced.

Although not specifically dealing with reading at near, the results of a study by Brown and Lovie-Kitchin (1983) are included as they show the effect that ARMD has on the distance VA-luminance response. Subjects with ARMD often complain of problems with light adaptation and achieve best VA under a critical range of lighting conditions. This may be due to an alteration of retinal function. Dark adaptation curves were determined for eight subjects with ARMD and for six normals. At the end of the dark adaptation period a projection Bailey-Lovie chart with a background luminance of 0.35 cdm^{-2} was presented and the subject read as far as possible down the chart. Chart luminance was then increased by 1 log unit and the procedure repeated. VA was determined in this manner at 0.35, 3.5 and 35 cdm^{-2} for each subject.

Both the normal and the study group showed approximately 0.2 logMAR (log minimum angle of resolution) units increase in VA per log increase in background luminance, although the VA of the ARMD subjects was depressed. Results from the ARMD group were variable and two subjects showed very little increase in VA with increased luminance. The ARMD group produced some extremely flat functions with almost no effect of luminance on VA. Other

functions had two sections, quite flat at lower luminances and a discontinuity at 3.5 cdm^{-2} changing to an extremely steep function at higher luminances. All subjects were screened with a visual field analyser and had intact function in the area of the retina tested during the study.

The investigators suggested that ARMD is not restricted to areas shown to be reduced in sensitivity by conventional clinical tests and stated that:

> 'These functions may reflect disturbances in control of the gain of contrast detection mechanisms of the retina, as a result of the disruption of horizontal and amarcrine cells at sites remote from the ophthalmoscopically visible lesion'.

Bullack (1984) [cited in Lindner *et al.*, (1989)] demonstrated that even if magnifiers were used, illuminance levels up to 4000 lux produced substantial improvements in VA.

Julian (1984) studied near and distance VA as functions of task illuminance for 27 partially sighted people (no subject details). Word reading ability was used as the near task, which was performed at a distance the observer desired, without the use of any low vision devices. Since the working distance was not fixed, design illuminance, rather than task illuminance was used as the variable. Design illuminance was defined as 'the illuminance produced on the task in its normal location on the tabletop'. This was considered to be a more realistic measure of what could be expected in the real environment.

Near reading VA was determined at design illuminances of 50, 100, 300, 600, 1200 and 1800 lux and the results analysed for statistical dependence upon illuminance for any changes. A paired t-test was used and any significance was arbitrarily set at the 0.05 confidence level. The near tests showed that reading VA improved from N24 at 50 lux to N15 at 600 lux.

Julian (1984) concluded that if moderately high task illuminances were used for near tests then some partially sighted people would not need low vision devices, and for others the efficiency of their devices would be improved. He went on to suggest that:

> 'Improvements in visual performance are dependent upon the achievement of suitable environmental illuminances which do not produce localised veiling luminances or retinal adaptation effects'.

Interestingly, he advised that the whole of the visual environment be illuminated rather than using local, isolated task lighting and that environmental illuminances should not be less than 25% of local task illuminance or less than 50% of the working plane illuminance if local lighting was not used.

Lagrow (1986) attempted to determine the most efficient light for practical reading. He defined this as 'the optimal illumination for the specific task performed in the study with which a 100% correct response occurred in the least amount of total time elapsed'. Sixty visually impaired subjects, 11 of whom had ARMD as the primary ocular condition, were used. The test room, waiting room and hallway were all maintained to provide an ambient illuminance of at least 560 lux. Newspaper articles were used in the pre- and post-test measurements. Subjects were randomly divided into two subgroups, one of which was arbitrarily selected to be the control group and the other the study group.

The main test consisted of reading sequences of five randomly selected letters, and this was used to assess the optimal illumination level required to produce the greatest number of correct words per minute (CWPM). Illuminance, provided by a high intensity lamp, was manually varied from 700 to 16146 lux by increasing the voltage from 50 to 140 volts (V) in 10 V increments. The optimal level of illumination at which 100% accuracy occurred in the test was identified for each subject. The post-test measurement for the study group was conducted using the optimal illumination selected by each subject during the main test. Subjects were asked to comment on their perceived comfort of reading for each level of illuminance.

Data analysis indicated that there was a range of optimal luminance levels from 700 to 15070 lux and that no one single level was identified as optimal, although the median level was 2099

lux. For the study group, CWPM was higher with the post-test optimal luminance than the normally illuminated pre-test, while no such difference was demonstrated for the control group. No details of any statistical analysis are provided.

Work carried out by Collins (1987) attempted to demonstrate that reading performance in low vision might vary with illuminance. Three luminaires were used in the evaluation:

- Luxo T87E compact fluorescent desk luminaire 11 W equivalent to 75 W incandescent lamp (The Partially Sighted Society, Queen's Road, Doncaster, South Yorkshire, DN1 2NX, UK).
- Anglepoise 90 luminaire fitted with a 100 W daylight tungsten incandescent lamp (Daylight Studios, 223A, Portobello Road, London, W11 1LU, UK), which simulated northern daylight and was equivalent to a 60 W tungsten incandescent lamp.
- Standard desk luminaire fitted with a 60 W Opal Tidylite incandescent tungsten lamp (department store lighting department).

Subjects predominantly suffered from ARMD although the study group also included retinitis pigmentosa (RP) and age-related cataract. The near task comprised a Keeler A series chart, which was read with each luminaire in turn. No mention is made of the distance from the lamp to the chart and no details of luminaire randomisation are provided.

Subjects stated their preferred luminaire and the investigator noted any improvement in near VA. The high level of local lighting improved near VA for all the subjects but there was no significant variation for any one luminaire in particular. There was an almost equal preference for the Luxo compact fluorescent tube and the 100 W daylight tungsten incandescent lamp. Interestingly, no subject stated a preference for the 60 W Opal Tidylite daylight tungsten incandescent lamp.

It was concluded that visually disabled people generally performed better under high levels of

illuminance and that natural white light was preferred to yellow light. This evaluation was not performed under strict laboratory conditions, there was no control group and the results are very much anecdotal.

In a similar, but scientifically more rigorous study, Soldatova (1990) used four light sources: incandescent, fluorescent, mercury arc and natrium lamps to ascertain any variation in VA, visual field, colour perception and photo-stress, collectively described as visual performance. The study group contained 46 subjects with macular dystrophy, and a control group of 50 normal subjects. Spectral composition had more of an influence on all the visual variables for the low vision group. The natrium lamp (yellow light) produced the best visual performance. The short wavelength light of the mercury arc and the fluorescent lamp decreased visual performance in the low vision group, but had no effect on the control group.

Cornelissen *et al.* (1991) cited Lagrow (1986) and noted that the required level of illumination should be determined individually in order to obtain optimal visual performance. They went on to state that:

> 'Such a direct assessment is costly in time for both the investigator and the low vision person and therefore a better approach might be to first determine whether someone is likely to gain from adapted illumination, which could then be followed by more detailed assessment'.

They determined the smallest readable letter size on a near word chart for 32 subjects with varied ocular pathology and used low (100 lux), middle (500 lux) and high (2000 lux) illuminance. Light was provided by two fluorescent lamps and illuminance varied by adjusting the height of the lamps above the chart. Observers were allowed to use their preferred working distance. Twenty percent of the study group had best near VA at the highest illuminance, 30% at the middle illuminance and for the remaining 50% near VA did not change under the different levels of illuminance. Interestingly, 60% preferred the highest, 25% the middle and 3% the lowest level of illuminance. Only one subject was indifferent towards the level of

illuminance. The authors concluded that near VA alone may not be a sufficient measure of the illuminance dependence of visual performance and that 'more detailed investigation of the relation between illuminance, VA, visual performance and preferences is necessary'.

Eldred (1992) sought to determine the optimal levels of illumination for reading in 18 ARMD subjects. The study group was experienced in the use of low vision magnifiers. No control group was used. Six groups of random words and letters were selected from the Pepper Visual Skills for Reading Test (sequences of letters and words) and presented at six levels of illuminance; 484, 1075, 2960, 4304, 5918 and 7532 lux. These figures were based on Sloan *et al.* (1973) data and were chosen to be above and below the optimum levels recommended by the Sloan study.

Ambient illuminance level was kept constant at 482 lux. Target illumination, provided by two adjustable lamps, was masked from the observer, and the order of presentation randomised as was the presentation of the test words and letters. Each subject was asked to read words and letters aloud from a reading stand and the CWPM calculated. Target size was one line larger than reading VA as measured on the Feinbloom near VA card for each subject. Pre- and post-test measurements were made using only the ambient illumination in order to determine if there were any learning or practice effects. The illuminance level at which the greatest CWPM occurred was taken as the optimal level for that particular subject.

No significant difference in the mean CWPM for different illuminance levels was noted and little or no learning or fatigue effects occurred. The fact that there was no significant difference between mean CWPM at each illuminance level can be explained in three ways. Either it is subject specific, there is no effect of illuminance on reading at all, or the experimental design lacked the statistical power to demonstrate a significant effect (n=18).

For most subjects the highest CWPM occurred at 5918 or 7532 lux. Several subjects commented on a bleaching effect (loss of contrast) after testing, similar to that noted by Sloan

et al. (1973). Eldred concluded that high illuminance levels might only be beneficial for short term reading tasks.

Brown and Garner (1983) analysed the effects of luminance on CS in ARMD using a study group of six subjects with ARMD and a control group of five age-matched normals. The contrast sensitivity function (CSF) for each subject was measured at four luminance levels, 72, 7.2, 0.72 and 0.072 cdm^{-2} produced by ND filters mounted in goggles. CS was measured at six spatial frequencies (SF) 0.5, 1.0, 2.0, 3.0, 8.0 and 16 cycles per degree (cpd). The poorer eye was occluded and fixation was not controlled. Ten minutes adaptation to each intensity was allowed.

At high luminance levels the CSF was depressed in the six ARMD subjects when compared to the five age-matched controls. At low luminance the peak of the CSF tended towards the lower SF values. From these results it was inferred that the contrast detection systems at low luminance were intact in the ARMD group but that these became progressively disrupted at higher luminance levels with an associated SF loss, even though high contrast VA may not be greatly affected. This inability to maintain CS suggests that normal adaptation control mechanisms are compromised in ARMD and this could account for the fading effect described by Sloan *et al.* (1973) and Eldred (1992).

Effects of colour on reading in low vision

Legge and Rubin (1986) cited Van Nes and Bouman (1967):

> 'For the normal eye that is diffraction limited by a small pupil, the diameter of the Airy disc is proportional to the wavelength for monochromatic light. Resolution should be greater in blue than in red light and wavelength effects on CSF can be attributed to differences in diffraction'.

This was investigated by Legge and Rubin (1986) who used psychophysical methods to measure the effects of wavelength on the reading performance of four normals, two

dichromats and 25 low vision subjects with various ocular pathologies including congenital cataracts, ARMD and other retinal lesions. They compared performance under four luminance matched conditions: 0.6, 0.06, 0.006 and 0.0006 cdm^{-2} and suggested that at these low photopic levels pupil size would not impose a diffraction limit on visual resolution, and therefore would not produce a positive bias for blue. Sets of coloured Wratten and ND filters {blue [430nm (#47B)], green [550nm (#58)] deep red [650nm (#29)] and a 1.6ND (approximately 5% transmission) (#96)} were placed in front of a TV screen. A 1.0 ND (10% transmission) filter was used with the green filter to equate luminance across the three colour conditions.

Reading rates were measured for the text scanned across the face of the TV. Text was selected from materials designed to test reading ability and ranged in difficulty from age eight years to secondary school level. Magnification was set so that eight character spaces filled a 20 cm aperture on the TV screen. Character luminance was 6 cdm^{-2} and the Michelson contrast exceeded 94%. Reading rates were measured for letters subtending six degrees at a viewing distance of 25 cm. Subjects were tested using coloured letters on a black background and, where appropriate, chromatic aberration was compensated for using spherical lenses. Pupil size was not controlled.

The results from seven observers with cloudy media indicated that wavelength specific effects on reading are uncommon. The four low vision subjects with advanced forms of photoreceptor degeneration read better in the blue or the green rather than the red, with spectral sensitivities tending to be highest in the green. The investigators described this effect as 'scotopisation', and suggested that it may reflect a role played by rods in the reading process.

For low vision observers with central versus peripheral field loss, the results indicated that central or peripheral field loss is not associated with any clear wavelength specific effects in reading. Generally, green and grey were the colours for which subjects showed the least

departure from the maximum performance, which occurred when using black characters on a white background. This implied that these are colours best suited for the design of reading displays for subjects with low vision.

Similar psychophysical techniques were used by Legge *et al.* (1990) to compare the effects of colour and luminance contrast on reading rates using eight normal and 10 low vision subjects. The study was designed to consider the possibility that colour might enhance reading for large character text. They cited Mullen, (1985) who had previously suggested this and had demonstrated a 'cross-over' in colour and luminance contrast sensitivity functions (CSF) at low spatial frequencies. She found that chromatic contrast sensitivities are greater than luminance contrast sensitivities below 0.3 cpd, differing by a factor of three at 0.1 cpd.

Legge *et al.* (1990) constructed text by adding together red and green images each of which had the same luminance contrast. When added in phase, yellow text resulted and the letters and background differed in luminance. Out of phase they yielded red-on-green text in which the letters and background differed in chromaticity but had the same luminance. No adjustment was made for chromatic aberration. Subjects were presented with single sentences of text displayed on a TV monitor and each sentence had 13 characters including spaces, on each of four lines. The presentation time was reduced until subjects could no longer read the entire sentence and the reading rate was then calculated.

Normally sighted subjects produced reading rates for high colour contrast that were as fast as those for high luminance contrast. The data indicated that readers rely on information conveyed by colour contrast or luminance contrast whichever yields the better performance. Low vision subjects read text composed of six degree characters faster with luminance contrast, and generally low vision reading was hampered and not enhanced by colour contrast. However, the experimenters concluded that for those low vision subjects who are sensitive to any loss in the text contrast, the addition of colour and luminance contrast might enhance

reading above that obtained using luminance contrast alone.

Therefore, these studies had shown that there is little or no practical advantage in coding text letters or backgrounds with colour. Colour video-magnifiers were not examined and the authors concluded that there may be some advantage when the user needed to perform tasks involving object recognition.

Jacobs (1990) reported effects of video-magnifier screen colour on CS and reading performance in low vision. Amber, green and white backgrounds on a Televaid video-magnifier were adjusted so the luminance of the characters was between 100 and 110 cdm^{-2}, and the background luminance between 0.8 and 1.2 cdm^{-2}. Lines consisting of 20 words of text were presented on the screen so the number of return movements with the x-y table (a flat surface that can be moved sideways as well as forwards and backwards) was not excessive.

Sixteen experienced video-magnifier users with various ocular conditions were recruited and practised prior to the testing. They used spectacles and working distances usually used with their own video-magnifiers. Magnification was adjusted initially to find the minimum required to enable each subject to read N6 print from a Bailey-Lovie near word reading card. Reading speed was calculated in two ways: as CWPM, and as the time in seconds required to read a line of text 10 cm long. This second method, which effectively counts letters, rather than words, 'may better reflect the incremental method by which video-magnifier users with severely reduced visual fields scan each letter and use many rapid fixations to build up the visual image of print'.

ANOVA on the data from all subjects showed that screen colour had no effect on reading speed measured in either way. There were significant differences between subjects, which would be expected with a heterogeneous group of people with low vision. There was also a significant difference between the reading speeds of the first run and the repeated measure,

which indicated a learning effect.

No single colour enabled a subject to have improved performance. However, white and amber as a class yielded better speeds than did amber and green as a class. Jacobs concluded that a low vision clinic did not need more than one video-magnifier screen colour for assessments. Jacobs *et al.* (1997) attempted to relate CS of 24 low vision subjects to reading performance with coloured text to determine if there was an optimum colour that should be used for video-magnifier backgrounds. Nine had diabetic retinopathy, eight optic atrophy and seven ARMD. Age range was 14 to 89 years. An additional lens was used over the spectacle correction for presbyopic subjects to correct for the video-magnifier viewing distance.

CS was measured by presenting horizontal sine gratings of 1 cpd SF either on the right or left side of a monitor. Each grating subtended a circular area of four degrees. The luminance of the background and average luminance of the gratings for each colour (white, red, green, and yellow) was set to 18 cdm^{-2}. Subjects indicated their choice of where the grating was presented and the threshold value for each subject was determined in contrast percentage. The colour of the grating was chosen randomly.

Reading rates were also measured for stationary and rapid serial visual presentation (RSVP) modes using the four different colours. Character size was six degrees since Legge and Rubin (1986) had shown that this size provided the optimum reading rates for most low vision subjects. Green, yellow, red, and white texts were luminance matched to 18 cdm^{-2} with ND filters placed over the subject's test eye. Text was presented as coloured letters on a dark background in random order. Four lines (average three words per line) were presented in stationary mode to determine the reading rate. For the RSVP mode, a paragraph was presented one word at a time in the centre of the screen. No association was found between CS values for the different colours and reading performance.

For the subjects as a whole, stationary reading performance was best for the yellow text (30% better than red or white) followed by green (12% better than red or white). Red text resulted in the minimal reading speed. These differences were significant at the $p \leq 0.05$ confidence level. The better reading performance with the yellow text was mainly due to the ARMD subjects whose reading speed showed an appreciable increase when yellow was used. The trend for the RSVP mode was similar but the results were not significant (rejection level $p \leq 0.05$). Reading rate versus reading acuity for the different colours of the stationary and RSVP modes were analysed. As reading acuity decreased performance using the red text decreased. These results were significant only for the RSVP mode. The overall results from this study were consistent with those found by Legge and Rubin (1986).

Jacobs et al (1997) proposed that the spectral sensitivity of their subjects was reduced in short and long wavelengths. To estimate the impact of these losses on reading performance, they determined the relative effective luminance to white, for the green, yellow and red text using spectral sensitivity functions with just a short wavelength sensitivity loss, just a long wavelength sensitivity loss, equal losses in sensitivity at short and long wavelength spectral regions, and losses in the short and long wavelengths but with a greater loss in the short.

They theorised that a combined loss of both short and long wavelengths sensitivity results in the effective luminance of red being approximately half that of white, whereas the effective luminance of green is approximately 10% greater than white, and yellow is approximately equal to white. This trend was present when the short wavelength loss was equal to the sensitivity loss at the longer wavelength and when the short wavelength sensitivity loss was greater. Whether the yellow is brighter or dimmer than white is dependent on the luminance ratio of the red and green phosphors. If the spectral sensitivity loss is just at the shorter wavelengths, then the effective luminance of the green is equal to white, while the red and yellow are about 10% brighter. Except for the red colour, when losses occur just at long wavelengths, the changes relative to white are small and would probably have negligible

effects on reading speed.

The authors suggested that selective losses in spectral sensitivity would have marginal effects on the relative luminances of broad band white, green and yellow stimuli. These marginal effects probably would not influence reading speed with text luminance greater than 10 cdm^{-2} (Legge and Rubin, 1986).

These two factors could partially explain why Jacobs (1990) did not find any significant effect on reading speed with video-magnifier screen colours of white, green and amber when using a luminance level of 100 cdm^{-2}. The predicted marginal changes in the green and yellow relative to white also partially explain the lack of significant results found for CS. Although there may be a loss in effective luminance of the red, this decrease in luminance is not enough to effect CS for 1 cpd. Even if there is a drop in effective luminance of 50%, the dimmer luminance is still in the range where Weber's Law holds, and as a result CS would not be affected.

Jacobs (1990) went on to suggest that low vision subjects should be advised against using red text and that yellow or green text should be tried. However, increasing the luminance of that colour can compensate for selective losses at a particular spectral region. For a red or white display they suggest that the upper limit of this luminance range should be at least 30% greater than the yellow or green display in order to compensate for spectral sensitivity losses.

In practice this compensation is possible with white text, but not red because the dynamic range of the red phosphors is small. However, at luminance levels typically used by low vision observers, a 30% increase in luminance may not make a dramatic change in reading performance, so other factors such as magnification, and the maximum and minimum possible contrast on a monitor are probably more important.

(Il)luminance, colour and object recognition

Zhokhov *et al.* (1976) investigated the influence of illumination levels and coloured

backgrounds on visual discrimination ability for 119 subjects with low vision of varied aetiology; VA ranged from 6/60 to 6/600. In order to be able to distinguish achromatic objects against a coloured background various levels of illuminance were required; 500 to 1000 lux for high myopia; 100 to 500 lux for congenital eye disease, including media opacities, retinal disease, and optic nerve atrophy.

Subjective and objective assessment indicated that a green background appeared to be the most 'comfortable' for subjects with retinal lesions, green and blue for media opacities, red in high myopia with VA worse than 6/150, and green and yellow in high myopia with VA better than 6/150. For optic nerve atrophy, blue and grey were the better background colours. The authors concluded that discrimination ability for the study group depended on 'brightness' and on a combination of object and background colour.

Wurm *et al.* (1993) investigated the effects of colour on object recognition in 16 low vision subjects. They noted that in previous studies of object recognition in low vision, luminance characteristics varied across the colour conditions. In this study colour stimuli were presented as digitised images and real, common food items, identical except for chromaticity and matched for luminance with the colour images. Reaction times to name the images were measured.

It was concluded that colour speeds up object recognition for subjects with low vision, low VA slows down object recognition, and VA and colour act independently in low vision object recognition.

Cornelissen *et al.* (1995) investigated the relationship between illumination level and the ability of visually impaired subjects with varied pathology to detect and recognise objects in a realistic visual environment. The task involved recognising everyday objects in a light laboratory that simulated a domestic living room. Integrated contrast sensitivity (ICS), a

summary measure for the area beneath the CSF was found to be better at predicting performance than either VA or peak CS. However, when combined, VA and peak CS predicted performance as well as ICS. Some subjects continued to show substantial improvement at light levels where normal subjects had achieved maximum performance. Interestingly, one subject with high myopia and macular degeneration found light levels above 500 lux to be too bright.

The authors concluded that for many visually impaired subjects individually adapted illuminance was important and for some vision was better with less light. However, standardised optimal levels were difficult to provide, since even subjects with similar pathology may have very different lighting needs and the required level is task and age dependent. They also stressed the importance of determining lighting needs for every person individually.

Often, low vision practitioners state that an increase in illuminance improves print contrast *per se*. This is unlikely to be the case, since the differential in the reflectance between the print and the background will remain constant irrespective of the amount of external illuminance. The perceived increase in contrast is more likely to be due to:

- Increased light passing through media opacities even when the opacities are not clinically significant (however, this could also result in more ocular scattering and retinal image degradation),
- a reduction in the size of the macular scotoma (Bullimore and Bailey, 1995),
- an increase in the observer's contrast sensitivity function peak (Brown and Garner, 1983) or
- a combination of all these factors.

Conclusions

This review illustrates that most investigators agree on the positive effects of luminance

contrast on reading in low vision, albeit these effects may be short lived. Studies that evaluated colour contrast using text presented on TV monitors suggest that there is very little benefit to be gained from using colour contrast to improve reading in low vision. However, object recognition may be assisted with colour cues. See tables 1.00 and 1.01 for an overview. Knoblauch and Fischer (1991) question whether chromatic contrast may be an effective cue for tasks besides reading, such as visual search.

Reviewing the literature has highlighted that the following factors should be considered when designing an experimental protocol to assess the effects of colour on reading rate in low vision:

- Distance and size of test targets need to be recorded.
- Learning and fatigue effects should be controlled.
- Reading rate to be measured at or near the reading acuity threshold.
- Illuminance and extent of the field surrounding the test object to be noted.
- Subjects need to be at least partially luminance and colour adapted.
- Data on type and intensity of illuminance recorded.
- Data on colour wavelength recorded.
- An age-similar normal control group used.
- Experiments designed to mimic normal real world reading conditions as closely as possible.
- Control for motivational effects.
- Control for personal colour preferences.

The design of an experiment incorporating all these factors would be difficult. However, it is important to be aware of the shortfalls of an experiment to be able to comment on the accuracy and relevance of the data. A design as close as possible to everyday conditions would allow any positive observations to be easily applied in clinical assessment, and in the home and work environment.

Table 1.00

Overview of research on the effects of illuminance in low vision

Investigators	Ocular condition	Outcome measure	Results	Comments
Sloan (1969)	optic pathway lesions, strabismic amblyopia, macular disease	distance VA	high luminance required, and reduced maximum possible VA in ARMD	demonstrated usefulness of high intensity luminance in low vision
Sloan *et al.* (1973)	ARMD	near letter VA	weaker low vision magnifiers can be used when inconjunction with high luminance	some subjects commented on fading vision
Shirshkov (1974)	various	visual work	large range of optimal illuminance 20-800 lux, 10% of subjects preferred 20-150 lux	observers with achromatopsia, juvenile macular degeneration and cataract required reduced illuminance

Table 1.00 contd

Overview of research on the effects of illuminance in low vision

Investigators	Ocular condition	Outcome measure	Results	Comments
Zhokhov *et al.* (1976)	various	achromatic objects	subjective and objective assessment indicated that a green background was the most 'comfortable' for subjects with retinal lesions, green and blue for media opacities, red in high myopia with VA worse than 6/150, and green and yellow in high myopia with VA better than 6/150. For optic nerve atrophy, blue and grey were the better background colours	discrimination ability for the study group depended on 'brightness' and on a combination of object and background colour.
Silver *et al.* (1978)	various	Reading acuity and distance VA	normal home conditions were found to have a median illuminance value of 177 lux-median home optima illuminance value was 1675 lux-over 90% of all subjects showed some improvement in reading acuity or distance VA with increased lighting.	highlighted how poor the illuminance was in the home environment

Table 1.00 contd

Overview of research on the effects of illuminance in low vision

Investigators	Ocular condition	Outcome measure	Results	Comments
Hartmann (1980)	various	distance VA	disease specific dependence in the range 380-1000 lux	normal younger subjects had a high lighting demand
Brown and Garner (1983)				
Brown and Lovie-Kitchin (1983)				
Julian (1984)	no details	distance letter VA and near word reading acuity	reading acuity improved from N24 at 50 lux to N15 at 600 lux	variable reading distance
Bullack (1984)	various	no details	luminance levels up to 4000 produced an increase in magnifier VA	
LaGrow (1986)	various	near letter VA	range of optimal levels 700-15070, median 1099 lux and study group read better with optimal luminance	no statistical analysis
Collins (1987)	various	near word reading acuity	equal subjective preference for compact fluorescent and daylight incandescent bulb, no objective differences	poorly designed study

Table 1.00 contd

Overview of research on the effects of illuminance in low vision

Soldatova (1990)	macular dystrophy	VA, visual field, colour perception and photo-stress	natrium lamp (yellow light) produced best visual performance, mercury arc and fluorescent lamp reduced performance in low vision	no statistical details
Cornelissen *et al.* (1991)	various	near letter VA	20% percent had best near VA 2000 lux-30% at the 500 lux-for the remaining 50% near VA did not change under the different levels of illuminance	near VA alone not sufficient measure of illuminance dependence of visual performance-'more investigation of relation between illuminance, VA, visual performance and preferences necessary'
Eldred (1992)	ARMD	near letter and word reading VA	for most subjects highest CWPM occurred at 5918 or 7532 lux-no significant difference in the mean CWPM for different levels of illuminance	individual observer response discussed
Cornelissen *et al.* (1995)	various	object recognition	high illuminance helped improve object recognition for some subjects	integrated contrast sensitivity (area beneath CSF) useful performance predictor

Table 1.01

Overview of research on the effects of colour in low vision

Investigators	Ocular condition	Outcome measures	Results	Comments
Legge and Rubin (1986)	cataract, ARMD and other retinal lesions	reading rate	reading rates for green and grey greater than red and blue	used TV monitor to present reading task
Legge *et al.* (1990)	various	reading rate	better response with luminance contrast than chromatic contrast but subjects may benefit from both	used TV monitor to present reading task
Jacobs (1990)	various	video-magnifier screen colour and reading text	no screen colour effect on reading speed	low vision clinic only needs one video-magnifier screen colour
Wurm *et al.* (1993)	various	object recognition	chromatic contrast may help in object recognition	useful for rehabilitation in activities of daily living
Jacobs *et al.* (1997)	various	video-magnifier coloured text related to CS and reading performance	for stationary text yellow text gave best reading performance followed by green	spectral sensitivity of low vision observers reduced in short and long wavelengths

TINTED LENSES AND LOW VISION: A REVIEW

Introduction

Tinted lenses are currently used by optometrists and opticians to assist in maximising the use of residual vision, improve visual function, control glare and improve orientation and mobility skills, for people with low vision. Tinted lenses are frequently used in RP, ARMD, cataract, cone dystrophy and oculo-cutaneous albinism. This review will concentrate on studies investigating the use of tinted lenses in rehabilitation of people with visual dysfunction, and highlight areas where more research would be useful. Proposed effects on progressive eye disease (especially RP) is very controversial and will not be discussed in detail.

Commercially available filters

Corning filters

The optical division of Corning Glass has developed the Corning Photochromic Filter (CPF) range, which is considered by some practitioners to be the gold standard for use in low vision rehabilitation. These filters have been designed, and are marketed specifically, to improve the comfort and visual performance of visually impaired people who suffer from a range of ocular disorders, and evolved from research in the late 1970s investigating the possible detrimental effects of visible light on the ocular system.

According to Corning marketing literature, short wavelength light 'has been shown to cause visual discomfort, hazy vision, reduced contrast and prolonged adaptation times'. It is implied that the filters can alleviate some or all of these effects by filtering out blue light in the visible portion of the spectrum, at the wavelengths which create problems for the photophobic or ageing eye. They are designed to filter short wavelength light of solar and artificial origin.

A base borosilicate, photochromic glass, similar to Photogray Extra™, is used in the manufacturing process. This goes through a firing treatment that changes the chemical

structure of the silver halide crystals at the surface of the lens. The tint produced by this 'chemtempering technique' is independent of thickness and is even across the lens surface. A prescription can been ground on to the surface and the lens glazed into a spectacle frame.

There are four CPF standard (S) filters, each with a different wavelength cut-off level; CPF450, CPF511, CPF527, CPF550, and also CPF550XD (extra dark). The number corresponds to the wavelength in nanometers, above which light is transmitted. CPF 'design' filters (marketed as CPF527DN) have similar characteristics to the standard filter but have a multi-layer, reflective, mirror-effect coating for 'cosmetic enhancement and extra effect in strong sunlight conditions'. These are designed for outdoor activities and the manufacturers claim that they filter a minimum of 98% blue light, 98% UVA and 100% UVB. Table 1.02 for CPF transmission details.

CPF450 has the lightest tint (pale yellow) and the CPF550 the deepest tint (red) in the range. CPF450 is recommended by Corning for indoor use, for tasks such as reading, watching TV, VDU and office work, for 'hobbyists' and as a shopping aid. Corning maintain that the CPF511 and CPF527 have been found to be of benefit by many people who experience visual problems associated with developing cataract or macular degeneration (table 1.03 for CPF usage guidelines and table 1.04 for suggested applications).

Table 1.02 transmission details for the CPF range (from Corning marketing material)

	CPF450S	CPF511S	CPF511DN	CPF527S	CPF527DN	CPF550S
wavelength cut-off (nm)	450	511	511	527	527	550
% light transmission (lightened)	73	47	34	34	26	20
% light transmission (darkened)	18	12	10	9	8	5
UV absorption						
min. UVB	100	100	100	100	100	100
min. UVA	97	99	99	98	99	99

At the time of writing no data was available for the CPF550XD. It is not clear from Corning marketing literature if these figures have been corrected to take into account the luminosity curve of the eye.

Table 1.03 glare control lens usage guidelines (percentage of people choosing)

Diagnosis	CPF511	CPF527	CPF550
Macular degeneration	49	41	10
Cataracts	59	37	4
Retinitis pigmentosa	24	36	40
Diabetic retinopathy	26	62	12
Glaucoma	55	33	12
Aphakia and pseudo-phakia	52	32	16
Photophobia	36	44	20
Myopia	48	45	7
Retinal degeneration	21	79	
Rod/cone dystrophy	92	21	37
Detached retina	22	66	12

Data for table 1.03 is from Corning marketing material (some people chose more than one filter and therefore not all rows add up to 100%). No details of CPF450 were available at the time of writing. Note the large difference between CPF511 and 527 for the rod/cone dystrophy group.

Table 1.04 suggested applications for CPF filters (from Corning marketing literature)

Diagnosis	First choice	Second choice
Progressive cataract	CPF511	CPF527
Intra-ocular implants	CPF511	CPF527
Aphakia	CPF511	CPF527
Glare sensitivity	CPF511	CPF527
Photophobia	CPF527	CPF511
Macular degeneration	CPF527	CPF511
Diabetic retinopathy	CPF527	CPF511
Glaucoma	CPF511	CPF527
RP	CPF550	CPF527
Corneal dystrophy	CPF527	CPF511
Optic atrophy	CPF511	CPF527
Albinism	CPF527	CPF550
Aniridia	CPF550	CPF527

No details of CPF450 were available at the time of writing.

CPFs are available in a spectacle frame, with or without side-shields and in a variety of forms and materials:

- Single vision 1.5 index glass (+6.00 to -8.00DS and up to 4.00DC).
- Single vision 1.7 and 1.8 index laminated glass (+6.00 to -23.00DS up to 4.00DC).
- C28 bifocal (+6.00 to -8.00DS and up to 4.00DC with 0.75 to 4.00 add)
- Laminated progressive (+6.00 to -8.00DS and up to 4.00DC with 0.75 to 3.50 add).
- Plano fixed-tint, plastic clip-ons.

Corning advise that prospective users are given enough time to test the filters and recommend the use of a plano, fixed-tint, plastic clip-on to allow the user experience with all the filters, both in and out doors over a trial period.

There are several CPF facsimiles produced and marketed in Europe which are claimed to perform in a similar way to CPFs, but none have as yet been scientifically appraised.

UVShield and NoIR filters

NoIR Medical Technologies (6155, Pontiac Trial, PO Box 159, South Lyon, MI 48178, USA) market two types of filter for use by people with low vision; the UVShield and the NoIR filter. According to marketing literature produced by the manufacturer, the UVShield provides protection for 100% UV and visible light and the NoIR filter eliminates near infra-red, 100% UV and 'provides visible light protection, for maximum eye comfort'. There are 22 UVShields and 12 NoIR filters produced for use in the low vision field. Table 1.05 for details.

Constructed from polycarbonate, they retain their original shape and will not stretch or deform with use. Supplied in large fit-over moulded form, with wide temples which double as side-shields, made from the same material and having the same colour as the front. A wide field of view is allowed. The design helps to shield the eyes from light incident from above and also that reflected from below. During the manufacturing process an ultraviolet and infrared absorbing chemical is blended with polycarbonate before it is moulded into the final product. A hard-coated version is available.

Table 1.05 suggested applications for UVShield and NoIR filters (marketing literature)

Ocular problem	UVShield (%transmission)	NoIR (%transmission)
Albinism	4% dark grey #23 4% dark plum #80 4% dark grey-green #33	1% dark grey-green #08 2% dark amber #07 4% dark green #39
Dermatology	13% dark grey #22 32% medium grey #21 90% clear #10	10% amber #01 40% light amber #11

Table 1.05 contd suggested applications for UVShield and NoIR filters (from NoIR marketing literature)

Ocular problem	UVShield (%transmission)	NoIR (%transmission)
Post-operative cataract	7% grey-green #30 10% grey-green #32 13% dark grey #22 16% medium amber #40 20% medium plum #81 40% light plum #88 50% light grey-green #38 53% light amber #48	10% amber #01 40% medium green #31 40% light amber #11
ARMD	4% dark orange #63 4% dark plum #80 16% medium amber #40 40% light plum #88 49% orange #60 52% light orange #68 54% yellow #50 58% light grey #20 65% light yellow #58	4% dark orange #69 10% amber #01 40% light amber #11 40% medium green #31
Achromatopsia	4% dark plum #80 4% dark red #93 20% medium plum #81 45% red #90 59% light red #98	4% dark red #99 14% medium red #95 40% light red #91

Table 1.05 contd suggested applications for UVShield and NoIR filters (marketing literature)

Ocular problem	UVShield (%transmission)	NoIR (%transmission)
Pre-cataract	10% grey-green #32 13% dark grey #22 32% medium grey #21 49% orange #60 54% yellow #50	10% amber #01 18% grey-green #02 40% light amber #11
RP	49% orange #60 52% light orange #68 54% yellow #50 65% light yellow #58	2% dark amber #07 10% amber #01 40% light yellow #51 40% light amber #11
Diabetic retinopathy	4% dark plum #80 10% grey-green #32 13% dark grey #22	10% amber #01 18% grey-green #02
Glaucoma	7% grey-green #30 10% grey-green #32 13% dark grey #22	18% grey-green #02
Night blindness	54% yellow #50 65% light yellow #58	40% light yellow #51

A literature search produced several papers that investigated the use of tinted lenses as a method of improving visual performance in low vision. Studies can be divided according to the predominant type of ocular condition(s) investigated, i.e. RP, cataract, ARMD, cone dystrophy, and mixed ocular disease. The following is a critical review of these studies.

Retinitis pigmentosa

Frith (1980) described his ideal filter for RP as having low transmission characteristics so

that both cones and rods are protected, ideally rods to a greater extent than cones. He suggested that this could be achieved by selecting a material of transmittance such that only a small proportion of the light entering the eye would be of the type absorbed by rhodopsin. He recommended that such a filter should have low luminous transmittance, but with no transmittance below 540 nm, in order to protect the rod pigment. Long wavelengths not capable of bleaching rhodopsin could be fully transmitted, and if there was also a transmission band of approximately 100 nm in the green-yellow region, the array of colours perceivable would probably be enlarged when compared to visual performance without such a filter.

In the same study, Frith went on to describe his experiences in prescribing a NoIR 7% transmission, amber filter to 13 RP subjects, with fairly advanced field loss (no other subject details provided). Nine subjects reported relief from photophobia, described as dramatic in some cases. Most reported a subjective increase in VA, and three demonstrated an objective improvement in VA. Five subjects reported subjective increases in peripheral vision, and in mobility. Frith concluded that although these results were preliminary, all RP patients should be offered the opportunity to try low transmission filters.

The study failed to provide adequate subject details, there is no mention of any attempt to control for the placebo effect, subjects were not given an alternative filter to choose from, learning and fatigue effects, or investigator bias, and no quantitative results or data analyses are presented.

Lynch and Brilliant (1984) compared the effects of CPF550 and a 20% transmission ND filter on the visual performance of 16 RP subjects (age range 23 to 74 years). Filters were assigned a letter and only at the end of the testing period were the subjects told which one was the CPF550. It is not clear whether the filters were matched for overall effect on luminance. VA was determined using a Feinbloom low vision chart, using the following scoring system. Each line was assigned the value of one, and dividing one by the number of characters on the line

determined the value given to each individual character in question. Compared to the ND filter, the CPF550 improved VA in 24 eyes, one decreased, and in seven it remained unchanged. Eight eyes that had improved VA with the ND filter had greater improvement with the CPF550. Mean improvement with the CPF550 was +0.743 (no units) and the ND filter +0.009; the relative improvement for the CPF was +0.736. This was significant at the 0.01 confidence level using the correlated t-test formula.

Colour vision was assessed using the CPF, ND filter, and without any filter. The City University colour vision test (TCU) with standard illumination C and a colour-naming test involving the presentation of coloured blocks were used. Colour normal subjects were able to pass TCU with the CPF550 and ND filter. Colour deficient subjects missed even more plates with the CPF550 (the mean was two). The missed plates continued in the same direction as the original colour defect, i.e. CPF550 did not introduce a new defect but made an existing one worse. The ND filter did not change the number of missed plates for the colour deficient subjects. CPF550 had more of an effect on the colour naming test with an average 50% of blocks being misnamed, compared to zero without. Those same subjects missed an average of less than one block with the ND filter.

Sinusoidal spatial frequency gratings of 0.5, 1.0, 2.0, 3.0, 4.0, 8.0 and 16 cpd, generated on a black and white TV, were employed to measure CS. The CPF and ND filter presentation was alternated with each successive subject. CS was unchanged with both filters, when compared to the no filter presentation. The investigators commented however, that there were some subjects (number not specified) who were able to see a higher frequency with the CPF550 than either without, or with the ND filter, even at the 99% contrast level.

To investigate adaptation time, the smallest line that each subject could read on a standard VA chart at 10 ft was noted. The subject was then taken into daylight for five minutes and returned to the clinic, where the time taken to read the same line on the chart was measured. It was

noted that this was a functional rather than laboratory based approach, and there was no control over outdoor illumination. CPF550 was compared to a NoIR sun-wear filter (no other filter details provided) with an alternate mode of presentation.

Adaptation time improved with the CPF550 and NoIR filter, compared to the no filter assessment, but this was expected since both filters reduce retinal illumination. There was no significant statistical difference between the performance of the two filters. Subjects were then informed which was the CPF550 and given time to perform any task with any of the filters so far used. Seven questions were asked on which they had to grade their responses on a scale of one to five, with one being very negative, five being very positive, and three being neutral.

It was concluded that the average 25% improvement in VA provided by the CPF550 would be of help for RP subjects with borderline VA for some tasks. Although there was no clinical improvement in CS, many subjects felt that the CPF550 did reduce glare sensitivity. Subjects reported that the photochromic nature of the CPF550 was an advantage when compared to the fixed, surface tinted, polycarbonate NoIR filter, although the brow and side shields, and the lower cost of the latter were also considered beneficial.

It was recommended that practitioners warn prospective users of the problems that the CPF550 could cause with colour recognition, especially greens and blues, and in particular green traffic lights, which may appear black when viewed with the filter.

The following factors may have caused the placebo effect to influence the outcomes of this study:

- The obvious difference between the presentation with filters and without filters.
- The marked difference in colour between the CPF550 (red) and the ND filter (grey).
- The CPF550 was a photochromic filter, while the filters ND and NoIR filters were a fixed tint.

- The cosmetic appearance of the CPF550 mounted in a conventional spectacle frame and the less conventional fit-over style of the NoIR filter.
- Subjects may have had prior knowledge of the use of red lenses in RP, which could have influenced their objective performance (placebo effect) and subjective comments.

To help eliminate any learning effect the order of presentation of the filter was alternated with each successive subject, however as VA was always measured without any filter first, followed by presentation of one of the filters, a learning effect could have occurred. No details are provided of attempts to control investigator bias. However, the study did attempt to relate objective measurements to subjective preferences.

Morrissette *et al.* (1984) presented results from a retrospective, subjective questionnaire based survey of 36 RP subjects with experience of using CPF550. The study aimed at verifying the manufacturer's claims on satisfaction rate, perceived benefits, repurchase intent, and to seek additional data including frequency of use, cosmetic acceptability, usefulness in different weather conditions, and drawbacks.

All subjects were asked to trial a CPF550 for three days and were then divided into two groups; those that had continued to use the filter for at least 30 days after the trial (26), and those that had rejected the lenses after the trial (10). They were questioned about the effect of CPF550 on adaptation time, ocular comfort, visual functioning, satisfaction with tint strength in various lighting conditions, cosmetic appearance, effects of weather, and replacement intent. Most users (no details) rated the CPF550 as the best filter ever tried.
The results from the 10 non-users were divided. Subjects did not respond unanimously, either positively or negatively, to any question. It was concluded that the overall findings supported the manufacturer's recommendation for a trial use of the CPF550 for several days to allow effective user evaluation.

It is not clear whether the investigators themselves or an independent group collated the data. If carried out by the investigators, subject responses may have been influenced by concern of jeopardising future rehabilitation or treatment at the centre involved in the study. With this in mind, volunteered information may not have been as critical as it could have been.

Silver and Lyness (1985) attempted to ascertain whether RP patients who experienced light related problems preferred to wear red photochromic lenses rather than other lenses with broadly similar fixed tints, using a single-masked, randomised, controlled trial. They proposed that a marked subjective preference might be present if the manufacturer's (no details provided) claims for the red photochromic lens were valid.

Twenty-seven subjects from an RP self-help group were used. Subjective reactions to a choice between the red photochromic filter mounted in a frame with dark side cups, and a wrap-around industrial eye-protector, specially dyed brown to give a similar overall transmittance to the lightened tint of the red filter were compared.

Refractive status was confirmed, best distance VA obtained and the visual field assessed. A single cross over method was used for the filter assessment. Each patient was supplied with a filter of each type, identified with a coded label. Initial preference was recorded at the dispensing stage. Subjects were asked to wear one filter for two weeks for as much as possible and then the second filter for a further two weeks; the order of wear was randomised.

At one-month follow-up, VA was assessed with and without filters. Subjective responses to both filters were again recorded. Twenty-five preferred to use a filter. Twelve subjects preferred the red photochromic filter and 12 the brown and one preferred his own sun spectacle. Interestingly, final choice did not always coincide with the initially expressed preference.

For the group which preferred the red photochromic filter there was no objective VA improvement, although there was often a reported subjective improvement. Several subjects reported an improvement in discrimination in low contrast situations and better TV viewing. Most of the group claimed that adaptation time was reduced. Many found difficulty identifying colours with the filter, but this problem either reduced with time or was deemed unimportant when compared to the perceived advantages. The cosmetic appearance of the filters caused some concern.

Subjects preferring the brown filter liked the panoramic view inherent in the design, the normal style, and claimed a negligible change in colour discrimination. There is no mention of any effect of this filter on VA in the study. The investigators accepted that there might be aesthetic or psychological reasons for the choices made.

The findings were criticised by the manufacturer of the red photochromic filter since the two filters were presented dissimilarly. A second study was therefore conducted and the photochromic filter was matched with a surface tinted, plastic filter that had a similar appearance to the red photochromic filter; both were fitted into the same type of conventional spectacle frame, which was coded.

Different subjects were used from the first study but all had RP; clinical examination was not conducted in view of the lack of correlation in the first study. Subjective preferences were obtained from a questionnaire completed by each subject. Fifty-three subjects compared the filters; 14 disliked both, 12 preferred the red photochromic filter, 25 the surface tinted plastic and two were happy with either.

It was concluded that even though there was no clinically measured improvement in VA, overall the subjects preferred some sort of filter. There was no evidence that the red photochromic filter had any subjective advantages over filters with fixed red or brown tints,

and a trial period for those people who might be expected to benefit from a photochromic prescription lens was advised (prior to provision) since initial preferences were not reliable.

The investigators did attempt to control for placebo effect by randomising the group and conducting a single masked study, i.e. subjects did not know which was the study filter. However, as subjects were obtained from a RP self-help group, they may have had some prior knowledge of the proposed visual benefit from red filters and this may have influenced their performance.

The filters were dissimilar in form (photochromic glass and fixed, surface tinted plastic) as well as in colour. It is not clear whether the examiners, when measuring VA in stage one, were masked as to which was the study filter, or whether it was only the subjects who were masked. Subjective reports of VA improvement may not have been verified clinically because of the use of insensitive VA charts, details of which are not provided. Also, it would be useful to know how many subjects preferred filters used in the two weeks immediately prior to follow-up.

Van den Berg (1990) used 18 RP subjects who had experience with red filters (no details provided). He assessed Landolt C acuity, CS (sinusoidal spatial frequency gratings on a CRT and with VisTech charts), colour vision (D-15), visual field (Humphrey Visual Field Analyser), dark adaptation and glare sensitivity (entoptic stray-light measurement system).

Tests were performed monocularly, with and without a preferred red filter. Not all tests were performed on all subjects, since van den Berg concentrated on tests that became promising as he proceeded. Learning and fatigue effects were controlled by assessing VA without a filter, with a filter, and again without. For some subjects a 50% transmission ND filter was used to determine whether any effects of the red filters were due to a decrease in retinal illumination.

Red filters caused a -0.002 log unit decrease (an improvement) in the mean difference in VA for the RP group. CS determined with the CRT at 1.25, 2.5, 5, 10, and 20 cpd, and 1.5, 3, 6, 12 and 18 cpd with the Vistech chart (not specified if distance or near version used), produced a mean decrease of -0.025 log units with the red filters (an improvement).

Colour vision testing was performed with and without a red filter. Three normals and one RP subject made no mistakes with the filters, three subjects made no errors without a filter, but made two, six and seven errors respectively along the tritanopic confusion line with a filter. Two other RP subjects showed very erratic behaviour overall and six made errors without a filter, but more errors with a filter, along the tritanopic confusion line.

The program used to assess visual field depended on the state of progression of the disease; 30-2 (30 degree grid), 10-2 (10 degree grid) or 'macula' (3 degree grid), all with a 116 minutes of arc target. To control for fatigue and learning effects the test with a filter was interposed between two tests without a filter. For the normal controls the sensitivity decreased due to the overall decrease in intensity caused by the filter. Those subjects with relatively preserved visual fields lost some sensitivity. Some subjects with very restricted fields had a very slight improvement when using a filter.

Effects of intra-ocular light scatter were assessed using an annular flickering (8 Hz) light source presented at four different distances, ranging from 3.75 to 30 degrees, from the subject. This arrangement produced an observable flicker, due to scattered light, in the central area. Each subject was asked to minimise or abolish the flicker perception, by adjusting a counterphase flickering light. A red filter did not decrease the light scatter when compared to white light or green filters for one RP subject with cataract. For other RP subjects and for subjects with just cataract, the light scatter was not different for these three colours and it was concluded that the use of red filters to decrease intra-ocular light scatter is not indicated.

A dark adaptation test was conducted on seven subjects with a Tübinger perimeter using only the CPF527, which did not darken during pre-adaptation. Four conditions were tested with and without filters:

- Central vision with continuous filtering.
- Extrafoveal vision with filtering during pre-adaptation-only in cases with complete loss of rod function.
- Extrafoveal vision with continuous filtering in the presence of 10 cdm^{-2} background illumination in cases with some rod function.
- Extrafoveal vision with filtering during pre-adaptation-only in cases with some rod function.

For conditions one, two and three, there was no difference between the conditions with and without a red filter. However, under condition four the filter accelerated the dark adaptation rate. Van den Berg postulated that the mechanism for this probably involves the reduction of rod light adaptation when in a bright environment, since rods are insensitive to red light. When the filter was removed in the dark, the rods adapted quicker since they were less light adapted in the first place.

It was concluded that when treated as a group the subjects did not perform differently with the filter for any of 11 tests when compared to a normal control group. However, van den Berg was reluctant to discount the use of red filters for RP subjects, because some subjects did show an improvement in CS, even if the effects were limited. It may have been that some of the measurement techniques were too insensitive to detect subtle quantitative changes in visual performance. A positive effect however small could be of value in RP.

Although there is a lack of statistical support, the study demonstrates that even when no group effects are apparent, there may be some individual effects within the group, i.e. ocular disease may not result in homogeneous effects for all sufferers.

Cataract

Bailey *et al.* (1978) assessed reading acuity and reading speed with various filters using Bailey-Lovie near word reading cards for nine subjects with cataract, and nine normal subjects who had cataract simulated by frosted glass. Bailey-Lovie word cards were made up as transparencies and viewed against an opal Plexiglas screen transilluminated with incandescent lamps. The white parts of the chart had a luminance of 350 cdm^{-2}. Twenty different charts with the same features but containing different words were used to prevent learning effects. Six different yellow filters were used:

- Roscolene theatrical lighting filter sheets (#805 and #806) placed as overlays on the transilluminated charts.
- A yellow trial case lens of unidentified origin.
- Kodak Wratten filter #21 placed in Halberg clips mounted over spectacle lenses.
- NoIR fit-over (no model details provided).
- Amber slip-in filters (no other details provided).

Trials were also conducted with three ND filters (75%, 50% and 12.5% transmission). All subjects read aloud monocularly with each filter in turn and the time taken to complete each line of six words at each size level was noted. No details of order of filter use are given.

Cataract subjects in general demonstrated a small reduction in reading acuity with all filters, which was not statistically significant at the 95% confidence level (apart from the NoIR filter). The simulated cataract group showed a statistically significant decrease in reading acuity for all but the Roscolene #805 filter at the 95% confidence level, again the greatest decrease occurred with the NoIR filter. ND filters all produced a reduction in reading acuity for both groups. By comparing reductions produced with the ND filters to those found with the yellow filters both averaged and individual data showed that the yellow filters marginally reduced reading acuity due to the reduced illuminance produced on the reading card rather than because of their colour.

Speed of reading was slowest with the NoIR filter and the amber slip-in for the cataract group; the NoIR filter produced fastest reading for the simulated cataract group. The investigators felt that this was because the subjects had to hold these appliances during testing and that this may have led to impatience with the younger, simulated cataract group, which resulted in faster reading.

This study provides strong evidence that yellow filters are of no visual benefit in reading with cataract. Several test filters were used, and therefore investigator bias is less likely, full experimental details are provided, there was a normal control group, and the data for groups and individuals was statistically analysed. Conclusions have been drawn without reliance on subjective reports and are therefore more likely to be accurate.

Tupper *et al.* (1985) assessed the effects of CPF550 on VA, for 39 cataractous eyes, as measured with pastel, pink-orange E optotypes, in random orientation, on a sky-blue background, when viewed at 2 ft. A glare source was produced by mounting the test chart on a single-panel view box, which when activated produced a background glare with luminance 15 cdm^{-2}. In effect CPF550 made the target background darker relative to the letters, thereby increasing contrast.

With the glare source activated VA was determined first without a filter, with CPF550 alone, with CPF550 and an overlying sheet of translucent dark red acetate with a central 6.5 mm clear hole, and finally with the aid of the red acetate alone. Tests were repeated without the glare source. Percentage change in VA for each subject was calculated by comparing the VA without a filter, to the VA with each of the different filters, for all conditions.

In the non-glare situation those subjects with cortical spokes, or nuclear sclerosis, or a combination of both, averaged a 15% increase in VA with CPF550, which increased to 40% when the dark red acetate filter with a 6.5 mm viewing aperture was added. When the glare

source was activated, those with cortical, nuclear, combined and posterior sub-capsular changes demonstrated a 70% improvement with the CPF550 alone, and 95% when used with the red overlay. Subjects with initial VA of 6/24+ to 6/60 showed most improvement with CPF550 in the glare situation.

As well as increasing letter contrast, the investigators postulated that as the CPF550 transmitted only 21% of incident light, the retina received less light, causing the pupil to dilate, enabling subjects with central opacities to view around the obstruction. The red acetate probably worked by filtering peripheral extraneous light. Some of the results may be accounted for by a learning effect, since the presentation was always in the order, no filter, CPF550 alone, CPF550 with red acetate.

Cataract and ARMD

Zigman (1990) studied the influence of a 2 mm thick, polycarbonate filter that totally absorbed wavelengths shorter than 480 mm (Seemore filter) on the CS of elderly and visually impaired subjects. The cut-off for the filter is very sharp, between 450 and 480 nm, with nearly total transmission above 500 nm.

Letters of diminishing size and contrast, displayed on a TV monitor, were used to determine VA. The Vistech Contrast Test System (no details of whether distance or near version) was used to measure CS. Five low vision subjects, two with ARMD and cataract (ages 62 and 83 years), two with ARMD only (ages 55 and 62 years) and one with multiple sclerosis (age 41 years) were used.

VA improved for all subjects with the filter compared to the no filter measurement. Four age related normal subjects (seven healthy eyes and one with glaucoma, age range 70 to 74 years) also demonstrated one line improvement in VA with the filter, using the same presentation technique. In low contrast regions VA improved by several lines. When using the Vistech

Contrast Test System on 21 subjects with cataract (average age 74 years) and eight subjects with ARMD (average age 76 years), contrast thresholds were lowered in the high frequency regions with filter use. This enhancement of contrast threshold was statistically significant (ANOVA, $p=0.05$).

In a second study, Zigman (1992) determined the effect of the Seemore filter on VisTech CS for 14 normal eyes (average age 63.5 years), 15 cataractous eyes (average age 76.5 years), nine aphakic eyes (average age 75.8 years) and 10 eyes with ARMD (average age 75.0 years). For the normal eyes the filter improved CS significantly (ANOVA, $p= 0.03$) in the 3 to 12 cpd region, but no significant differences were found at lower or higher frequencies. In cataractous eyes the filter improved CS most significantly in the high frequency range. In aphakic eyes CS improved similarly to the normal eyes, but at all frequencies. This was statistically significant (ANOVA, $p<0.025$). For ARMD subjects, contrast was improved mainly in the lower frequency area; at higher frequencies less significant changes were observed. Zigman concluded that a sharp cut-off filter that does not transmit wavelengths shorter than 450 nm should enhance visual function.

Throughout the study no details are given as to the order of presentation of the filter and no filter situation, and there is no attempt to control for the placebo effect, investigator bias, learning or fatigue effects. These factors may have influenced the results.

Cone dystrophy

The efficacy of CPF527 for five children with cone dystrophy, aged five to 13 years, was investigated by Bremer *et al.* (1987). Visual acuity ranged from 6/24+ to 6/60 and did not improve with one month of filter use. One subject increased reading acuity from J3 to J2 (working distance not specified). Three subjects had improved central field sensitivity, but peripheral fields remained unchanged. Three subjects and their parents felt there was a significant general improvement in visual and visual-motor function. Two subjects and their

parents felt that there was little benefit over preferred conventional sunglasses.

The major advantage was less glare outdoors and the major disadvantage was that the orange tint caused peer teasing. The tint also interfered with learned colour responses for those with residual colour vision, although this was not considered to be a problem by the subjects. Parents were concerned at the significant increase in cost of CPF527 compared to a ND filter.

Interestingly, electro-physiological testing demonstrated that CPF527 was effective in eliminating rod saturation. Light reaching the retina was decreased by 50% with the filter, which prevented rod saturation and resulted in more rod contribution to the flash visual evoked response (VER), the amplitude of which increased by 100%. An increase in latency from 36 msec to 51 msec and a six-fold increase in amplitude of the light-adapted electro-retinagram (ERG) B-wave were taken to indicate that CPF527 allowed the rods to function in environmentally photopic conditions. The electro-diagnostic results supported the subjective improvement in visual performance and reduction in photophobia reported by the subjects.

Multiple ocular disease studies

Hoeft and Hughes (1981) studied 100 consecutive photosensitive low vision subjects (age range 18 to 80 years) with 21 different ocular conditions, who complained of light sensitivity. Three-quarters of the subjects had VA between 6/15 and 6/72. Subjects were divided into three groups; pre-retinal disease, retinal disease and others. Five NoIR filters were tried and the 'most satisfactory' was chosen by each subject:

- Amber #101 (10% transmission).
- Grey-green #102 (18% transmission).
- Dark amber #107 (2% transmission).
- Dark green #108 (1% transmission).
- Dark green #109 (2% transmission).

Preferences in the order amber, grey-green, dark amber and dark green, and several trends, were noted. Diabetic and glaucoma subjects preferred grey-green (18% transmission) and amber (10% transmission). Subjects with albinism preferred amber filters (10% and 2% transmission). More than 50% of the subjects with RP selected the dark-amber filter (2% transmission). Subjects with retinal detachment, optic atrophy, cataract, and ARMD showed no great filter preference. Subjects with other retinal pathologies selected filters in the following order; amber (10%), grey-green (18%), dark amber (2%) and grey-green (1%).

It was concluded that light sensitive subjects, with some types of ocular pathology, prefer to use a particular filter to diminish their sensitivity to light. The results are weakened by the lack of objective data and statistical analysis.

Barron and Waiss (1987) determined VA for 53 low vision and 50 normal subjects, using CPF527, a 40% transmission ND filter (transmission approximately the same as the lightened CPF) and a clear plano lens. To prevent learning effects, three different versions of the Lighthouse Low Vision Distance Acuity Chart with randomly arranged letters, were used. The low vision group consisted of eight subjects with cataracts, 16 with maculopathy (no information given on type), nine RP, four with oculo-cutaneous albinism, four with optic atrophy, and two with proliferative diabetic retinopathy. Age ranged from 10 to 85 years and VA from 6/10 to 6/120. Normals were age and sex matched, had no evidence of ocular pathology, and VA levels of at least 6/6.

Visual acuity was measured for a random order of presentation of CPF527, the ND filter, and the plano lens. A correlated t-test indicated that there was no significant difference in the average VA obtained with CPF527, and the clear plano lens (ANOVA, $p=0.01$). A similar test showed that the average VA with the ND filter was significantly less than with CPF527 for both groups (ANOVA, $p<0.01$). The results of a Pearson correlation test (CPF versus VA, $r=0.99$) demonstrated that CPF527 had no selective effect on VA for any particular ocular

pathology.

It was concluded that subjects impression of better vision with CPF527 as found by the earlier Lynch and Brilliant (1984) study, may not be equivalent to the conventional definition of VA as measured with a high contrast and high spatial frequency optotype chart.

Maino and McMahon (1986) conducted a retrospective study of 318 low vision subjects who complained of glare, photophobia or light sensitivity. There were 24 different ocular conditions and VA ranged from 6/9 to 6/150. Five NoIR filters were tested:

- Amber #101 (10% transmission).
- Light grey-green #102 (18% transmission).
- Dark amber #107 (2% transmission).
- Dark grey-green #108 (2% transmission).
- Dark green #109 (2% transmission).

If weather allowed, subjects were assessed outside, otherwise testing was conducted indoors with simulated glare conditions. Each subject used a filter of choice for a period of a few hours to three days before the final NoIR was prescribed. Filters were preferred in the following descending order; dark amber (2% transmission), light grey-green (18% transmission), amber (2% transmission), dark green (2% transmission), and dark grey-green (2% transmission). Fifty percent selected amber (10%), and 33% light grey-green (18%) filters. Those with ARMD, RP, and chronic open angle glaucoma tended to prefer the amber filters. Very few selected the darker grey-green and green filters.

This study relies on subjective preferences with no statistical analysis of the data. Experimental information is brief, especially with respect to the outdoor and indoor lighting conditions and no comments are made as to why subjects preferred certain filters and rejected others. In view of these flaws no firm conclusions can be drawn from this investigation.

Leat *et al.* (1990) assessed the effects of filters on CS for 44 subjects (age range 18 to 53 years) with low vision due to a variety of ocular conditions (cataract, aphakia, ARMD, RP, aniridia, glaucoma, diabetic retinopathy, corneal dystrophy, optic atrophy, and albinism). Square-wave gratings with spatial frequency 2 and 12 cpd, and contrast 90, 77, 55, 33 and 11% were presented randomly in one of four directions; vertical, horizontal, oblique to the right and left. Subjects were required to identify the orientation of the gratings. Initial presentation distances were based on best-corrected VA, and then increased in 0.5 m steps until three out of five presentations were correct.

Grating acuity was determined without a filter and then with four ND filters (31.6%, 10%, 5% and 1% transmission) mounted in goggles, and beginning with the darkest. Grating acuity was again measured without any filter and then consecutively with CPF550, CPF527 and CPF511. These filters were mounted either in frames or as clip-ons for those with existing spectacles. Five minutes were allowed for dark adaptation to the darkest filter and no light adaptation was permitted while changing filter.

A third series of measurements of VA and grating acuity (at 55% or 33% contrast) were taken with and without a glare source (60 W tungsten bulb at 1 m). Under glare conditions grating acuity was measured with a 50% transmission ND filter, CPF550, CPF527, and CPF511 in succession. Five minutes were allowed to adapt to the ND filter. A significant improvement in grating acuity was defined as an increase of 0.1 log MAR unit at one contrast level (equivalent to one line on a Bailey-Lovie chart), or an increase of 0.05 log MAR units at two or more contrast levels.

Of the 44 subjects that were assessed under non-glare conditions, 48% showed no improvement with either CPFs or ND filters, 20% improved with both types of filter, 27% improved with CPFs but not with the ND filters. Only 4.5% showed an improvement with the ND filter alone. Subjects with diabetes, maculopathy, and nystagmus did not improve with

filters. Those with RP were also represented in the group gaining no improvement. Anterior eye conditions such as coloboma, aniridia, iritis, albinism, and corneal opacification, were more numerous in the group gaining improvement with CPFs, as were those with some pre-retinal disease in conjunction with another condition. Some subjects with macular disease increased their performance with ND filters. CPF511 and CPF527 were almost equally effective, although the CPF511 was the optimum filter on a greater number of occasions. The 31.6% transmission and 10% transmission ND filters were the most commonly effective.

Of the 26 subjects that took part in the assessment under glare conditions, 27% showed no improvement in VA either with or without glare, while 73% did show an improvement with filters either with or without glare. There was a higher incidence of both anterior eye conditions (37%) and conditions with some pre-retinal component (52.6%) compared to the group gaining no improvement (14% and 28% respectively).

Of those that demonstrated an improvement with filters, 58% improved in both glare and non-glare conditions (37% improved more under glare), 21% improved under glare and not in normal viewing and similarly 21% improved only in the non-glare situation. No subjects performed better with the ND filters than with the CPFs, and only one who gained with both did not gain more with the CPFs. CPF511 produced the best results of all the CPFs.

It was concluded that subjects with an anterior or pre-retinal component to the ocular condition are most likely to benefit from the use of short wavelength absorbing filters, probably because of a reduction of the abnormal scatter of these wavelengths within the eye. Those with RP, diabetes without a pre-retinal component, and maculopathies are less likely to have benefit from CPFs. However, all the RP subjects showed a reduction in performance with ND filters but no reduction with CPF511. This study demonstrates that a glare condition could isolate more people who may benefit from CPFs. The results are weakened by the lack of a statistical analysis and there may have been an idiosyncratic component to some of the results.

Cohen and Waiss (1991) compared the effectiveness of the CPF527 (12% transmission darkened) and NoIR 511 (amber, 40% transmission) filters with horizontally louvered (Venetian blind style) sunglasses. The louvered glasses are claimed to work by reducing the amount of stray light entering the eye. Light from the object of regard is unaffected but the non-essential glare light from above and below is blocked out. Twenty-eight subjects with a variety of ocular conditions were used (22 had glare complaints and six did not). No age data are provided. VA was measured indoors and outdoors with best correction and with the three different glare control devices. Four different randomised Lighthouse distance acuity charts (at 10 ft or closer) were used to prevent memorisation, with the subject facing into the afternoon sun.

For those subjects with cataracts there were no cases where the tints were more effective than the louvered glasses and for those without cataract there was only one instance where a tint (NoIR) was more effective. There was not a single case where the CPF lens was better than the alternative devices. Subjective preferences matched the device that gave the best VA. The authors suggested that the best way to determine which glare control device will be most successful is to conduct an outdoor evaluation of several different types of device.

Gawande *et al.* (1992) assessed the following filters:

- PLS530 (orange), PLS540 (brown), PLS550 (red) (Protective Lens Series by Younger Optics, 3788 South Broadway Place, Los Angeles, CA 90007, USA).
- CPF511, CPF527 and CPF550.
- NoIR dark brown #107 (2% transmission), NoIR medium green #102 (18% transmission).
- Custom dyed blue filter.
- Custom dyed ND filters, matched for photopic transmission with either the PLS530 or the PLS550.

Effects on the 'visual abilities' of 20 subjects with RP (7), Stargardt's maculopathy (5), and

ARMD (8), were investigated. Filters were compared subjectively, using a grading scale of +1 for a great improvement, +0.5 for a slight improvement, 0 as no effect and -1 as worse, under different outdoor, indoor, or night vision situations. Different subjects tried different combinations of filters, and some did not rate filters in all situations.

For outdoor, daytime conditions, the yellow and orange filters were always of some value, irrespective of disease. Those with RP found every filter better than no filter outdoors. All RP and ARMD subjects found the lighter filters to be useful indoors, even at night. In general the darker lenses were rejected for use indoors and at night. Six RP and two ARMD subjects found ND filters, except for night time, to be either just as effective or slightly better, than the PLS530 and PLS550.

Variable results were obtained when CS of seven subjects (four Stargardt's maculopathy, two RP, and one ARMD) were tested with and without filters. Generally, lighter filters such as the PLS530 and CPF527 had little effect on CS, while the darker PLS550 and PLS540 were detrimental. VA for these seven and another five RP subjects either remained unchanged or decreased with filters. Interestingly, neither CS nor VA results correlated with subjective ratings. An improvement in one or both clinical tests was not necessarily predictive of the subjective impression.

The investigators concluded that the usefulness of filters is probably related to optical density, i.e. a reduction in luminance, rather than the colour of the filter, and that subjective visual improvement with filters is not a function of either improved CS or VA. These conclusions however, are weakened by the lack of statistical analysis of the results.

Leguire and Suh (1993) assessed the effects of five filters on subjects with macular dystrophy (4), generalised retinal or choroidal dystrophy (5), and RP (3) [age range 10.0 to 42.3 years; average logMAR acuity of tested eye was 0.401 (6/18)]. All were free from any anterior

segment anomalies. Nine normal subjects acted as controls [age range 11.0 to 40.0 years; average logMAR acuity of 0.0 (6/6)]. The five test filters were:

- Sunglasses with a 95% cut-off UV filter (16.9% transmission).
- ND filter (25.6% transmission).
- NoIR #111 (35.2% transmission) (no colour details provided).
- CPF527 (43.6% transmission).
- Yellow filter (86.0% transmission).

A CSF was plotted for each subject with and without a filter, using the Vistech VCTS6500 chart at 3 m and a cool white lamp as a glare source. In the presence of the glare source the sunglasses produced a statistically significant decrease in mean log CS (paired t -2.71, $p<0.03$) while the other filters had little effect and served to slightly improve CS at higher spatial frequencies in the study group. Normal subjects however exhibited a systematic loss of CS with the same filters, and the amount of loss correlated with light transmission.

The investigators suggested that when compared to normal subjects, the study group did show a relative improvement in visual function. Moderate reduction of photopic luminance with light filters may slightly improve CS at high spatial frequencies, and maintain overall mean log CS. The benefit of light filters to subjects with retinal degeneration is most likely to be due to the reduction of photopic luminance. No information is given as to order or mode of filter presentation (clip-ons or conventional spectacle frames), there are no attempts to control for investigator bias, and there is no statistical analysis.

Nguyen and Hoeft (1994) conducted a study in an attempt to answer the following questions:

- What filter, if any, is chosen more frequently by patients?
- Is there an association between age and filter chosen? Is there an association between gender and filter chosen?
- Is there an association between disease and filter chosen?

- Is there significant improvement in VA with one or more filters?
- Is there one filter that is beneficial for pre-retinal versus retinal conditions?

One hundred and sixty one records of low vision subjects ranging in age from 10 to 104 years were examined and divided into the following groups; diabetic retinopathy (32), ARMD (19), glaucoma (15), RP (11), retinal degeneration (8), Stargardt's macular degeneration (7), optic atrophy (7), cataract (6), myopic degeneration (6). Another group consisted of miscellaneous conditions with low frequency occurrence. Ocular conditions were also categorised into pre-retinal, retinal and other types.

Test filters were the standard CPF450, 511, 527, 550, and the 550XD. These were presented to the subjects in order of increasing wavelength attenuation, placed over the distance correction. Subjects were asked to make subjective and qualitative choices in deciding on the most appropriate filter. Best-corrected VA was measured with the Designs for Vision Distance Number chart and ranged between 6/6 and 6/2400.

The study did not reveal any statistically significant improvement in VA, but as the investigators stated, some subjects did show an improvement in VA of one line or more which may be significant to them. CPF450 was chosen by 52.80% of the study group, 28.57% chose CPF511, 11.18% CPF527, 4.35% CPF550, and 3.11% CPF550XD.

Subject mean age was 60 years; mean age of the subjects who chose CPF450 was 65 years, and for those who chose CPF511, 527, 550, and 550XD, the mean ages were 55.50, 55.00, 55.14 and 50.60 years, respectively. ANOVA was determined to be statistically significant ($p=0.02$), i.e. subjects who chose CPF450 tended to be older than those who selected the other CPFs.

A Pearson Chi squared test showed no significant association between gender and chosen

filter. An identical analysis for disease and chosen filter was only slightly significant (p=0.025). The majority of subjects with ARMD preferred the CPF450 (this filter is recommended by Corning for use in ARMD). Those with diabetic retinopathy preferred the CPF450 and CPF511 almost equally. RP subjects preferred the CPF511 slightly to the CPF550, however statistical analysis was difficult due to the small number (11) of observers.

Subjects with poorer VA tended to choose the longer wavelength attenuating filters (ANOVA, p=0.00). Some of the filters produced an improvement in VA of one line, but this was not statistically significant (ANOVA, p=0.28). A Pearson Chi square test showed no statistical correlation between the location of the ocular disorder (pre-retinal, retinal or other types) and the filter chosen (p=0.78). However, subjects in all three categories preferred the CPF450 to other filters. This preference may be explained by short wavelength filtration, while TLT is maintained at a high level.

The authors admitted that subjects may have predominantly chosen the CPF450 because of its similarity to commonly available filters used to enhance contrast for skiers, shooters and aviators, and thus they may have already been aware of its benefits. Various age-related changes to the ocular media and pupil size that occur in the older eye tend to increase blue light scatter and decrease retinal luminance. This may explain why the older subjects preferred this filter.

There is no record of attempts to control for placebo or investigator bias. No details are provided on the order of filter presentation and there was no assessment without a filter. Subjects may have chosen the CPF450 because it has the palest tint and would have been cosmetically the most acceptable. Similarly to Van den Berg's (1990) study it was noted that even though the group did not show objective improvements with filters for averaged data, some subjects improved on an individual basis.

Discussion

Do tinted lenses improve visual performance in low vision? This review demonstrates that a substantial amount of research has produced equivocal results, which have failed to prove objectively, any consistent benefit of filters. The use of filters in low vision therefore remains controversial.

Studies can be divided into those that suggest that there is visual benefit to be gained by the use of filters, and those that don't. Many are poorly controlled for placebo effect, investigator bias, and learning and fatigue effects. Few have managed to relate reported subjective improvements to clinically determined objective improvements. This may have been because the clinical tests that were used for assessing visual function (VA and CS in particular) were too insensitive to detect subtle changes in performance. The mechanism by which improvement is gained in many of these cases is unclear.

Based upon an extensive review of the literature, Clark (1969) concluded that VA for normal observers through yellow, brown, or orange tinted lenses was identical to VA through luminance-matched neutral tints. This conclusion was reinforced by Kinney *et al.* (1983) who showed that visual performance with dark yellow and light yellow filters was better than ND filters for targets of low contrast but were identical for targets of either higher contrast or higher spatial frequency. As most VA charts have high contrast targets this may explain why subjects often report improved visual performance in the real world, where most objects are of low to medium contrast, which cannot be consistently replicated in clinical or research setting.

It may be more appropriate to use a test which provides information on functional vision such as the Pelli-Robson contrast threshold letter chart (Pelli *et al.*, 1988), in an attempt to determine whether the visual benefits often perceived by users of filters, have a physiological or psychological mechanism.

More rigorous experimental designs controlled for placebo and investigator bias aimed at obtaining data for statistical analysis are required.

Hence, there is little evidence that filters improve visual function and even less information is available about whether filters with particular spectral characteristics are better than ND filters or conventional tinted spectacle lenses. Clinical experience in low vision assessments indicates that many people with ARMD present with difficulties in reading, TV viewing, and recognising faces of relatives and friends. Orientation and mobility difficulties, photophobia and photosensitivity are problems regularly encountered in RP. The ability to read at least correspondence (spot or survival reading) may allow a person with ARMD to maintain an independent lifestyle. The ability to move comfortably and confidently in the environment may allow a person with RP to gain employment. No studies have directly addressed whether filters may be of use for these tasks, although Bailey *et al.* (1978) did make a direct assessment of reading with filters for subjects with cataracts.

When looking for trends within a group of people with an ocular disease, it cannot be assumed that the disease has a homogenous effect on all sufferers; it is important to look for individual effects. This is highlighted by the studies of Lynch and Brilliant (1984), Van den Berg (1990) and Nguyen and Hoeft (1994), which did not show a filter effect for averaged data, but visual performance did improve for some subjects on an individual basis.

CPF450 is the filter recommended for reading by Corning for people with ARMD and was preferred by the majority of the ARMD observers in the Nguyen and Hoeft (1994) study. More objective data, obtained from well-controlled experiments, and rigorous analysis, is required to determine whether there is any real benefit to be gained in reading with this filter. These experiments ideally need to use conditions and tasks that are similar to those found in the real world.

It is important that more work is done in this area since the low vision clinician needs to be able to provide accurate advice on whether filters will provide a long-term benefit, prior to their recommendation. They are relatively expensive compared to ND filters or sunglasses and this cost is borne either by the individual or by a government funded agency.

A study that compared the performance of the CPF450 with a ND filter, and a tint prescribed after testing with the Intuitive Colorimeter® (Wilkins *et al.,* 1992) using a stationary printed word task, is described later in this thesis [Chapter 3-Primary Experiments (experiment 5b)].

Conclusions

- Some studies demonstrate a subjective improvement in visual performance with filters, but objective data is equivocal, i.e. subjective reports are unreliable and variable.
- Many experiments are poorly designed and do not adequately control for placebo effect, investigator bias, and learning and fatigue effects.
- Statistical analysis of data is uncommon.
- Most diseases do not have a homogeneous effect on all sufferers, and therefore, as well as averaging and analysing group data, individual subject results need to be studied to look for intra-group, as well as inter-group variation.
- Some people with low vision report difficulties with reading, TV viewing, and recognising faces-ARMD, and with orientation and mobility-RP; studies using objective techniques and statistical analyses, investigating possible benefits from the use of filters in these situations, would be useful.
- The present situation of relying mainly on anecdotal reports and clinical observations in the provision of filters is unscientific and unsatisfactory.
- Interestingly, the latest research dates from 1994.
- Further studies should make use of readily available equipment and filters, so that any positive outcomes can easily and quickly be adapted to everyday use. See table 1.06 for a summarised overview of the review described above.

Table 1.06

Overview of research on the use of tinted lenses in low vision

Investigators	Condition	Outcome measure	Results	Comments
Frith (1980)	RP	visual comfort, subjective VA, objective VA, subjective peripheral vision and mobility	visual comfort, subjective VA, peripheral vision and mobility improvement, limited objective VA improvement	only one filter presented, no control for placebo, investigator bias, learning or fatigue, no presentation of data or analysis
Lynch and Brilliant (1984)	RP	objective VA, colour vision, CS and adaptation time	objective VA and adaptation time improvement, poorer colour discrimination, no group effect on CS, but some positive individual effects, positive effect on adaptation time	no control for placebo, investigator bias, learning or fatigue, limited data and analysis, attempted to relate objective measurements to subjective preferences
Morrissette *et al.* (1984)	RP	subjective impression of adaptation time, visual comfort, visual functioning, satisfaction with tint under various lighting conditions, cosmetic appearance, effects of weather, replacement intent	subjective visual improvement, no unanimous positive or negative response to any other criteria	no objective data, no control for placebo, investigator bias, learning or fatigue, no presentation of data or statistical analysis

Table 1.06 contd

Overview of research on the use of tinted lenses in low vision

Investigators	Condition	Outcome measure	Results	Comments
Silver and Lyness (1985)	RP	objective VA and objective visual fields, subjective responses to filters, subjective adaptation time	subjective but no objective visual improvements	single masked, randomised controlled trial, no control for investigator bias, no statistical analysis
Van den Berg (1990)	RP	objective VA, CS, colour vision, visual field, dark adaptation and glare sensitivity.	decrease in average objective VA and CS, no effect on glare sensitivity, reduced sensitivity of central visual field, improved adaptation to light, individual CS improvements	no statistical analysis
Bailey *et al.* (1978)	cataract	objective near reading acuity and reading speed	yellow filters reduced objective near reading acuity by lowering illuminance	no reliance on anecdotal evidence, detailed description of procedures, placebo controlled, little investigator bias, statistically analysed objective data
Tupper *et al.* (1985)	cataract	objective VA with and without glare source	improved objective VA, more pronounced with glare source	results probably confounded by learning effect, filter presentation not randomised, no statistically analysis of objective data

Table 1.06 contd

Overview of research on the use of tinted lenses in low vision

Investigators	Condition	Outcome measure	Results	Comments
Zigman (1990, 1992)	cataract, ARMD, and aphakia	objective VA and CS	improved objective VA and CS	no details on order of filter presentation, no control for placebo, investigator bias, learning or fatigue; statistical analysis of objective data
Bremer *et al.* (1987)	cone dystrophy	objective VA, near reading acuity, central and peripheral visual fields, subjective general visual and visual motor function, colour discrimination, objective electro-diagnostics	minimal objective near reading acuity improvement (for one subject), improved central visual field sensitivity, subjective visual performance improvement, decreased colour discrimination, increase in latency and amplitude of light adapted ERG-B wave	subjective evidence supported by electro-diagnostic data
Hoeft and Hughes (1981)	mixed	subjective impression of best filters	subjective improvements especially in visual comfort	no objective data collected, lacking in design details
Barron and Waiss (1987)	mixed	objective VA	objective VA improvement	objective VA improvement compared to ND filter but not compared to clear filter, no placebo control, no statistical analysis

Table 1.06 contd

Overview of research on the use of tinted lenses in low vision

Investigators	Condition	Outcome measure	Results	Comments
Maino and McMahon (1986)	mixed	subjective impressions on glare, photophobia and photosensitivity	subjective preferences for individual filters	brief description of design, no objective data or statistical analysis presented
Leat *et al.* (1990)	mixed	CS, grating acuity under glare and non-glare conditions	objective visual improvement in CS and grating acuity especially for anterior ocular conditions with glare source	detailed design, no statistical analysis
Cohen and Waiss (1991)	mixed	VA indoors and outdoors	not a single case where the CPF lens was better than the alternative devices	subjective preferences matched the device that gave the best VA, best way to determine which glare control device will be most successful is to conduct an outdoor evaluation of several different types of device.
Gawande *et al.* (1992)	mixed	subjective impression, objective CS and VA	neither objective CS or VA correlated with subjective ratings	used arbitrary grading scale for anecdotal reports, no statistical analysis
Leguire and Suh (1993)	mixed	CS function	CS function reduced especially at higher spatial frequencies	no information on order of presentation, no control for investigator bias, learning or practice

Table 1.06 contd

Overview of research on the use of tinted lenses in low vision

Investigators	Condition	Outcome measure	Results	Comments
Nguyen and Hoeft (1994)	mixed	objective VA, subjective filter choice, association between age and choice of filter, between gender and filter chosen, between aetiology and filter chosen	objective VA improvement not statistically significant, subjective evidence, individual improvements	no details on order of presentation of filters

RESEARCH RATIONALE

Introduction

The literature reviewed in this chapter has highlighted the following:

- Very little work had been conducted using stationary text under laboratory conditions that are similar to the real world reading environment.
- Although work had been conducted on the effects of varying intensity of illuminance, little is known about the effects of coloured illuminance, or any coloured intervention, on reading in low vision.
- Few studies have used age-similar normal controls, and few have attempted to control for placebo, learning or fatigue effects.
- Further studies on the possible use of colour as a rehabilitative intervention in low vision, with as many of these practical limitations as possible overcome, would be useful.
- As the number of ocular pathologies that cause low vision is large, it seems sensible to concentrate efforts on the disease that is most common, namely ARMD.
- Although people with this eye condition have difficulties with many tasks, from personal clinical experience, they most frequently complain of difficulty with reading. Therefore, a study of the effects of coloured interventions on reading with ARMD would be particularly useful.
- Few studies have compared inter-and intra-subject variations in reading performance for a series of conditions, which affect visual factors. Non-visual factors are very difficult to control for but are likely to be confounding factors.
- Gross cognitive and higher level factors could be controlled for on the basis that any subject who seemed to have difficulties understanding the instructions was rejected. It would however, be difficult to control for subtle cognitive and motor abnormalities.

- Binocular vision (BV) anomalies can produce reading problems similar to those produced by ARMD. In order to reduce the possibility of confounding the overall results it would be useful to determine if subjects with low vision also have a coexistent BV anomaly.

One or more of the above factors has affected previous studies and limited the conclusions that can be drawn. This project has attempted to address as many of these as possible, in order to be able to draw stronger conclusions from objective data.

The primary aims of this research were to address and answer the following questions using a series of objective, subject based, age-similar controlled experiments:

- Can one or more coloured interventions enhance reading performance in ARMD?
- If coloured interventions do improve reading with ARMD, is the effect general or is it idiosyncratic and specific?
- How do less costly coloured interventions such as coloured gel filters, Intuitive Coloured Overlays® and fixed-tint spectacle lenses, fare against more expensive coloured interventions such as specialised glass photochromic tinted spectacle lenses, and video-magnifiers with a colour text/background facility?

Secondary aims were to address and answer the following questions:

- Do subjects with low vision also have coexistent binocular vision anomalies?
- Is there a difference in reading performance in ARMD with three different types of commercially available local light sources?
- Can the Intuitive Colorimeter® be used to detect and map out acquired reduction of colour vision discrimination in ARMD?
- Can the Humphrey 630 Visual Field Analyser be used to map out biocular visual field defects in ARMD?

Chapter 2-Pilot Experiments

EXPERIMENT 1-IS THERE A NEED FOR BINOCULAR VISION EVALUATION FOR SUBJECTS WITH ARMD?

Introduction

People with ARMD often describe near vision related symptoms such as blurring of print, and moving letters and words. People with binocular vision (BV) anomalies, such as convergence insufficiency and decompensating exophoria at near, sometimes report similar problems.

It is important to know whether near vision problems experienced in ARMD are due to the disease *per se*, due to a coexistent BV anomaly or a combination of both. A reduced visual field or a degraded retinal image due to a macula scotoma will impair fusional lock and could result in unstable binocular function. Therefore, any BV anomaly could be directly related to the ARMD or occur coincidentally. This study was performed in order to determine how prevalent BV anomalies are in people with ARMD. The outcome was used to determine whether ARMD subjects used in subsequent experiments in this series had to be screened for BV problems.

From personal clinical experience in low vision work, a lack of binocular vision testing on individuals with symptoms that are reminiscent of those experienced by people with BV anomalies, was noted. These individuals often failed with successive low vision appliances and were frequently re-appointed for further assessment, which sometimes resulted in management by monocular occlusion. Referral for orthoptic evaluation was rare.

It was also noted that there are several rules of thumb used in the low vision field, to determine the size of prism to incorporate into high addition lenses (above +4.00DS) to aid convergence for near tasks. These rules of thumb are varied but consist of three main types (Farrall, 1991):

- Lebensohn's rule, by which the amount of prism (Δ) required at near is calculated by dividing the difference between the distance and near pupillary distance (PD) by the near working distance plus one.
- Fonda's rule, which recommends that lenses are decentred by 1 mm per dioptre add.
- Jackson and Silver point out that 1 metre angle (MA) of convergence is required for every dioptre of focussing at near, therefore at a working distance of 25 cm, 4 MA of convergence are required. Metre angles can be converted to prism dioptres (Δ) by multiplying by half the far PD in centimetres.

Table 2.00 shows the total value of incorporated prism calculated using these three rules of thumb for a +6.00D add, distance PD 66 mm, near PD 63 mm and working distance 16.67 cm.

Table 2.00 calculated prism for high addition lenses

Rule	Prism (Δ)
Lebensohn	1.0
Fonda	3.6
Jackson and Silver	2.0

Since these rules produce different results for the same optical and subject parameters, some practitioners use a 'guestimate' of either 1Δ base in each eye for every dioptre add, effective at the distance PD, or 1Δ base in each eye for every dioptre add over +3.00DS (Farrall, 1991). These rule of thumb methods for prism prescription without measurement seem inappropriate since all rules of thumb are by their very definition only estimations. If ARMD causes additional stress on the sensory system further strain on motor fusion from incorrect prisms

may not be tolerated and lead to the rejection of high add spectacles.

Analysis of texts on optometric assessment of low vision subjects revealed a lack of information and advice on how to evaluate the BV system for this type of low vision subject (Bier, 1970; Faye, 1970 and 1984; Rosenbloom and Morgan, 1991). Discussion is basic and peripheral at best (Farrall, 1991; Fonda, 1970a; Johnston and Lawrence, 1990; Freeman and Jose, 1991). This may imply that people with low vision can be managed adequately without reference to the status of their BV system. However, this criticism may not be justified since anecdotal evidence would suggest that many people with low vision are monocular. A literature search on BV evaluation in low vision revealed one relevant study (Fonda, 1970b). This paucity of information was one of the prompts for this study.

The aims of the study were to ascertain whether BV anomalies are associated with low vision and to determine whether there is a need for a screening evaluation of subjects chosen for subsequent experiments in this series. It was beyond the scope of this study to classify any such BV anomalies into those directly related and those not related to ARMD.

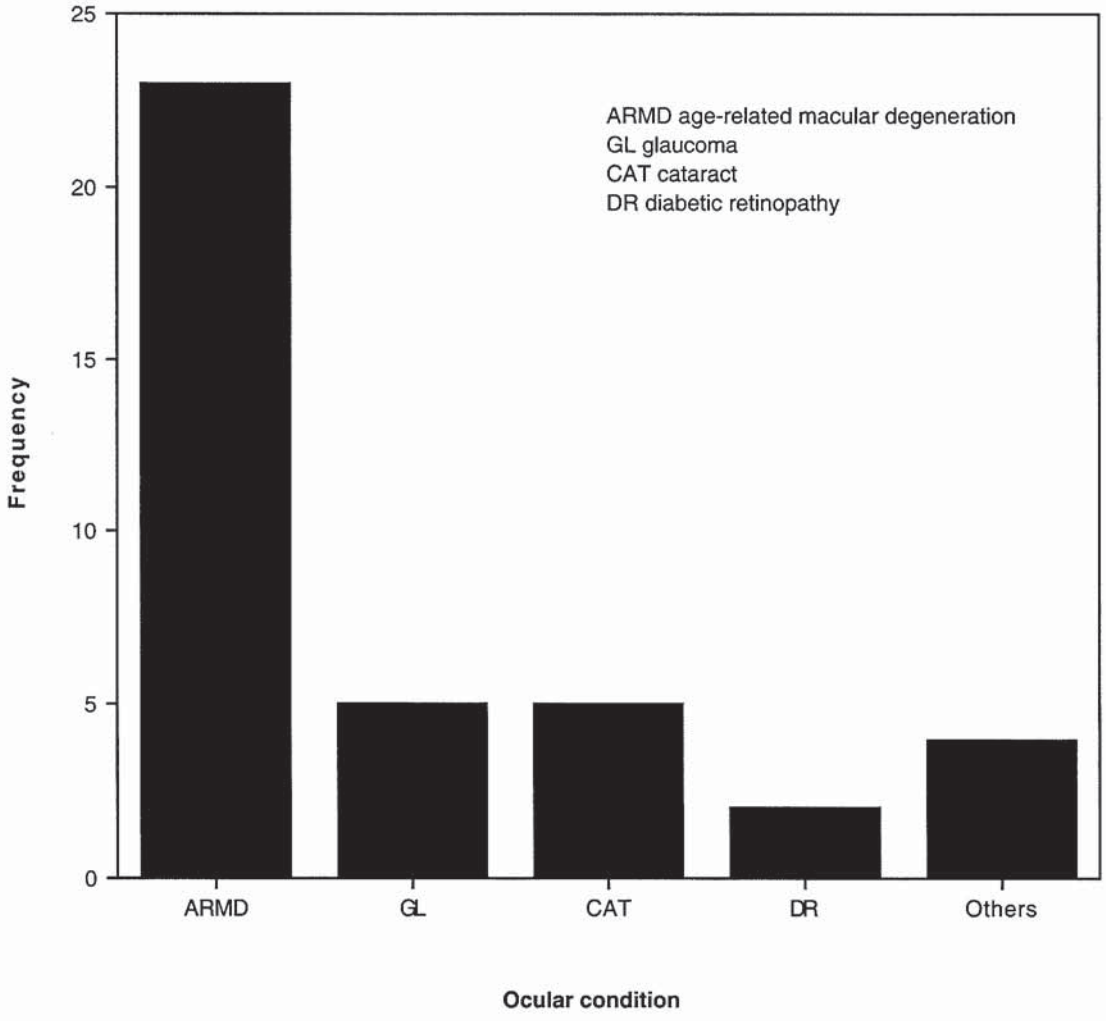
Methods

Subjects

The study group consisted of 30 low vision subjects, 13 males and 17 females with various ocular pathologies (figure 2.00 and table 2.01 for details) selected from records at the Birmingham Focus on Blindness Low Vision Centre. The age range was from 46 to 96 years with a mean of 78.7 years. Selection criteria required each subject to have a VA of at least 6/60 and N48 at 25 cm (Bailey-Lovie near word reading card) with each eye, and to appreciate a cross using Bagolini lenses at near. This latter criterion was necessary in order to be able to confirm the presence of binocularity.

Figure 2.00 study group pathologies

Figure 2.00-study group pathologies



Procedure

BV evaluation consisted of:

- Detailed history and symptoms with an emphasis on the occurrence of near vision difficulties. History included type of symptom, duration and frequency, precipitating factors and strategies for overcoming symptoms. Subjects were specifically questioned about blurred vision, jumbled or moving print, asthenopia and diplopia.
- Cover test at near, prism cover test, ocular motility, convergence amplitude, horizontal step vergence reserves (measured with a prism bar) and testing for the presence of binocular single vision with Bagolini lenses. All tests were conducted to a light to ensure that both eyes could see the target and that a standardised testing procedure was maintained throughout the study for all subjects.

Table 2.01 subject age (years), ocular conditions and monocular threshold reading acuity details for experiment 1 (BV anomalies)

Subject	Age (years)	Ocular condition	RVA	LVA	RVA	LVA
ES	90	ARMD+CAT	6/60	6/60	N36	N36
FH	77	CAT	6/24	6/18	N18	N6
DL	83	ARMD	6/9	6/36	N18	N24
CB	47	TOX	6/36	6/36	N18	N18
LB	83	ARMD+CAT+GLA	6/24	6/60	N12	N36
VT	89	ARMD+GLA	6/60	6/36	N48	N18
MG	71	ARMD	6/18	6/24	N10	N10
JE	71	ARMD	6/60	6/60	N12	N48
JH	77	GLA+MAH	6/36	6/36	N5	N5
GH	73	ARMD	6/18	6/36	N5	N48
SL	46	DRP	6/60	6/36	N24	N18

Table 2.01 contd subject age (years), ocular conditions and monocular threshold reading acuity details for experiment 1 (BV anomalies)

SC	93	ARMD	6/18	6/36	N12	N36
AA	74	ARMD	6/36	6/24	N18	N12
HH	88	ARMD	6/9	6/9	N5	N5
AW	72	CVA	6/18	6/24	N8	N12
HW	74	ARMD	6/9	6/36	N5	N24
LH	84	ARMD	6/36	6/9	N48	N6
JW	72	GLA+DRP	6/18	6/60	N12	N48
EB	80	ARMD	6/12	6/12	N8	N8
CS	76	MYD	6/36	6/36	N14	N24
TJ	76	ARMD	6/24	6/36	N12	N12
BM	83	ARMD	6/12	6/18	N8	N20
PR	68	ARMD	6/24	6/12	N8	N8
JH	74	ARMD	6/12	6/36	N8	N20
FD	79	ARMD+CAT+GLA	6/60	6/36	N32	N32
AJ	73	ARMD	6/12	6/24	N8	N12
VW	86	ARMD	6/24	6/18	N10	N10
BP	83	ARMD	6/12	6/24	N8	N10

Key: RVA=right visual acuity at distance or near; LVA=left visual acuity at distance or near; CAT=cataract; TOX=toxoplasmosis; GLA=glaucoma; MAH=macular hole; DRP=diabetic retinopathy; CVA=cerebro-vascular accident; MYD=myopic degeneration.

Results

Symptoms that subjects complained of and the BV anomalies that were detected are presented in the form of histograms in figures 2.01 and 2.02 respectively. Note that symptoms and anomalies were present either singularly or in combination.

Figure 2.01 study group symptoms and figure 2.02 study group BV anomalies respectively

Figure 2.01-study group symptoms

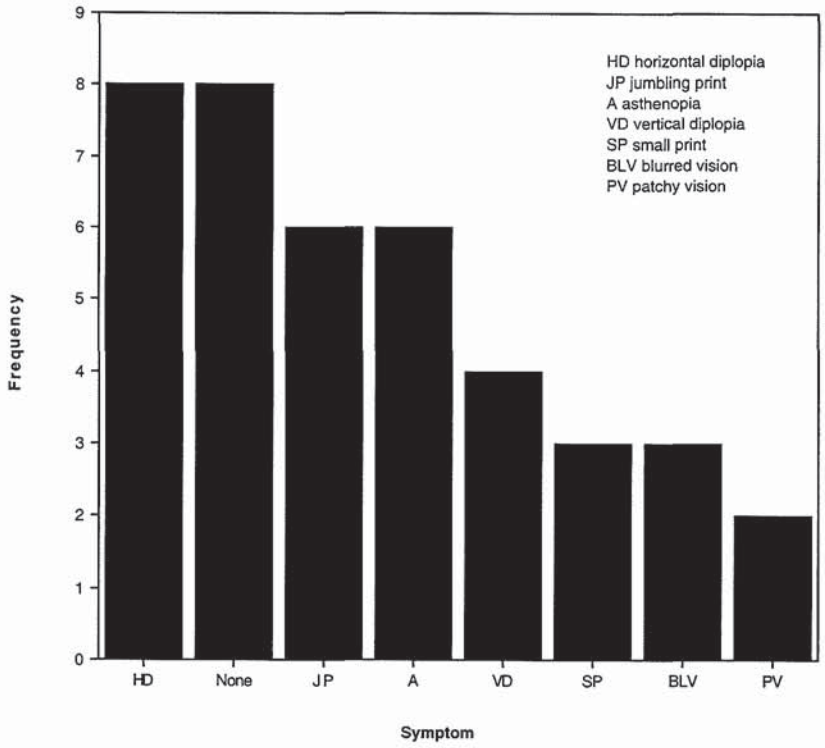
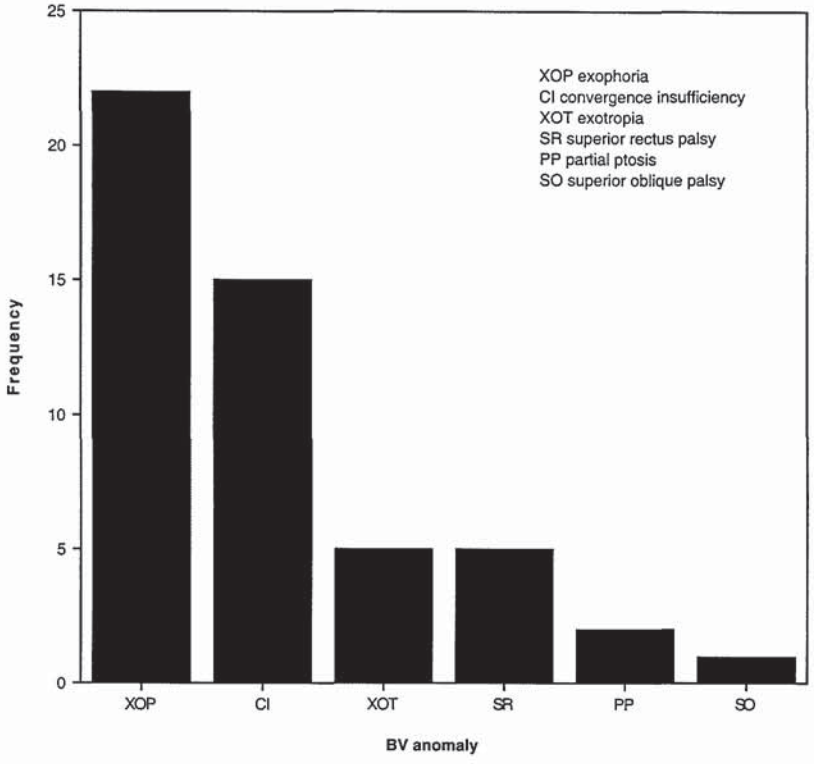


Figure 2.02-study group BV anomalies



Discussion

In the management of low vision patients it is important for the clinician to adopt a holistic approach when assessing the visual system. Most subjects with low vision will have some form of ocular pathology but as this study shows they may also have a coexisting BV anomaly.

Many study subjects complained of jumbled print, asthenopia, and blurred vision when reading. These symptoms are often reported by people with ARMD, and also by people with BV anomalies. In this study as most of the subjects had both ARMD and a BV anomaly it is difficult to ascertain the exact cause of their symptoms.

Exophoria greater than 6Δ at near [the physiological estimate at 65 years of age as determined by Pickwell and Frier (1983) cited by Evans (1997a)] was a common occurrence in the study group. Convergence insufficiency, defined as an objective near point of convergence of greater than 10 cm as measured with the RAF rule and a 6/9 target, also occurred frequently. It is possible that these anomalies may result in stress on the binocular vision system, which could then lead to visual discomfort when performing near tasks such as reading (Evans *et al.* 1994a).

Since the majority of people with low vision are elderly they are more susceptible to systemic diseases such as diabetes, hypertension and cerebral vascular accidents, all of which can precipitate imbalances of the binocular system. Therefore, the likely occurrence of a BV imbalance needs to be considered for the low vision population, as for any other group.

Many people with low vision have large inter-ocular VA differences but may still have some form of gross BV, and therefore may be susceptible to a BV disorder. Macular lesions, cataract and glaucoma when present unilaterally or bilaterally asymmetric can behave as dissociative factors to binocularity. Ocular disease and BV anomalies may cause near vision

disorders that affect the efficiency of near tasks, especially reading. Hence, it is important to distinguish between the two and to determine the aetiology of the presenting visual complaint.

It may be possible to alleviate symptoms due to a BV anomaly through the use of vision therapy (orthoptic eye exercises) without having to resort to prismatic correction. However the following factors need to be considered: patient general health, motivation, coherence and the logistics of frequent follow up. Most low vision subjects will be lacking in one or all of these areas.

When vision therapy is inappropriate alleviating prisms can be prescribed. However, the often-used rule of thumb prescribing of prisms in high addition spectacle lenses may be inaccurate in the presence of BV anomalies. It would be better to consider the need of each subject on an individual basis.

Diagnosis and, where possible, the elimination of a BV anomaly will facilitate the provision of the correct optical aid and appropriate training in its use. Failure to recognise a BV anomaly may lead to an inappropriate prescription in conjunction with both clinician and subject frustration. Further research is needed in this field to:

- Determine the relationship between inter-ocular VA differences and binocularity.
- Assess the use of revised vision therapy in low vision.
- Determine the viability of Fresnel prism trials instead of rule of thumb prescribing of prisms for high addition lenses.
- Determine the best methods of diagnosis of a BV anomaly for individuals with low vision.

Limitations of study

It would have been useful to have a control group of subjects whose visual complaints were most likely to be due to ARMD alone, e.g. central part of words missing but no complaints that were more likely to be due a BV anomaly, e.g. words moving. Then to compare this group

with a study group of ARMD subjects whose symptoms were more likely to be due to a BV anomaly.

The experiment could have been masked to the investigators. Subjects could have been selected and divided into study and control groups by one experimenter and a masked BV analysis conducted by a different experimenter.

Determination of whether a near exophoria is compensated (non-symptom producing) or decompensated (symptom producing) can be carried out with a near Mallet unit using the standard OXO targets. However, subjects with reduced VA and a central scotoma are unlikely to be able to resolve this target. It may have been appropriate to check for compensation using the larger OXO target originally designed for assessment of the presence of harmonious abnormal retinal correspondence. It would be interesting to investigate the use of this target further.

Percival (1892) cited by Evans (1997a) proposed that for visual comfort at near, the convergent and divergent fusional reserves should be balanced so that one should not be less than half the other. This criterion could be used to determine if a phoria is compensated or decompensated in those cases where Mallet unit testing is not possible. Further research would be useful.

Conclusions

Tailored questioning and a modified BV assessment can be used to reveal symptoms and signs that may be partly attributable to a BV anomaly and not exclusively due to ocular disease. Acquiring this information should facilitate the implementation of the most appropriate course of management. Optimisation of residual visual function for the individual's interaction with the environment with respect to rehabilitation, orientation and mobility is paramount for improved quality of life.

It is however, extremely difficult to determine if the BV anomaly was present before the occurrence of ARMD, or if it is directly due to the ARMD

Note: All ARMD subjects in subsequent experiments in this series were screened for BV anomalies, using the protocol described above. Only those subjects whose near vision difficulties were most likely due to ARMD were used as observers.

EXPERIMENT 2-EFFECTS OF ILLUMINANCE VARIED IN COLOUR AND INTENSITY ON READING PERFORMANCE IN ARMD

Introduction

Recent studies on the effects of (il)luminance and colour on reading in low vision have mainly been based on laboratory experiments involving rapid serial visual presentation (RSVP), or drifting text on TV monitors (Legge and Rubin, 1986; Legge *et al.*, 1990; Jacobs *et al.*, 1997) (see Chapter 1-Background and Research Rationale). Legge (1991) described the drifting text method as:

> 'An objective psychophysical means for evaluating the visual component of reading and designed to be insensitive to non-visual factors that influence everyday reading such as text complexity, cognitive or linguistic ability, reading strategy (skimming) and motivation.'

Useful measures of reading performance have been obtained, and attempts have been made to apply the results to conventional reading. However, these experimental conditions are far from those that are experienced by people with low vision when in the work or home environment. Other studies (Sloan, 1969; Sloan *et al.*, 1973; Zhokhov *et al.*, 1976; Silver *et al.*, 1978; LaGrow, 1986; Eldred, 1992) (see Chapter 1-Background and Research Rationale) have investigated the use of illumination in low vision, and used clinically based techniques in which the visual task has been static, and consisted of a near letter acuity or reading acuity card, or text designed to replicate a real-world reading demand.

From results of this work there is reasonable consensus that high illuminance can improve reading performance. Generally reading rate is found to be fastest when the luminance difference between text and background is maximal. However, conclusions on the use of colour to improve reading performance are contradictory (see discussion Chapter 1-Background and Research Rationale).

Experiment 2 was planned as the first of a series of studies using experimental conditions which are more likely to be experienced in the real-world, e.g. using stationary, printed text, close to the binocular reading acuity threshold at near, with poor ambient lighting, and good local lighting. It is usually under poor ambient lighting conditions that people with ARMD often attempt to carry out near tasks and report problems (Levitt, 1978; Silver *et al.*, 1978).

The primary aim of this second pilot study was to compare the effects of a coloured intervention (illuminance) of various intensities, on two groups of normals, young (YN) and senior (SN), and a group with ARMD. The study was conducted to determine whether there are any age-related, disease-related, or disease and age related effects. The secondary aim was to assess the experimental design in terms of its limitations and then to modify the design for other experiments in this series.

As outlined in the research rationale for this project, experimental conditions for this study were chosen in order to replicate as close as possible the conditions of the real-world environment in which subjects may attempt to read on a daily basis, i.e. small stationary print with typically poor ambient luminance. Instrumentation and procedures were kept low-tech and inexpensive, in order to facilitate a long-term aim of a quick and easy transfer of any positive outcomes into clinical, and home or work environments with little modification.

No previous work was located in the literature search that compared the effects of varied illuminance colour and intensity on YN, SN, and ARMD subjects.

Method

Subjects

Three groups, YN, SN and ARMD, each with 10 subjects were used (table 2.02). It was ascertained either from recent ocular records or direct monocular ophthalmoscopic observation that none had any clinically significant media opacities. None of the normals had any retinal

disease or any systemic disease, and no subject was taking any prescribed medication that may have interfered with vision. None were aware of any congenital colour vision defects or any recent changes in colour discrimination. All subjects were naive as to the possible benefits of colour on reading. None had any apparent cognitive deficits, although this was not tested psychometrically. All had English as their first language.

Subjects who normally used a refractive correction for reading wore their own glasses for all test conditions. Observers were not refracted for different illuminance colours to compensate for chromatic aberration, since the use of a trial frame would have restricted the field of view and created more artificial conditions. None of the ARMD group was observed to be fixing eccentrically although this was not monitored in any way and all groups used natural pupils.

The YN group consisted of seven females and three males, who were qualified or trainee paramedical practitioners working for the Birmingham Health Authority. All had a near binocular reading acuity of at least N5 with the Bailey-Lovie near word reading card, at their habitual reading distance.

The SN group consisted of five males and five females, who were attending for routine eye examination at the Department of Optometry and Vision Sciences at Aston University, or members of staff at the Birmingham Focus on Blindness Low Vision Centre. All had a near binocular reading acuity of at least N5 with the Bailey-Lovie near word reading card at their habitual reading distance.

The ARMD group consisted of nine females and one male, which were attending the Birmingham Focus on Blindness Low Vision Centre. All had bilateral non-exudative ARMD to varying degrees. None were currently under going any medical ocular treatment. The visual qualifying criteria for this group was a best corrected binocular reading acuity of N18 or better, at their habitual reading distance with the Bailey-Lovie near word card. This level of

vision was used as a cut-off since it approximates to the font size used in large print books. From personal clinical experience, this was considered to be the smallest font size that a person with ARMD would be likely to attempt to read in daily life, without having to resort to the use of a low vision device.

It had been intended to use a spouse, age-similar control group but this was not possible as all the ARMD subjects available for the study were widowed. It also proved difficult to find other age-similar control subjects without ocular disease, and therefore the SN group is statistically younger than the ARMD group ($t=4.384$, $p=0.004$). The SN group cannot strictly be termed a control group and is best described as an age-similar comparison group. This will be further discussed in the results section.

Note, a parametric test was used to analyse the age data as this type of test is very flexible when applied to factorial analysis. However, it is possible that the age data was not normally distributed but, moderate departures from normality are considered not to affect the validity of the test. Also, the distribution of the sample means will be normally distributed even if the individual measures are not.

Table 2.02 subject age (years) and threshold binocular reading acuity for experiment 2 (projection gels)

YN	Age	Reading acuity	SN	Age	Reading acuity	ARMD	Age	Reading acuity
MR	24	N3	VS	76	N5	EC	79	N6
RE	27	N2.5	EE	68	N4	BP	83	N8
YL	25	N3	RA	47	N4	VW	86	N5
AB	24	N3	JH	55	N3	BH	75	N10
PW	26	N2.5	DB	54	N5	MH	74	N12
SA	29	N2.5	LE	60	N6	RR	70	N6
IC	29	N2.5	ME	61	N5	VB	69	N8
AM	18	N3	JA	63	N4	BM	72	N6
JC	18	N3	GE	51	N3	FP	67	N8
JM	26	N2	BE	64	N4	BCM	71	N5

YN, mean age (years) 24, median 25.5, range 18 to 29, standard deviation (SD) 4.25; SN, mean age (years) 60, median 60.5, range 47 to 76, SD 8.54; ARMD, mean age (years) 74, median 73, range 67 to 86, SD 6.24.

Materials

- Table mounted standard electric slide projector incorporating a 150W incandescent halogen lamp. This was positioned behind and to the right of the subject at an angle of 45 degrees, 60 cm from the test print which was supported by a floor standing copy-holder with a flexible arm.
- Bailey-Lovie reading near word reading acuity card (Lighthouse Inc., New York, NY, USA) was used to determine threshold binocular near reading acuity at each observer's habitual working distance. This was carried out prior to the experimental investigation and under local lighting of 3330 lux at 25 cm, produced by a 11W cool white PL, compact fluorescent tube (model DS 507, Daylight Studios, 223a, Portobello Road, London, W11 1LU, UK).

- Illuminance colour was varied by means of four coloured gel filters; red, yellow, green and blue[1] (see figures 2.03a, b, c and d for transmission curves). These were mounted as 35 mm slides and placed in a standard slide carousel. TLT was measured as; red 65.66%, yellow 69.08%, green 44.61% and blue 59.90%. Dividing by the green filter TLT (this had the lowest TLT) gave normalised TLT values of green 1.00, blue 1.34, red 1.42 and yellow 1.55.
- Intensity was varied by means of three ND filters with 12.5%, 25% and 50% TLT (ND filters produce a change in the intensity but not colour). A fourth intensity (100% TLT) was obtained by not using any ND filter. Combinations of four coloured filters and four ND transmissions produced 16 test conditions.
- A Macam Digital Photometer Model L103 (Macam Photometrics Ltd, 10 Kelvin Square, Livingston, EH1 5PF, UK) was used to measure the TLT through each coloured filter and ND combination.
- Test print consisted of a bank of 128 commonly occurring four-letter words such as shop, bank and song (appendix 6 for full list). Groups of 24 words from the bank were randomly chosen and printed on a 300 dpi Apple® laser printer on white, matt postcards (9 cm by 14 cm) in bold upper case Geneva font in an unjustified format, produced by Microsoft Word® 5.0. Font size ranged from N3 to N18 with ten cards in each font size; each card, at each size, had a different combination of words with four lines per card and six words per line. Test cards had minimal linguistic and semantic aspects, stressed the visual aspects of reading and could be tackled by subjects with only modest reading ability.
- White, matt card (30 cm by 45 cm) placed on the adjustable floor mounted copyholder.
- Standard dictating type tape-recorder.

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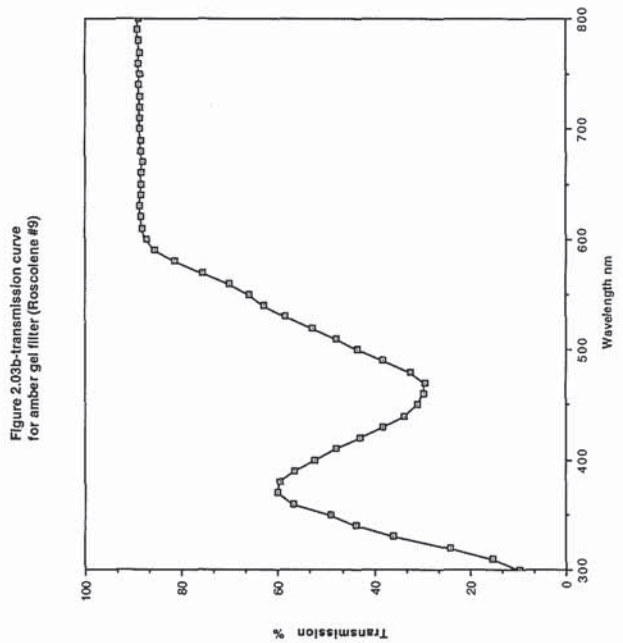
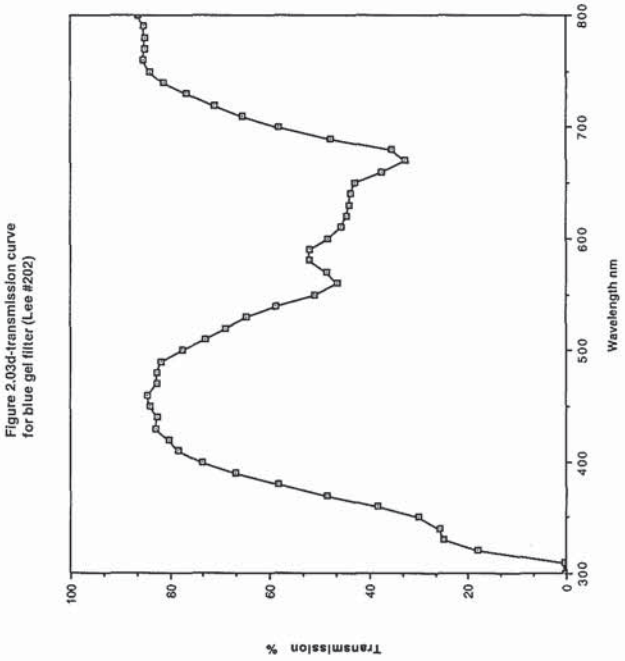
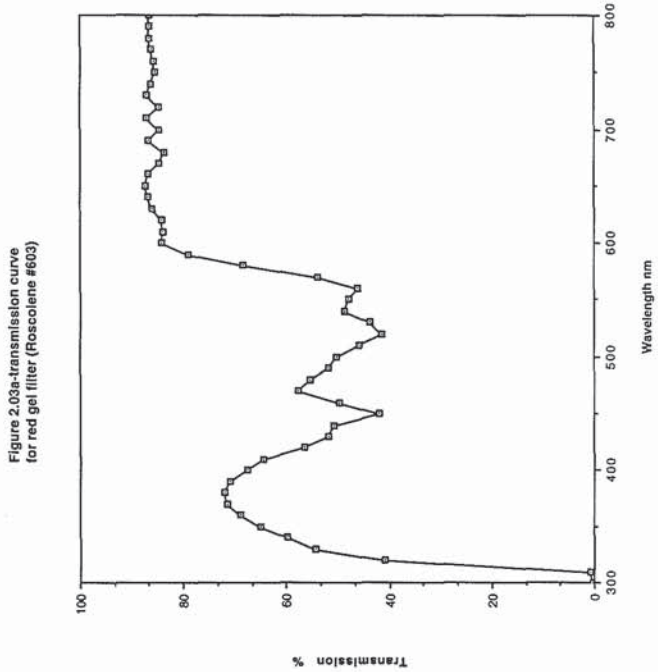
[1] Red (Roscolene #603, 65.66% total transmission, wavelength at maximum transmission 790 nm), yellow (Roscolene #09, 69.08% total transmission, wavelength at maximum transmission 600 nm) (Rosco, Blanchard Works, Kangley Bridge Road, Sydenham, London, SE26 5AQ, UK), green (Lee #244, 44.61% total transmission, wavelength at maximum transmission 500 nm) and blue (Lee #202, 59.90% total transmission, wavelength at maximum transmission 450 nm) (Lee Filters, Central Way, Walworth Industrial Estate, Andover, Hampshire, SP10 5AN, UK).

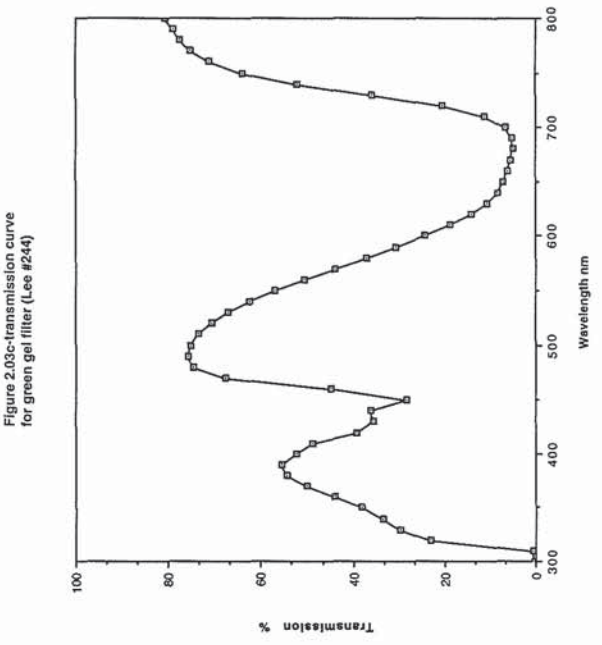
- Stopwatch.
- Score sheet (enlarged version of the test print).

Figures 2.03a, b, c and d transmission curves for projection gels









Procedure

For logistical reasons each study group was assessed in a different location, but at each location the same equipment and the same lighting conditions were used. The procedure was explained and each subject gave verbal consent. Threshold binocular reading acuity VA was determined at each subject's habitual working distance using a Bailey-Lovie near word card while wearing any necessary habitual refractive correction. Threshold levels of binocular reading acuity were recorded as the last line for which at least 50% of the words were correctly identified. Prior to testing, subjects were allowed to partially adapt for 15 minutes in a darkened room (ambient illuminance from extraneous sources, e.g. gaps between door and door frame was measured as 35 to 40 lux at the test surface).

Note

Each subject was encouraged to use an ergonomically and visually comfortable reading distance, which was monitored for consistency throughout the testing session for consistency. This distance varied across the subjects. This variation was not considered to be a confounding factor because

Levitt (1978) showed that lighting in the homes of many elderly people did not achieve the standards recommended in the Code of Illuminating Engineering Society. The code recommended 225 to 400 lux for casual reading and 450 to 600 lux for detailed near tasks such as sewing. Illuminance levels found by Levitt for 20 subjects in their own homes, ranged from 30 to 240 lux, and the most frequent values were in the range 50 to 70 lux. This was the reason why the ambient lighting for experiment 2 had an illuminance as low as 35 to 40 lux.

During the time allowed for adaptation to the test room light levels, it was explained to each subject that the test session would be tape-recorded, the tape analysed and then erased. A large white card was placed on the copyholder and illuminated by the projector light with a randomly chosen coloured gel slide and ND filter. A further five minutes were allowed for

partial adaptation to this illuminance. No other light source apart from the projector and the small amount of extraneous light was used. During this adaptation period the subject was reminded that they would need to read out loud from each text card, with maximum accuracy rather than maximum speed.

A text card with font size one point larger than the binocular threshold reading acuity was placed in the centre of the large card, producing a test target of black letters on a coloured background. Print close to the threshold binocular reading acuity was used in order to stress the visual system and allow subtle variations in performance to be detected. Legge and Rubin (1986) noted that for normal observers reading was influenced by wavelength only for characters near the acuity limit.
Subjects were instructed to read as quickly as possible without making any errors.

The experiment was designed to provide an acuity reserve (Whittaker and Lovie-Kitchin, 1993) of approximately 1:1[2] since in the real-world, people with ARMD need to, and often demand to be able to read the smallest print size resolvable. In ARMD this is especially important for survival or spot reading and personal independence often depends on the ability to do this. CS was not measured in this experiment but it was assumed that as the print had approximately 90% contrast, both the normal groups had excess contrast reserve[3] (Whittaker and Lovie-Kitchin, 1994) and that the ARMD group had at least some reserve for spot reading.

On completion of the testing session the tape recording was replayed. Each subject was scored by noting the errors on a score sheet, and by measuring the total time taken in seconds to read

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[2] Whittaker and Lovie-Kitchen (1993) determined that a 'reserve' of word reading was needed by people with low vision, so that the size of print that could be fluently read was 1.5 to 2 times larger than the threshold print size, while for spot/survival reading no reserve was required.

[3] Whittaker and Lovie-Kitchen (1994) gave tentative criteria for contrast reserves necessary for fluent reading as 10 times the threshold contrast and 3 times for spot/survival reading.

each paragraph. Errors were defined as missing out or miss-identification of a word; the introduction of extra words was not scored as an error, as this would be reflected in the reading rate.

Reading rate was calculated by noting the time taken in seconds to read the test card; this figure was divided into 60 and the result multiplied by the total number of words read correctly. Reading accuracy was determined by calculating the percentage of words read correctly from the total of 24 per card. All subjects attempted to read all words on each card presented. Using this procedure reading rate in terms of a score of CWPM and reading accuracy in terms of percentage of words read correctly was determined for each of the 16 test conditions for each subject.

ANOVA

The data was analysed using a three-factor ANOVA split-plot in a randomised design with subject group as the major factor. ND filter transmission and gel filter colours were sub-plots. Following the ANOVA, a comparison between the individual means was made using Scheffé's *post hoc* test (table 2.03 and 2.04).

Results

Reading rate

See appendix 1.00 for raw data.

Table 2.03 ANOVA: 3-factor split-plot randomised design for reading rate

Effect	F	p
Subject groups	7.129	0.003
ND transmission	5.277	0.001
ND transmission x subject group	2.164	0.046
Gel filter colour	6.897	0.002
gel filter colour x subject groups	5.064	0.001
Gel filter colour x ND transmission	0.767	0.648
Gel filter colour x ND transmission x subject group	0.608	0.894

- An overall main effect of subject group (p=0.00), (figure 2.04).
- A significant effect of ND transmission (p=0.00), (figure 2.05).
- A significant effect of gel filter colour (p=0.00), (figure 2.06).
- A significant interaction between ND transmission and subject group (p=0.05), (figure 2.07).
- A significant interaction between gel filter colour and subject group (p=0.00), (figure 2.08).
- No significant interaction between ND transmission and gel filter colour (p=0.65).
- No significant interaction between ND transmission, gel filter colour, and subject group (p=0.89).

Scheffé's *post hoc* analysis of the reading rate data suggested:

- An ARMD related effect with a significant interaction between the ARMD group and the

SN group (p=0.01).

- A combined age and ARMD related effect with a significant interaction between the ARMD group and the YN group (p=0.01)
- No age-related effect, i.e. there is no significant interaction between the SN and YN groups (p=0.99).

Reading accuracy

Table 2.04 ANOVA: 3-factor split-plot, randomised design for reading accuracy

Effect	F	p
Main effect between subject groups	4.273	0.024
ND transmission	1.875	0.140
ND filter x subject group	1.163	0.508
Gel filter colour	0.766	0.508
Gel filter colour x subject groups	3.513	0.002
Gel filter colour x ND filter	0.660	0.745
Gel filter colour x ND filter x subject group	1.149	0.302

- Overall main effect of subject group (p=0.02), (figure 2.09).
- Significant interaction between filter colour and subject group (p=0.00), (figure 2.10).
- No significant effect of ND transmission (p=0.14).
- No significant effect of gel filter colour (p=0.51).

- No significant interaction between ND transmission and subject group (p=0.33).
- No significant interaction between ND transmission and gel filter colour (p=0.75).
- No significant interaction between ND transmission, gel filter colour, and subject group (p=0.30).

Scheffé's *post hoc* analysis of reading accuracy data indicated:

- An age-related effect with a significant interaction between the SN and YN groups (p=0.03).
- No ARMD related effect as there is no significant interaction between the ARMD group and SN group (p=0.66).
- No combined effect of ARMD and age, as there is no significant interaction between the ARMD and the YN group (p=0.17).

Some subjects may have read quickly but inaccurately and *vice versa*, i.e. there may have been a reading rate versus accuracy trade-off. The calculation required to determine if there was a reading rate versus accuracy trade-off is complicated by the large number of variables. It is doubtful whether any meaningful results could be obtained. A reading rate versus accuracy trade-off calculation has been conducted for several of the other experiments in this series. The results from experiment 2 are summarised in table 2.05.

Figure 2.04-subject group versus reading rate averages

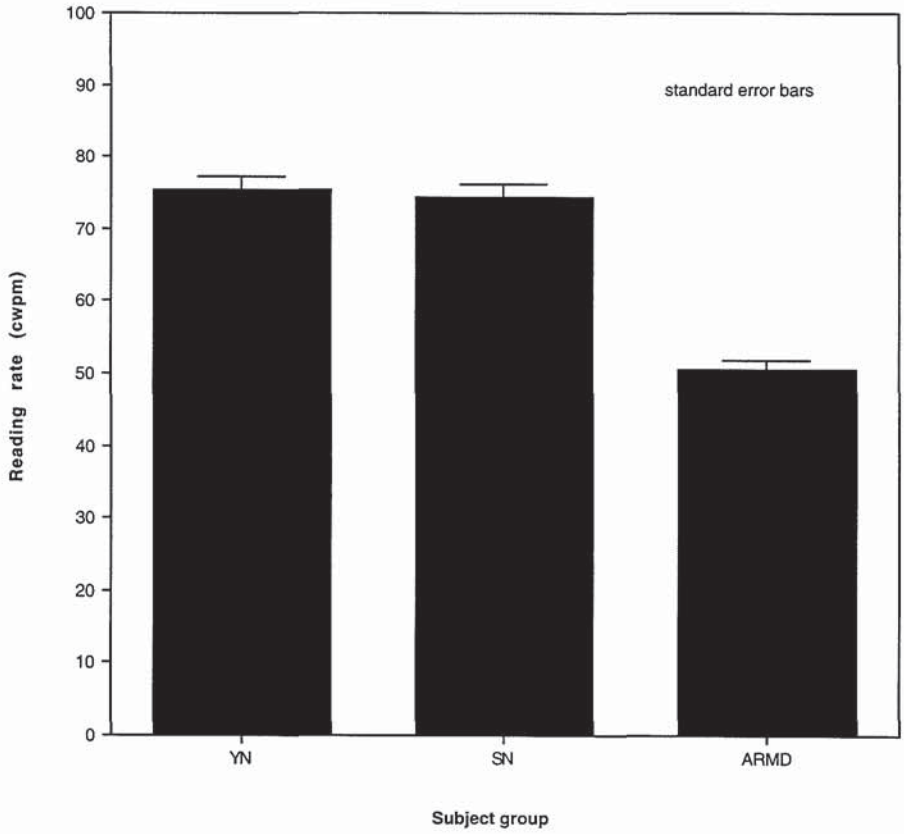


Figure 2.05-ND transmission versus reading rate averages

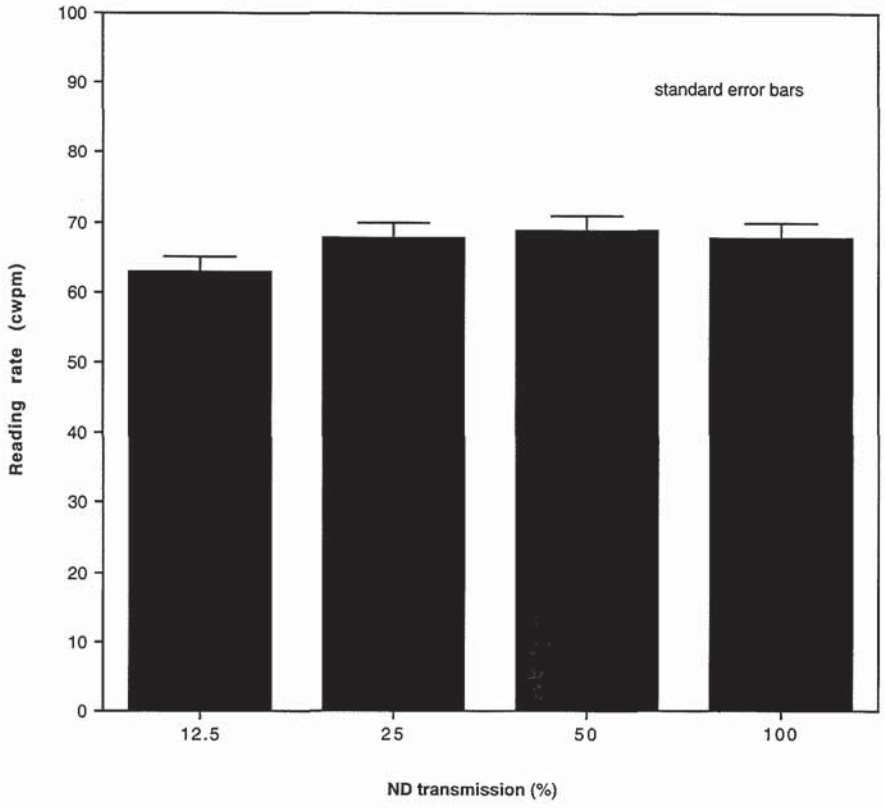


Figure 2.06-Coloured gel filter versus reading rate averages

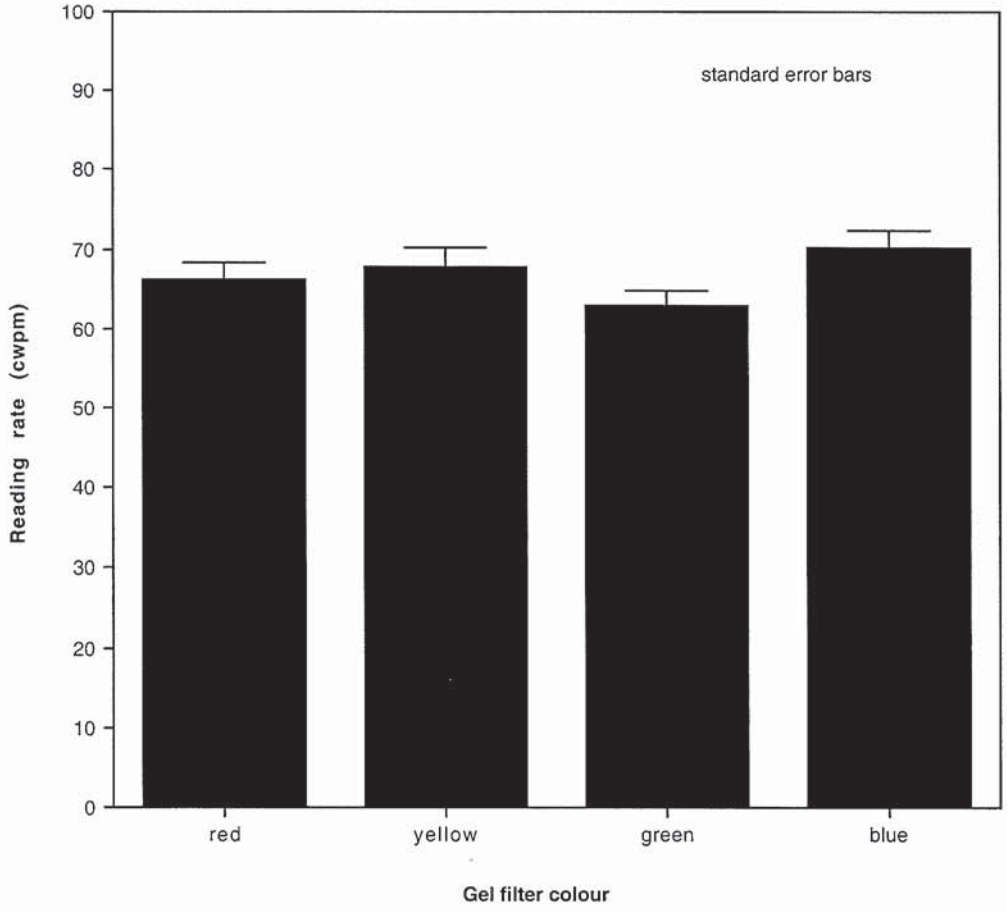


Figure 2.07-ND transmission versus
subject group for reading rate averages

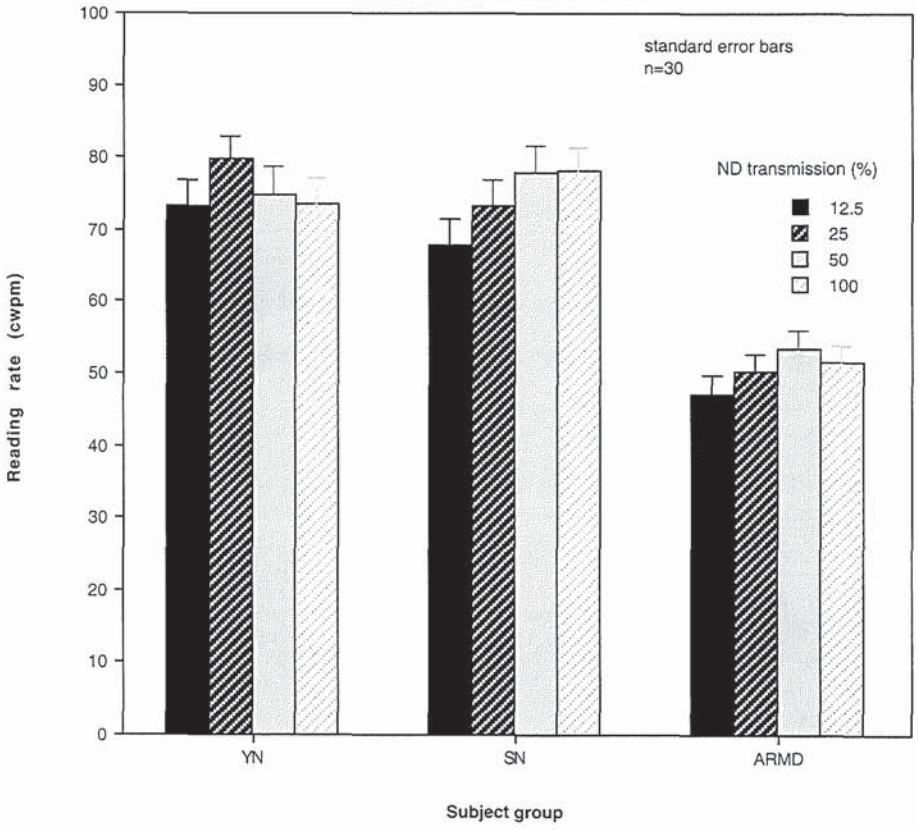


Figure 2.08-Gel filter colour versus
subject group for reading rate average

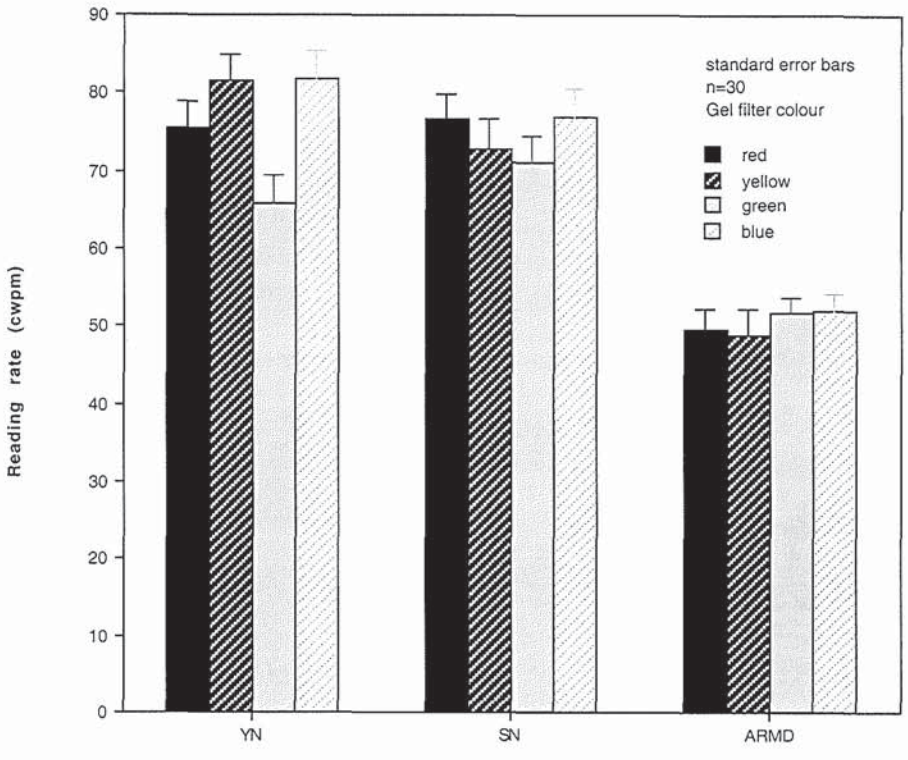


Figure 2.09-main effect of subject group on reading accuracy

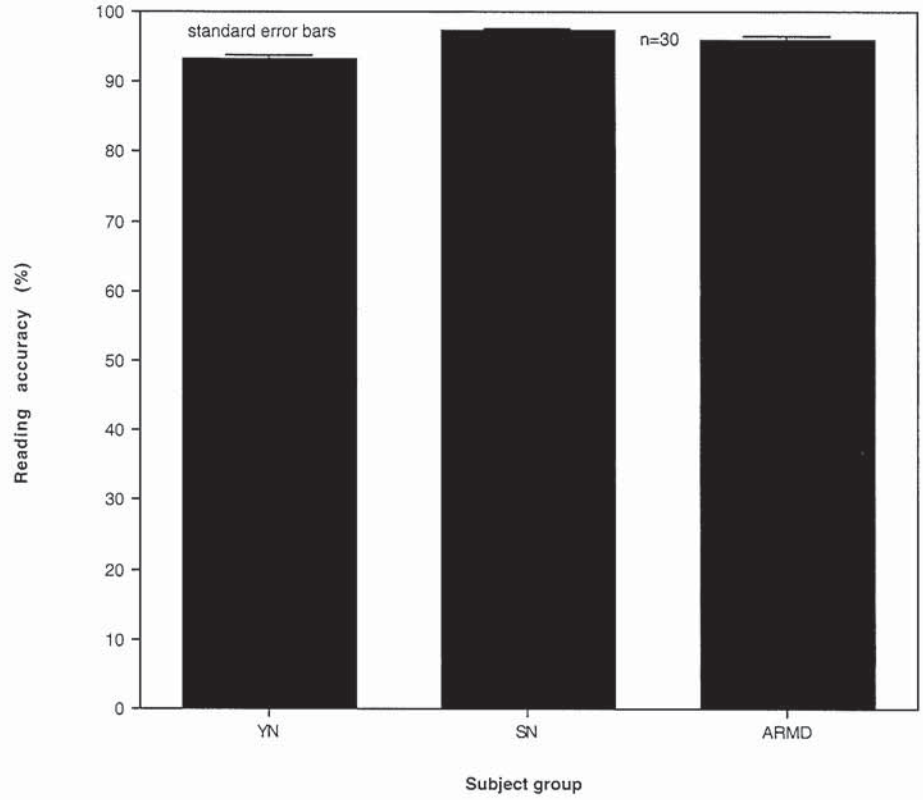


Figure 2.10-Gel filter colour versus
subject group for reading accuracy changes

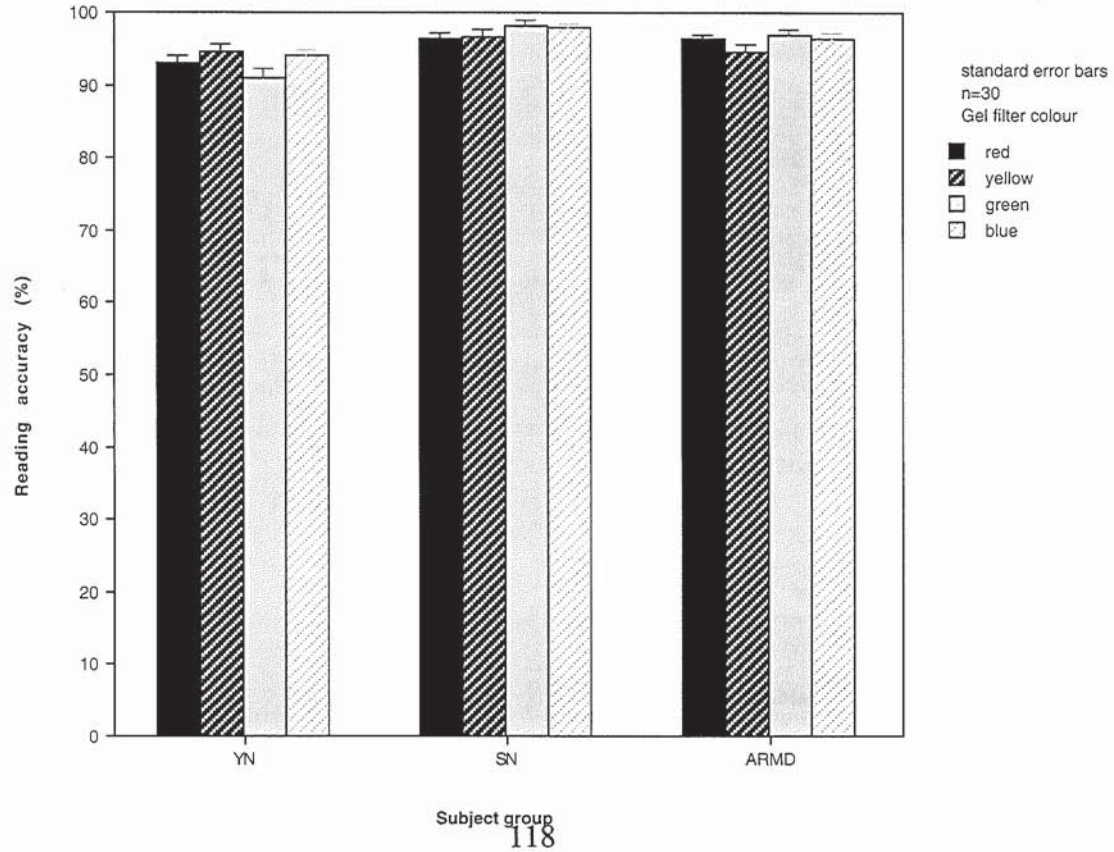


Table 2.05 summary of results for experiment 2-(projection gels)

Type of analysis	Results
ANOVA reading rate	YN>ARMD, SN>ARMD, YN=SN
ANOVA reading accuracy	SN>YN, SN=ARMD, YN=ARMD
Trends in the reading rate data	YN yellow and blue, and 25% ND
	SN blue and red, and higher TLT
	ARMD blue and green, and higher TLT
Trends in reading accuracy	YN yellow and blue, SN blue and green
data	ARMD no obvious trend

Discussion

This experiment was complex from the outset. It was designed to be a preliminary investigation to identify trends for further work and not to make detailed conclusions about specific effects of coloured and ND filters on subject groups.

Age and disease effects

YN and SN subjects read at approximately the same rate when averaged over the test conditions. Although there was no indication of clinically significant lens opacities in the SN group, intuitively they would have been expected to read slower because of other visual, perceptual and ocular changes associated with ageing. Wright and Drasdo (1985) have reported measurable losses in high spatial frequency contrast sensitivity, diminished low spatial frequency enhancement of contrast sensitivity due to temporal modulation in people over 60 years of age, and an age-related reduction in contrast sensitivity for moving gratings. With respect to this last point, images of letters move across the retina during reading, and therefore age-related deficits in reading text composed of very large letters could be expected.

Yellowing of the crystalline lens is considered to reduce retinal contrast, and this could also affect reading performance (Legge and Rubin, 1986). Not only did the SN group show a trend

to read at a similar rate as the YN group (figure 2.04), but also they were more accurate as a group (figure 2.09) therefore, overall reading performance was better. This suggested that reading rate is not affected by age while reading accuracy may have improved with age for the study population. These results agree with those presented by Legge (1991) in which a SN group did not show an age effect for reading rate, but subjects with ARMD did show such an effect.

Legge (1991) suggested that:

> 'Some unknown interaction between age and the presence of low vision depresses reading rates, and that one possible cause is the extra attention required to read in the face of visual impairment and that less capacity is available to older people.'

Akutsu *et al.* (1991) compared reading speeds of YN and SN subjects and found no significant difference over the range of character sizes (0.3 to 1 degree) for which normal reading speed is maximum. However, the SN subjects showed a slight reduction in reading speed (to about 70% of the YN rate) for very small and very large characters. It was concluded that advancing age *per se* has very little or no effect on maximum reading speed.

The ARMD group read slowest, but were approximately as accurate as the SN group. This may be one reason why people with ARMD are often observed to become frustrated when reading, they are accurate but their progress is slow. It is possible that the ARMD group performed slower than the SN group because of the lack of context in the test text, i.e. ARMD subjects need context more than normals to read effectively. However, work by Fine and Peli (1996) indicated that visually impaired readers use contextual cues available in sentences to about the same degree as readers with normal vision.

Reading accuracy differences between YN, SN and ARMD groups could be due to the time element of the investigation. The YN group may have competed to produce a 'high score' with respect to time and have less regard for accuracy. Senior subjects may have been keener on

being accurate rather than quick. Bailey *et al.* (1978) commented that their results may have may have been confounded by such an effect.

Trends in the data

It is interesting that there was a trend for better reading rates with 25% ND transmission than with 100% transmission for the YN group (figure 2.07). In other words a lower illuminance produced a better reading performance for the YN subjects in this particular study. The reason for this is unclear and this is in contrast to data reported by Lindner *et al.* (1989) who found that a group of normally sighted young subjects had higher subjective lighting needs than elderly subjects.

Unsurprisingly, trends for better reading rates were obtained with the higher transmissions for both the SN and ARMD groups (figure 2.07), i.e. YN subjects read adequately with dimmer light, but both senior groups read better with a brighter light. This differed from the results of Lagrow (1986) who noted that best reading performance did not occur at the highest illuminance (15070 lux) for a low vision population and that the median level for best reading performance was 2099 lux. This may be linked to the effect described by Sloan *et al.* (1973) and Eldred (1992) and investigated by Brown and Garner (1983), whereby subjects reported a fading of print with time when using high intensity illumination. They proposed a reduction in contrast detection to explain this phenomenon.

The natural peak spectral sensitivity of the retina indicates that for a subject with an intact and functioning fovea, i.e. the YN and SN groups, yellow illumination should produce the best reading performance (Hecht, 1928). Certainly for the YN group there was a trend for higher reading rate (figure 2.08) and reading accuracy (figure 2.10) with yellow illumination. It is unclear why there was also a similar trend with blue illumination. Poorer performance by this group with green illumination cannot be explained by the fact that the green filter had the lowest TLT, since this group as a whole performed better with the 25% ND filter. There could

be some colour specific reason why YN subjects as a whole performed poorly with the green filter.

The blue filter had the next lowest TLT, and therefore, green and blue gel filters should have produced the poorest reading performance, especially for the senior groups, as illuminance is usually more critical. However, inspection of figure 2.08 revealed trends in the data that indicated a higher reading rate with blue or red illumination for the SN group. Inspection of figure 2.10 revealed a trend for SN subjects to read more accurately with blue or green illumination.

It is surprising to find that the SN group performed well with blue or green illumination since age-related yellowing of the crystalline lens has been proposed to be the cause of increased intra-ocular scattering, especially with short wavelengths, even without the presence of an overt lens opacity (Weale, 1963). Carlyle *et al.* (1988) and Legge and Rubin (1986) have also postulated that glare due to scatter from the background of the text is likely to reduce retinal contrast and result in decreased reading ability. The reason why reading rate for the SN group was good with red illumination is difficult to explain and may have been due to peak retinal sensitivity factors.

A trend for higher reading rate with blue or green illumination can also be identified for the ARMD group (figure 2.08). Legge and Rubin (1986) found that for low vision observers with central versus peripheral field loss, generally, green and grey were the colours for which subjects showed the least departure from the maximum performance. They termed this scotopisation.

Wilkins *et al.* (1984) proposed that some non-visually impaired people are susceptible to cortical hyper-excitability, produced when the horizontal grating pattern made by lines of print on a page is viewed. He used the term pattern glare to describe this effect. An inappropriate

physiological excitation is thought to be responsible for perceptual distortions, such as words moving, lines of print wobbling, appearance of shapes within the body of the text, and colours around letters and words. Wilkins (1995) theorised that characteristics of this hyper-excitability implicate the magnocellular pathway as playing a role in this effect, and colour, in the form of overlays or tinted lenses may change the characteristics of the page, redistribute the patterning of cortical nervous activity and avoid areas of hyper-excitability.

None of the subjects in this study were questioned about the appearance of the test print, and some may have experienced perceptual distortions. However, ARMD often causes metamorphopsia (distortion of size and shape) and therefore it would be difficult to determine if the presence of distortions was due to pattern glare or ARMD. If present and due to pattern glare, these distortions may have been partially or totally alleviated with one or more of the filter colours and therefore resulted in a better reading performance. Phrased another way, some of the subjects may have improved in reading due to a colour effect on areas of cortical hyper-excitability and not because of a colour effect on age- or disease-related changes to the media or retina. It is not known if cortical hyper-excitability persists into old age, but the occurrence of migraine, which is often associated with the presence of visual distortions when reading, is known to decrease with age.

Subjects with central scotoma must rely more on peripheral vision for reading. Abramov and Gordon (1977) found that the peripheral retina of normal observers had an enhanced sensitivity to short wavelengths. Therefore, as people with central field loss may use paramacular and peripheral retina to read, it may be advantageous for them to use blue rather than red illumination. Results from the ARMD group agree with this proposal, since a trend to read quicker and more accurately with short wavelength (blue and green) illumination was identified. Conversely however, Legge and Rubin (1986) reported that the presence of a central scotoma was not predictive of wavelength effects on reading.

This discussion will be expanded in Chapter 5-General Discussion.

Limitations of the study

Because of the pilot nature of experiment 2 there are several limitations that may have confounded the results.

There was no control or standardisation of pupil size, however, some studies have suggested that the reduction in pupil size observed with age for normal observers does not produce any marked deterioration in visual function (Legge *et al.*, 1985; Elliot *et al.*, 1990). Work by Winn *et al.* (1994) indicated that older subjects have approximately the same pupil size as younger subjects at high luminance levels, but smaller pupil size at lower luminance levels. Therefore the use of a non-standard pupil size probably did not affect the results.

There was no attempt to correct for ocular chromatic aberration. This could have been achieved using a trial frame and lenses, however the need for a good field of view and scanning eye movements made this impractical. Knoblauch *et al.* (1991a) calculated luminance artefacts associated with lateral chromatic aberration on a model eye, for equiluminant text, and found they occurred along vertical but not horizontal chromatic borders. Their relevance to reading has yet to be determined.

Information on the binocular extent and depth of the central scotoma for each ARMD subject would have allowed any interaction between scotoma size, reading performance and illuminance to be determined. However, Bullimore and Bailey (1995) found that for their ARMD subjects, scotoma size was only moderately associated with reading speed.

ARMD is known to result in acquired colour vision defects. Blue-yellow defects are common in early stages with red-green defects occurring as VA worsens (Campbell and Rittler, 1972). Colour vision evaluation using a matching test such as the Lanthony or PV-16 (both modified

D-15 tests for use in low vision) would allow confounding effects from any acquired colour vision defects to be determined.

There was no normalisation of coloured gel filter TLT. In an attempt to keep the experiment simple, and to make use of materials that were unmodified from their commercial form, standard gel filters were used and TLT was not normalised. A confounding factor is introduced which makes it difficult to establish whether effects are purely due to a change in gel filter colour, or due to combined effect of gel filter colour and illuminance. It may have been more appropriate to use the gel filters in an unmodified form as well as in a normalised for TLT form, to determine whether effects on reading performance were due to colour or illuminance or a combination of both. Also, a no filter (colour or ND) test condition would have allowed a comparison between reading performance with coloured and unmodified illuminance [see Experiment 3 (gel filters), Chapter 3-Primary Experiments].

Test words were chosen to be ordinary and every day, which were unlikely to provide any cognitive difficulties for any of the subjects. It would have been more appropriate to choose test words from a compendium listing the most common written English words (Hofland and Johansson, 1982). Also, a conventional reading age test would have provided psychometric data to demonstrate that all subjects had at least a certain minimum reading age, e.g. the British Ability Scales (Elliott *et al.*, 1983) (appendix 4).

The reading task was a naming test since unrelated words were used. This is similar to, but not the same as, reading since there are no contextual clues. A passage of text with meaning would present a more real world reading task. However, to produce several passages of similar difficulty and context level, for use under many different test conditions would prove difficult. One study has shown that readers with central field loss use contextual clues in sentences to about the same degree as readers with normal vision (Fine and Peli, 1996) and that random word lists are not the most appropriate measure of potential reading rates. But Legge *et al.*

(1989) have shown that reading rates for contextual sentences and random words are correlated. Reading rates for random words will be slower than sentences. Due to the contextual advantage of sentences not all words need to be fixated. Hence, the use of random words might exaggerate the effect of visual anomalies and visual interactions making this task more suitable for this type of study.

It is useful to know the extent to which learning and fatigue influence results. A repeat of the first test condition at the end of the experiment could help evaluate possible effects due to these factors.

The SN group was not identical in age to the ARMD group and this may have introduced a source of error. Pearson's correlation coefficient indicated no statistical association between the age of the SN group and reading rate and accuracy (r=-0.311 and -0.578) or between the age of the ARMD group, and reading rate and accuracy (r=-0.222 and -0.302) at the 0.05 confidence level. Hence, the lower age of the SN group probably did not confound the results.

Jeanes *et al.* (1997) found that 51 to 54% of children from two school classes (not screened for learning problems, binocular vision dysfunction or the presence of perceptual distortions) preferred to read with one or more coloured overlays over the text, and that colour choice was idiosyncratic. Tyrrell *et al.* (1995) also found that 50% of children with average or above reading ability preferred to read with a coloured overlay rather than a clear overlay. These studies suggest that some individuals with normal academic performance may prefer to read with colour on the page of text. This phenomenon may have affected the results presented here, in that some of the differences in reading performance between colours may have been due to this effect, rather than to an age or ARMD related effect. Future work can overcome this by comparing the colour which provides the best reading performance for each subject, with that of a ND filter matched to give the same overall transmission as the coloured filter [Experiment 3 (gel filters), Chapter 3-Primary Experiments].

The outcome measures of reading rate and accuracy could be confounded, since rate is defined as the number of words correctly read, and subjects were instructed to read words aloud as quickly as possible without errors. By using a simple task and asking the subjects not to make errors it may have been possible to use only reading rate as a measure of reading performance (Evans, 1998).

Jeanes *et al.* (1997) addressed this issue in normal children by looking at the correlation between rate and accuracy. They showed that the type of errors did not differ between children who chose coloured overlays for reading compared with those who did not. Also they demonstrated that those who read fastest tended to be most accurate ($p<0.001$) and presumed that subjects were following the instruction to read as fast as they could but for consistent accuracy. This is also demonstrated in the present study. Those subjects who read quickly also read accurately and therefore, it may be sufficient to use reading rate as the only parameter to monitor the effects of various colour interventions for the other experiments in this series.

The conclusions derived from the data presented here are based on averages of reading rate and accuracy, and since there is considerable variation in standard clinical measures for ARMD subjects, it is unlikely that the findings described can be applied to every individual case. The experiment was too complex with too many variables. This meant that statistical analysis was difficult. Other experiments in this series had simpler designs with fewer variables and therefore the results were easier to analyse.

These limitations, discovered either during the testing procedure or data analysis, have been used to refine subsequent experimental designs in order to facilitate the provision of more detailed and specific results and conclusions.

Questions raised by the study

- Why did both SN and ARMD groups perform better with short wavelength illuminance?

- Can colour be used to modify local lighting, and improve reading performance in ARMD? If yes, does the same colour assist all ARMD subjects, and will this colour affect reading rate and reading accuracy in the same way; what mechanism may be responsible for this effect, and where in the visual system could this mechanism operate?
- Do reading rate and reading accuracy decrease with time due to 'fading', and if so how long does this take? Is this why people with ARMD have to take frequent breaks when reading?

Some of these questions will be further discussed in Chapter 3-Primary Experiments.

Conclusions

The main aims of identifying interactions and suggesting trends that could be analysed with further work and of establishing experimental limitations to allow refinement of future investigations have been achieved. The results allow the following conclusions to be reached:

Reading rate

- ARMD has a negative effect, ARMD combined with age has a negative effect, but age alone does not have an effect on reading rate.
- There is a trend in the data for the YN group to have a higher reading rate with yellow or blue illumination; the SN group with blue or red illumination; the ARMD group with blue or green illumination.

Reading accuracy

- Increasing age had a positive effect, there was no disease effect, and there was no combined disease and age effect.
- There is a trend in the data for the YN group to have a higher reading accuracy with yellow or blue illumination; the SN group with blue or green illumination; no trends were clearly identifiable by inspection from the ARMD reading accuracy data.

Chapter 3- Primary Experiments

Introduction

This chapter forms the main part of the thesis. It includes methods, results, discussions and conclusions for the following experiments:

- Experiment 3-Investigation of the effects of five coloured gel filters on reading performance in ARMD.
- Experiment 4-Investigation of the effects of Intuitive Coloured Overlays® on reading performance in ARMD.
- Experiment 5-Comparison of the effects of several tinted lenses on reading performance in ARMD.
- Experiment 6-Comparison of the effects of several video-magnifier background screen colours on reading performance in ARMD.

Subjects

Three groups of subjects were used; 15 YN subjects; 13 SN subjects; 16 ARMD subjects (table 3.00). Not all groups and not all subjects were used in all experiments. For logistical reasons YN, SN and ARMD subjects varied for each experiment and none were used from experiments 1 or 2. For most subjects the experiments were conducted over two or three test sessions. Due to individual time constraints and fatigue many of the ARMD subjects required three sessions.

It was ascertained either from recent ocular records or direct monocular ophthalmoscopic observation that none of the normals had any clinically significant media opacities or retinal

disease. Subjects with media opacities were excluded in order to equalise selective absorption effects between groups. None of the subjects had any systemic disease, and none were taking any prescribed medication that may have interfered with vision. All had English as their first language.

Subjects who normally used a refractive correction for reading wore their own glasses for all test conditions. Observers were not refracted for different illuminance colours to compensate for chromatic aberration. None of the ARMD group was observed to be fixing eccentrically although this was not monitored technically and all groups used natural pupils (see below). None were aware of any congenital colour vision defects or any recent changes in colour discrimination. All subjects were naive as to the possible benefits of colour on reading. None of the subjects had any apparent cognitive deficits, although this was not formally tested psychometrically.

Sloane *et al.* (1988) found that older adults even when considered clinically normal, tend to experience significant losses in spatial CS that were exacerbated under low environmental light levels. Vision loss was especially significant at the lowest luminance. The results indicated that this was not due to age-related miosis. When the senior adults' pupils matched the pupil size that naturally occurred in young adults at that light level, older observers still exhibited approximately the same magnitude of vision loss. In addition, the older adults' CS loss at any of the tested light levels could not be compensated for by a simple increase in diameter of the entrance pupil. Older adults' best CS was often with the natural pupil, despite the fact that it was miotic at the lower light levels and thereby reduced retinal illumination.

Contrary to common claims in the literature, it is incorrect to suggest that age-related miosis is a detriment to older adults' spatial vision; age-related miosis does not appear to hamper, CS, and in some cases is a hidden asset in that it slightly improves spatial CS. This could be due to the fact that the older eye has increased optical density of the ocular media, particularly the

crystalline lens (Weale, 1963), which increases intra-ocular light scatter thereby degrading the retinal image and reducing image contrast. A smaller pupil may actually be an asset under these circumstances, since it limits optical aberration and improves depth of focus, which facilitates image formation in the older eye.

The YN group consisted of six male and nine female undergraduate optometry students from the Department of Optometry and Vision Sciences at Aston University. All had a near binocular threshold reading acuity of at least N5, with the Bailey-Lovie near word reading acuity card, at their habitual working distance.

The SN group consisted of seven male and six female patients attending for routine eye examination at the Department of Optometry and Vision Sciences at Aston University. All had a near binocular threshold reading acuity of at least N5, with the Bailey-Lovie near word reading acuity card, at their habitual working distance.

The ARMD group consisted of one male and 15 female patients who had attended for a low vision evaluation at Birmingham Focus on Blindness Low Vision Centre. All had bilateral non-exudative ARMD to varying degrees. None had undergone any form of ocular medical or surgical treatment.

The visual qualifying criteria for this group was a best corrected near binocular threshold reading acuity of at least N20 their habitual reading distance with their own spectacles. This level of vision was used as a cut-off since it approximates to the font size used in large print books. From personal clinical observation, this is considered to be the smallest font size that ARMD subjects are likely to attempt to read in daily life, without having to resort to the use of a low vision magnifier.

It had been intended to use a spouse, age-similar control group but this was not possible as the

Table 3.00 subject age (years) details for primary experiments

YN	Age	SN	Age	ARMD	Age
AC	23	DL	71	BM	87
AG	32	DP	71	CP	80
DS	20	EC	73	DS	70
EM	24	EE	74	EH	78
FR	29	FF	66	GH	85
GF	20	GM	63	GS	82
KB	20	JS	73	ID	82
LB	33	MW	60	KH	76
NC	20	RP	69	MA	87
NH	20	RT	71	MB	80
NL	21	SL	61	MC	81
NS	41	TH	66	MH	87
RT	20	VG	74	MJ	84
SB	27			MS	86
SD	21			NJ	73
				WH	79

ARMD subjects available for the study were all widowed. It also proved difficult to find other age-similar control subjects without ocular disease. Statistical analysis using a t-test indicated that the SN group was younger than the ARMD group (see each subsequent experiment for specific details). Thus the SN group cannot strictly be termed a control group and is best described as an age similar group. This will be further discussed in the results section.

For logistical reasons the YN and SN groups were assessed in the Department of Optometry and Vision Sciences, Aston University, and the ARMD group was assessed at the Birmingham

Focus on Blindness Low Vision Centre. Experimental conditions were matched for the two locations.

Procedure

The procedure for each experiment is described in detail in each individual write-up. It was decided from the out set to use each coloured intervention in its standard commercially available state with little or no modification. In experiment 3 (gel filters) ND filters were added to the gel filters in order to normalise the TLT with respect to the green gel filter, which had the lowest transmission (Evans, 1997b). However, as one aim of this work was to determine the effect of specific interventions rather than effect of the colour of that intervention, interventions were not normalised for transmission in subsequent experiments.

Materials

Specific materials used in each individual experiment are described in the respective write-up. However, a description of the reading charts used throughout the series is included here. Two types of chart were used to measure reading rate and reading accuracy, the Bailey-Lovie near word reading acuity cards and the Wilkins Rate of Reading Test ® (WRRT).

BAILEY-LOVIE NEAR WORD READING ACUITY CHART

(Clement Clarke International, Edinburgh Way, Harlow, Essex, CM20 2TT, UK).

This chart was used in experiments 3 (gel filters) and 7 (luminaires).

Introduction

These charts have been designed for use mainly in clinical low vision research and practice, and to provide systematic assessment of reading acuity and visual efficiency for reading. They enable the clinician to predict how much extra detail would be resolvable if the working

distance, the dioptric power of the addition, or the magnification of the system were to be changed. The can also be used to predict how much change in the working distance, dioptric power of an addition, or magnification is required to enable the reading of a certain size of print

Design

This is a series of near-vision cards in which the type face, the size progression, size range, number of words per row, spacings and word selections were chosen in an endeavour to achieve a standardisation of the test task. A reasonable degree of literacy is required and therefore the cards are not useful for evaluating the capacity of individuals to read efficiently.

The range of size on these cards extends from 80-point to 2-point print, and the progression of size is essentially logarithmic (80, 64, 48, 40, 32, 24, 20, 16, 12, 10, 8, 6, 5, 4, 3, 2.5 and 2). There are six words per row in the 11 lower size levels. To keep the chart as a manageable size, there are fewer words per row at the six largest levels; the three upper most rows have two words, and the next three rows have three words. Lower case 'Times Roman' type face is used on the charts because it is similar in appearance and legibility to the styles of typefaces customarily used in newspapers and books. The spacing between letters and between rows is standardised by setting the type with the closest spacings that would be used in regular type setting. The charts have been printed by offset printing on matt white cards 26 x 20.5 cm.

In each of the six-word rows there are two 4-letter, two 7-letter and two 10-letter words. Three notations of size have been used on the charts. Each row carries a label indicating the point size of the print. These labels are under the heading 'N' and logMAR required to read the print when the chart is 25 cm from the eye. The logMAR range is from 0.0 for the smallest (2-point) print up to 1.6 for the largest (80-point) print. The third notation is M units where, by definition, 1.0M print has letters which subtend 5 seconds arc at one metre (Bailey and Lovie, 1980).

Reading rate was calculated by noting the time elapsed, in seconds, prior to cessation of reading; this figure was divided into 60 and the result multiplied by the total number of words read correctly. Reading accuracy was determined by dividing the number of words correctly identified by the sum of the number of words attempted including those that the observer passed on. This procedure was used to determine reading rate in terms of correct words per minute (CWPM) and reading accuracy in terms of percentage for each measurement for every subject.

Note: Reading accuracy calculated as a percentage of the total words on each card is not a true measure of reading accuracy but more a measure of reading acuity. Reading accuracy has to be measured in terms of the percentage of words read correctly up to the subject's acuity threshold. Words at print sizes smaller than the reading acuity threshold cannot be included since the subject would be unable to read them.

WILKINS RATE OF READING TEST® (WRRT)

(IOO Marketing Ltd, 56-62 Newington Causeway, London SE1 6DS).

This chart was used in experiments 4 (overlays), 5 (tinted lenses), and 6 (video-magnifier).

Introduction

The WRRT was originally designed to measure the effects on reading of visuo-perceptual distortions of text, such as apparent movement of the words and letters, blurring and coloured halos. Subjects are required to read text that looks like a passage of prose, but consists of random words. The reading is independent of syntactic and semantic constraints but requires all the usual visual and visuo-perceptual processing.

The test is used to compare an individual's performance under one set of visual conditions with that under another. It is claimed to take less than two minutes to administer for a

normally sighted subject, and to be sufficiently sensitive to reliably reveal the improvement in reading fluency that often results for children with learning problems when coloured overlays are used (Wilkins *et al.,* 1996). The test can be used to compare reading performance under different conditions, e.g. with and without a coloured intervention for a low vision group.

The individual is required to read the text aloud as rapidly as possible; the reading is timed and errors are noted. Reading ability is assessed in terms of rate and errors rather than in terms of difficulty of the words read. The syntactic and semantic properties of the text are minimised by the use of randomly ordered words. All the words are of very high frequency of occurrence in everyday text and should be familiar to subjects of age seven and above. The same 15 common words are used in each line, in a different random order. All the words used in the test are selected from the 110 most frequent words in a count of words in children's reading books (see, the, look, dog, and, not, is, you, come, up, play, to, my, for, cat).

Multi-equivalent versions of the test are available by rearranging the word order. The reading of equivalent passages can therefore be assessed under different visual conditions and the effects of practice balanced over time. The test is not designed to compare one individual subject with others of the same age or ability.

Performance of the test is reliable on retest, but is not strongly correlated with age, or with performance on other more conventional reading tests. There is no evidence that individuals with normal vision who read faster do so because they tolerate a greater number of errors. In general, the conditions that give rise to errors also give rise to slower reading (Wilkins *et al.*, 1996). This test chart has not yet had independent validation.

Administration and scoring of the WRRT (from WRRT manual)

- The reading test can only be given to subjects who can correctly read the words printed in large type. Ask the subject to read aloud all the words printed in large type. If there are

errors, correct them, and ask the subject to re-read the words. If the subject continues to make errors, stop the test at this stage.

- Tell the subject the task is to read a passage with just these words in, and to read the words aloud as quickly as possible without errors.
- Start the stopwatch and tape recorder as the subject is instructed to begin.
- Stop the watch after the passage has been completed.
- This process is repeated for each coloured intervention.
- Replay the tape and use a score sheet (enlarged version of the text) to calculate the number of words correctly read per minute for each coloured intervention. The reading speed is usually the best single measure of performance because most errors tend to decrease the speed either by reducing the number of words correctly read or by increasing the time taken to read the passage.

Reading rate for all experiments was calculated by noting the time elapsed, in seconds, prior to cessation of reading; this figure was divided into 60 and the result multiplied by the total number of words read correctly. Reading accuracy for all experiments involving the WRRT was determined by calculating the percentage of words read correctly from the total presented. Using this procedure reading rate in terms of CWPM and reading accuracy in terms of percentage of words read correctly was determined for each of the six test conditions for each subject.

Note: Reading accuracy calculated as a percentage of the total words on each card is a true measure of reading accuracy and not a measure of reading acuity, since all the words presented to each observer were the same point size. Therefore reading accuracy could be measured in terms of the percentage of words read correctly out of all the words on the card.

The reading task was a word recognition or naming test since unrelated words were used. This is similar to, but not the same as, reading since there are no contextual clues. Legge *et al.*

(1989) have shown that reading rates for contextual sentences and random words are correlated. Reading rates for random words will be slower than sentences. Due to the contextual advantage of sentences not all words need to be fixated. Hence, the use of random words might exaggerate the effect of visual anomalies and visual interactions making random words more suitable for this type of study.

Analyses

ANOVA

Reading rates were compared across coloured interventions and subject groups with an ANOVA and *post-hoc* examination of significant differences using Scheffé's S test (a conservative *post-hoc* test) (Snedecor and Cochran, 1989) or the Duncan New Multiple Range test (a less conservative test) for those single factor ANOVA p values equal to or less than 0.05. The results of individual groups were examined in a similar way. A conservative *post hoc* test is one that is less likely to suggest there is a significant interaction or relationship between sets of data, when one doesn't in fact exist.

Chi squared analysis

Data was also analysed in terms of ranking frequencies, i.e. coloured interventions were ranked according to how many times each one performed the best, how many times it came second, third etc. Frequencies were then further analysed using a Chi squared technique to determine if there was any statistical significance in distribution. It was not possible to carry out this analysis using a parametric ANOVA, since the data consisted of a few small whole numbers. Non-parametric ANOVA is a complex process and not as appropriate as Chi squared analysis in this case.

Individual subject analysis

Coloured intervention effects were assessed by expressing reading performance scores as percentages of the scores achieved with no filter. It is possible that a coloured intervention

might not be beneficial for all subjects. Therefore a *post-hoc* search was made through the individual percentage change scores for any individuals who had significant reading benefits produced by the coloured interventions. All occurrences in which there was an arbritary 20% improvement in either reading rate or reading accuracy, when compared to the no coloured intervention test condition, were identified, as described by Yolton *et al.* (1995).

Learning and fatigue analysis

For each experiment and for each observer the first test condition was repeated at the end of the test. Even though the order of coloured intervention presentation was randomised, it was still considered necessary to determine if there were any learning or fatigue effects that may confound the results. The 'before and after' data were statistically compared using a matched pairs t-test.

Reading rate and reading accuracy trade-off analysis

Jeanes *et al.* (1997) showed that reading rate and reading accuracy were positively correlated (Pearson correlation) for a group of school children when using coloured overlays for reading, i.e. the increase in rate resulting from the use of overlays was associated with an increase in accuracy. Both measures were therefore consistent in showing improvements with the overlay and there was no evidence for any rate/accuracy trade-off.

Despite this result, Wilkins (1998) has advised that it may not be adequate to use reading rate alone as an outcome measure. It would be important to look at reading accuracy for low vision individuals as it may prove to be different from a population of school children. Therefore all reading rate and accuracy data was analysed for trade-off using the Pearson correlation technique. This technique does however assume that there is a linear relationship between rate and accuracy and it would not detect a non-linear relationship.

EXPERIMENT 3-EFFECTS OF FIVE COLOURED GEL FILTERS ON READING PERFORMANCE IN ARMD

Introduction

This experiment was a continuation of experiment 2, using a refined, less complex design with fewer variables. The aim was to produce less complex data, that could be statistically analysed, and to draw stronger conclusions than those from experiment 2.

In experiment 2, YN subjects performed well with yellow illumination; this was expected since the young retina is maximally sensitive to approximately 550 nm wavelengths, which produce yellow light (Hecht, 1928). Higher reading rates obtained with blue illuminance are more difficult to account for.

The SN group had a trend for better reading rate with blue or red illuminance, and for better reading accuracy with the blue or green illuminance. This was a surprising outcome since age-related yellowing of the crystalline lens has been proposed to result in increased intra-ocular scattering, especially with short wavelengths as transmitted by the blue and green gel filters, even without the presence of an overt crystalline lens opacity (Carlyle *et al.*, 1988). The resultant retinal image degradation, could produce a reduced reading performance, compared to a filter transmitting longer wavelengths (Weale, 1963).

Legge and Rubin (1986) postulate that glare due to scatter from the background of the text is likely to reduce retinal contrast and result in decreased reading ability. Therefore a poorer performance with blue illuminance would have been expected. The trend for a better reading rate for the SN group with red is also difficult to account for, but may be related to less scattering of long wavelengths.

Experiment 2 indicated that subjects with ARMD had a trend for improved reading

performance with a blue or green filter. This was surprising since these filters had the lowest TLT, and therefore produced the lowest illuminance out of the four filters used (red, yellow, green and blue). A better performance with gel filters that produced a higher illuminance on the page would have been expected from the results of earlier research (Sloan, 1969; Sloan *et al.*, 1973; Zhokhov *et al.*, 1976; Silver *et al.,* 1978; Lagrow, 1986; Collins, 1987; Cornelissen *et al.*, 1991).

As experiment 2 was a pilot study it had many limitations which affected the results and therefore limited the strength of the conclusions; there were too many variables which made analysis of the results complex. One of the main criticisms of experiment 2 was the lack of normalised TLT for the coloured gel filters. This made it difficult to ascertain whether variation in reading performance was due to a change in colour, or light transmission or both (Evans, 1997b). In an attempt to overcome this, gel filters in experiment 3 were normalised to produce approximately constant TLT. ND filters were attached to the red, yellow and blue gel filters to reduce TLT to approximately match that of the green gel filter.

The findings for the ARMD group from experiment 2 were unexpected, i.e. blue and green illuminance produced trends of better reading performance, than did yellow for both groups of senior subjects. This warranted further investigation with an improved experimental design.

The two main groups of interest were the SN and ARMD groups. Older people often complain of reduced reading performance in poor light conditions, probably due to various factors including pupil miosis and subsequent reduced retinal illuminance, yellowing of the crystalline lens resulting in light scatter, and a general depression in retinal sensitivity at low light levels. People with ARMD have to contend with the effects of a degenerative macula as well as these physiological changes. The YN group was included solely to determine if there were any age-related, or age combined with disease, related effects.

Aim

To assess the effect of local lighting filtered with five coloured gel filters on reading performance for YN, SN and ARMD subjects.

Method

Subjects

See table 3.01 for subject age and threshold binocular reading acuity.

Table 3.01 subject age (years) and threshold binocular reading acuity for experiment 3 (gel filters)

YN	Age	Reading acuity	SN	Age	Reading acuity	ARMD	Age	Reading acuity
AC	23	N3	DL	71	N5	BM	87	N12
AG	32	N2.5	DP	71	N3	CP	80	N10
DS	20	N3	EC	73	N5	DS	70	N16
EM	24	N2.5	EE	74	N4	ID	82	N10
FR	29	N2.5	FF	66	N6	KH	76	N8
GF	20	N4	GM	63	N6	MA	87	N6
KB	20	N2.5	JS	73	N3	MB	80	N16
LB	33	N2	MW	60	N5	MC	84	N8
NC	20	N3	RP	69	N5	MH	87	N6
NH	20	N3	RT	71	N3	MJ	81	N8
RT	20	N2	SL	61	N4	NJ	73	N8
SB	27	N2.5	VG	74	N4	WH	79	N16

Binocular threshold reading acuity as measured with a Bailey-Lovie near word card at each observer's habitual working distance. YN mean age (years) 24, median 21.5, range 20 to 33, SD 5.01; SN mean age (years) 69, median 71, range 60 to 74, SD 5.08; ARMD mean age (years) 81, median 81, range 70 to 87, SD 5.48. The difference between the average age for the SN and ARMD groups was statistically significant ($t=5.406$, $p=0.001$).

Materials

- Luminaire Model 871, IBJ, with a 11W cool white PL, compact fluorescent lamp. The spectral distribution of this lamp was unknown. (Daylight Studios, 223a, Portobello Road, London, W11 1LU)
- Four coloured gel filters; red (Roscolene #603), yellow (Roscolene #09), green (Lee #244) and blue (Lee #202) as used in experiment 2.
- 50% and 70% (approximately) ND transmission filters.
- Five different Bailey-Lovie reading acuity near word cards.
- Stop watch.
- Dictating type mini-tape recorder.
- Score sheet.
- Light meter (Eurisem Technics EP 628, Digital Lux Meter).

The filters had the following transmissions as determined using the light meter; red 65.66%, yellow 69.08%, green 44.61%, and blue 59.90%. A 69.30% transmission ND filter was attached to the red, yellow and blue filters to produce the following TLT values; red 45.50%, yellow 47.87%, and blue 41.51% respectively. The green filter with 44.61% TLT was not treated with the ND filter. This was the closest match possible in TLT with the available ND filters. The light meter was not calibrated as relative and not absolute values of TLT were required.

Procedure

Subjects were seated at a desk that was illuminated by the reading lamp placed at 25 cm from the surface of the desk producing 3330 lux at the desk surface. Testing was conducted in a dark room with minimal ambient illuminance (35 to 40 lux). Those that needed refractive correction for the reading distance wore their current pair of spectacles, either bifocals or single vision.

A Bailey-Lovie reading acuity near word card was placed flat on the desk and subjects were asked not to move or tilt the card and the position of the luminaire adjusted to reduce the chance of disability glare from the card. Each subject was given the same instructional set but was not told of the aims of the research. They were asked to read out loud from the card, as accurately and as quickly as possible (the emphasis was placed on accuracy) starting at the top of the card and reading down until the words were too small to see. All subjects were informed that the words had no contextual clues and therefore the reading would not make sense. Subjects were allowed to read at their habitual working distance, were advised not to move closer when attempting to read the small words, and were encouraged to guess or pass on words they were unsure about.

Subjects were advised that they would be tape-recorded and that the tape would be analysed later to determine reading rate and reading accuracy, and then erased. Reading performance was taped with each filter (red, yellow, blue, green and 50% ND filter) and with local lighting only, i.e. without any filter in place. Filters were attached directly in front of the compact fluorescent lamp with sticky tape.

Reading acuity cards and gel filters were randomly selected in order to reduce the possibility of learning and fatigue effects. If the cards had been presented in the same order for each subject an improvement may have occurred with the last presentations due to learning. Conversely, the last presentations may have been effected by subjects becoming tired. Both these effects should have been minimised by random presentation. Because there were six different test conditions and only five different reading acuity cards, one card was randomly selected and presented for two of the test conditions. The no filter condition was used at the start of the investigation and then repeated at the end using the same Bailey-Lovie near word reading card. By comparing performance at the beginning and the end of the test session, using exactly the same conditions and test card, any learning or fatigue effects could be detected.

Tape recordings were replayed and each subject scored by measuring the total time elapsed until the subject could not continue reading because of the small size of the words and by noting errors on a score sheet which comprised a computer printed N14 version of the Bailey-Lovie reading card. Errors were defined as missing out a word, miss-identification, and passing on a word. The introduction of extra words was not scored as an error, as this would be reflected in the reading speed. Reading rate and reading accuracy were calculated as described in the introduction to Chapter 3-Primary Experiments. Reading rate and accuracy at the beginning and at the end of the test were averaged and compared, using the Pearson correlation technique, to check for any learning or fatigue effects.

Questions to be answered

- Does data analysis reveal any inter-group effects of the gel filters on reading performance? That is, are there any disease, age, or disease combined with age related effects?
- If reading rate and accuracy values are normalised to the no filter condition, is it possible to demonstrate beneficial effects of filters on an individual subject basis?
- Are there any individuals who show exceptionally strong beneficial effects of the filters, and if so, what factors might account for these?
- If there is an effect, does one coloured filter consistently produce the best reading performance?
- Are there any learning or fatigue effects?
- Was there a reading rate versus reading accuracy trade-off?

Results

See appendix 1.01 for raw data.

ANOVA

Reading rates were compared across coloured gel filters and subject groups with an ANOVA spilt-plot and *post-hoc* examination of significant differences using Scheffé's S test for those

ANOVA p values less than or equal to 0.05. The results of individual groups were examined in a similar way.

ANOVA indicated there was a main effect for subject group but no coloured gel filter versus subject group interaction for reading rate. Scheffé's S *post-hoc* test on subject group highlighted a significant difference between the ARMD and SN groups, ARMD and YN group, and no significant difference between the results of the SN and YN groups (table 3.02), i.e. there is a disease effect and also a an age combined with disease effect but no age alone effect on reading rate. There is no significant colour effect for any individual group on reading rate (table 3.03).

For reading accuracy (table 3.04) there was also a main effect for subject, and as for reading rate no coloured gel filter versus subject group interaction. Scheffé's *post-hoc* test for subject group highlighted a significant difference between the YN and ARMD groups, but not between YN and SN groups, and SN and ARMD groups, i.e. there was an age combined with disease effect but no age and no disease alone effect on reading accuracy. When the groups were analysed individually (table 3.05) there was no significant effect of colour on reading accuracy for any group.

Table 3.02 ANOVA spilt-plot and Scheffé's S *post hoc* table for all subjects for reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	2	77187.67	38593.83	18.09	.0001	replicant (subject)
replicant (subj...	33	70415.25	2133.80	23.70	.0001	Residual
colour	5	235.75	47.15	.52	.7581	Residual
colour * subject	10	1078.82	107.88	1.20	.2956	Residual
Residual	165	14856.15	90.04			

Dependent: reading rate

Scheffe's S
Effect: subject
Error term: Type III sum of squares for replicant (subject)
Dependent: reading rate
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
ARMD	SN	27.20	19.73	.0050	S
	YN	46.05	19.73	.0001	S
SN	YN	18.85	19.73	.0636	

S = Significantly different at this level.

Table 3.03 ANOVA spilt-plot for YN, SN, ARMD groups respectively for reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	48230.29	4384.57	22.17	.0001	Residual
colour	5	948.31	189.66	.96	.4510	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	10879.12	197.80			

Dependent: reading rate

Note the only relevant effects are replicant, filter colour and filter colour versus subject. The ANOVA software did not allow for deletion of the non-relevant sections of this table.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	5875.21	534.11	14.97	.0001	Residual
colour	5	130.02	26.00	.73	.6047	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	1961.90	35.67			

Dependent: reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	16309.75	1482.70	40.47	.0001	Residual
colour	5	236.24	47.25	1.29	.2817	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	2015.13	36.64			

Dependent: reading rate

Table 3.04 ANOVA spilt-plot and Scheffé's S *post hoc* table for all subjects for reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	2	1096.87	548.43	5.01	.0126	replicant (subject)
replicant (subj...	33	3612.31	109.46	6.13	.0001	Residual
colour	5	16.95	3.39	.19	.9661	Residual
colour * subject	10	118.10	11.81	.66	.7590	Residual
Residual	165	2946.71	17.86			

Dependent: reading accuracy

Scheffe's S
Effect: subject
Error term: Type III sum of squares for replicant (subject)
Dependent: reading accuracy
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
ARMD	SN	4.10	4.47	.0781	
	YN	5.25	4.47	.0182	S
SN	YN	1.16	4.47	.8034	

S = Significantly different at this level.

Table 3.05 ANOVA spilt-plot for YN, SN, ARMD groups respectively for reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	67.07	6.10	2.43	.0153	Residual
colour	5	1.41	.28	.11	.9891	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	138.20	2.51			

Dependent: reading accuracy

Note the only relevant effects are replicant, filter colour and filter colour versus subject. The ANOVA software did not allow for deletion of the non-relevant sections of this table.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	292.16	26.56	3.75	.0005	Residual
colour	5	32.24	6.45	.91	.4806	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	389.16	7.08			

Dependent: reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	3253.07	295.73	6.72	.0001	Residual
colour	5	101.40	20.28	.46	.8035	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	2419.35	43.99			

Dependent: reading accuracy

Chi squared analysis

Data was also analysed in terms of ranking frequencies as described in the introduction to Chapter 3-Primary Experiments (table 3.06a, b, c)

The no coloured gel filter condition (averaged before and after test session data) produced third place ranking a significantly greater number of times than any other position for the YN group for reading rate (Chi squared=18, p=0.01). Yellow and red filters ranked significantly in first place for YN subjects (Chi squared=17, $p < 0.05$ and Chi squared=12, $p<0.05$ respectively). The green gel filter ranked first significantly more times than any other position (Chi squared =12, $p<0.05$) for reading accuracy for the SN group. For the ARMD group the only significant result was for green in first place for reading accuracy position (Chi squared =11, $p<0.05$). There were no significant results for reading rate.

Individual subject analysis

As mentioned in the introduction to this chapter, it is possible that the coloured gels might not be beneficial for all subjects, and that benefits for individual subjects may be lost in the averaging of data for conventional statistical analysis. Therefore, a *post hoc* search was made through normalised reading rate and accuracy values for individuals who had significant reading improvement in performance produced by one or more coloured gel filters, in other words, all occurrences in which there was a 20% improvement between the coloured gel filter and no filter condition were identified.

None of the YN group showed such an improvement with any of the coloured gel filters. One SN subject, GF demonstrated a 30% increase in reading rate with the red coloured gel filter and a 31% increase with the yellow coloured gel filter. However, four ARMD subjects demonstrated an increase in reading rate of over 20%: DS blue 36%; KH yellow 35%; MC blue 28% and ND 83%; WH ND 25%. No such affects were detected for reading accuracy.

Table 3.06a

Ranking frequencies and Chi squared analysis

YN	reading rate (cwpm)						reading accuracy (%)					
gel	no gel	rose	yellow	green	blue	ND	no gel	rose	yellow	green	blue	ND
ranking	(average)						(average)					
1	1	1	4	2	2	3	4	6	7	5	5	5
2	2	2	1	3	2	1	2	1	0	1	2	0
3	7	0	1	2	1	1	2	0	1	2	0	0
4	2	2	3	3	1	1	2	3	0	0	1	2
5	0	4	3	0	1	4	1	1	2	2	3	1
6	0	3	0	2	5	2	1	1	2	2	1	4
Chi^2	18*	5	6	3	6	4	3	12*	17*	7	8	4

*significant at the 0.05 confidence level

Table 3.06b

Ranking frequencies and Chi squared analysis

SN	reading rate (cwpm)						reading accuracy (%)					
gel	no gel	rose	yellow	green	blue	ND	no gel	rose	yellow	green	blue	ND
ranking	(average)						(average)					
1	3	1	2	1	4	1	3	4	5	6	5	5
2	4	0	2	3	1	2	0	1	0	2	0	1
3	1	3	1	3	0	4	2	2	1	0	1	3
4	3	3	1	1	1	3	1	2	2	1	2	0
5	0	3	4	2	3	1	4	1	3	1	1	1
6	1	2	2	2	3	1	2	2	1	1	3	2
Chi^2	6	4	3	2	6	4	5	3	8	12*	8	8

*significant at the 0.05 confidence level

Table 3.06c

Ranking frequencies and Chi squared analysis

ARMD	reading rate (cwpm)						reading accuracy (%)					
gel ranking	no gel (average)	rose	yellow	green	blue	ND	no gel (average)	rose	yellow	green	blue	ND
1	2	2	1	0	4	3	5	5	6	5	5	5
2	3	2	1	2	2	2	1	1	0	1	3	2
3	2	3	2	0	2	3	3	2	1	0	2	1
4	2	1	2	4	1	2	2	3	1	0	0	0
5	3	1	2	2	3	1	1	0	2	3	1	2
6	0	3	4	4	0	1	0	1	2	3	1	2
Chi^2	3	2	3	8	5	2	8	8	11*	10	8	7

*significant at the 0.05 confidence level

Figure 3.0a-YN gel filters
reading rate versus reading accuracy

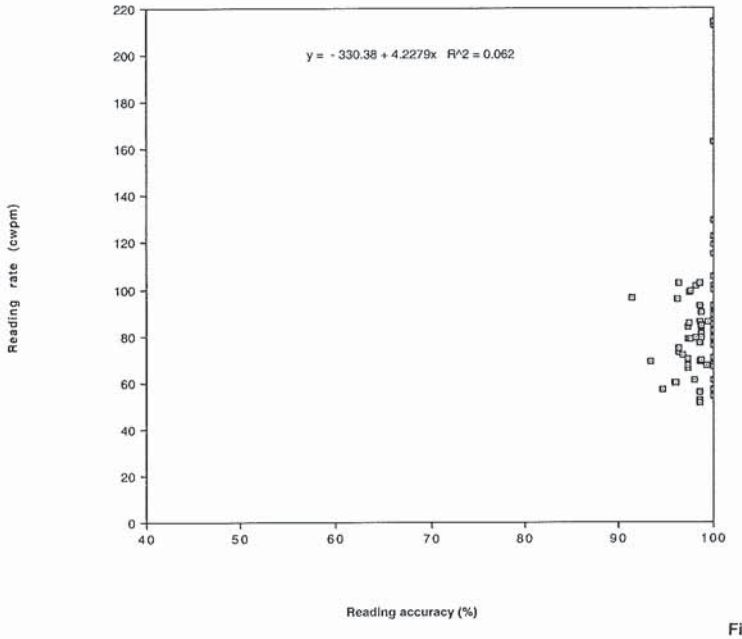


Figure 3.0b-SN gel filters
reading rate versus reading accuracy

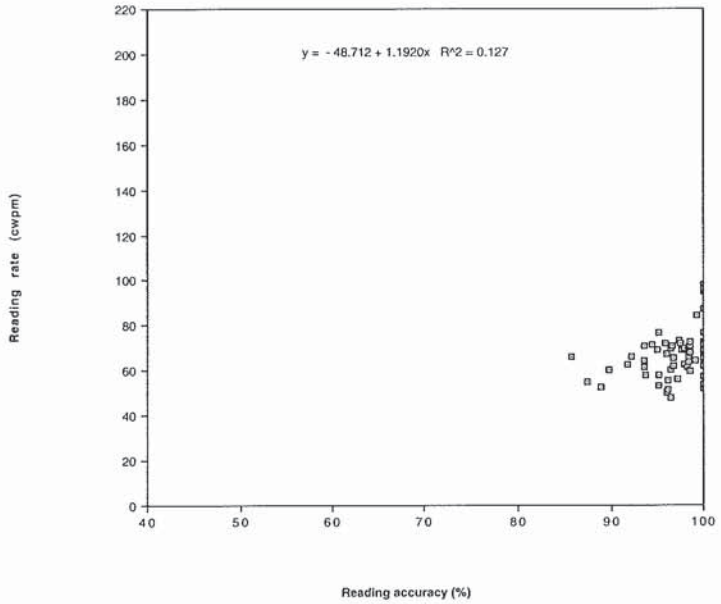
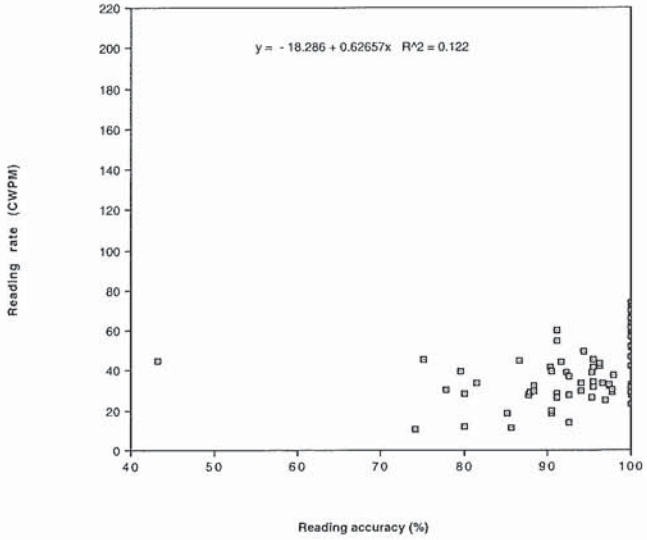


Figure 3.0c ARMD gel filters
reading rate versus reading accuracy



Reading rate versus reading accuracy trade-off analysis

There may have been a reading rate versus reading accuracy trade off in this experiment, i.e. those subjects that read quickly may have done so at the cost of reduced accuracy, and those that read slowly may have had better accuracy. In order to investigate this reading rate was plotted against reading accuracy for subject groups and the Pearson correlation coefficient (r) and the coefficient of determination (r^2) were calculated for each group (figures 3.00a, b, and c). For YN, r^2 =0.062, r=0.249 ($p<0.05$); SN r^2 =0.127, r=0.356 ($p<0.05$); ARMD r^2 =0.122, r=0.349 ($p<0.05$).

This suggested that for the YN group 6.2% of the variation in reading rate is attributable to the linear variation of reading accuracy (statistically significant at the 0.05 confidence level), and therefore 83.8% of the variation is attributable to other factors not measured or accounted for in this study.

For SN group 12.7% of the variation in reading rate is attributable to the linear variation of reading accuracy (statistically significant at 0.05 confidence level), and therefore 87.3% of the variation of reading rate is attributable to other factors not measured or accounted for in this study.

For the ARMD group 12.2% of variation in reading rate is can be accounted for by the linear variation of reading accuracy (statistically significant at 0.05 confidence level), and therefore 87.8% of the reading rate variation is due to other factors.

For all groups r is positive and indicates that as reading rate increased so did accuracy.

Learning and fatigue effects

There was no statistically significant difference in reading rate for any group when the before and after results were compared: YN t= -0.868, p=0.40; SN t= -0.249, p=0.81; ARMD t = -

0.533, p=0.65. Similarly there was no difference for reading accuracy: YN t= -0.484, p=0.63; SN t= -1.028, p=0.32; ARMD t=0.700, p=0.49.

Discussion

ANOVA indicates that there was no significant overall interaction between subject group and coloured gel filters for reading rate and accuracy, i.e. there was no inter-group effect of coloured gel filters. Scheffé's *post-hoc* test suggested a negative effect of ARMD, and age combined ARMD with on reading rate (table 3.02) but no effect of age alone. There is also a negative effect of age combined with ARMD on reading accuracy but no effect of age and disease alone (table 3.04). In summary, the data indicated that ARMD combined with age had a detrimental effect on reading performance but, interestingly, there was no significant effect of age alone, and ARMD had an effect on reading rate but no effect on reading accuracy.

Ranked frequency analysis highlighted that for the YN group the only significant differences in ranking was for the no gel filter condition, which performed marginally better (ranked third) than any of the other conditions for reading rate and, i.e. the YN group as a whole read faster with un-filtered illuminance. YN subjects read more accurately with the yellow and red filters, and this could be explained by the higher sensitivity of the young visual system to medium wavelengths.

For SN subjects the only significant effect was for the green gel filter, which ranked significantly in first for reading accuracy. This is surprising given that age related crystalline lens changes (even when not clinically significant) are thought to result in ocular scattering and retinal image degradation. This may be explained by spherical aberration effects in the crystalline lens and which are thought to result in a clearer focus of short wavelength light on the retina than long wavelength light.

For the ARMD group there were no significant differences in ranking for reading rate but the

yellow filter ranked significantly first for reading accuracy. This may be explained by a yellow bias in the older crystalline lens.

Individual analysis revealed that one SN subject experienced a substantial increase in reading rate with the red and yellow gel filters. In the ARMD group, one subject read faster with yellow, two with blue, and two with ND filters. Reading improvements with gel filters producing long wavelengths (red or yellow) may be explained in terms of the crystalline lens scattering phenomenon, i.e. long wavelengths are scattered less than short wavelengths and therefore result in a better quality retinal image. The positive effect of the blue gel filter for two ARMD subjects may be explained using the theory of increased peripheral retina sensitivity to blue light proposed by Abramov and Gordon (1977) (see Chapter 5-General Discussion).

These results differ from those of experiment 2, in which trends for improved reading performance with different coloured gel filters was identified (yellow or blue best for YN; red, blue, or green best for SN; blue or green best for ARMD). Because the coloured gel filters used in experiment 2 were not normalised for TLT, these observed trends may have been produced by a variation in TLT, or TLT combined with gel filter colour, and not gel filter colour alone.

An interesting feature of the results from this experiment is the difference in results from the three analysis techniques, i.e. ANOVA, Chi squared and individual subject analyses. The first two would suggest no real benefit to be gained from the use of coloured gel filters (in fact some of the results suggested a poorer reading performance with filters than without). However, the individual analysis does show that for some subjects, especially those with ARMD, coloured gel filters can produce a substantial improvement in reading rate.

Correlation coefficients indicate that a relatively small, but statistically significant, proportion

of the variation in reading rate can be attributed to the variation in reading accuracy. In other words, it is unlikely that there was a substantial reading rate versus reading accuracy trade-off for the any of the study groups. In future research of this kind and in clinical assessment it may, therefore, be acceptable to analyse only one of these parameters as an outcome measure.

Reading rate and accuracy at the start and at the end of the session were not statistically different. This demonstrates that there were no significant effects of fatigue and learning on the results.

Conclusions

Reading rate

- ANOVA analysis indicated a negative effect of ARMD, and age combined with ARMD on reading rate, but no effect of age alone.
- Chi squared analysis indicated that local illuminance alone (no filter) produced a moderately good reading rate for the YN group.
- Individual analysis indicated that some people with ARMD could achieve substantial improvements in reading rate with a yellow, blue or ND filter.

Reading accuracy

- ANOVA analysis indicated a negative effect of age combined ARMD on reading accuracy, but no effect of age or disease alone.
- Chi squared analysis indicated that the yellow and red filter produced good reading accuracy for the YN group; green produced the best results for the SN group and yellow for the ARMD group.
- There were no individual effects of filters on reading accuracy.

See table 3.07 for summary of results from experiment 3 (gel filters).

Table 3.07 summary of results for experiment 3 (gel filters)

Type of analysis	Results
ANOVA reading rate	YN>ARMD, SN>ARMD, YN=SN
ANOVA reading accuracy	YN>ARMD, SN>ARMD, YN>SN
Chi squared reading rate	YN no gel filter third
Chi squared reading accuracy	YN yellow and red first
	SN green first
	ARMD yellow first
Individual reading rate	YN none
	SN red 30%, yellow 31%
	ARMD blue 28% and 36%, ND 25% and 83%,
	yellow 35%
Individual reading accuracy	none
Rate versus accuracy	YN 6.2%* SN 12.7%*, ARMD 12.2%*
Learning/fatigue	none

*significant at the 0.05 confidence level

EXPERIMENT 4-EFFECTS OF INTUITIVE COLOURED OVERLAYS® ON READING PERFORMANCE IN ARMD

Introduction

Experiments 2 and 3 were conducted using coloured gel filters that were originally designed to alter the colour of lighting used in theatrical performances. One of the most interesting findings from experiment 3 was that individual subject analysis might reveal reading performance improvements that were not apparent from ANOVA or Chi squared analyses. Using individual analysis yellow, blue and ND gel filters were identified as interventions that produced a substantial benefit in reading performance for some subjects with ARMD.

At the time that experiments 2 and 3 were conducted coloured gel filters were also being used by some eye care practitioners and also by teachers, in research, clinical, and educational environments, with people who had a non-ocular disease related, acquired reading dysfunction, especially that caused or exacerbated by Meares-Irlen Syndrome[4]. The aim was to reduce the visual distortions and discomfort associated with this syndrome by reading through coloured gel filters placed on printed text.

Coloured gel filters sample colour space in a random non-scientific manner, i.e. the available range of colours is not wide enough to ensure that colour space is amply represented and some subjects may not be tested with the colour they require. Therefore, Wilkins (1994) designed a set of coloured plastic overlays (Intuitive Coloured Overlays®), for use as a reading aid by

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[4]Meares-Irlen Syndrome can be summarised as the presence of symptoms (eyestrain, headache and anomalous visual effects such as illusions of shape, motion and colour) which are alleviated by coloured filters. (Evans *et al.* 1994b). Anomalies of binocular vision have been proposed as the cause of perceptual distortion, resulting in headaches and eyestrain (Schieman *et al.*, 1990) but Evans *et al.* (1994a) have now refuted this. Wilkins *et al.* (1984) suggested that some of the perceptual origins have a central origin. They proposed a neurological theory of visual discomfort that attributed the distortions to a cortical hyperexcitabilty (see Chapter 5-General Discussion).

those with Meares-Irlen Syndrome, in an attempt to improve reading and consequently learning skills. The overlays sample CIE 1976 colour space (hue angle h_{uv} and saturation s_{uv}) in an ordered and scientific manner, systematically and efficiently (appendix 2). It is recommended that they are placed over printed text at near, under average classroom or home lighting conditions, produced by a mixture of fluorescent and tungsten sources. They are now commercially available.

When experiments 2 (projection gels) and 3 (gel filters) were designed and conducted, Intuitive Coloured Overlays® were not yet available. Results from these two experiments may have in some way been influenced by the fact that coloured gel filters do not sample colour space accurately.

Some practitioners have already conducted clinical assessments on low vision individuals and have used subjective observations in their decision to supply Intuitive Coloured Overlays® as a reading aid (Lightstone, 1997a). This could be described as premature in view of the lack of objective clinical data in this field.

Experiment 4 was designed to investigate the possible application of Intuitive Coloured Overlays® to aid reading with ARMD, in a scientifically rigorous manner, with an experimental design that was improved in view of the experience gained in experiments 2 (projection gels) and 3 (gel filters).

Any positive outcome from this assessment of Intuitive Coloured Overlays® would be more easily adaptable and versatile in the home or work environment. A visual impaired person would probably find it easier to place a coloured overlay on the printed page, compared to fixing, and possibly later removing a coloured filter gel from a reading lamp as used in experiment 3.

Aim

To assess the effect of Intuitive Coloured Overlays® on reading performance, for YN, SN and ARMD subjects.

Method

Subjects

Table 3.08 contains subject age (years) and threshold binocular reading acuity.

Table 3.08 experiment 4 (overlays)-subject age (years) and threshold binocular reading acuity

YN	Age	Reading acuity	SN	Age	Reading acuity	ARMD	Age	Reading acuity
AC	23	N3	EC	73	N4	BM	87	N12
AG	32	N2.5	EE	74	N5	CP	80	N10
DS	20	N3	DL	71	N6	DS	70	N14
EM	24	N2	DP	71	N3	EH	78	N18
FR	29	N2.5	FF	66	N4	GH	85	N17
GF	20	N2	GM	63	N6	ID	82	N6
LB	33	N3	JS	73	N4	KH	76	N8
NC	20	N3	MW	60	N5	MC	81	N8
NL	21	N2.5	RP	69	N5	MH	87	N6
NS	41	N2.5	RT	71	N5	MJ	84	N8
SB	27	N2.5	SL	61	N3	MS	86	N4
SD	21	N2.5	VG	74	N6	WH	79	N10

Threshold binocular reading acuity measured with a Bailey-Lovie near word card observer's habitual working distance. YN mean age (years) 26, median 23.5, range 20 to 41, SD 6.68; SN mean age (years) 68, median 71.5, range 60 to 74, SD 5.08; ARMD mean age (years) 81, median 81.5, range 70 to 87, SD 5.07. There is a statistically significant difference in the

average age of the SN and ARMD subjects (t=6.00, p=0.00).

Materials

- Intuitive Coloured Overlays® (IOO Marketing Ltd., 56-62 Newington Causeway, London, SE1 6DS, UK) comprise ten, A5 sized, plastic coloured sheets, in the following colours (figures in brackets are luminance values in cdm^{-2}); rose (230), pink (220), purple (195), aqua (210), blue (195), lime-green (240), mint-green (230), yellow (270), orange (240), and grey (205) (figure 3.01 for overlay transmission curves). A clear overlay (360 cdm^{-2}) (Roscolene #00) with 100% transmittance was used to allow comparison with a non-filtered condition, i.e. with the reading lamp alone and also to act as a control filter. These luminance values have been obtained from marketing literature and the conditions under which they were made is not known.

Note the following measures were taken to convince subjects that this clear filter was 'special' and to enhance the associated placebo effect. The control filter was described as clear overlay with a special ultra-violet light coating developed in the USA and this was thought to 'reduce glare from the page and to improve reading'.

- The WRRT (IOO Marketing Ltd., 56-62 Newington Causeway, London, SE1 6DS, UK) was modified and printed in font sizes ranging from four to 18-point. There were 12 different paragraphs in each font size, with 10 lines and 15 words per line, resulting in a total of 150 words per block. Each line had the same words (see, the, look, dog, and, not, is, you, come, up, play, to, my, for, cat) but in a different arrangement.
- Fourteen-point size version of WRRT used as a score sheet (appendix 8.00).

The following as in experiment 3 (gel filters):

- Compact fluorescent lamp.
- Light meter.
- Stop watch.
- Dictating type mini-tape-recorder.

Procedure

Subjects were seated at a desk that was illuminated by general room lighting (strip fluorescent) and a local compact fluorescent lamp, 25 cm from the desk surface (total of 3330 lux at desk surface). It had been intended to use a font size for the test paragraphs one point larger than the threshold binocular reading acuity obtained with the Bailey-Lovie reading card at each observer's habitual reading distance. However, during test sessions many subjects, especially those with ARMD, found reading with a font size so close to threshold to be fatiguing and on occasion unpleasant. Therefore the smallest WRRT test paragraph font size that each subject found acceptable in terms of visual and mental comfort was used.

Prior to the start of the testing session, subjects were shown large print (N40) versions of the words used in the WRRT and asked to read them out loud twice to encourage familiarity. They were informed that the test paragraphs comprised solely of these words, and that each line had a different arrangement of the same words, that the paragraphs had no contextual clues and that the reading would not make sense. For each subject the same size font was used in each paragraph and for each test condition, but font size varied between subjects.

Each subject was given the same instructional set but was not told of the aims of the research. They were asked to 'read out loud from the paragraph, as accurately and as quickly as possible with the emphasis on accuracy starting at the top of each paragraph and reading until the end was reached'. Subjects were encouraged to either guess or to say pass on words they were unsure about, and were advised that they would be tape-recorded and that the recording would be analysed later to determine reading rate and accuracy, and then erased. Subjects were advised to read at their habitual working distance, which was monitored for consistency. They were asked not to move closer when attempting to read small or more difficult words.

There were 12 different test conditions and 13 measurements (the first and last test conditions were identical, i.e. no overlay used). Blocks of print were presented in the same order for all

subjects but overlays were randomly selected in order to reduce the possibility of the results being confounded by learning effects. Each subject was asked to read one block of 150 words with each overlay with both placed on a flat desk surface. Some subjects found this task very tiring and managed to read only 75 words with each overlay. Tape recordings were later replayed after each testing session and each subject scored by measuring the total time taken to read each paragraph (or part paragraph if the subject was unable to complete), and noting the errors on a score sheet. Errors were defined as missing out a word, miss-identification or passing on a word. The introduction of extra words was not scored as an error, as this would be reflected by the reading rate.

Reading rate and accuracy were calculated and fatigue and learning effects investigated as outlined in the introduction to this chapter.

Questions to be answered

- Does data analysis reveal any inter-group effects of the overlays on reading performance? In other words, are there any disease, age, or disease combined with age related effects?
- Are there any beneficial reading performance effects demonstrated for any of the overlays?
- If there are any individuals who show exceptionally strong beneficial effects of the overlays, what factors might account for this?
- If there are any effects, either on a group or individual basis, does one coloured filter consistently produce the best reading performance?
- Are there any learning or fatigue effects?
- Was there a reading rate versus reading accuracy trade-off?

Results

See appendix 1.02 for raw reading rate and accuracy data.

ANOVA

Reading rate and accuracy were compared across overlays and subject groups using a split plot ANOVA procedure and Scheffé's S test *post-hoc* examination of significant differences for those ANOVA p values less than or equal to the 0.05 confidence level. The results for each group were examined in a similar way.

There is a significant subject effect on reading rate (F, 11.11, p=0.00, df 2, 330) (table 3.09) and reading accuracy (F, 5.10, p=0.01, df 2, 330) (table 3.10). This is not surprising as the ARMD group was expected to have a poorer reading performance compared to the YN and SN groups. F-values for colour effect, and colour versus subject interaction were not significant at the 0.05 confidence level for reading rate or accuracy.

Scheffé's *post-hoc* test indicated a significant difference in reading rate between the ARMD and SN groups (p=0.03) and the ARMD and YN groups (p=0.00), and for reading accuracy between the ARMD and YN groups (p=0.01). There was no significant difference between the SN and YN groups for reading rate and between ARMD and SN, and SN and YN for reading accuracy.

The results of a split plot ANOVA for each group for reading rate and reading accuracy are shown in table 3.11 and 3.12. For all groups there is no significant colour effect on reading rate or reading accuracy at the 0.05 confidence level.

Table 3.09 ANOVA split-plot and Scheffé's S test *post-hoc* table for all subjects for reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	2	258130.86	129065.43	11.11	.0002	replicant (subject)
replicant (subj...	33	383393.85	11618.00	99.61	.0001	Residual
colour	10	2066.57	206.66	1.77	.0647	Residual
colour * subject	20	2346.26	117.31	1.01	.4546	Residual
Residual	330	38489.56	116.64			

Dependent: reading rate

Scheffe's S
Effect: subject
Error term: Type III sum of squares for replicant (subject)
Dependent: reading rate
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
ARMD	SN	37.74	34.01	.0268	S
	YN	62.06	34.01	.0002	S
SN	YN	24.32	34.01	.2020	

S = Significantly different at this level.

Table 3.10 ANOVA spilt-plot and Scheffé's S test *post-hoc* table for all subjects for reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	2	6022.99	3011.49	5.10	.0117	replicant (subject)
replicant (subj...	33	19473.70	590.11	28.89	.0001	Residual
colour	10	297.18	29.72	1.45	.1552	Residual
colour * subject	20	644.70	32.24	1.58	.0559	Residual
Residual	330	6741.77	20.43			

Dependent: reading accuracy

Scheffe's S
Effect: subject
Error term: Type III sum of squares for replicant (subject)
Dependent: reading accuracy
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
ARMD	SN	5.43	7.66	.2082	
	YN	9.52	7.66	.0120	S
SN	YN	4.10	7.66	.4015	

S = Significantly different at this level.

Table 3.11 ANOVA split-plot tables for YN, SN and ARMD groups respectively for reading rate

Note the only relevant effects are replicant, filter colour and filter colour versus subject. The

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	143902.90	13082.08	86.01	.0001	Residual
colour	10	1894.86	189.49	1.25	.2704	Residual
colour * subject	0	•	•	•	•	Residual
Residual	110	16731.03	152.10			

Dependent: reading rate

ANOVA software did not allow for deletion of the non-relevant sections of this table.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	121743.52	11067.59	122.62	.0001	Residual
colour	10	838.52	83.85	.93	.5097	Residual
colour * subject	0	•	•	•	•	Residual
Residual	110	9928.62	90.26			

Dependent: reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	117747.43	10704.31	99.53	.0001	Residual
colour	10	1679.45	167.95	1.56	.1276	Residual
colour * subject	0	•	•	•	•	Residual
Residual	110	11829.91	107.54			

Dependent: reading rate

Table 3.12 ANOVA split-plot tables for YN, SN and ARMD groups respectively for reading accuracy

Note the only relevant effects are replicant, filter colour and filter colour versus subject. The ANOVA software did not allow for deletion of the non-relevant sections of this table.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	41.71	3.79	2.76	.0034	Residual
colour	10	14.74	1.47	1.07	.3909	Residual
colour * subject	0	•	•	•	•	Residual
Residual	110	151.38	1.38			

Dependent: reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	3908.00	355.27	28.95	.0001	Residual
colour	10	111.67	11.17	.91	.5268	Residual
colour * subject	0	•	•	•	•	Residual
Residual	110	1349.76	12.27			

Dependent: reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	15524.00	1411.27	29.62	.0001	Residual
colour	10	815.48	81.55	1.71	.0868	Residual
colour * subject	0	•	•	•	•	Residual
Residual	110	5240.62	47.64			

Dependent: reading accuracy

Chi squared analysis

Data was also analysed in terms of ranking frequencies. Chi squared analysis indicated no statistical difference in ranking frequency distribution, for YN and SN reading rate, for any overlay (table 3.13a and b). ARMD results indicated a significant cluster for rose in 7th and 8th positions (Chi squared, 22.83, p=0.05), blue 9th and 10th positions (Chi squared, 19.17, p=0.05), and purple in 11th (Chi squared, 21.00, p=0.05), (table 3.13c).

For reading accuracy most of the overlays had a significant cluster in first position for the YN group, although clear was ranked first the greatest number of times (ten) (table 3.13d). SN results indicated a significant cluster for clear, (Chi squared, 28.33, p=0.01), ND (Chi squared, 21.00, p=0.05), and mint-green overlays (Chi squared, 39.33, p=0.01) in 1st position, although mint-green was ranked first the greatest number of times (seven) (table 3.13e). For the ARMD group clear (Chi squared, 28.33, p=0.01), and lime-green overlays (Chi squared, 22.83, p=0.05) produced significant clusters in first position, although the clear overlay was ranked first the greatest number of times (table 3.13f).

Individual subject analysis

It is possible that the Intuitive Coloured Overlays® were not beneficial for all the subjects. Therefore, all reading rate and reading accuracy values were normalised to the clear overlay reading condition, and a *post hoc* search was made through the normalised reading rate and accuracy values for any individuals who had significant reading benefits produced by the overlays. All occurrences in which there was an arbritary 20% improvement were identified.

From the YN group the following subjects demonstrated reading rate improvements: LB; lime-green 40%, yellow 24%, rose 31%; AG blue 23%, grey 22%, mint-green 36%, pink 32%; EM pink 24%. From the SN group: RP; grey 37%; EC rose 23%. None of the ARMD subjects improved by as much as 20%. These values are for reading rate; none of the overlays produced a 20% increase in reading accuracy for any of the subjects.

Table 3.13a

Ranking frequencies and Chi squared analysis for the YN group reading rate

YN reading rate (CWPM)

colour / ranking	rose	pink	purple	aqua	blue	yellow	ND	clear	mint-green	orange	lime-green
1	1	1	1	1	1	1	0	1	1	1	3
2	2	1	1	1	2	1	0	0	0	2	1
3	1	0	0	0	3	2	1	3	1	0	1
4	1	2	0	1	1	2	2	0	0	1	2
5	0	1	1	0	0	2	0	3	1	2	2
6	1	1	2	0	1	0	1	1	2	3	0
7	1	0	1	4	0	2	0	0	1	2	1
8	3	3	0	0	1	2	3	0	1	0	0
9	1	0	2	1	0	0	0	2	3	1	2
10	0	2	4	2	2	0	2	0	0	0	0
11	1	1	0	2	1	0	3	2	2	0	0
Chi^2	6.3	8.2	13.7	13.7	8.2	8.2	13.7	13.7	8.2	10.0	10.0

Table 3.13b

Ranking frequencies and Chi squared analysis for the SN group reading rate

SN reading rate (CWPM)

colour / ranking	rose	pink	purple	aqua	blue	yellow	ND	clear	mint-green	orange	lime-green
1	1	2	1	0	0	1	2	2	1	1	1
2	0	2	2	0	1	0	1	1	1	1	4
3	1	2	1	2	0	1	1	1	1	0	1
4	0	0	0	1	2	4	1	1	1	1	0
5	0	1	0	4	1	0	1	1	2	1	1
6	1	3	0	1	3	0	1	1	1	0	1
7	5	0	2	1	1	1	0	0	0	2	0
8	1	0	4	0	0	1	0	0	1	1	2
9	1	1	2	1	1	3	1	1	0	2	0
10	1	0	0	1	1	1	2	2	1	2	2
11	1	1	0	1	2	0	2	2	3	0	0
Chi^2	17.3	10.0	15.5	11.8	8.2	15.5	4.5	4.5	6.3	6.0	13.7

Table 3.13c

Ranking frequencies and Chi squared analysis for the ARMD group reading rate

ARMD reading rate (CWPM)

colour / ranking	rose	pink	purple	aqua	blue	yellow	ND	clear	mint-green	orange	lime-green
1	1	0	0	1	0	2	1	4	0	0	3
2	1	1	2	1	2	1	0	1	0	0	3
3	1	1	1	0	0	1	2	1	3	2	0
4	0	0	2	2	2	2	1	1	1	0	1
5	0	2	0	2	0	0	1	2	2	3	0
6	0	2	0	1	0	3	2	2	2	0	0
7	3	2	0	3	1	0	2	0	0	0	1
8	5	2	1	0	0	1	0	1	1	1	0
9	0	1	0	0	3	0	1	0	1	4	2
10	0	1	1	2	4	1	1	0	1	1	0
11	1	0	5	0	0	1	1	0	1	1	2
Chi^2	22.8*	6.3	21.0*	10.0	19.2*	8.2	4.5	13.7	8.2	17.3	13.7

*significant at 0.05 confidence level

Table 3.13d

Ranking frequencies and Chi squared analysis for the YN group reading accuracy

YN reading accuracy (%)

colour / ranking	rose	pink	purple	aqua	blue	yellow	ND	clear	mint-green	orange	lime-green
1	5	4	6	6	4	6	5	10	6	8	6
2	0	0	0	0	0	1	1	1	0	0	0
3	0	0	0	0	1	2	1	0	1	1	1
4	0	0	0	0	0	0	0	0	0	0	0
5	3	2	1	0	1	1	1	1	4	2	1
6	0	0	0	0	0	0	0	0	0	0	0
7	1	1	0	0	1	1	0	0	0	0	0
8	0	3	2	1	2	0	1	0	0	0	3
9	2	1	2	1	2	1	0	0	1	1	0
10	0	0	0	0	1	0	0	0	0	0	1
11	1	1	1	4	0	0	3	0	0	0	0
Chi^2	24.7*	17.3	30.2*	37.5*	13.7	28.3*	22.8*	81.5*	37.5*	52.2*	32.0*

*significant at 0.05 confidence level

Table 3.13e

Ranking frequencies and Chi squared analysis for the SN group reading accuracy

SN reading accuracy (%)

colour	rose	pink	purple	aqua	blue	yellow	ND	clear	mint-green	orange	lime-green
ranking											
1	3	3	3	4	4	5	5	6	7	5	3
2	0	0	0	2	2	1	0	0	2	1	0
3	1	3	1	1	0	1	2	0	0	0	1
4	1	0	1	2	1	1	0	0	0	0	0
5	0	1	2	1	0	1	1	1	0	1	2
6	1	0	1	0	0	1	0	1	0	1	1
7	2	1	1	0	3	0	1	2	1	0	2
8	1	1	2	1	0	1	1	1	1	1	1
9	1	0	0	1	1	0	0	0	0	1	1
10	1	0	1	0	1	1	0	1	0	1	1
11	0	3	0	0	0	0	2	0	1	1	0
Chi^2	8.0	15.5	8.2	13.7	17.3	17.3	21.0*	28.3*	39.3*	17.3	8.2

*significant at 0.05 confidence level

Table 3.13f

Ranking frequencies and Chi squared analysis for the ARMD group reading accuracy

ARMD reading accuracy (%)

colour	rose	pink	purple	aqua	blue	yellow	grey	clear	mint-green	orange	lime-green
ranking											
1	2	2	3	4	4	2	2	6	3	1	5
2	1	1	1	1	0	0	2	1	1	0	1
3	1	0	2	0	0	0	2	1	0	1	1
4	2	0	1	3	0	2	1	1	1	1	1
5	1	1	0	0	2	1	0	0	0	0	1
6	2	2	1	2	3	1	0	2	1	2	0
7	2	1		1	0	0	1	1	0	1	0
8	1	2	1	0	1	0	1	0	2	2	0
9	0	1	1	0	1	0	2	0	2	0	0
10	0	1	0	1	1	2	1	0	2	3	0
11	0	1	2	0	0	4	0	0	0	1	3
Chi^2	6.3	4.5	8.1	17.3	17.3	15.5	6.3	28.3*	10.0	8.2	22.8*

*significant at 0.05 confidence level

Reading rate versus reading accuracy trade-off analysis

There may have been a reading rate reading accuracy trade off in this experiment, i.e. those subjects that read quickly may have had a reduced accuracy, and those that read slowly may have had better accuracy. In order to investigate this the correlation coefficient (r) and the coefficient of determination (r^2) was calculated for each group (figure 3.02a, b and c). YN r^2 =0.018, r=0.134, p>0.05; SN r^2 =0.048, r=0.219, p<0.05; ARMD r^2 =0.036, r=0.190, p<0.05. Reading rate and accuracy have a positive relationship for all the groups, i.e. as one increases so does the other.

This suggests that for the YN group 1.8% of the variation in reading rate is attributable to the linear variation of reading accuracy (not statistically significant at the 0.05 confidence level), and therefore 92.2% of the variation is attributable to other factors not measured or accounted for in this study.

For SN group 4.8% of the variation in reading rate is attributable to the linear variation of reading accuracy (statistically significant at the 0.05 confidence level), and therefore 95.2% of the variation of reading rate is attributable to other factors not measured or accounted for in this study.

For the ARMD group 3.6% of variation in reading rate is can be accounted for by the linear variation of reading accuracy (statistically significant at the 0.05 confidence level), and therefore 96.4% of the reading rate variation is due to other factors.

Learning and fatigue effects

There was no statistically significant difference in reading rate for any group when the before and after results were compared. (YN t= -0.859, p>0.05; SN t=0.551, p=0>0.05; ARMD t= -1.170, p>0.05). Similarly there was no difference for reading accuracy (YN t= -0.880, p>0.05; SN t= -0.838, p>0.05; ARMD t=0.761, p>0.05). This demonstrated that the results were

unlikely to have been confounded by learning and fatigue effects.

Figures 3.02 a, b, c scattergrams

Figure 3.02a-YN overlays
reading rate versus reading accuracy

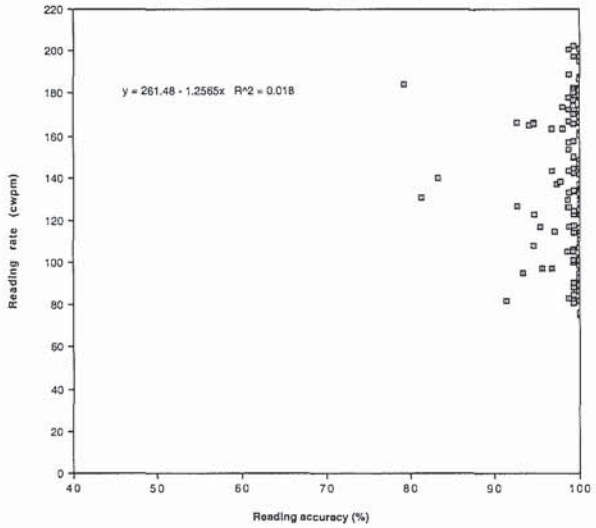


Figure 3.02b-SN overlays
reading rate versus reading accuracy

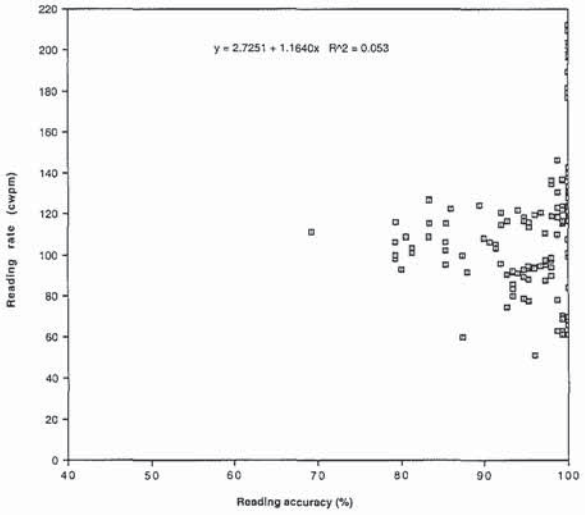
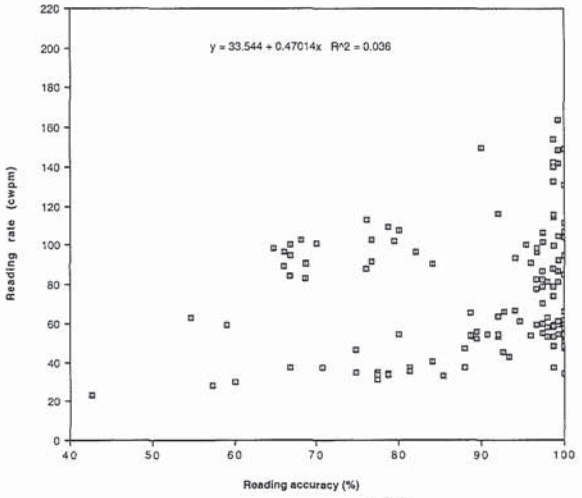


Figure 3.02c-ARMD overlays
reading rate versus reading accuracy



See table 3.14 for summary of results.

Table 3.14 summary of results for experiment 4 (overlays)

Type of analysis	Results
ANOVA reading rate	YN>ARMD, SN>ARMD, YN=SN
ANOVA reading accuracy	YN>ARMD, SN=ARMD, YN=SN
Chi squared reading rate	ARMD rose 7th and 8th, blue 9th and 10th, purple 11th
Chi squared reading accuracy	YN clear 1st, rose 1st, purple 1st, aqua 1st, yellow 1st,
	ND 1st, mint-green 1st, orange 1st, lime-green 1st
	SN clear 1st, ND 1st, mint-green 1st
	ARMD clear 1st, lime-green 1st
Individual reading rate	YN lime green 40%, yellow 24%, rose 31%, blue 23%,
	grey 22%, mint-green 36%, pink 24% and 32%
	SN grey 37%, red 23%
	ARMD none
Individual reading accuracy	none
Rate versus accuracy	YN 1.8%, SN 4.8%*, ARMD 3.6%*
Learning/fatigue	none

*significant at the 0.05 confidence level

Discussion

Results indicated that for reading rate there is a disease effect, a combined disease and age effect, but no age effect, i.e. ARMD alone, and ARMD in combination with age reduced reading rate, but age on its own had no effect. As there was no significant difference in reading rate between SN and YN subjects, the relationship between the SN and ARMD groups is unlikely to have been confounded by the significant difference in age between the two groups. The difference between YN and ARMD results is more significant (p=0.00) than the difference between SN and ARMD results (p=0.03). This could signify that even though age

alone has no significant effect on reading rate, when combined with ARMD it reduces reading rate to a greater extent than ARMD alone.

There is a disease combined with age effect on reading accuracy, but not a disease specific or age specific effect. This indicated that neither ARMD nor age alone effects reading accuracy, i.e. older subjects with ARMD read as accurately as older subjects without ARMD and older subjects read as accurately as young subjects. However, when combined with age (as it usually is) ARMD reduced reading accuracy.

ANOVA and Chi squared analyses suggested there is very little benefit to be gained from using Intuitve Coloured Overlays® when reading, for any study group. ANOVA revealed no effect of overlays on reading performance.

Chi squared analysis revealed that rose, blue and purple overlays produced poorer reading rates than the other overlays including the no overlay condition for the ARMD group, while the clear overlay produced the highest accuracy for the YN and ARMD groups, and mint-green for the SN group.

Individual subject analysis revealed that a range of overlays produced a substantial improvement in reading rate only for the YN group (lime-green, yellow, rose, blue, grey, and mint-green all for different individual subjects, and pink for two subjects); for the SN group, only two overlays produced a 20% or more improvement in reading rate (grey, and rose for one subject); there were no overlay benefits for the ARMD group.

One would expect overlays that produce short wavelengths to result in a poorer reading performance due to increased scattering within the aged eye. This may explain the particularly poor performance of the ARMD group with the purple and blue overlays.

Chi squared analysis for the YN group suggested that most subjects did not read to threshold, since nearly all the overlays produced a high accuracy, i.e. there was a ceiling effect which was probably caused by either the words being too simple or too large. This could have resulted in a failure to detect any subtle differences in reading accuracy that may have been present. SN results are interesting in that the mint-green, clear and ND overlays had a similar effect. Reduced light intensity with the ND overlay would have been expected to reduce reading performance for this group. The most significant positive effect occurred with the mint-green overlay. Because of chromatic aberration a sharper retinal focus for green light when the object of regard is at near. This may account for the superior performance with this overlay, i.e. the text may have been clearer.

Coefficient of determination values (r^2) indicated that even when there was statistically significant reading rate versus reading accuracy relationship for the SN and ARMD, the trend is unlikely to be clinically significant. In future research and clinical assessment of this kind, it may be acceptable to analyse only one of these parameters as an outcome measure. Based on the findings from this study it maybe appropriate to use reading rate as the sole outcome measure since a ceiling effect is less likely to occur with this parameter.

Reading rates at the start and at the end of the session were not statistically different. This demonstrated that there were no effects of fatigue and learning on the results, similarly to experiment 3 (gel filters)

Conclusions

Reading rate

- ARMD combined with age has a more negative effect on reading rate than ARMD alone, while age alone has no affect.
- Reading performance in ARMD did not improve with Intuitive Coloured Overlays®, when compared to a clear overlay. Chi squared analysis revealed that rose, blue and purple

overlays produced poorer reading rates than the other overlays including the no overlay condition for the ARMD group.

- Individual analysis demonstrated that several Intuitive Coloured Overlays® produced at least a 20% reading rate improvement but only for YN subjects. This is interesting since none of the YN subjects claimed any reading difficulties in every day life.

Reading accuracy

- ARMD and age had a negative effect on reading accuracy, but ARMD alone, and age alone had no significant effect.
- Only mint-green overlay produced any positive effects for reading accuracy and this was for the SN group.

None of the Intuitive Coloured Overlays® improved reading performance for the ARMD group as a whole or for any individual subject. This is perhaps not too surprising as Wilkins (1995) theorised that the mechanism of the effect noted in subjects with Meares-Irlen Syndrome and migraine is probably of a cortical nature (peripheral effect) and that ARMD is a retinal photoreceptor disease (ocular–retinal effect) (Lightstone, 1997b). In the context of these findings it could be stated that the provision of Intuitive Coloured Overlays® to individuals with ARMD for use as a reading aid is at present inappropriate. Several anecdotal reports indicate that some eye care practitioners are supplying these overlays in this manner.

The results and conclusions from experiment 4 (overlays) are further discussed in Chapter 5- Overall Discussion.

Experiment 5a and 5b compared the effects of several tinted lenses, including one derived from the Intuitive Colorimeter®, on reading performance with ARMD.

EXPERIMENT 5A-USE OF THE INTUITIVE COLORIMETER® IN THE ASSESSMENT OF READING PERFORMANCE WITH ARMD

Introduction

Experiment 4-(overlays) indicated that an ARMD group did not benefit in reading performance when using Intuitive Coloured Overlays®. It is possible, however, that whereas overlays failed to produce a detectable benefit, reading performance may be improved with tinted lenses. Overlays absorb light twice, once before and once after reflection from the text, and as a result the spectral absorption is multiplied by two. Also the perception of colour of an object such as an overlay is the result of a neural computation that takes into account the spectral properties of the illuminating source, as estimated from the spectral power distribution of light reflected from surrounding objects.

However, when tinted lenses are worn the tint has the effect of contributing to the colour of the illuminating source and is thereby discounted (Wilkins and Neary, 1991). In other words the brain takes the colour of the illuminating source into account and it does so on the basis of light reflected from coloured surfaces. These brain mechanisms enable an object to appear the same colour under a wide range of lighting colour conditions, so called colour-constancy. When using overlays the mechanisms of colour constancy should not necessarily act in the same way as they do when colour is provided by tinted lenses (Wilkins, 1995).

There is some evidence that people with ARMD read better when wearing certain specialised tinted spectacle lenses (Chapter 1-Background and Research Rationale). These are often expensive, difficult to obtain and rely heavily on subjective evaluation. It would be useful to know whether other types of tinted lens can be used, and how they compare with the specialised lenses.

The Intuitive Colorimeter® was developed by Wilkins *et al.* (1992) to assess people with

Meares-Irlen Syndrome, in order to determine the optimum tint that reduces visual distortion and discomfort (appendix 3). The assessment procedure is time consuming and relies on clinical experience in the interpretation of subjective comments.

Experiment 5a was designed to allow objective determination of the optimum tinted lens colour for best reading performance in ARMD. No reports of this type of use for the Intuitive Colorimeter® were found in the literature survey.

Aim

To establish whether the Intuitive Colorimeter® can be used to determine the colour of a tinted lens to aid in reading performance with ARMD.

Methods

Subjects

Table 3.15 for subject age and threshold binocular reading acuity.

Equipment

- Intuitive Colorimeter®, see photograph 1 (Cerium Visual Technologies, Cerium Technology Park, Appledore Road, Tenterden, Kent, TN30 7DE, UK).
- Precision Tinted® trial lenses, see photograph 2 (Cerium Visual Technologies, Cerium Technology Park, Appledore Road, Tenterden, Kent, TN30 7DE, UK)
- Luminance meter (Spectra Mini-spot™ Silicon Cell Spot Meter, Photo-Research Div., Kollmorgan Corp., Burbank, CA, USA).

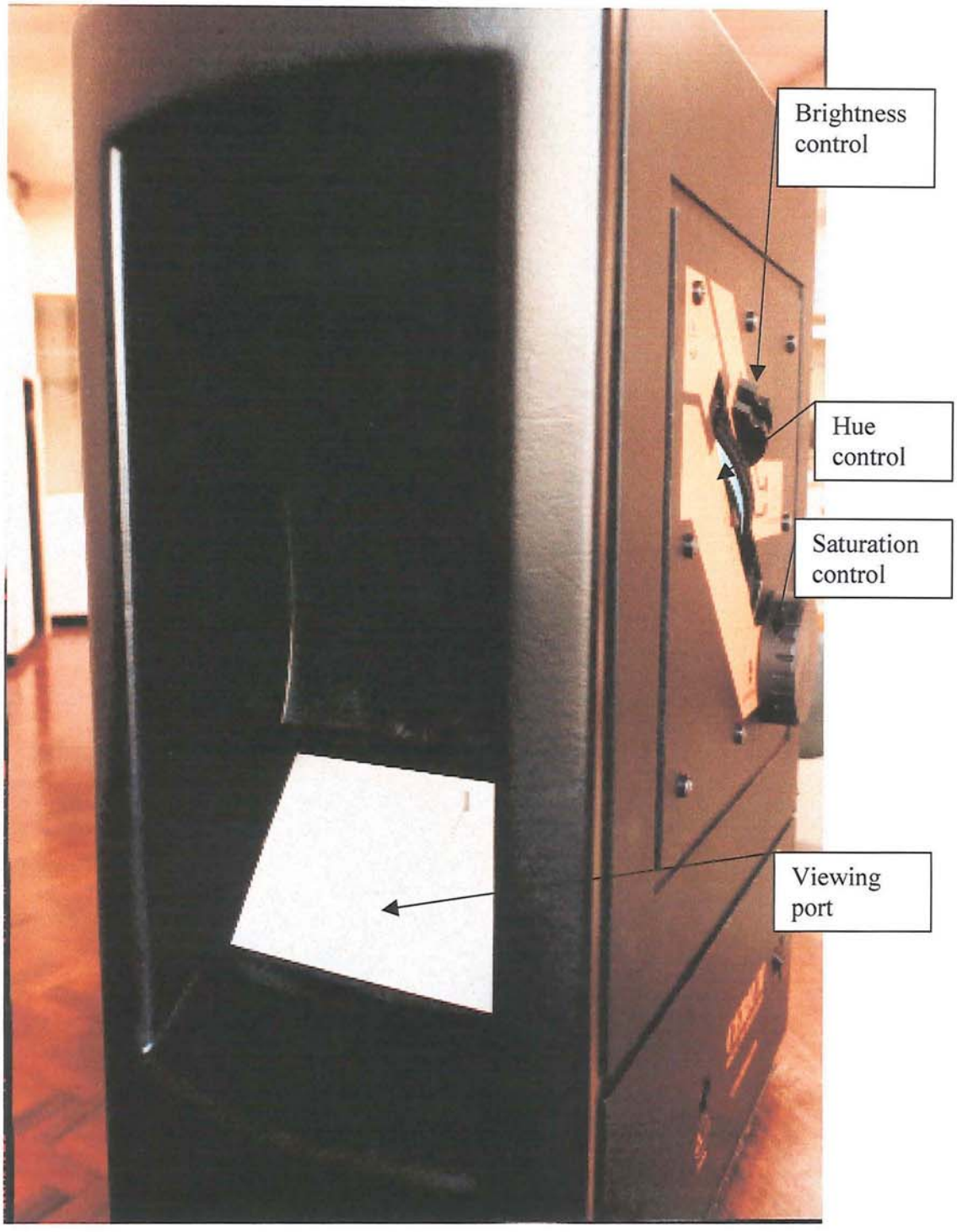
As in experiment 3:

- Stop watch.
- Dictating type mini-tape-recorder.
- Light meter.

As in experiment 4:

- Wilkins Reading Rate Test® (WRRT).
- Score sheet (enlarged version of WRRT) (appendix 8.1).

Photograph 1 Intuitive Colorimeter



Photograph 2 Precision tinted lenses

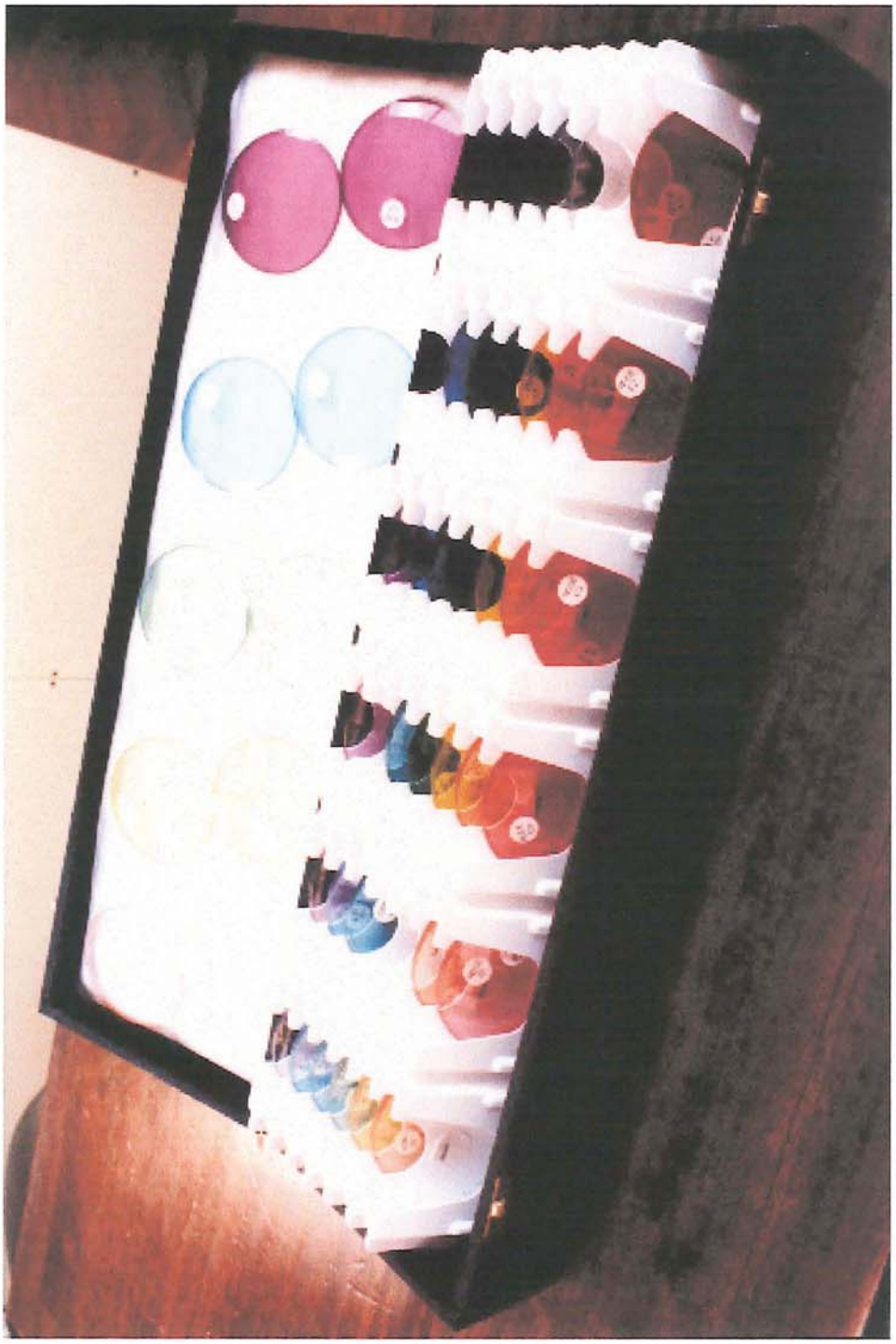


Table 3.15 subject age (years) and threshold binocular reading acuity for experiment 5a (colorimetry)

SN	Age	Reading acuity	ARMD	Age	Reading acuity
DL	71	N4	BM	87	N10
DP	71	N4	CP	80	N8
EC	73	N4	GS	82	N5
EE	74	N4	ID	82	N8
FF	66	N4	MA	87	N12
GM	63	N4	MB	80	N16
JS	73	N2.5	MC	84	N5
MW	61	N2.5	MH	87	N6
RP	69	N3	MJ	81	N6
RT	71	N3	MS	86	N4
TH	66	N4	NJ	73	N8
VG	74	N4	WH	79	N16

Binocular threshold reading acuity as measured with a Bailey-Lovie near word card at observer's habitual working distance. SN mean 69.25 years, 71.5 median, range, 61 to 74, SD 4.37; ARMD mean 82.37 years, 82.5 median, range 73 to 87, SD 4.19. The difference in the average age of the two groups is statistically significant (t=7.437, p=0.00)

Procedure

Previous experiments described in this series had used three subject groups, YN, SN, and ARMD. It was decided at this stage that the extra logistical difficulty, and extra time involved in recruitment and assessment of the YN subjects, out weighed the amount of useful data that this group produced. For these reasons it was decided to conduct experiment 5a with only the SN and ARMD groups.

Subjects had taken part in at least one of the earlier experiments described and were

familiar with the concept of reading from passages of print lacking context, with various types of coloured interventions. All used spectacles for the testing session; they were advised to position themselves in front of the colorimeter looking down into the aperture as advised by Wilkins *et al.* (1992).

Testing was conducted with the room lights off (35 lux ambient illuminance, as measured on horizontal desk surface 0.74 m above the floor). With neutral grey illuminance (195 lux) 'dialled in' on the hue control, WRRT text size was chosen to allow maximum visual comfort for each subject. Because the neutral grey setting had low illuminance, the size of the test print required for each subject was considerably larger than that which might be considered necessary from the threshold binocular reading acuity data. The Intuitive Colorimeter® has two ND filters of 50% and 75% attenuation that can be used to lower illuminance further, Neither of these were used in this study.

It had been intended to use a font size for the test blocks one point larger than the threshold binocular reading acuity obtained with the Bailey-Lovie reading card at each observer's habitual reading distance. However, during the test sessions, many subjects and especially those with ARMD, found reading with a font size so close to threshold, to be very fatiguing and on occasion very uncomfortable. Therefore, the smallest WRRT test block font size that the subject found acceptable in terms of visual and mental comfort was used.

The WRRT was used to provide an objective assessment of which colour provided the best reading performance. WRRT text was typed up on a word processor, the word order rearranged and then reprinted to provide 13 blocks of print using only WRRT words, as described in experiment 4 (overlays). A different block of print was presented in the viewing box for each colour condition.

Prior to the start of the testing session, subjects were shown large print (N40) versions of the

words used in the WRRT and asked to read them out loud twice to encourage familiarity. They were informed that the test blocks contained text comprised solely of these words, and that each line had a different arrangement of the same words. They were informed that the blocks had no contextual clues and that the reading 'would not make sense'. For each subject the same size font was used in each test block, but subjects had different font sizes.

The same instructional set was used and subjects were not told of the aims of the research. They were asked to read out loud from the blocks, as accurately and as quickly as possible (the emphasis was placed on accuracy) starting at the top of each block and reading until the end was reached. Subjects were encouraged to either guess or to say pass on words they were unsure about. Blocks of test print were presented in the same order for all subjects but colours were randomly selected in order to reduce the possibility of confounding the results through learning and fatigue effects.

Each subject was asked to read one block of 150 words with each colour presentation. Some subjects found this tiring or uncomfortable and managed to read only 75 words. Subjects were advised to read at their habitual working distance, which was monitored, for consistency (range from 25 to 35 cm). They were not allowed to move closer when attempting to read smaller or more difficult words. The test session was tape-recorded and later analysed to calculate reading rate and accuracy.

Rotation of the colour wheel changed the colour of the illuminance (see photograph 1). Test print was changed and reading rate and accuracy determined for every 30 degrees of hue; this gave 13 test conditions and 14 measurements (the first and last test conditions were identical, i.e. neutral grey illumination). Luminance (at 27 cdm^{-2}) and saturation (20 arbritary units) remained constant throughout the test session.

Tape recordings were later replayed and each subject scored by measuring the total time taken

to read each block (or part block if the subject was unable to complete), and noting the errors on a score sheet. Reading rate and reading accuracy were calculated as described in the introduction to Chapter 3-Primary Experiments.

Learning and fatigue effects were investigated by using the same print block at the beginning and at the end of the assessment with the neutral grey illumination. Before and after reading rate and accuracy were then compared.

The optimum illuminance colour for each subject was calculated by adding the reading rate to the reading accuracy and calculating the total. The colour that gave the highest combined value was then matched with a combination of tinted trial lenses. Most colours were adequately matched with either one or a combination of two trial lenses.

Questions to be answered

- How did subjects cope with the procedure?
- Did one particular colour produce the best reading performance?
- How did the two subject groups compare?

Results

See appendix 1.3 for raw reading performance data and table 3.16 for details of optimum colour and tinted lens match.

This experiment was conducted to obtain a surface tinted lens and to compare it with other tinted lenses in experiment 5b. Therefore, ANOVA, Chi squared and individual subject analyses of the reading performance data were not conducted for experiment 5a. Similarly, it was not considered necessary to conduct a reading rate versus reading accuracy trade-off assessment. However, it was important to know whether there had been any learning or fatigue effects, as this may have affected the results. There was no significant difference in reading

rate for any group when the before and after results were compared. (SN t= -0.017, p=0.868; ARMD t= -0.343, p=0.74). Similarly there was no significant difference for reading accuracy (SN t= -0.541, p=0.59; ARMD t=1.432, p=0.17).

The two histograms (figure 3.03a and b) depict the frequency of occurrence of the optimum colours for reading performance.

Table 3.16

Optimum hue angle and tinted lens match for experiment 5a (colorimetry)

SN	optimum hue angle	TLT (%)	tinted lenses matched to optimum colour	ARMD	optimum colour	TLT (%)	tinted lenses matched to optimum colour
DL	90	52	yellow C3+green C3	BM	60	74	yellow B4+green B4
DP	60	74	yellow B4+green B4	CP	30	53	orange D2
EC	0	53	rose D3+C4	GS	270	38	blue D2+purple D3
EE	180	29	turquoise D2+blue D2	ID	180	20	turquoise D2+blue D2
FF	210	28	blue E1+C3	MA	0	53	rose D3+C4
GM	180	29	turquoise D2+blue D2	MB	180	20	turquoise D2+blue D2
JS	180	29	turquoise D2+blue D2	MC	0	53	rose D3+C4
MW	240	32	blue C3+E1	MH	210	21	turquoise D2+blue E1
RP	0	53	rose D3+C4	MJ	30	60	orange D2+rose B5
RT	0	53	rose D3+C4	MS	180	20	turquoise D2+blue D2
TH	150	49	rose C4+purple D3	NJ	300	33	purple E2+blue C3
VG	210	17	turquoise D2+E1	WH	30	66	orange D2

Figure 3.03a-SN optimum colour frequencies

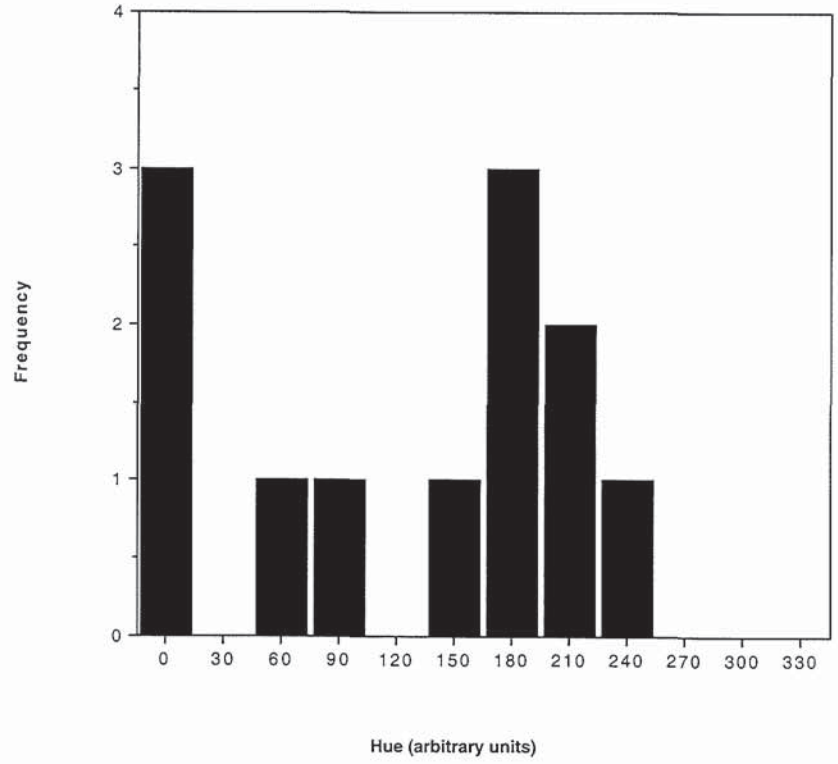
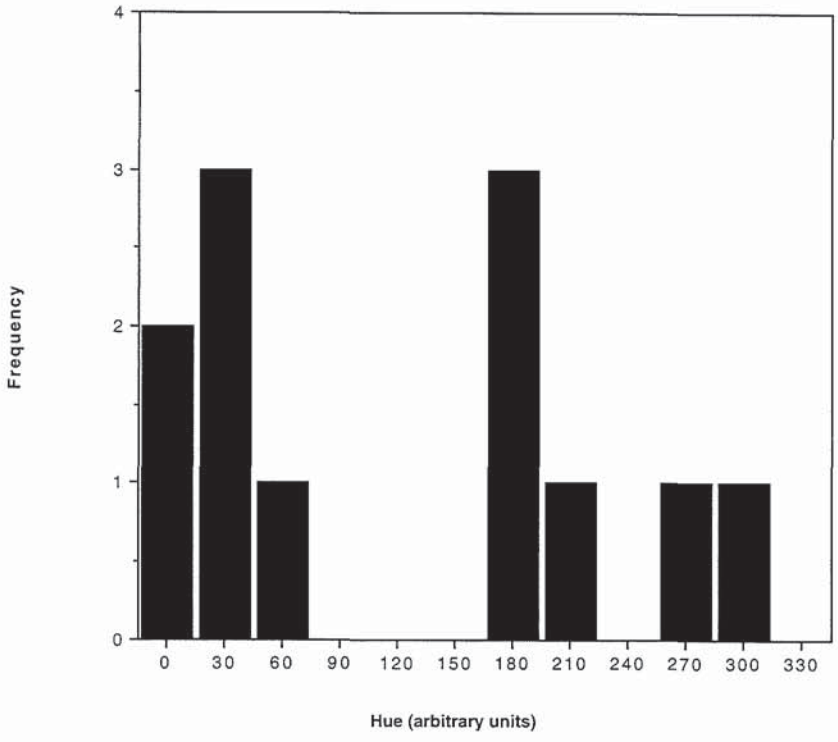


Figure 3.03b-ARMD optimum colour frequencies



Discussion

Many subjects found the colorimeter ergonomically and visually uncomfortable to use. Several complained of postural discomfort, as they had to sit very close in order to bring the test print within the focal range of their reading glasses. They also complained that the illumination inside the colorimeter was poor and 'strained' their eyes, especially with the neutral grey colour. Some observers could not sustain reading long enough to complete the 150 words test blocks and therefore some reading performances are determined from 75 words.

Histograms for SN and ARMD optimum colour hue angles highlighted in figure 3.03a and b indicate that for the SN group optimum hue angles are 0 (orange), 180 (green) and 210 (blue) degrees; for the ARMD subjects optimum hue angles were 30 (yellow) and 180 (green) degrees.

Conclusions

- The Intuitive Colorimeter® can be used in the low vision field with ARMD subjects, to determine the optimum colour for tinted lenses to produce the best reading performance.
- The reading task has to be short in length to avoid visual and postural discomfort and fatigue.

Histograms of optimum hue angles for the two study groups showed peaks at 0 (orange), 180 (green) and 210 (blue) degrees; for the ARMD subjects optimum hue angles were 30 (yellow) and 180 (green) degrees.

EXPERIMENT 5B-COMPARISON OF THE EFFECTS OF SEVERAL TINTED LENSES ON READING PERFORMANCE IN ARMD.

Introduction

Experiment 5a-(colorimetry) indicated that the Intuitive Colorimeter® could be used to obtain a surface tinted plastic lens that provided optimum reading performance for both the SN and ARMD groups.

The CPF range of lenses is marketed to improve visual function, visual comfort and mobility performance of people with low vision. They are photochromic and are recommended for both indoor and outdoor use. CPF450 the palest of these filters (light yellow), was designed for indoor use and is claimed by the manufacturers to enhance reading in ARMD. However, there is very little objective data to substantiate their use (Chapter 1-Backgound and Research Rationale).

Experiment 5b was designed to compare reading performance with a plastic, surface tinted lens obtained during experiment 5a using the Intuitive Colorimeter®, with a CPF450 glass photochromic, a ND (50% TLT) filter, and a clear 100% TLT filter.

Aims

To determine whether reading performance can be improved for SN and ARMD subjects using tinted lenses.

Methods

Subject

The same subjects were used as in experiment 5a. See table 3.17 for details.

Table 3.17 subject age (years) and threshold binocular reading acuity for experiment 5b (tinted lenses)

SN	Age	Reading acuity	ARMD	Age	Reading acuity
DL	71	N4	BM	87	N10
DP	71	N4	CP	80	N8
EC	73	N4	GS	82	N5
EE	74	N4	ID	82	N8
FF	66	N4	MA	87	N12
GM	63	N4	MB	80	N16
JS	73	N2.5	MC	84	N5
MW	61	N2.5	MH	87	N6
RP	69	N3	MJ	81	N6
RT	71	N3	MS	86	N4
TH	66	N4	NJ	73	N8
VG	74	N4	WH	79	N16

Binocular threshold reading acuity as measured with a Bailey-Lovie near word card at observer's habitual working distance. SN mean 69.25 years, median 71.5, range 60 to 74, SD 4.38; ARMD mean 82.37 years, median 82.5, range 73 to 87, SD 4.19. The difference in the average age of the two groups is statistically significant (t= 7.437, p=0.00).

Materials

- CPF450 lenses, plano, photochromic clip-on, 68% TLT in lightened state (The Norville Group, Paul Street, Gloucester, GL1 4NY, UK)
- Plastic tinted trial lenses determined with the Intuitive Colorimeter® in experiment 5a.
- Clear filter (100% TLT) clip-on.
- ND filter (50% TLT) clip-on.

The following all as experiment 3:

- Reading lamp with an 11W cool white PL compact fluorescent lamp.

- Light meter.
- Stop watch.
- Dictating type mini-tape recorder.
- Bailey-Lovie near word reading acuity cards (five different versions). This was used because of the relatively low number of interventions assessed in this experiment.
- Score sheets (large print versions of each Bailey-Lovie card).

Procedure

Subjects were seated at a desk illuminated by the reading lamp placed at 25 cm above the desk surface. Testing was conducted in a well lit room with ceiling mounted fluorescent lamps. Total illuminance at the horizontal desk surface 0.74 m above the floor was 3830 lux.

A Bailey-Lovie near word reading acuity card was placed on the desk and subjects were asked not to move or tilt the card during the test session. Each subject was given the same instructions but was not told of the aims of the research or about any possible benefits of any of the test lenses. They were asked to read out loud from the card, as accurately and as quickly as possible (the emphasis was placed on accuracy) starting at the top of the card and reading down until the words were too small to see.

All subjects were informed that the words had no contextual clues and therefore the reading would not make sense. Subjects were allowed to read at their habitual working distance, were advised not to move closer when attempting to read small or difficult words, and were encouraged to guess or pass on words they were unsure about. Subjects were also advised that they would be tape-recorded and that the tape would be analysed later to determine reading rate and reading accuracy, and then erased.

The Intuitive Colorimeter® trial lenses as generated in experiment 5a were held by each subject in front of each eye at the same time, close up to their own spectacles. The CPF450,

ND and clear filters were mounted as plano clip-ons and attached directly to the subjects own spectacles. The CPF was used in the fully lightened state (68% TLT).

All cards and lenses were randomly selected in order to reduce the effects of learning and fatigue when the results were averaged for the groups. A no-tinted-lens condition was used at the start of the investigation and then repeated at the end using the same Bailey-Lovie near word reading acuity card. There were five different test conditions and six measurements per subject.

Reading rate and reading accuracy were calculated as described in the introduction to Chapter 3-Primary Experiments for each of the six test conditions. Reading rate and accuracy at the beginning and at the end of the test were compared to detect any learning or fatigue effects.

Questions to be answered

- Does data analysis reveal any inter-group effects of tinted lenses on reading performance? In other words, are there any disease or disease combined with age, related effects?
- Do individually prescribed tints allow a better reading performance than 'off-the-shelf' tints?
- If reading rate and accuracy measurements while reading with the tinted lenses are normalised to the no filter condition, is it possible to demonstrate beneficial effects of lenses on an individual subject basis?
- Are there any individuals who show exceptionally strong beneficial effects of the tinted lenses, and if so, what factors might account for these?
- If there is an individual subject effect, does one tinted lens consistently produce the best reading performance?
- Are there any learning or fatigue effects?
- Was there a reading rate versus reading accuracy trade-off?

Results

For experiment 5b raw data see appendix 1.04.

ANOVA

Reading rate and accuracy were compared across subject groups and tinted lenses using a split plot ANOVA procedure and *post-hoc* examination of significant differences for those ANOVA p values less than or equal to 0.05. The results for each group were examined in a similar way.

There was no significant interaction between subjects and tinted lenses for reading rate or accuracy (table 3.18). When individual group data was analysed there was a significant filter effect on reading rate for the ARMD group (F, 3.62, p=0.02, df 0, 33) (table 3.19). There were no significant results for the same analysis of reading accuracy data (table 3.20). However, despite the significant effect for filters indicated by ANOVA, Scheffé's S test *post-hoc* analysis revealed no significant interactions between the filters, i.e. there was no significant difference in reading performance between the clear and ND filters and CPF450 for the ARMD group. Scheffé's S test is a conservative *post hoc* analysis and therefore the Duncan New Multiple Range test, a less conservative test was also used to determine what the filter effect was. This highlighted a significant relationship between the CPF450 and the ND filter, and the CPF and the Intuitive Colorimeter® lens. A review of the raw data showed that the CPF produced better reading rates.

Table 3.18 ANOVA split-plot tables for all subjects for reading rate and reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject group	1	8143.85	8143.85	1.93	.1784	replicant (subject ...
replicant (subj...	22	92703.77	4213.81	20.79	.0001	Residual
filter	3	1425.54	475.18	2.34	.0810	Residual
filter * subjec...	3	576.63	192.21	.95	.4226	Residual
Residual	66	13379.88	202.73			

Dependent: reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject group	1	63.64	63.64	.21	.6531	replicant (subject ...
replicant (subj...	22	6744.83	306.58	5.58	.0001	Residual
filter	3	313.23	104.41	1.90	.1380	Residual
filter * subjec...	3	273.23	91.08	1.66	.1845	Residual
Residual	66	3624.84	54.92			

Dependent: reading accuracy

Table 3.19 ANOVA split-plot tables for SN and ARMD groups respectively for reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject group	0	•	•	•	•	replicant (subject ...
replicant (subj...	11	34110.30	3100.94	9.10	.0001	Residual
filter	3	1299.73	433.24	1.27	.3003	Residual
filter * subjec...	0	•	•	•	•	Residual
Residual	33	11248.04	340.85			

Dependent: reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject group	0	•	•	•	•	replicant (subject ...
replicant (subj...	11	58593.47	5326.68	82.45	.0001	Residual
filter	3	702.44	234.15	3.62	.0230	Residual
filter * subjec...	0	•	•	•	•	Residual
Residual	33	2131.85	64.60			

Dependent: reading rate

Scheffe's S
Effect: filter
Dependent: reading rate
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value
ND	IC	.49	9.66	.9991
	clear	4.07	9.66	.6770
	CPF450	9.58	9.66	.0529
IC	clear	3.57	9.66	.7575
	CPF450	9.08	9.66	.0722
clear	CPF450	5.51	9.66	.4322

None were significantly different at this level.

Duncan New Multiple Range
Effect: filter
Dependent: reading rate
Significance level: .05

	Vs.	Diff.	Crit. diff.	
ND	IC	.49	6.68	
	clear	4.07	7.03	
	CPF450	9.58	7.23	S
IC	clear	3.57	6.68	
	CPF450	9.08	7.03	S
clear	CPF450	5.51	6.68	

S = Significantly different at this level.

Table 3.20 ANOVA split-plot tables for SN and ARMD groups respectively for reading accuracy

Note the only relevant effects are replicant, filter colour and filter colour versus subject. The ANOVA software did not allow for deletion of the non-relevant sections of this table.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject group	0	•	•	•	•	replicant (subject ...
replicant (subj...	11	2225.56	202.32	7.32	.0001	Residual
filter	3	34.05	11.35	.41	.7466	Residual
filter * subjec...	0	•	•	•	•	Residual
Residual	33	912.55	27.65			

Dependent: reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject group	0	•	•	•	•	replicant (subject ...
replicant (subj...	11	4519.26	410.84	5.00	.0002	Residual
filter	3	552.41	184.14	2.24	.1019	Residual
filter * subjec...	0	•	•	•	•	Residual
Residual	33	2712.30	82.19			

Dependent: reading accuracy

Chi squared analysis

Data was also analysed in terms of ranking frequencies. Tinted lenses and filters were objectively ranked for reading performance for each subject, i.e. how many times each filter was ranked first, second, third, and fourth. These ranking frequencies were then further analysed using a Chi squared procedure, to determine if there was any statistical significance in their distribution (table 3.21).

Chi squared analysis indicated no statistical difference in ranking distribution, for SN subjects for reading rate, but a significant cluster (Chi^2, 8.00; p=0.05) for first position for reading accuracy with the ND filter. ARMD results indicate a significant cluster for CPF450 in first position (Chi^2, 8.67, p=0.05) for reading rate, and for the clear filter (Chi^2, 10.00, p=0.05) for reading accuracy.

Table 3.21 ranking frequencies and Chi squared analyses for experiment 5b (tinted lenses)

SN reading rate reading accuracy

filter	clear	CPF 450	IC filter	ND	clear	CPF 450	IC filter	ND
ranking								
1	5	3	1	3	5	2	2	7
2	3	2	3	4	4	0	3	3
3	2	5	2	3	0	6	4	1
4	2	2	6	2	3	4	3	1
Chi^2	2.0	2.0	4.7	0.7	4.7	6.7	0.7	8.0*

* significant at 0.05 confidence level

Table 3.21 contd ranking frequencies and Chi squared analyses for experiment 5b (tinted lenses)

ARMD reading rate reading accuracy

filter	clear	CPF 450	IC filter	ND	clear	CPF 450	IC filter	ND
ranking								
1	4	7	0	1	7	2	1	2
2	2	3	5	2	1	4	4	6
3	3	2	2	5	0	3	4	4
4	3	0	5	4	4	3	3	0
Chi^2	0.67	8.7*	6.0	3.3	10.0*	0.67	2.00	6.7*

* significant at 0.05 confidence level

Individual subject analysis

It is possible that the tinted lenses were not beneficial for all subjects. Results for each subject were normalised against the clear lens result and a *post hoc* search was made through the normalised reading rate and accuracy values for individuals who demonstrated a 20% or more reading improvement. Two occurrences in which there was a such an improvement were identified; for the SN group, RP who had a 34% increase in reading rate with the CPF lens; for the ARMD group, NJ who had 23% increase in reading rate with the ND lens.

Reading rate versus reading accuracy analysis

There may have been a reading rate versus reading accuracy trade-off. In order to investigate this a correlation coefficient (r) and the coefficient of determination (r^2) were calculated for each group (figure 3.04a and b). SN r^2 =0.064, r=0.253, $p<0.05$; ARMD r^2 =0.236, r=0.486, $p>0.05$. This would suggest that for the SN and ARMD group there is a positive relationship between reading rate and reading accuracy, i.e. as one increases so does the other.

For the SN group 6.4% of the variation in reading rate is attributable to the linear

variation of reading accuracy (not statistically significant at the 0.05 confidence level), and therefore 93.6% of the variation is attributable to other factors not measured or accounted for in this study.

For the ARMD group 23.6% of the variation in reading rate can be accounted for by the linear variation of reading accuracy (statistically significant at the 0.05 confidence level), and therefore 76.4% of the reading rate variation is due to other factors.

Figures 3.04a and b

Figure 3.04b-ARMD tinted lenses
reading rate versus reading accuracy

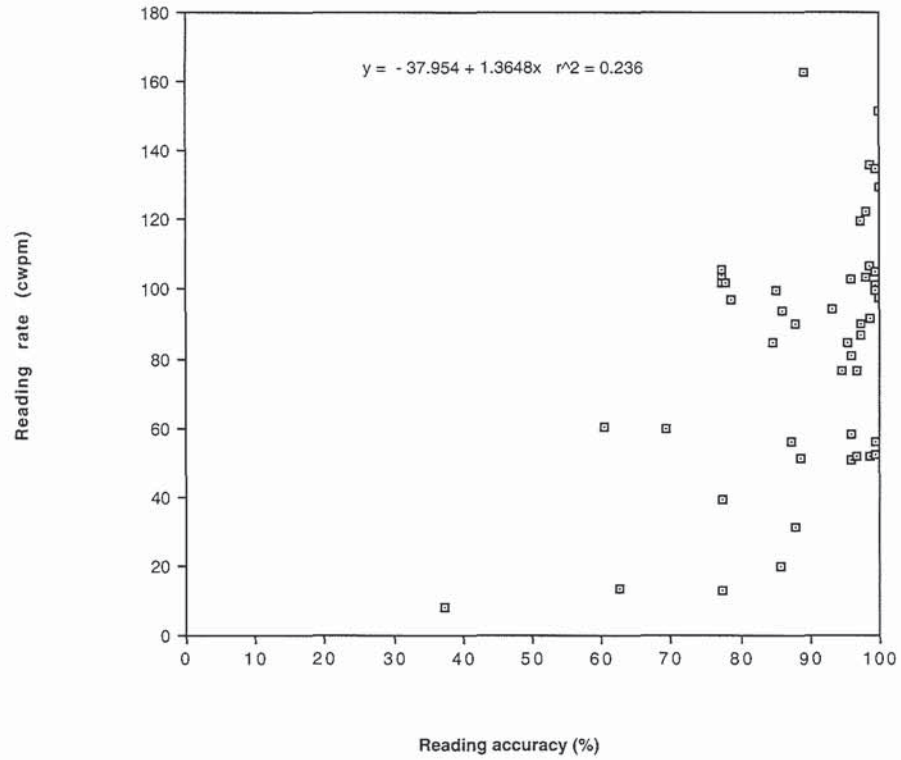
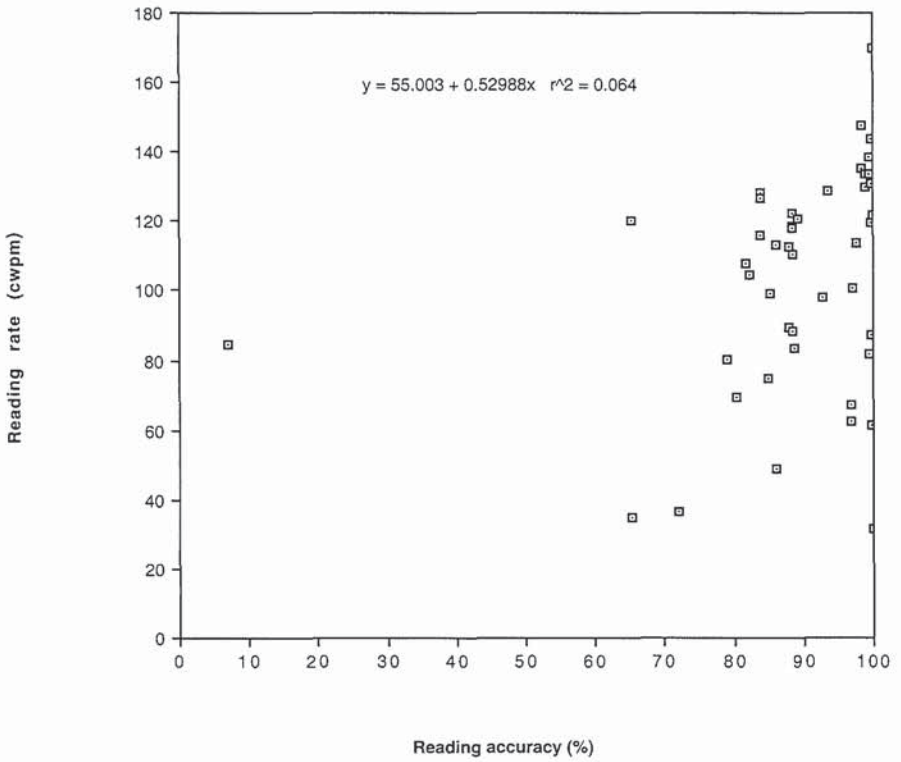


Figure 3.04a-SN tinted lenses
reading rate versus reading accuracy



Learning and fatigue effects

There was no statistically significant difference in reading rate for any group when the before and after results were compared. (SN, t=0.108, p=0.915; ARMD, t= -0.290, p=0.78). Similarly there was no difference for reading accuracy (SN, t= -0.557, p=0.58; ARMD, t=0.734, p=0.471).

Discussion

No difference in reading rate or reading accuracy between the SN group and the ARMD group for any of the tinted lenses was detected using ANOVA, i.e. there is no disease-related effect. This is counter-intuitive since it would be expected that subjects with ARMD would have had a poorer overall reading performance than the SN group. This could indicate that the power of this experiment to detect change might have been poor. However it may have been useful to not if the ARMD subjects stopped reading before the SN subjects. This could have been used to indicate whether subjects read a smaller print size when using filters.

Post hoc analysis of the ANOVA revealed a significant effect of the CPF and the clear filter on ARMD reading rate compared to the other two filters. The CPF450 did rank significantly higher in the Chi squared analysis for reading rate with ARMD, but the clear filter ranked highest for reading accuracy. Again the reasons for this are unclear. It is possible that the CPF450 blocked short wavelength light, which in turn reduced intra-ocular scatter resulting in a sharper image and a greater reading rate. However, the CPF did not produce any significant effects on reading accuracy.

The reason for the high ranking of the ND filter in the Chi squared analysis for reading accuracy is unclear. This would suggest that the SN group had greater accuracy when reading with reduced illuminance, which contradicts findings from previous studies (Sloan, 1969; Sloan *et al.*, 1973; Zhokhov *et al*, 1976; Silver *et al.,* 1978; Lagrow, 1986; Collins, 1987; Eldred, 1992). The experiment was designed to avoid glare, however, the high contrast of

black print against a white background may have inadvertently acted as a glare source; several subjects commented that the page was 'bright'. This may account for the higher ranking of the ND filter, as this would have reduced the effects of any glare source.

Personal clinical experience would suggest that many individuals with ARMD prefer to read with greater accuracy than speed, and therefore local lighting without any tinted lens could be beneficial to this group. However, if reading rate were paramount then it may be more appropriate to use a CPF450 lens.

Individual subject analysis highlighted one SN subject who had a 34% increase in reading rate with the CPF lens, and one ARMD subject who experienced a 23% improvement with the ND filter. The reasons for these results, especially for the ARMD subject, are unclear. This subject had a better reading performance with 50% reduced illuminance, which is the converse of previous research findings. Perhaps this subject was sensitive to glare produced by black text on a white background as discussed above? Neither subject had any clinically significant media opacities or light fundus pigment.

Results with the Intuitive Colorimeter® generated lens may have been affected by the fact that this was the only lens that was hand held, the others were all spectacle mounted. This may have had a negative effect on reading performance, although none of the subjects complained and none were observed to have any difficulties holding the lenses or experience any discomfort.

The CPF450 lens is currently commercially available for use as a reading aid in ARMD. It is relatively expensive when compared to the other types of filters used in this study, and is not readily obtainable. Also, there is very little independent research to justify its use. In this study ANOVA indicated that the clear filter performed as well as the CPF450, while the Intuitive Colorimeter® lens and ND filter performed less well. Chi squared analysis revealed that

CPF450 performed well on reading rate. Individual analysis showed a 34% improvement in rate for one SN subject only. These findings will be further discussed in Chapter 5-Overall Discussion.

Based on the out come of the Chi analyses it may be appropriate to recommend the CPF450 to people with ARMD who need to read faster. This lens also has an advantage in that it is photochromic and therefore will adapt to various environmental light conditions that may occur even indoors.

The results also indicated that for the ARMD group there is a positive relationship between reading rate and reading accuracy and a substantial part of the linear variation in rate can be accounted for by the variation in accuracy. The results are summarised in table 3.22.

Conclusions

Reading rate

- ANOVA did not detect any disease-related effect on reading rate. Such an effect would have been expected and this suggested that the experiment might have had poor power for detecting change.
- Duncan New Multiple Range test showed that for the ARMD group reading rate, the CPF lens and clear filter performed equally well; the Intuitive Colorimeter® lens and ND filter performed poorer than the clear filter and CPF lens.
- Chi squared analysis showed that optimum performance for the ARMD group occurred most frequently with the CPF.
- Individual subject analysis indicated that one SN subject gained a substantial improvement with the CPF lens, and one ARMD subject with the ND lens, perhaps due to a reduction in glare.

Reading accuracy

- ANOVA did not detect any disease-related effect on reading accuracy. Such an effect would have been expected and again this suggested that the experiment had poor power for detecting change.
- Chi squared analysis surprisingly showed optimum performance for the SN group occurred most frequently with reduced illuminance.
- Chi squared analysis for the ARMD group indicated optimum performance occurred most frequently with a clear lens.
- As the clear lens performed equally well as the CPF450 for reading rate and the clear lens performed better than any other lens for accuracy it may be in the individual's best interest to use a clear lens.

Table 3.22 summary of results for experiment 5b (tinted lenses)

Type of analysis	Results
ANOVA reading rate	SN=ARMD
	ARMD CPF>ND, CPF>IC, CPF=clear
ANOVA reading accuracy	SN=ARMD
Chi squared reading rate	ARMD CPF 1st
Chi squared reading accuracy	SN clear 1st, ND 1st
	ARMD clear 1st
Individual reading rate	SN CPF 37%
	ARMD ND 23%
Individual reading accuracy	none
Rate versus accuracy	SN 6.4%, ARMD 25.6%*
Learning/fatigue	none

*statistically significant at the 0.05 confidence level

Experiment 5b (tinted lenses) surprisingly did not show a disease related effect on reading rate

or accuracy. ANOVA suggested that there was no benefit gained in ARMD reading performance with tinted lenses compared to a clear filter, but Chi squared analysis indicated a reading rate was optimum with the CPF450. The results are therefore ambiguous.

Experiment 6 (video-magnifier) described in the next section examined the use of another coloured intervention in the form of video-magnifier screen background.

EXPERIMENT 6-EFFECTS OF VIDEO-MAGNIFIER SCREEN COLOUR ON READING WITH ARMD.

Introduction

A video-magnifier for visually impaired people is essentially a short-range version of a surveillance closed circuit television. The camera screen and interfacing module may be fixed together as a single structure or may be connected by cables. The system has a camera optimised for close range and controls to enhance screen contrast. Many systems have magnification-level controls and additional features.

Television electronics introduced two major advances for people with low vision: higher levels of magnification without the light-losing characteristics of purely optical systems and the ability to manipulate the video signal electronically to enhance the image so as to create one that has greater contrast than what is viewed by the naked eye. Video magnification is derived from two processes, (i) electronic conversion of the camera image to the much larger display screen, and (ii) the optical effect of the camera zoom lens (Uslan *et al.*, 1996).

The range of magnification is continuously variable, up to extreme limits if necessary, on the instrument itself. Angular magnification (the increase in visual angle subtended by the object at the eye by optical means) can be further increased, without detriment to the image, by viewing at a distance closer to the monitor. Equally important is that this 'approach-magnification' increases the field of view. Furthermore, binocular viewing can extend the field as far into the retinal periphery as is practicable.

In her case study of the use of video-magnifiers by people with low vision, Sloan (1974) identified seven advantages:

- Viewing the screen from a normal reading distance enables people with binocular vision to use their vision without an excessive demand on convergence.

- The zoom lens allows for the rapid change in magnification.
- The reversal of contrast to a black screen and white text (reversed contrast) is often less fatiguing than is the use of a white screen and black text.
- The video-magnifier can be used for handwriting.
- Higher levels of magnification are available than is possible with purely optical solutions.
- A larger field of view is available than is possible with purely optical solutions.
- The use of a x-y table (this can be moved forwards, backwards and sideways) is beneficial for people with visual field restrictions who have difficulty keeping their place when reading.

Brown (1981) suggested that video-magnifier images have better optical qualities than those from purely optical devices and that the increased depth of field and reduction of postural tension afforded by video-magnifier systems allowed significant increases in time for which the devices can be used.

For many years video-magnifier manufacturers have marketed and promoted the use of electronic systems, which have the ability to change the appearance of standard text, which commonly consists of black characters on a grey background. Many systems are able to convert black print to red, green, blue, yellow or white when presented on the screen. Screen background can usually be altered in a similar way, and therefore there are many permutations of text and screen colour. Video-magnifiers are also the only devices that allow print contrast *per se* to be enhanced.

As mentioned, the standard display is of dark print on a grey background, but some individuals prefer white print on a black background (often described as contrast reversal). This is particularly useful for those people who have an ocular condition that makes them susceptible to veiling luminance (also known as disability glare). Rosenberg (1984) described this as 'stray light that interferes with visual resolution because it is random and thereby

reduces the contrast of the figure/ground in the retinal image'. The scattering of light caused by ocular media opacities such as those due to corneal dystrophy and cataracts, and also by RP, often produces complaints of glare. These people usually prefer to reverse the contrast.

Jacobs (1990) investigated effects of different video-magnifier screen colours (white, green and amber) with a luminance level of 100 cdm^{-2}, on reading speed for low vision observers (Chapter 1-Background and Research Rationale). Screen colour had no significant effect on reading speed and there were significant differences between subjects, which would be expected with a heterogeneous group of people with low vision. Jacobs concluded that a low vision clinic does not need more than one video-magnifier screen colour for its assessments.

Jacobs *et al.* (1997) measured CS of low vision subjects in an attempt to relate it to reading performance of green, yellow and red texts to determine if there is an optimum colour that should be used for video display terminals and video-magnifiers. Better reading performance was achieved by the ARMD subset using stationary yellow text. The trend for a RSVP mode was similar but not significant. The effects were very marginal and probably would not influence reading speed with text luminance greater than 10 cdm^{-2}.

Apart from these two studies by Jacobs there is no other work that has investigated this type of coloured intervention and effects on reading performance in ARMD. However, current video-magnifiers are still marketed with a text/background colour manipulation facility. It would be useful to know whether there is any enhancement of reading performance with one of the latest versions of this type of video-magnifier, and if the higher cost is justified or perhaps a simpler video-magnifier, with standard black-on-white and contrast reversal facilities would suffice for subjects with ARMD.

Aims

This study was designed to determine whether the Eschenbach Optik ELG-01 Television

Reader video-magnifier screen colour has any affect on reading performance for a group with ARMD

Methods

Subjects

Only an ARMD group was used for this experiment (table 3.23). They had all been involved in at least one of the previous experiments in this series and were therefore experienced. However, none had ever used a video-magnifier prior to this study.

It was not considered necessary to assess an age-similar normal group as this would not provide any useful data and would markedly increase the logistical difficulties of the study. Older subjects without ocular disease would not use a video-magnifier in the real world. The only information that the inclusion of a SN group would provide, is whether there is a disease effect on the use of a video-magnifier and this was not considered relevant or useful enough to justify the assessment of another group of subjects.

Materials

- Eschenbach Optik ELG-01 Television Reader video-magnifier (Associated Optical, Unit 2, 64 High Street, Burnham, Bucks, SL1 7JT, UK) (see photograph 5 in appendix 10).
- Panasonic TV Monitor, Model TC145IR/BH, 16-inch screen size (source unknown).
- +3.00D clip-on lenses.

As experiment 2:

- Dictating type mini-tape recorder.
- Stop watch.

As experiment 4:

- Luminance meter.
- Five different arrangements of WRRT words (appendix 8.02)
- Score sheet.

Photograph 5 Video-magnifier

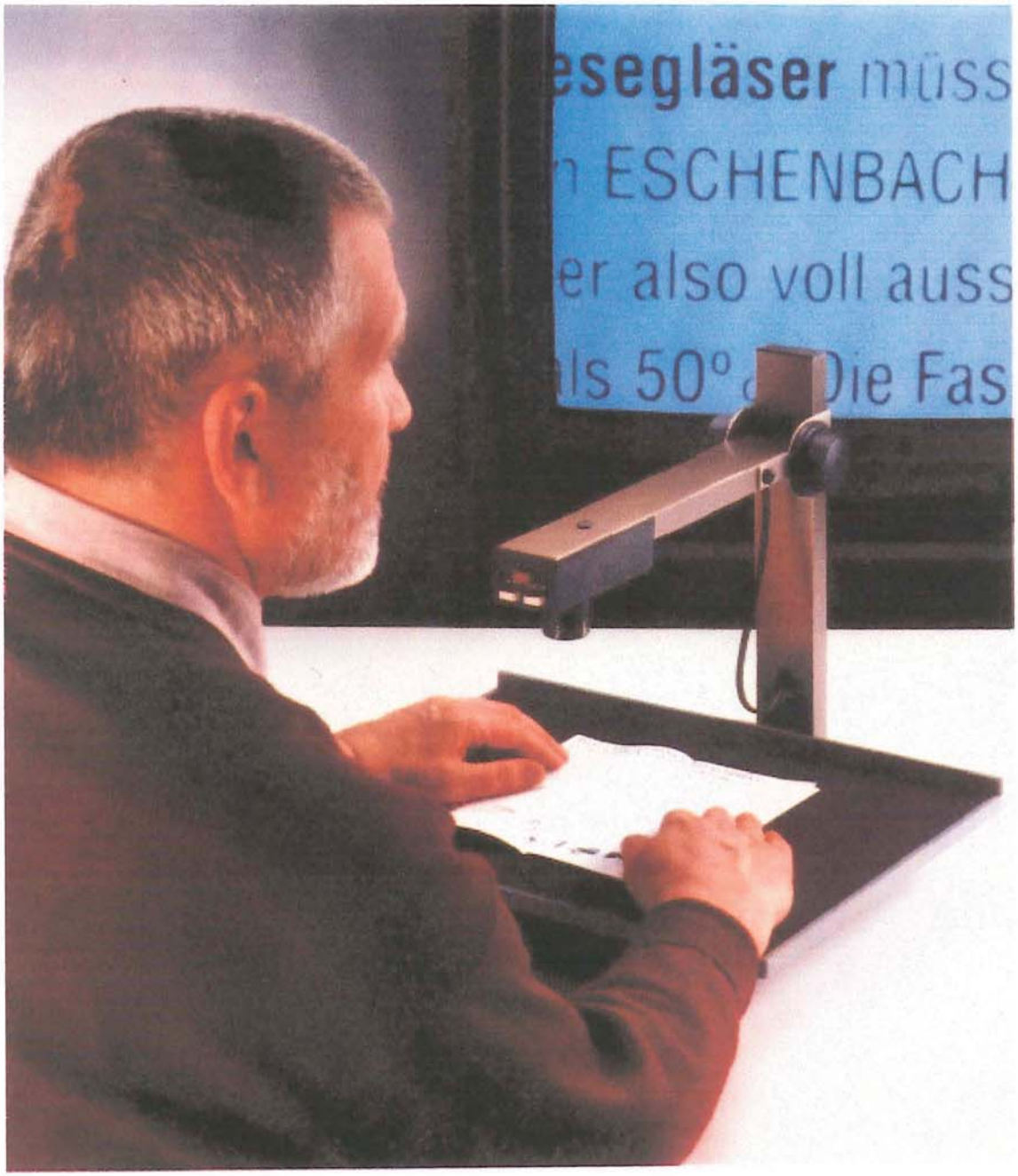


Table 3.23 subject age (years) and threshold binocular reading acuity for experiment 6 (video-magnifier)

Subject	Age	Reading acuity
BM	87	N10
CP	80	N8
DS	70	N16
EH	78	N20
GH	85	N16
ID	82	N8
KH	76	N8
MB	80	N16
MC	84	N5
MH	87	N6
MJ	81	N6
MS	87	N4

Binocular threshold reading acuity as measured with a Bailey-Lovie near word card at each observer's habitual reading distance. ARMD mean (years) 81.42, median 81.5, range 70 to 87, SD 5.13.

Procedure

All subjects used their habitual spectacles for the testing session, were seated and viewed the video-magnifier screen from 33 cm through their distance prescription on to which was attached a +3.00 DS full eye size clip-on. A block of black WRRT print on matt white paper was placed on the video-magnifier x-y table and magnified to fill the screen area. The same block of black text on a grey screen background was presented at the start of and end of each session to determine if there were any fatigue or learning effects. Other blocks with different arrangements of WRRT words were used for each of five screen colours. Blocks were presented in the same order for all subjects but screen colour was randomly selected in order to reduce the possibility of confounding the results through learning effects. Luminance values

for the screen colours were; grey 130 cdm^{-2}, black 40 cdm^{-2}, red 75 cdm^{-2}, yellow 160 cdm^{-2}, green 160 cdm^{-2}, blue 35 cdm^{-2}.

The WRRT was used to provide an objective measurement of which screen colour provided the best reading performance. The WRRT words were typed on a word processor rearranged in order and then reprinted to provide 6 blocks with 150 words in each block.

Prior to the start of the testing session, subjects were shown large print (N40) versions of the words used in the WRRT and asked to read them out loud twice to encourage familiarity. They were informed that the test blocks comprised solely of these words, and that each line had a different arrangement of the same words. They were reminded that the blocks had no contextual clues and that 'their reading would not make sense'. Subjects were not informed of the aims of the research.

Each subject was asked to read from the screen, beginning in the top left hand corner of the and reading each line of words out loud until the complete block had been read. They were asked to read as accurately and as quickly as possible; the emphasis was placed on accuracy. No movement of the x-y table was required to view the complete block. In fact subjects were discouraged from adjusting the x-y table in any way. They were encouraged to guess or pass on words they were unsure about, and were advised that they would be tape-recorded and that the tape would be analysed later to determine reading performance and then erased. Subjects were encouraged to read from a position that produced the clearest view of the screen text.

There were six different test conditions and seven measurements (the first and last test conditions were identical, i.e. black print on a grey background). Each subject was asked to read one paragraph of 150 words with each screen colour. Some subjects found some of the screen colours too uncomfortable to look at and could not manage to read the complete block of text.

Reading rate and reading accuracy were calculated as described in the introduction to Chapter 3-Primary Experiments. Before and after reading rate and accuracy were compared to determine whether there had been any learning and fatigue effects.

Questions to be answered

- Was there a screen colour that produced better reading performance than with standard black text on a grey background?
- How did reading performance with the black-on-grey presentation compare with the white-on-black?

Results

For raw data see appendix 1.05.

ANOVA

Reading rate and accuracy were compared across screen colour using a split plot ANOVA procedure and *post-hoc* examination of significant differences for those ANOVA p values less than or equal to 0.05.

ANOVA revealed a colour effect for reading rate (F, 30.40, p=0.00, df 0, 55) (table 3.24) and reading accuracy (F, 16.88, p=0.00) (table 3.25). Scheffé's S *post-hoc* test indicated that the blue and red screen colours performed significantly poorer than the other colours for reading rate and accuracy. There was no significant difference between the black-on-grey and white-on-black presentations.

Table 3.24 ANOVA split-plot and Scheffé's S *post-hoc* test tables for reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	61072.25	5552.02	23.97	.0001	Residual
colour	5	35208.39	7041.68	30.40	.0001	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	12740.67	231.65			

Dependent: reading rate

Scheffe's S
Effect: colour
Dependent: reading rate
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
blue	red	9.25	21.45	.8165	
	green	40.32	21.45	.0001	S
	yellow	45.31	21.45	.0001	S
	black	52.72	21.45	.0001	S
	grey	59.47	21.45	.0001	S
red	green	31.07	21.45	.0008	S
	yellow	36.06	21.45	.0001	S
	black	43.47	21.45	.0001	S
	grey	50.22	21.45	.0001	S
green	yellow	4.99	21.45	.9851	
	black	12.40	21.45	.5569	
	grey	19.15	21.45	.1092	
yellow	black	7.41	21.45	.9198	
	grey	14.16	21.45	.4045	
black	grey	6.75	21.45	.9449	

S = Significantly different at this level.

Table 3.25 ANOVA split-plot and Scheffé's S *post-hoc* test tables for reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	19474.39	1770.40	5.17	.0001	Residual
colour	5	28879.39	5775.88	16.88	.0001	Residual
colour * subject	0	•	•	•	•	Residual
Residual	55	18821.74	342.21			

Dependent: reading accuracy

Scheffe's S
Effect: colour
Dependent: reading accuracy
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
blue	red	13.30	26.07	.6846	
	yellow	46.17	26.07	.0001	S
	green	46.40	26.07	.0001	S
	black	49.23	26.07	.0001	S
	grey	51.01	26.07	.0001	S
red	yellow	32.87	26.07	.0051	S
	green	33.09	26.07	.0047	S
	black	35.93	26.07	.0016	S
	grey	37.70	26.07	.0008	S
yellow	green	.22	26.07	1.0000	
	black	3.06	26.07	.9994	
	grey	4.83	26.07	.9948	
green	black	2.83	26.07	.9996	
	grey	4.61	26.07	.9958	
black	grey	1.78	26.07	1.0000	

S = Significantly different at this level.

Chi squared analysis

Data was also analysed in terms of ranking frequencies. Screen colours were objectively ranked for reading performance for each subject, i.e. how many times each text colour was ranked first, second, third, fourth, fifth and sixth. These ranking frequencies were then further analysed, using a Chi squared procedure, to determine if there was any statistical significance in their distribution (table 3.26a and b).

Frequency analysis indicated a significant cluster for reading rate:

- grey background in first position (Chi^2, 39, p=0.01)
- yellow in third position (Chi^2, 15, p=0.05)
- green in fourth position ((Chi^2, 15, p=0.05)
- red in fifth position (Chi^2, 40, p=0.01)
- blue in sixth position (Chi^2, 40, p=0.01)

And for reading accuracy:

- grey background in first position (Chi^2, 12, p=0.05)
- red in fifth position (Chi^2, 24, p=0.01)
- blue in sixth position (Chi^2, 21, p=0.01)

Individual subject analysis

The results for reading rate and accuracy for each screen colour for each subject were normalised to the results from the black-on-grey presentation and a *post hoc* search conducted for any subjects that demonstrated a 20% or greater increase in reading performance. None were found.

Reading rate versus reading accuracy trade-off analysis

There may have been a reading rate reading accuracy trade off in this experiment, i.e. those subjects that read quickly may have had a reduced accuracy, and those that read slowly may

Table 3.26a ranking frequencies and Chi squared analysis for experiment 6 (video-magnifier) reading rate

ARMD reading rate

screen colour	white	red	yellow	green	blue	black
ranking	(ave.)					
1	10	0	0	0	0	2
2	1	0	3	3	0	5
3	0	0	6	3	0	3
4	1	0	3	6	0	2
5	0	10	0	0	2	0
6	0	2	0	0	10	0
Chi^2	39*	40*	15*	15*	40*	9

*significant at the 0.05 confidence level

Table 3.26b ranking frequencies and Chi squared analysis for experiment 6 (video-magnifier) reading accuracy

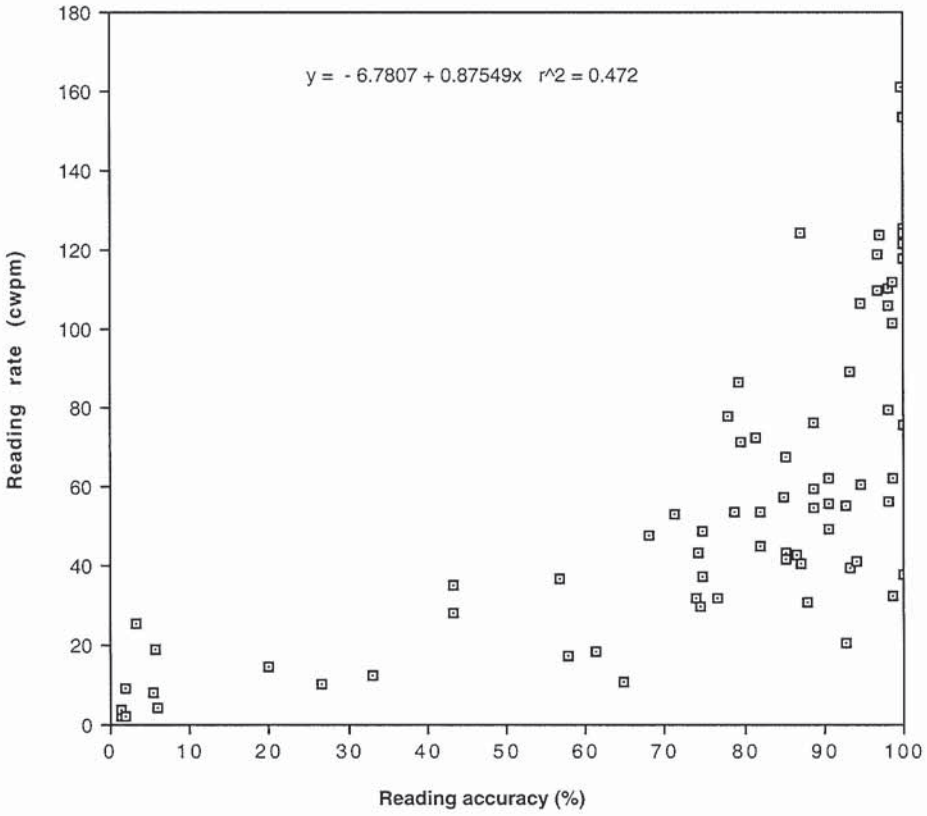
ARMD reading accuracy

screen colour	white	red	yellow	green	blue	black
ranking	(ave.)					
1	6	0	3	1	0	5
2	2	0	5	4	0	1
3	2	0	2	2	1	3
4	2	2	1	5	0	3
5	0	8	1	0	4	0
6	0	2	0	0	7	0
Chi^2	12*	24*	8	11	21*	10

*significant at the 0.05 confidence level

Figure 3.05 scattergrams

Figure 3.05 video-magnifier reading rate versus reading accuracy



have had better accuracy. In order to investigate this the correlation coefficient (r) and the coefficient of determination (r^2) were calculated for the group; $r^2 = 0.472$ and $r=0.687$ ($p<0.05$) (figure 3.05). These figures indicate that 47.2% of the reading data are related and that this is statistically significant. This would suggest that for the ARMD group there is a positive relationship between reading rate and reading accuracy, i.e. as one increased so did the other.

Learning and fatigue effects

There was no statistically significant difference in either reading rate or accuracy, for the group when the before and after test session results were compared (ARMD $t= -0.163$, $p=0.87$ and $t=0.933$, $p=0.36$ respectively).

Discussion

None of the screen colours produced a better reading performance than the grey display. In fact the red and blue background colours considerably reduced reading performance. The overall result agreed with the findings of Jacobs (1990) who also found negative results.

The Eschenbach video-magnifier used in this study produced black text on red and blue screens that was difficult to read even for a normal observer (FE). The clarity of the black text on blue or red screens was noted to change as people moved around the test room. This may have been due to interference with the signal from the camera to the screen, and also occurred with an identical model from this manufacturer. Therefore, it is difficult to determine whether the poorer reading performance with these two screen colours was due to screen colour *per se* or due to a design fault in the video-magnifier. No other brand of video-magnifier with a coloured background/text facility was available for study, and therefore this requires further investigation.

It is possible that the variation in contrast between the text and the various screen backgrounds and may have confounded the results (grey 130 cdm^{-2}, black 40 cdm^{-2}, red 75 cdm^{-2}, yellow

160 cdm^{-2}, green 160 cdm^{-2}, blue 35 cdm^{-2}) in that apart from the black screen the red and blue screens had the lowest luminance.

The study group consisted of ARMD observers with no clinically significant media opacities and therefore very little glare effects were expected. This may be why there was little difference between reading performance with the black-on-grey and white-on-black presentation modes. Different results would be expected for a RP or cataract group as these conditions often result in veiling glare.

Therefore, it can be stated that with this particular model of video-magnifier there is probably no advantage to be gained from using a coloured screen other than grey and there is no point in purchasing this model when a lower cost, standard system with a black-on-grey facility, would suffice. See table for summary of results.

Table 3.27 summary of results for experiment 6 (video-magnifier)

Type of analysis	Results
ANOVA reading rate	Green, yellow, grey, black>blue, red
ANOVA reading accuracy	Green, yellow, grey, black>blue, red
Chi squared reading rate	Grey 1st, yellow 3rd, green 4th, red 5th, blue 6th
Chi squared reading accuracy	Grey 1st, red 5th, blue 6th ARMD clear 1st
Individual reading rate	none
Individual reading accuracy	none
Rate versus accuracy	ARMD 42.7%*
Learning/fatigue	none

*significant at the 0.05 confidence level

Conclusions

- No advantage was gained from using the coloured screen facility of the Eschenbach Optik ELG-01 Television Reader video-magnifier for the study group.
- There was no difference between the black-on-grey and white-on-black presentation modes.
- It is possible that the difference in luminance contrast between the text and the background for the various screen colours may have confounded the results.
- Individuals with ARMD should be advised to undergo a formal objective testing period with other video-magnifier brands with colour facility or purchase lower cost standard video-magnifiers.
- People who already possess this brand of video-magnifier probably would not benefit from the use of black text on a red or blue background, although the numbers of subjects used in this study make this a tentative conclusion at best.
- Other brands of video-magnifiers with screen colour manipulation facilities need to be formally studied.
- The results from this study are only applicable to ARMD subjects and to this particular brand of video-magnifier.

Chapter 4-Secondary Experiments and Technical Notes

Introduction

Secondary aims of this study were to investigate the effects of local lighting produced by various types of lamps on reading performance, and the possible use of the Intuitive Colorimeter® as a colour vision analyser for subjects with ARMD. As Chapter 1-Background and Research Rationale highlighted that very little work has been done to assess the use of particular types of local lighting in low vision, and from personal clinical experience colour vision analysis is not routinely carried out in low vision evaluation.

Data on the extent and relative depth of the central scotoma for each ARMD subject would be useful in attempting to suggest a mechanism for any individual improvement in reading performance and therefore information on the biocular scotoma, using the Humphrey 630 Visual Field Analyser, was obtained

An outcome measure is required in order to determine levels of success in the clinical and research environment. Reading rate and reading accuracy are two measures that can be used to determine success, however there are several ways that these can be measured. Two that were used in this study are the Wilkins Rate of Reading Test® (WRRT) and the Bailey-Lovie near word reading acuity card.

This chapter describes two secondary experiments with methodology, results, analyses, discussion and conclusions for each:

- Experiment 7-Effects of three commercially available lamps on reading performance in YN, SN and ARMD groups.

- Experiment 8-Use of the Intuitive Colorimeter® as a colour vision analyser compared to the PV-16 (Precision Vision) colour vision arrangement test for SN and ARMD groups.

And two technical notes:

- Technical note 1-Use of the Humphrey 630 Visual Field Analyser to determine the area and depth of biocular scotoma in an ARMD group.
- Technical note 2-Comparision of the Wilkins Rate of Reading Test® with the Bailey-Lovie near word reading card for reading performance analysis in low vision research and clinical use.

EXPERIMENT 7-COMPARISON OF READING PERFORMANCE WITH VARIOUS LUMINAIRES IN ARMD

Introduction

Individuals with ARMD often complain of reading difficulties; they report that print is too small, dim, patchy or misty. Even when the desired print size is manageable, people with ARMD often rely heavily on contextual clues, fatigue quickly, and become frustrated because of a low reading rate and perceived or actual inaccuracy. Optometrists and low vision therapists sometimes recommend the use of a luminaire (reading lamp) placed near the task such as an Anglepoise, often described as local lighting, for people with ARMD. The aim is to achieve more efficient and comfortable performance of near vision tasks. Lighting technology terminology of lamp (bulb) and luminaire (fixture that holds the bulb) will be used throughout this section.

It is established that there is a progressive deterioration of the sensitivity of the eye to the visual environment during ageing (Bailey, 1972). Age-related miosis and lenticular yellowing result in decreased light transmission and increased intra-ocular scatter. In general these changes result in a diminution of retinal illuminance, reduced contrast sensitivity and a greater susceptibility to disability glare in the older eye (Hughes and Neer, 1981). The implications of the physiological changes with age are that to achieve visual performance equal to that of young people, older persons need two to three times the light level required by the young and lighting must be arranged particularly to eliminate sources of disability glare.

Previous research has suggested that appropriate local lighting can improve the ability of people with low vision to carry out a variety of tasks, especially reading. (Sloan, 1969; Sloan *et al.*, 1973; Shirshikov, 1974; Zhokhov *et al.*, 1976; Silver *et al.*, 1978; Julian, 1984; Lagrow, 1986; Collins, 1987; Soldatova, 1990; Cornelissen *et al.*, 1991; Taub and Sturr, 1991; Eldred, 1992; Cornelissen *et al.*, 1995). The following is a brief, non-exhaustive review of those

studies investigating the relationship between local lighting and reading acuity or near VA. Most of these studies have been fully described in Chapter 1-Background and Research rationale.

Weston (1945) highlighted how the performance of simple visual task, for normally sighted observers, is influenced by the size of its details, and illuminance. The performance of a visual task improves as the size of the test object is increased. The performance of the task is improved by about 135% when the size of the object is 3 minutes instead of one minute and that the improvement is nearly 200% when the size is increased to 10 minutes. Conversely if the size of the object is kept small (1 minute) and the illuminance is increased 10 times, only a 30% improvement in performance is achieved.

The ability to recognise detail in a task depends not merely upon its angular subtense, but also upon its contrast, either of luminance (brightness), colour or both, between the essential parts of the task and its immediate background. When different objects receive the same illumination, they will be seen more easily by luminance contrast if their reflection factors are very different.

Weston (1945) compared the effect of enhancing the contrast with increasing illuminance of a small detail task. He found even under a very low level of illuminance (50 lux), when poor contrast of the detail (0.28) is improved (0.97), i.e. the relative difference of brightness between the detail and its background is increased nearly three times, the gain in visual performance is 130%. Conversely, if the contrast remains poor but the illuminance is increased ten times, the gain in performance is only 20 to 30%. Improving the contrast of the task detail with it immediate background can have a far more significant effect. Unfortunately, improving the contrast of near objects, especially print is only achievable using video-magnifiers, and these are not readily available.

Silver *et al.* (1978) found that reading VA was considerably enhanced when lighting was improved for subjects with a variety of eye diseases including ARMD. Over 90% of all subjects showed some improvement in near or distance VA with increased lighting.

Gill and Silver (1982) tested the illuminance of nine types of commercial luminaires with tungsten incandescent lamps using a light meter. A 60W Thorn Decorspot 80 Diffused (an 'architectural-type spotlight') produced the highest illuminance of 3800 lux at 40 cm when mounted in an Anglepoise luminaire, nearly four times the next closest lamp.

Julian (1984) studied near and distance VA as functions of task illuminance for 27 partially sighted people (no subject details). Near word recognition tests showed that reading VA improved from N24 at 50 lux to N15 at 600 lux. Julian concluded that if moderately high task illuminances were used for near tests then some partially sighted people would not need low vision devices, and for others the efficiency of their devices would be improved. He advised that the whole of the visual environment be illuminated rather than using local, isolated task lighting and that environmental illuminances should not be less than 25% of local task illuminance or less than 50% of working plane illuminance if local lighting was not used.

Collins (1987) assessed the performance of three commercially available luminaires on a low vision population with a variety of ocular disorders. Subjectively the observers preferred luminaires with a compact fluorescent lamp and a daylight incandescent lamp equally. None preferred a luminaire with a standard incandescent lamp.

Cornelissen *et al.* (1991) determined the smallest readable letter size on a near word chart for 32 subjects with varied ocular pathology and used low (100 lux), middle (500 lux) and high (2000 lux) illuminance. Twenty percent of the study group had best reading VA at the highest illuminance, 30% at the middle illuminance and for the remaining 50% reading VA did not change under the different levels of illuminance. Interestingly, 60% preferred the highest, 25%

the middle and three the lowest level of illuminance. The authors concluded that reading VA alone may not be a sufficient measure of the illuminance dependence of visual performance and that 'more detailed investigation of the relation between illuminance, VA, visual performance and preferences is necessary'.

Often, low vision practitioners state that an increase in illuminance improves print contrast *per se*. This is unlikely to be the case, since the differential in the reflectance between the print and the background will remain constant irrespective of the amount of illuminance. The perceived increase in contrast is more likely to be due to increased light passing through media opacities even those which are clinically insignificant (however, this would probably result in more ocular scattering and retinal image degradation), a reduction in the size of the macular scotoma (Bullimore and Bailey, 1995), an increase in the observer's contrast sensitivity function peak (Brown and Garner, 1983) or a combination of all of these factors.

Standard clinical practice at Birmingham Focus on Blindness Low Vision Centre is to recommend the use of a luminaire with a compact fluorescent lamp. This produces an even light, the lamp does not become hot, and generates less heat than a tungsten incandescent lamp. At the time of writing the initial purchase price of a luminaire with a compact fluorescent lamp was three times greater than that of a luminaire with an incandescent tungsten lamp. However, they are less expensive in the long term as they use less electricity and last approximately ten times longer. Nevertheless, the initial purchase price differential may prevent organisations from recommending them and individuals from purchasing them.

The use of daylight simulation tungsten incandescent lamps has been recommended by some workers who suggest that these perform as well as compact fluorescent lamps but are less expensive to purchase. Daylight simulation lamps are blue filtered, tungsten incandescent and are promoted by the distributors (Daylight Studios, 223a, Portobello Road, London, W11 1LU, UK) as producing 'light which is relaxing for the eyes, excellent for detailed work and

reading; light quality with high level of contrast eases eyestrain'. The validity of these claims has not been scientifically tested (appendix 5).

Luminaires with tungsten incandescent lamps and daylight simulation tungsten incandescent lamps are often not recommended for use in low vision because of their heat emitting properties. Luminaires often have to be placed near to the task and near to the person and as they are usually constructed from metal, emit heat and can be uncomfortable to work near. They may even cause a burn if contact is made with the face or ear.

Because of the purchase price differential between compact fluorescent and tungsten incandescent luminaires some authorities prefer to recommend a luminaire with a tungsten incandescent lamp and provide advice on positioning to avoid discomfort from the heat output and reduce the possibility of a burn. Also, standard tungsten incandescent lamps may result in less glare for a person with a media opacity. Incandescent tungsten lamps have a long wavelength bias, whereas daylight simulation tungsten incandescent and compact fluorescent lamps have a short wavelength bias; the latter may cause more intra-ocular scattering, and therefore glare, which may produce a degraded retinal image and reduced reading performance (Bailey, 1972).

Less wealthy individuals with low vision are sometimes reluctant to use this type of local lighting because of increased electricity costs associated with tungsten incandescent lamps Incandescent tungsten lamps operate on 60 to 100W, while compact fluorescent lamps operate on nine to 11W and therefore, the latter have much lower long term operating costs.

When clinical evaluation has demonstrated improved visual function with increased illuminance for an individual with low vision, clinical experience has suggested that it is in the individuals best interests visually, ergonomically, and financially (long term) to use a luminaire with a compact fluorescent rather than an tungsten incandescent lamp. There is

however, scant objective information available and it is difficult to advise the low vision individual.

It would be useful to know if there is any advantage to be gained in reading performance from the use of a luminaire with a compact fluorescent, a daylight simulation tungsten incandescent, or a standard incandescent tungsten lamp, when compared to general ambient illuminance alone. This may allow recommendations to be made based on scientific data, rather than on anecdotal observations or personal preferences.

Aim

To objectively assess the effect of four types of lamp on reading performances for a group of SN and a group of ARMD subjects.

Methods

Subjects

See table 4.00 for subject age and threshold reading acuity details. Eleven SN and 12 ARMD subjects were used.

Age in years; SN mean age 69, range 61 to 74, SD 4.38; ARMD mean age 80, range 70 to 87, SD 5.33. There is a statistically significant difference in the average age of the SN and ARMD groups ($t=5.485$, $p=0.00$).

All subjects used glasses for reading and wore these for all test conditions. Some of the ARMD subjects had been advised of a possible benefit from the use of a luminaire with a compact fluorescent lamp at previous visits to the low vision centre and during testing some ARMD subjects recognised this luminaire. This may have resulted in a placebo effect in favour of this particular luminaire.

Table 4.00 subject details and binocular threshold reading acuity for experiment 7 (luminaires)

SN	Age (years)	Reading acuity	ARMD	Age (years)	Reading acuity
DP	71	N4	BM	87	N10
EC	73	N4	CP	80	N8
EE	74	N4	DS	70	N16
FF	66	N4	EH	78	N20
GM	63	N4	GH	85	N16
JS	73	N2.5	ID	82	N8
MW	61	N2.5	KH	76	N8
RP	69	N3	MB	80	N16
RT	71	N3	MC	84	N5
TH	66	N4	MH	87	N6
VG	74	N4	MJ	81	N6
			NJ	73	N8

Threshold binocular acuity measured with the Bailey-Lovie near word reading card at the observer's habitual working distance. SN mean 69.18 years, median 70, range 61 to 74, SD 4.56; ARMD mean 82.37 years, median 80.5, range 70 to 87, SD 5.33. The difference in the average age of the two groups is statistically significant (t=4.562, p=0.00)

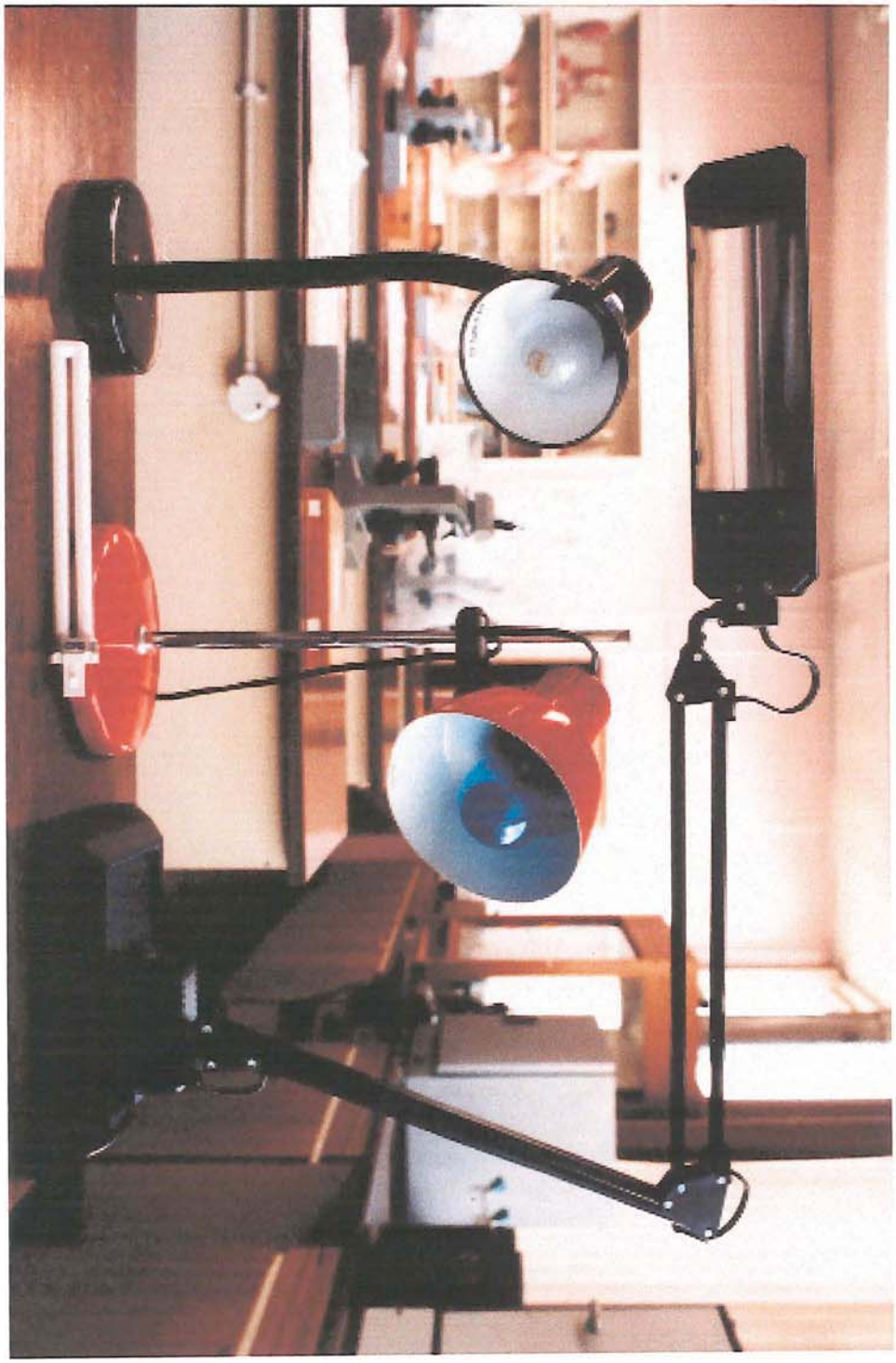
Materials

- Luminaire with clear 60W tungsten incandescent lamp, source unknown. Distance from lamp to desktop 25 cm; illuminance 3650 lux.
- Luminaire with daylight simulation (blue tint) 60W incandescent tungsten lamp (see appendix 5) (source of lamp, Daylight Studios, 223a, Portobello Road, London, W11 1LU, UK). Distance from lamp to desktop, 25 cm; illuminance 2140 lux.

Luminaire with compact 'cool white' fluorescent lamp 11W (Model 871, IBJ, Daylight Studios, 223a, Portobello Road, London, W11 1LU, UK). Distance from luminaire to desktop

25 cm; illuminance 3300 lux. See photograph 3 for luminaires.

Photograph 5 Luminaires



As in experiment 3:

- Five different Bailey-Lovie near word reading acuity cards.
- Stop watch.
- Light meter.
- Dictating type mini-tape-recorder
- Score sheet (words from the Bailey-Lovie reading cards, word processed and printed out on A4 sheets).

The light meter was placed horizontally on the desk surface immediately beneath each lamp and the illuminance measured. The calibration of the light meter was not checked, since only comparative measurements were required.

The daylight simulation tungsten incandescent lamp produced much less illuminance than the other two lamps. This lower illuminance lamp was used because Sloan *et al.* (1973) and Eldred (1992) had found that some low vision observers complained of print fading when using high intensity lamps for reading. Therefore, it was considered useful to investigate the effects of a 'medium intensity' illuminance. As discussed above operating cost is one factor that some low vision individuals consider when purchasing lamps; it was therefore decided to use a daylight simulation lamp with the same wattage (60 W) as a standard tungsten incandescent lamp even though the two lamps would differ in illuminance. The illuminance produced by the daylight simulation lamp approximately matched that found by Silver *et al.* (1978) to be the median home optimum level for maximum reading performance.

Illuminance values noted above do not include ambient room illuminance of 500 lux (maximum achievable) measured at desk surface (grey matt plastic) produced by tubular fluorescent lamps (Poly-Lux 800 F36 W colour code 840). All testing was conducted at this ambient room illuminance of 500 lux in an attempt to comply with Julian's (1984) recommendation that ambient illuminance should not be less than 25% of local task

illuminance. This level of ambient illuminance was still short of the criteria suggested by Julian (1984) for compact fluorescent and standard tungsten incandescent lamps (approximately 900 and 850 lux respectively). This high level of ambient illuminance (500 lux) at both testing sites that was far in excess of the that encountered in the home environment by Levitt (1978) and Silver *et al.* (1978), i.e. 50 to 70 lux and 177 lux respectively.

Procedure

Subjects gave verbal consent and were advised what to expect during the testing session and what was required of them. They were encouraged to position themselves for optimum visual and postural comfort and clarity of the text and to maintain the same working distance throughout the testing session. This was checked every few minutes using a standard tape measure.

They were asked to read from a Bailey-Lovie near word card as quickly as possible without making errors, using each luminaire; cards were placed on a flat desk surface and subjects were not allowed to move them. Subjects started with the largest word and read out loud from the card until they either made continuous mistakes, paused for more than five seconds or gave up, i.e. the subject had reached the reading acuity limit. They were encouraged to pass on words they found difficult. A different version of the near card was used for each lighting condition; there was also an ambient room illuminance only presentation (no local lighting). The ARMD subjects had experience reading from these cards gained from previous clinical testing. The luminaires were positioned at 25 cm above the word card, in front of but shielded from the subjects face and adjusted accordingly to avoid any disability or discomfort glare.

There were four different lighting test conditions and five measurements; the first and last test conditions were identical, i.e. ambient room illuminance only, using the same reading card to check for learning and fatigue effects. The presentation of reading cards was in the same order

for all subjects but luminaires were randomly selected to reduce the possibility of confounding the results through learning or fatigue effects. All test sessions were tape-recorded.
After the test session had been completed and the subject had left the tape recording was replayed. Reading rate was calculated by noting the time elapsed, in seconds, prior to cessation of reading; this figure was divided into 60 and the result multiplied by the total number of words read correctly. Reading accuracy was determined by dividing the number of words correctly identified by the sum of all words attempted including those that were passed.

Questions to be answered

- Did one lamp produce the best reading performance?
- How do the two study groups compare?
- How did reading performance with the lamps compare to that with ambient room lighting only?

Results

See appendix 1.06 for raw data.

ANOVA

Reading rate and accuracy were compared across subject groups and lamps using a split plot ANOVA procedure and *post-hoc* examination of significant differences. Scheffé's S *post-hoc* test was applied to those single factor ANOVA p values less than or equal 0.05. Results for each subject group were examined in a similar way.

There was a significant group effect on reading rate ($F=26.01$, $p<0.00$, df 1, 63) and reading accuracy ($F=4.32$, $p=0.05$, df 1, 63) (table 4.01). Scheffé's *post-hoc* test indicated a significant difference in reading rate and reading accuracy between the SN and ARMD groups ($p=0.001$and $p=0.05$ respectively). This was not surprising as the ARMD group was expected to have a poorer reading performance compared to the SN group. F-values for a lamp effect,

and lamp versus subject interaction were not significant at the 0.05 confidence level for

Table 4.01 ANOVA split-plot and Scheffé's S post-hoc test tables for all subjects for reading rate and accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	1	24226.89	24226.89	26.01	.0001	replicant (subject)
replicant (subj...	21	19563.34	931.59	27.59	.0001	Residual
lamp	3	140.04	46.68	1.38	.2563	Residual
lamp * subject	3	41.77	13.92	.41	.7447	Residual
Residual	63	2127.18	33.76			

Dependent: reading rate

Scheffe's S
Effect: subject
Error term: Type III sum of squares for replicant (subject)
Dependent: reading rate
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
ARMD	SN	32.49	13.25	.0001	S

S = Significantly different at this level.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	1	609.93	609.93	4.32	.0500	replicant (subject)
replicant (subj...	21	2961.56	141.03	15.15	.0001	Residual
lamp	3	4.30	1.43	.15	.9268	Residual
lamp * subject	3	77.35	25.78	2.77	.0488	Residual
Residual	63	586.27	9.31			

Dependent: reading accuracy

Scheffe's S
Effect: subject
Error term: Type III sum of squares for replicant (subject)
Dependent: reading accuracy
Significance level: .05

	Vs.	Diff.	Crit. diff.	P-Value	
ARMD	SN	5.15	5.15	.0500	S

S = Significantly different at this level.

Table 4.02 ANOVA split-plot for SN and ARMD groups respectively for reading rate

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	10	7011.63	701.16	36.21	.0001	Residual
lamp	3	137.97	45.99	2.37	.0898	Residual
lamp * subject	0	•	•	•	•	Residual
Residual	30	580.92	19.36			

Dependent: reading rate

Note the only relevant effects are replicant, filter colour and filter colour versus subject. The ANOVA software did not allow for deletion of the non-relevant sections of this table.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	12551.71	1141.06	24.35	.0001	Residual
lamp	3	39.56	13.19	.28	.8384	Residual
lamp * subject	0	•	•	•	•	Residual
Residual	33	1546.26	46.86			

Dependent: reading rate

Table 4.03 ANOVA split-plot for SN and ARMD groups respectively for reading accuracy

Note the only relevant effects are replicant, filter colour and filter colour versus subject. The ANOVA software did not allow for deletion of the non-relevant sections of this table.

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	11	2815.09	255.92	17.48	.0001	Residual
lamp	3	43.48	14.49	.99	.4096	Residual
lamp * subject	0	•	•	•	•	Residual
Residual	33	483.26	14.64			

Dependent: reading accuracy

Type III Sums of Squares

Source	df	Sum of Squares	Mean Square	F-Value	P-Value	Error Term
subject	0	•	•	•	•	replicant (subject)
replicant (subj...	10	146.47	14.65	4.27	.0010	Residual
lamp	3	38.39	12.80	3.73	.0217	Residual
lamp * subject	0	•	•	•	•	Residual
Residual	30	103.01	3.43			

Dependent: reading accuracy

Scheffe's S
Effect: lamp
Dependent: reading accuracy
Significance level: .05

	V...	Diff.	Crit. diff.	P-Value	
al	di	1.12	2.34	.5766	
	cf	2.05	2.34	.1036	
	si	2.41	2.34	.0409	S
di	cf	.93	2.34	.7117	
	si	1.29	2.34	.4558	
cf	si	.36	2.34	.9750	

S = Significantly different at this level.

reading rate. There was however, a significant lamp versus subject interaction ($F=2.77$, $p<0.05$, df 3, 63) for reading accuracy (table 4.03).

Individual group ANOVA

The results of a split plot ANOVA for the each group for reading rate indicated that there was no significant lamp effect on reading rate at the 0.05 confidence level (table 4.02). There was a significant lamp effect on reading accuracy for the SN group ($F=3.73$, $p<0.05$, df 3, 30) and Scheffé's *post hoc* analysis indicated a significant difference in reading accuracy between the no local lighting and the standard tungsten incandescent lamp conditions (table 4.03). *Post-hoc* analysis of the raw data showed that the no local lighting presentation resulted in a lower reading accuracy than ambient illuminance in conjunction with the standard tungsten incandescent lamp.

Chi squared analysis

Lamps were objectively ranked for reading performance. Each was ranked according to whether it resulted in the first, second, third, or fourth best performance for each subject. Ranking frequencies were then analysed using a Chi squared procedure, to determine if there was any statistical significance in the distribution (table 4.04a and b).

Chi squared analysis indicated no statistical difference in ranking distribution for SN subjects for reading rate. For reading accuracy there was a significant cluster in first place for the compact fluorescent lamp (Chi squared $=10.46$, $p<0.05$) and similarly for the standard incandescent tungsten lamp (Chi squared $=14.09$, $p<0.05$). For the ARMD subjects there was a significant reading accuracy cluster in first place for the ambient illuminance only condition (Chi squared $= 8.00$, $p<0.05$) and for the compact fluorescent lamp (Chi squared $= 8.67$, $p<0.05$).

table 4.04a and b

Table 4.04a

Ranking frequencies and Chi squared analysis for the SN group reading rate for experiment 7 (luminaires)

SN reading rate

lamp ranking	no localised lighting	compact fluorescent	standard incandescent	daylight incandescent
1	5	2	4	1
2	4	4	1	3
3	2	1	5	4
4	1	5	2	4
Chi^2	3.33	3.33	3.33	2.00

SN reading accuracy

lamp rank	no localised lighting	compact fluorescent	standard incandescent	daylight incandescent
1	4	4	4	2
2	5	3	1	4
3	1	4	4	4
4	2	1	3	2
Chi^2	3.33	2.00	2.00	1.33

Table 4.04b

Ranking frequencies and Chi squared analysis for the ARMD group reading accuracy for experiment 7 (luminaires)

ARMD reading rate

lamp ranking	no localised lighting	compact fluorescent	standard incandescent	daylight incandescent
1	3	4	3	2
2	6	3	1	2
3	2	3	3	4
4	1	2	5	4
Chi^2	4.67	0.67	2.67	1.33

ARMD reading accuracy

lamp ranking	no localised lighting	compact fluorescent	standard incandescent	daylight incandescent
1	3	5	2	4
2	1	6	2	2
3	7	0	2	5
4	1	1	6	1
Chi^2	8.00*	8.67*	4.00	3.33

*significant at the 0.05 confidence level

Individual subject analysis

It is possible that the lamps might not have been beneficial for all subjects in each study group. Therefore, all reading rate and reading accuracy values were normalised to the no local lighting condition and a *post hoc* search was made through this normalised data for individuals who had demonstrated significant reading improvement. All occurrences in which there was at least an arbritary 20% improvement were identified. None of the SN subjects benefited by as much as 20% for either reading parameter with any lamp. Three ARMD subjects showed an improvement in reading rate; MH, 53% and EH, 27% with the standard tungsten incandescent lamp and KH, 35% improvement with the compact fluorescent lamp. None of the ARMD subjects demonstrated a 20% improvement in reading accuracy.

Reading rate versus reading accuracy analysis

There may have been a reading rate reading accuracy trade off in this experiment, i.e. those subjects that read quickly may have had a reduced accuracy, and those that read slowly may have had better accuracy. To investigate this the Pearson correlation coefficient (r) and the coefficient of determination were calculated for each group or reading rate versus reading accuracy. Reading rate was plotted as the y-axis against reading accuracy as the x-axis for both subject groups; SN r^2 =0.053, r=0.230 ($p>0.05$), ARMD r^2 =0.286, r=0.535 ($p<0.05$) (figure 4.00a and b). A positive relationship between rate and accuracy is indicated for both groups, i.e. as one increased so did the other.

This would suggest that for the SN group 5.3% of the variation in reading rate can be attributed to the linear variation in reading accuracy and therefore, 94.7% of the variation of reading rate must be due to other factors not measured or accounted in this study. This value is not statistically significant. For the ARMD group, 28.6% of variation in reading rate can be accounted for by the linear variation of reading accuracy and therefore 71.4% of the reading rate variation was due to other factors. This is statistically significant at the 0.05 confidence level.

Figures 4.00a and 4.00b

Figure 4.00a Sn reading rate versus reading accuracy

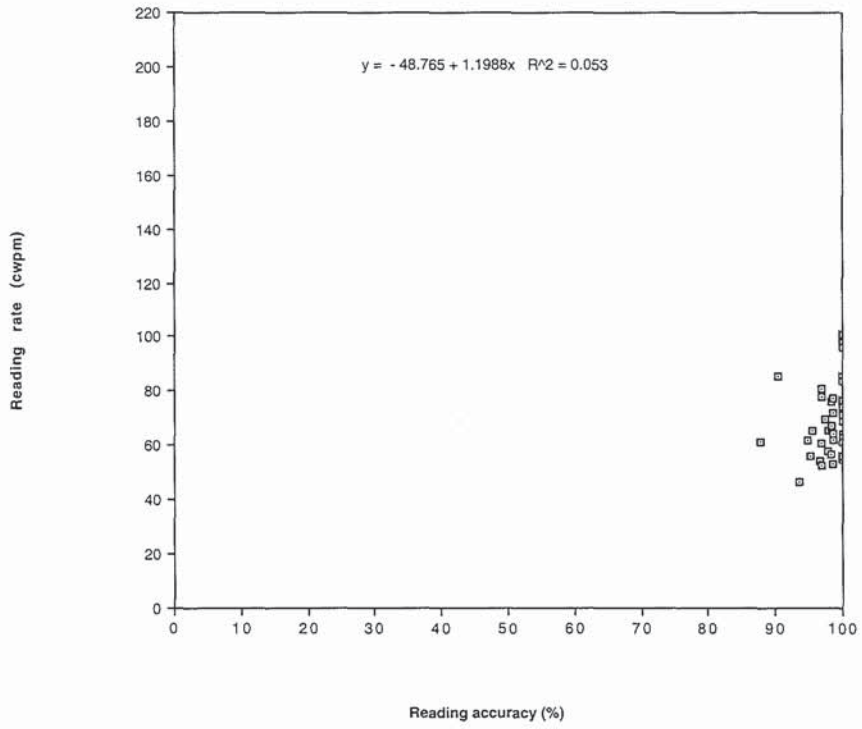
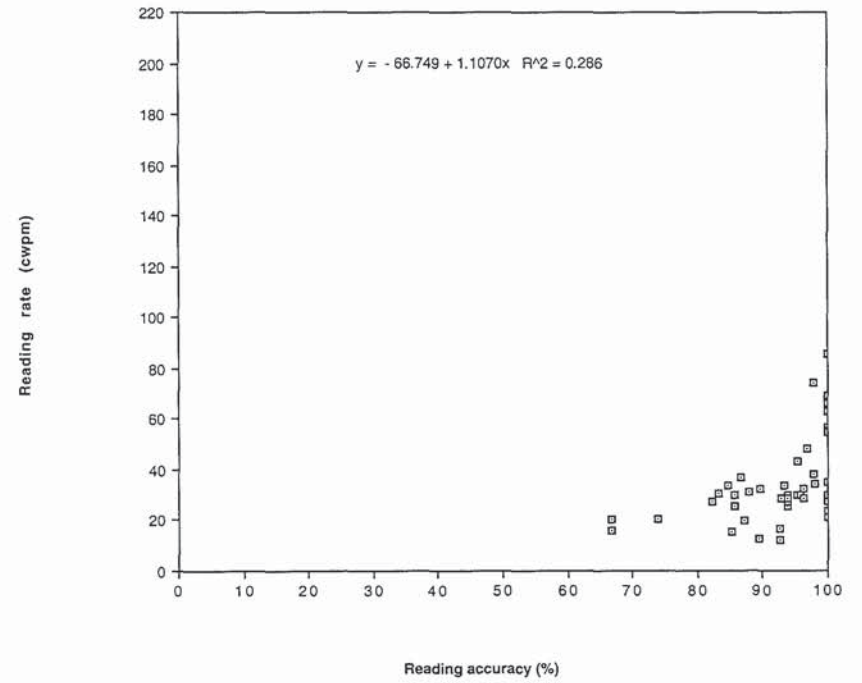


Figure 4.00b ARMD reading rate versus reading accuracy



Learning and fatigue effects

A t-test revealed that there is no significant difference between the reading rate and reading accuracy at the beginning and at the end of the testing for SN and ARMD groups, (SN t= -0.626, p=0.54 and t=0.376, p=0.71 respectively; ARMD t= -0.487, p=0.63 and t=0.193, p=0.85 respectively). Therefore, data from this experiment are unlikely to have been confounded by learning and fatigue effects.

See table 4.05 for a summary of the results from experiment 7 (luminaires)

Table 4.05 summary of results for experiment 7 (luminaires)

Type of analysis	Results
ANOVA reading rate	SN>ARMD
ANOVA reading accuracy	SN>ARMD
Chi squared reading rate	ARMD cf 1st and 2nd, no local light 3rd
Chi squared reading accuracy	ARMD ambient illuminance only and cf 1st
Individual reading rate	ARMD st 27% and 53%, cf 35%
Individual reading accuracy	ARMD st 40%, cf 25%, 80%
Rate versus accuracy	SN 5.3%, ARMD 28.6%*
Learning/fatigue	none

st=standard tungsten, cf=compact fluorescent, *statistically significant

Discussion

ANOVA and Scheffé's S test analyses showed that the SN group read significantly faster and more accurately than the ARMD group and that there was a lamp versus subject interaction for reading accuracy for the SN group. Individual group ANOVA indicated a significant lamp effect for SN reading accuracy and further analysis revealed a significantly better performance with the standard tungsten incandescent when compared to the no local lighting condition. It is surprising (especially for the ARMD group) that according to ANOVA local lighting did not

improve reading performance when compared to ambient illuminance alone.

Other work (Sloan *et al.*, 1973; Silver *et al.*, 1978; Lagrow, 1986; Collins, 1987) has clearly demonstrated the usefulness of local lighting for reading with some types of eye disease. Eldred (1992) however, found that there was no significant difference between the mean CWPM at each illumination level investigated (the minimum level used by Eldred (1992) is similar to the no local lighting condition used here). See figures 4.01a and b for bar charts depicting average reading rate and accuracy for each group and type of lamp.

Chi squared analysis for the SN group revealed significant ranking clusters for reading with the compact fluorescent and standard tungsten incandescent lamps. However, for ARMD subjects the only significant clusters were for the no local lighting condition and compact fluorescent lamp. The high performance under the no local lighting condition is again surprising and disagrees with earlier work cited above.

Figures 4.01a and 4.01b

Figure 4.01a
Average reading rate for each group and type of lamp

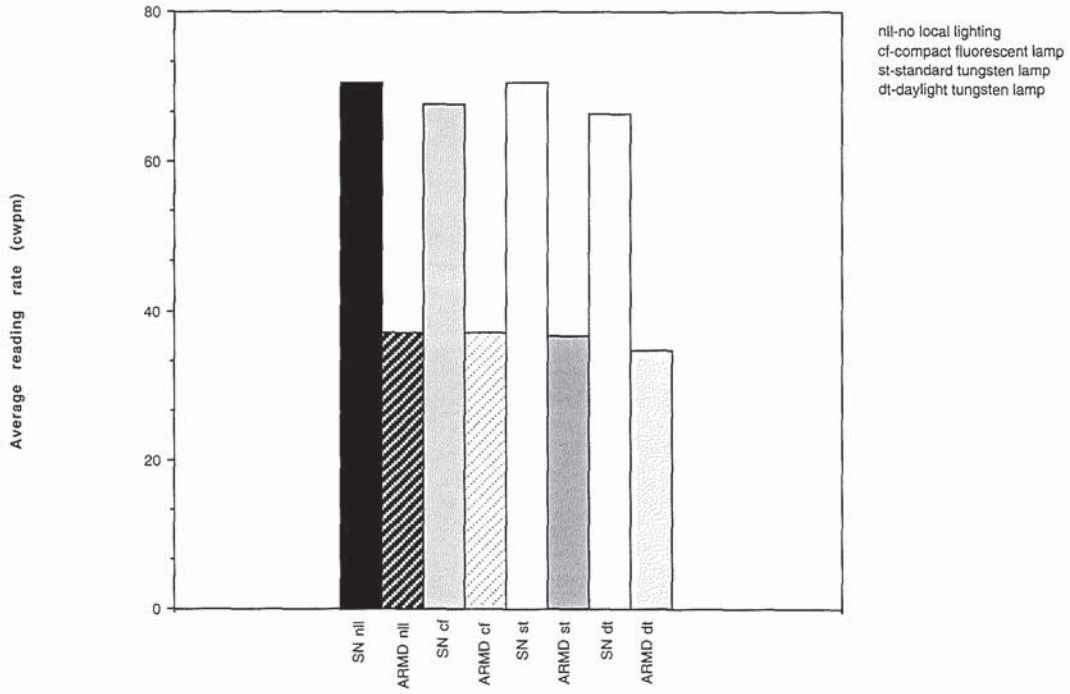
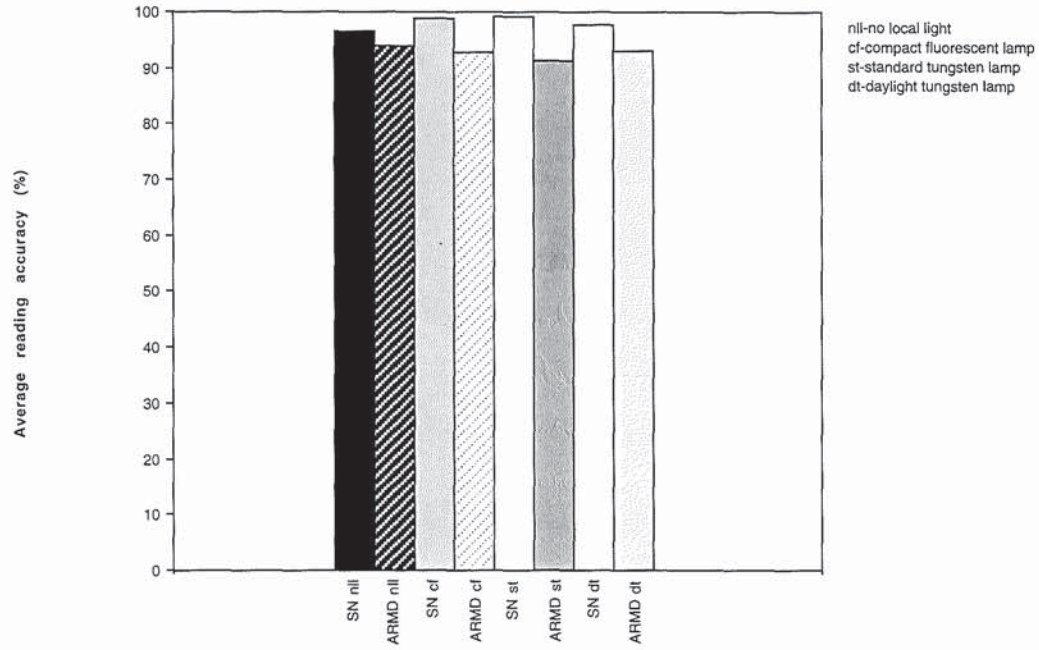


Figure 4.01b
Average reading accuracy for each group and type of lamp



Individual analysis highlighted that none of the SN group demonstrated a 20% reading performance improvement with any lamp. Two ARMD subjects improved substantially with the standard tungsten incandescent lamp and one subject with the compact fluorescent lamp for reading rate. This may indicate that some individuals with ARMD could benefit from local lighting produced by a standard tungsten incandescent or compact fluorescent lamp. These results differ from those presented by Collins (1987) who found no objective difference between a compact fluorescent, standard tungsten incandescent and daylight simulation tungsten incandescent lamps. However, the poorer performance of the daylight simulation tungsten lamp used in this study may have been because it had a lower illuminance than the two other lamps.

An anonymous referee that reviewed an earlier version of this discussion suggested that it was important to acknowledge the different colour properties e.g. 'x' and 'y' chromatic co-ordinates, colour temperature, correlated colour temperature and spectral power distribution of the luminaires used in this study. It is possible that one or more of these properties may have influenced the reading performance. However, the main aim of this project was to determine whether there were any reading performance differences between the luminaires in their commercially available form and not necessarily the cause of these differences. The specialised equipment required to measure the parameters listed above was not available for this study.

In summary, the ANOVA revealed significantly better reading performance for the SN group, while Chi squared analysis highlighted better reading with the no local lighting condition and the compact fluorescent lamp. Individual analysis also showed that some ARMD subjects benefited from the use of local lighting produced either by standard tungsten incandescent or a compact fluorescent lamp. None showed any improvement with the daylight simulation lamp but this may have been because of its lower illuminance rather than the fact that is was tinted blue.

In agreement with Lagrow (1986), when assessing the local lighting requirements of an individual with low vision in a clinical environment, it may be appropriate to analyse the results using an individual analysis as described in this study.

It is useful to know that the daylight simulation tungsten lamp performed poorly when compared to a standard tungsten incandescent lamp with the same wattage and a compact fluorescent lamp, but it would be interesting to compare reading performance with a daylight simulation tungsten lamp that produced a similar illuminance to a standard tungsten incandescent and compact fluorescent lamps.

It should be noted the ambient room illuminance of 500 lux was far in excess of the average room lighting to found in the homes of people with low vision (Levitt, 1978; Silver *et al.*, 1978) and the effects of local lighting on reading performance reported here may differ when used with poorer ambient lighting.

Conclusions

- Some individuals with ARMD benefited from the use of increased local illuminance produced by either a standard tungsten or compact fluorescent lamp when reading.
- No reading improvement occurred with a daylight simulation lamp when compared to ambient lighting alone, although this may be because this lamp produced low illuminance and not because it was tinted blue.
- SN subjects demonstrated a reading accuracy improvement with a standard tungsten lamp when compared to ambient illuminance alone.
- When assessing the local lighting requirements of an individual with low vision in a clinical environment, it may be appropriate to analyse the results using an individual analysis.
- There was no reading rate versus accuracy trade-off and no effects of learning and fatigue. In future research it may be adequate to use one of these parameters only, as an outcome

measure. In this study reading accuracy often produced a ceiling effect, i.e. 100% accuracy was often achieved by the observers. Reading rate may prove to be better out come as it is less likely to produce such an effect.

- It would be beneficial to conduct further research with lamps that have similar illuminance values and also to use a lower level of ambient lighting, more in accordance with that found by researchers in the real world.

EXPERIMENT 8-COLOUR VISION ANALYSIS IN ARMD USING THE PV-16 (PRECISION VISION) ARRANGEMENT TEST AND THE INTUITIVE COLORIMETER®

Introduction

Knoblauch *et al.* (1991b) stated:

> 'Defects and anomalies of colour vision that are acquired with eye diseases which produce low vision can effect luminosity and hence reduce effective contrast of most coloured visual stimuli. The partially sighted individual whose pattern processing capabilities are already challenged by a high degree of optical and/or neural image degradation often cannot afford additional losses in effective contrast arising from colour deficits acquired with ocular disease. In addition, colour, especially in graphic displays, often codes information or conveys aesthetic features that are important elements of the presentation to the user.'

Unfortunately, personal experience would suggest that colour vision analysis is not routinely conducted in low vision practice, and colour vision does not play a major role in management. This could be because appropriate tests for analysis are not readily available or perhaps because colour vision changes secondary to ocular disease tend to be unpredictable and change over time. Also, colour vision defects cannot be corrected.

Colour vision defects that are caused by ocular disease or trauma may affect cone cells, inner retinal layers, optic nerve fibres or the visual cortex. The structural and functional changes may be patchy or diffuse and may affect vision in one eye more than the other. Colour vision deficits vary greatly among eye disorders and individuals. This heterogeneity extends to colour appearances, and more importantly, to colour discrimination, i.e. colours that contrast optimally for one individual may actually be indiscriminable to another. Thus, it is unlikely to be possible to derive a single set of guidelines that are maximally effective for the entire ARMD population (Knoblauch *et al.*, 1991b).

If residual colour vision is present, however, then it is worthwhile to consider whether colours

that produce high contrast for those observers should be chosen for visual tasks, rather than using high luminance or achromatic contrasts. The answer to this question can be investigated by determining whether colour hues enhance task performance. The problem is further complicated by the diversity of visual problems experienced by low vision observers. A solution that works for one observer is not likely to be optimal for another.

Macular lesions often cause a defect in the blue-yellow range, or tritan axis in the early stages of the disease (Cavallerano *et al.*, 1997). This may be due to the fact that the majority of short wavelength cones are concentrated in a zone that subtends two degrees around the fovea. As the disease progresses and the lesion increases in size, more and more medium and long wavelength cones may become affected and produce colour defects in the red-green range, i.e. protan and deutan axes. However, if the macular lesion is small or patchy, then it is possible that either no axis forms or it varies from day to day.

In a normal subject, colour vision undergoes only minimal changes within a wide range of photopic lighting levels. However, at very high luminances blue and blue-green hues tend to appear bluer, while yellow-green, yellow and red hues tend to be more yellow, leading to a relative red-green defect. On the other hand at very low luminances blue-green, green and yellow-green hues tend to appear greener, while oranges and reds tend to appear redder, leading to a relative blue-yellow defect. This is known as the Bezold-Brücke effect. The luminance level beneath which the blue-yellow defect appears is at the limit between photopic and mesopic vision and corresponds to 3 cdm^{-2} according to Grigorovici and Aricescu (1958) and to about 1 cdm^{-2} according to Verriest *et al.*, (1963) (both cited in CIE Technical Report 123, 1997).

Bowman (1980) showed that in ARMD no further significant improvement in colour discrimination occurs above a given level of retinal illuminance, and similarly Julian, (1984) observed cases of ARMD in which increasing luminance led to no improvement in colour

vision. Ourgaud and Etienne (1961) and Verriest (1964) (both cited in CIE Technical Report 123, 1997) considered that the blue-yellow defect observed in the photopic condition in retinal diseases could be due to an increase of the thresholds for photopic vision. Hence, the blue-yellow colour vision defect should be simply the physiological mesopic defect (mesopisation). However, Bowman (1978) showed that this explanation does not hold in ARMD as the curve giving the relation between illuminance and the 100 hue score is shifted not only horizontally but also vertically.

Blue-yellow defects are common in early stages of ARMD with red-green defects occurring as VA worsens (Campbell and Rittler, 1972). Screening tests that are designed for revealing red-green defects do not detect acquired defects with a blue-yellow axis. A few screening tests, e.g. the City University colour vision test, have plates for blue-yellow defects. Also, most standard colour vision tests have been designed around the properties of CIE 1931 Standard Colorimetric Observer.

In keeping with the recommendation that this standard is valid for field sizes between one and four degrees angular subtense (Wyszecki and Stiles, 1982), most tests have also been designed to assay foveal areas of two degrees or less. Such an approach is reasonable for evaluating what mechanisms remain in congenital colour defectives, who may have no additional visual loss, or for evaluating the integrity of colour vision in the central visual field of acquired colour defectives. However, because of the relatively small retinal area examined, they provide little useful information in the investigation and rehabilitation of people with low vision due to central scotoma as in ARMD.

Testing with small stimuli provides information from the preferred retinal locus used for fixation, whereas results from testing with large stimuli give information on colour perception in everyday life. This is more important in rehabilitation, especially when attempting to enhance skills in activities of daily living.

The Farnsworth-Munsell 100-Hue test is well suited for the accurate clinical assessment of colour discrimination in ARMD with early visual loss. However, when functional visual loss becomes more substantial, colour discrimination poor and 100 Hue-test results less definitive, the D-15 (Dichotomous 15) provides a simple but reliable alternative technique. (Bowman, 1980).

The PV-16 (Precision Vision, 721 N. Addison Road, Villa Park, IL 60181, USA) is a quantitative, arrangement colour vision test and uses large cap sizes, which give more information about colour vision function in low vision individuals. It consists of a pilot and 15 test caps of the same hues as in the Farnsworth Panel D-15 test. The diameter of the stimulus area is 3.3 cm. When testing people with low vision a working distance of 20 cm is recommended, which gives a large stimulus angular subtense of 9.5 degrees. This compares with a stimulus area of 1.3 cm and stimulus angular subtense of 4.5 degrees for the D-15. It can also detect blue-yellow defects. Errors between caps close to each other are common, even in people with normal trichromatic colour vision. Confusions between colours farther apart from each other on the colour circle, i.e. across the colour circle also occur in normal colour vision, especially from cap #7 to #15. A crossing from cap #7 to cap #15 is accepted as normal because of the relatively large difference between the caps #7 and #8.

The information obtained from arrangement tests is crude and not readily related to practical situations relevant to a low vision observer. A better approach would be to measure chromatic discrimination directly.

The Intuitive Colorimeter® (appendix 3) was designed and developed to assist in the choosing of the optimum tint for a spectacle lens, to be used by adults and children with Meares-Irlen Syndrome. These tints often help reduce perceptual distortions such as moving print, words fading, colours around letters and words and disturbing patterns and shapes within the body of the text. These distortions are thought to contribute to reading dysfunction and also migraine

type headaches.

The instrument is expensive and, as it has such a specific and limited use, it would be useful to know if its role in optometric practice could be expanded to include colour vision analysis in acquired eye disease. The Intuitive Colorimeter® was not originally designed for colour vision analysis, however Knoblauch and Fischer (1991) used a similar device to generate colour vision chromatograms. These are polar plots depicting zones of poor and good colour discrimination, which provide clinical information on pairs of colours that subjects can and cannot discriminate between. This approach is more complex than that required to administer an arrangement test, in that a colour display and computer interface is necessary. The payoff is that a more accurate picture of the sensitivity of an observer to chromatic differences can be obtained.

Bowman (1978) has shown that for each of three study groups (normal, slight ARMD and definite ARMD) colour discrimination (with the 100 Hue-test) deteriorated with decreasing illuminance but also that it became more illuminance-dependent, deteriorating markedly with further decreases of illuminance. The tritan defect became more evident for each group at lower illuminance levels. Conversely, the acquired blue-yellow dyschromatopsia in ARMD decreases in severity with increasing illuminance, a level is however, reached above which further significant improvement does not occur. Therefore it is important to keep a constant luminance throughout for each test.

Aims

- To determine the extent of colour vision discrimination in a SN and ARMD group using the PV-16 arrangement test and the Intuitive Colorimeter®.
- To compare these two techniques.

Method

Subjects

See table 4.06 for subject age and threshold reading acuity details.

Table 4.06 subject age (years) and threshold binocular reading acuity for experiment 8 (colour vision analyser)

SN	Age	Reading acuity	ARMD	Age	Reading acuity
DL	71	N6	BM	87	N10
DP	71	N4	CP	80	N8
EC	73	N4	DS	70	N16
EE	74	N4	EH	78	N20
FF	66	N4	GH	85	N16
GM	63	N4	ID	82	N8
JS	73	N2.5	KH	76	N8
RP	69	N3	MB	80	N16
RT	71	N3	MC	84	N5
SL	61	N3	MH	87	N6
TH	66	N4	MJ	81	N6
VG	74	N4	MS	86	N4

Binocular threshold reading acuity as measured with a Bailey-Lovie near word card at each observer's habitual reading distance. SN, mean age (years) 69, median 71.5, range 61 to 74, SD 4.38. ARMD, mean age (years) 81, median 81.5, range 70 to 87, SD 5.03. The two groups were statistically different in age; t=6.233 p=0.00.

Materials

- Intuitive Colorimeter®.
- Black on white concentric target with cross-wires (10 cm diameter).
- PV-16 colour vision test.

- Luminaire with 60W blue daylight tungsten lamp (Daylight Studios, 223a, Portobello Road, London, W11 1LU, UK) [illuminance 1705 lux] (luminaire of unknown origin).

The recommended illumination for the PV-16 colour vision test is either natural overcast daylight at a window facing the northern sky (in the Northern Hemisphere) or artificial light with colour temperature of 6774 K (standard illuminant C). As neither of these was available at the time of testing a luminaire with a 60W daylight simulation lamp was used.

Procedure

Subjects gave verbal consent, were given an instructional set and wore their habitual near spectacle prescription for both sessions. None of the subjects were aware of congenital colour vision defects. All testing was binocular. For diagnostic purposes testing is usually conducted monocularly but for functional purposes binocular measurements are more informative.

Luminance was maintained at 500 lux (combination of daylight simulation lamp and ambient room lighting) for the PV-16. For the Intuitive Colorimeter® luminance was 27 cdm^{-2} for each colour at the 20 unit saturation level (combined internal colorimeter lighting and ambient room lighting), i.e. luminance for the PV-16 was at a far greater level.

Each subject was tested first with the PV-16 colour vision test under daylight simulation illumination (60W daylight incandescent tungsten bulb) at 20 cm producing an angular subtense of 9.5 degrees at the retina. Fifteen of the test elements were presented in a mixed group, and the pilot cap separately as a reference. The observer was instructed to choose a cap that was most similar in appearance to the reference cap. Thereafter, observers were instructed to choose the test element most similar to the previous element and continued in this fashion until all 15-test elements were placed. Test elements are numbered underneath according to the normal ordering. The arrangement is scored on the test sheet on which the numbers are arranged in roughly a circle. Numbers are connected in straight lines in the order produced by

the subject.

Each subject was then tested using the Intuitive Colorimeter®. They were asked to look into the colorimeter from a distance of 20 cm at a black-on-white cross wire target with a 22 cm^2 viewing area, in a normally illuminated room (500 lux at desk surface). This produced a 60-degree field. Subjects were encouraged not to move so close to the colorimeter that they shielded the surrounding colours of walls and other objects in the room. This was important in order to avoid the effect of colour constancy.

A neutral grey colour was presented first and was described to the observer as the starting colour. A randomly selected hue was dialled into the colorimeter and the saturation, gradually increased until the observer could just detect a change from neutral. A note was made of the saturation at this point. Intensity remained constant throughout the testing session, only hue and saturation were varied. This procedure was repeated and colour was randomly sampled every 30 degrees on the hue wheel. Results were obtained for 13 colour conditions. By measuring along several colour meridians, a map of the zone that appears achromatic or neutral for each observer was constructed. A chromatograph was plotted for each of the SN and ARMD subjects and presented as a polar diagram. The filled areas illustrate achromatic zones.

Questions to be answered

- Are there any colour deficient subjects in the SN and ARMD groups as detected by the PV-16 test or the Intuitive Colorimeter®?
- How does the Intuitive Colorimeter® compare with the PV-16?
- Can the colorimeter be used as a colour vision analyser in ARMD?

Results

For raw data see appendix 1.07.

PV-16

All the SN subjects completed the PV-16 test with perfect scores at the first attempt, and therefore record forms have not been included. Two ARMD subjects, KH and MC, demonstrated repeated colour vision defects with the PV-16, both with a tritan axis (figure 4.02 and 4.03). Two ARMD subjects MS and ID demonstrated colour vision defects, which were not repeated on re-testing (figure 4.04 and 4.05).

Analysis of the central 10-degree biocular visual field plot (Technical Note 1-Biocular Scotoma Analysis) for ARMD subjects KH and MC did not reveal any similarities in scotoma parameters.

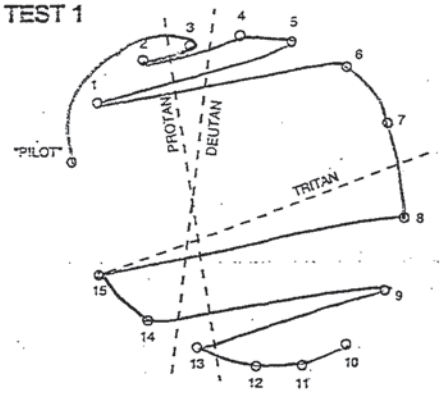
Figure 4.02 PV-16 colour vision analysis ARMD plot

THE PV-16 RECORDING FORM

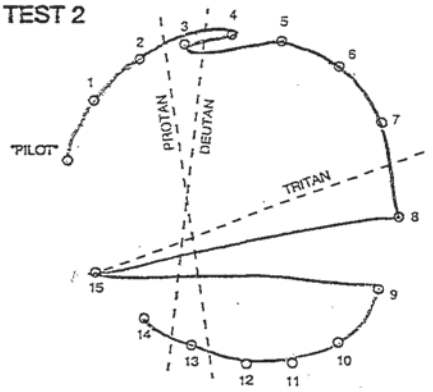
PATIENT'S NAME KH AGE 76

CASE HISTORY NO. ARMD DATE 15/6/99

TEST 1



TEST 2



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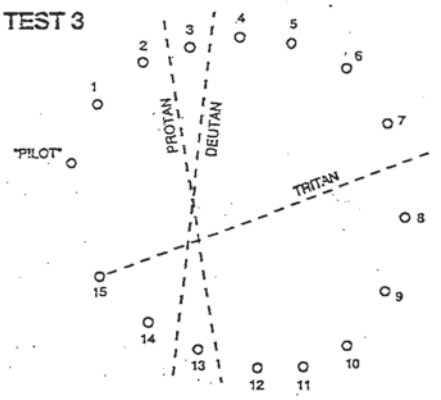

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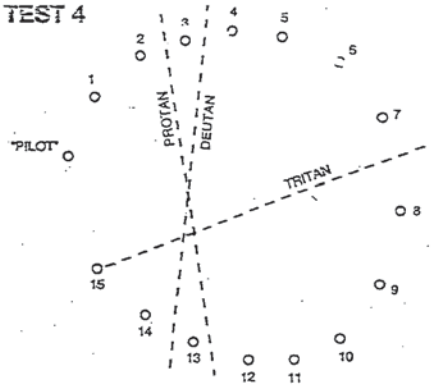

CONCLUSIONS AND RECOMMENDATIONS:

Probable tritan defect

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CAT NO. 2607

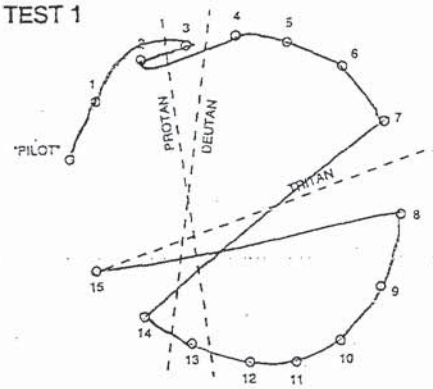
Figure 4.03 PV-16 colour vision analysis ARMD plot

THE PV-16 RECORDING FORM

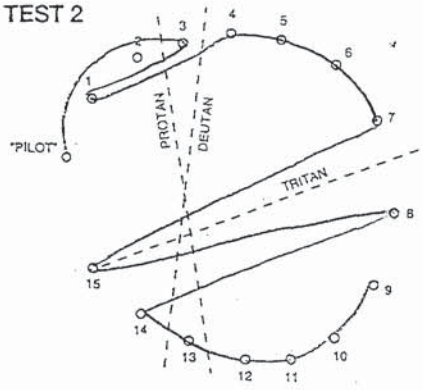
PATIENT'S NAME MC AGE 34

CASE HISTORY NO. ARMD DATE 24/8/93

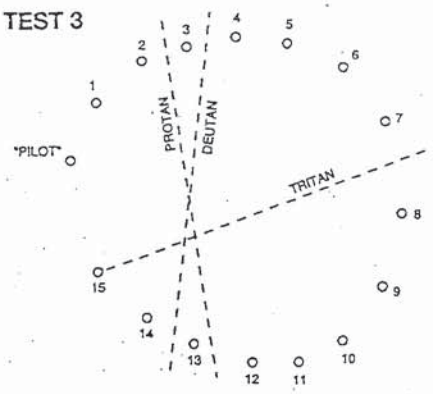
TEST 1



TEST 2



TEST 3



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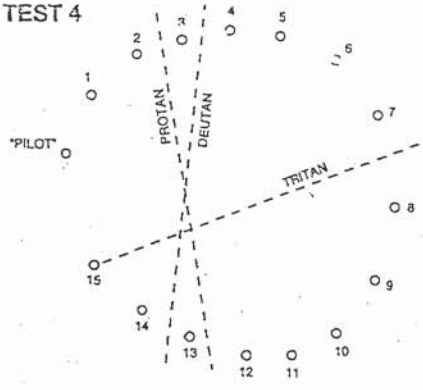

CONCLUSIONS AND RECOMMENDATIONS:

Probable tritan defect

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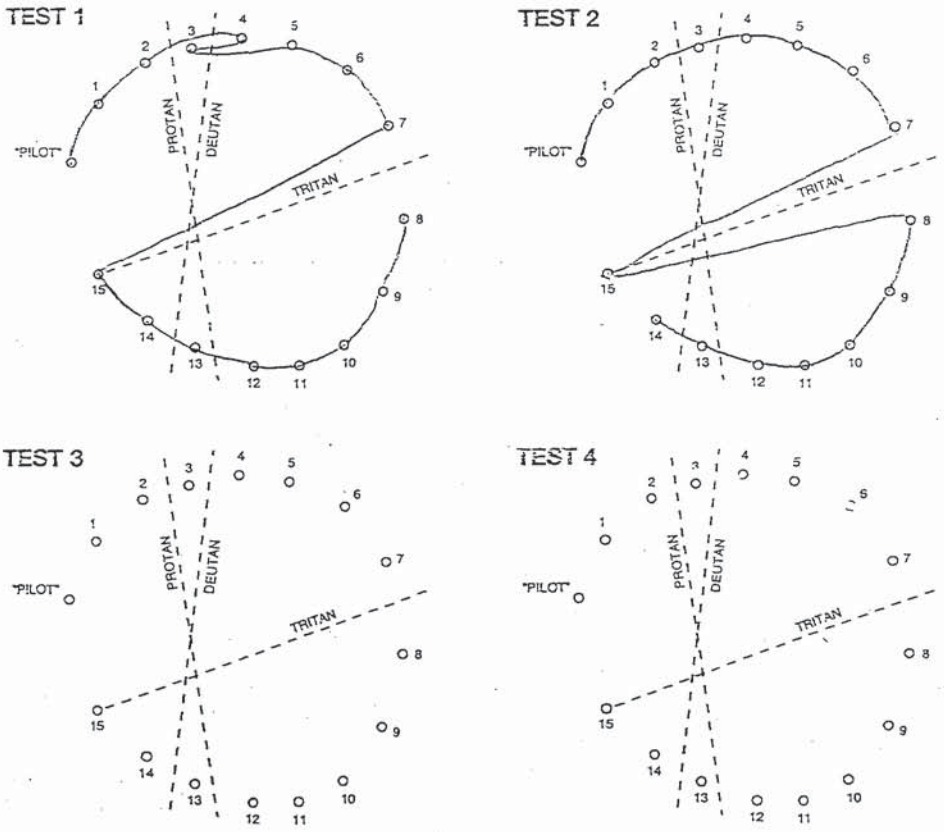
CAT NO. 2607

Figure 4.04 PV-16 colour vision analysis ARMD plot

THE PV-16 RECORDING FORM

PATIENT'S NAME MS AGE 36

CASE HISTORY NO. ARMD DATE 2/10/93



CONCLUSIONS AND RECOMMENDATIONS:

Probable normal colour vision - acceptable error.

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CAT NO. 2607

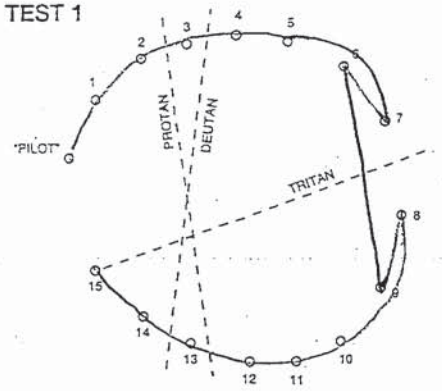
Figure 4.05 PV-16 colour vision analysis ARMD plot

THE PV-16 RECORDING FORM

PATIENT'S NAME ID AGE 32

CASE HISTORY NO. ARMD DATE 14/6/98

TEST 1



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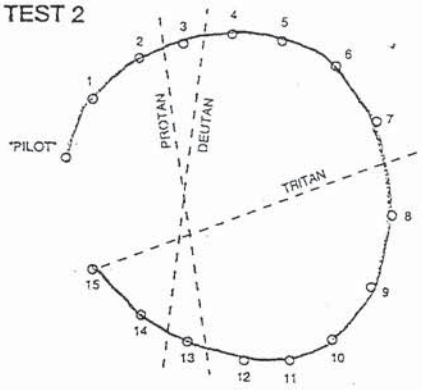
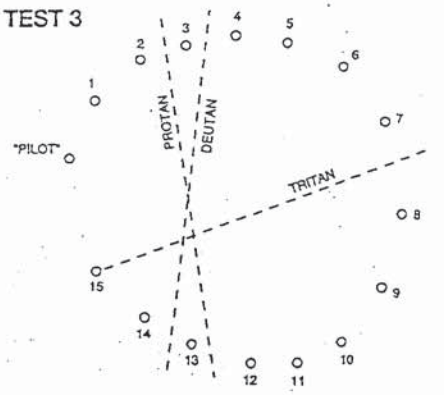


TEST 3



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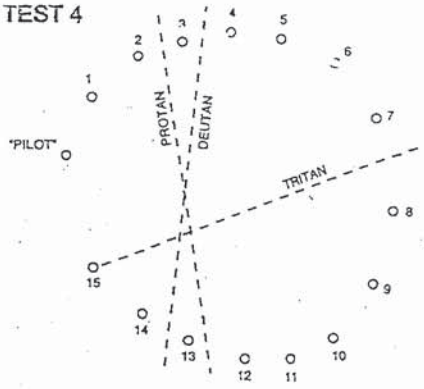

CONCLUSIONS AND RECOMMENDATIONS:

Normal colour vision - acceptable error.

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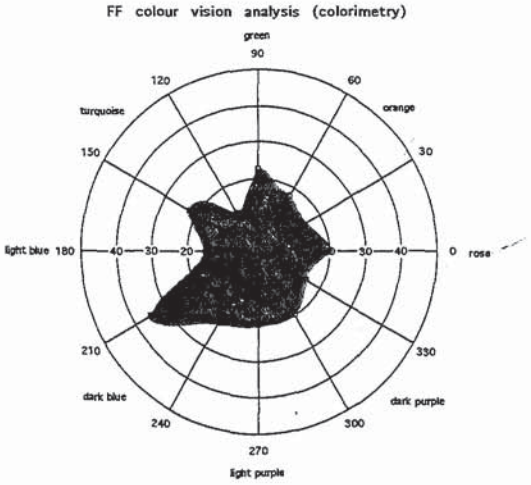
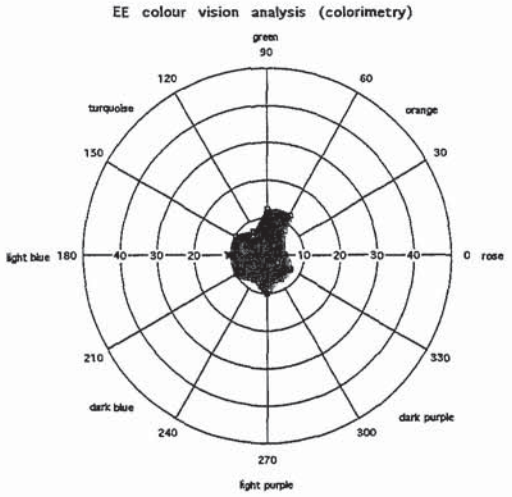
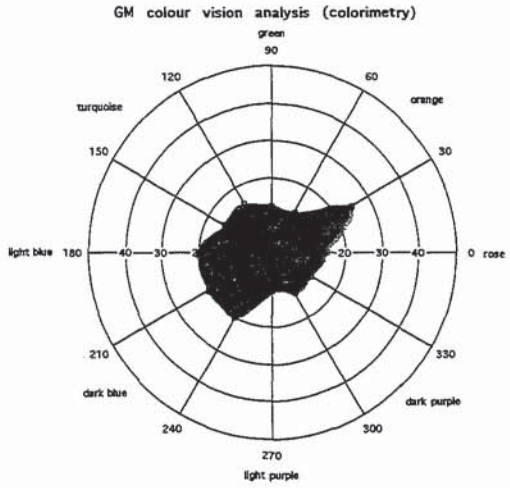
The shaded area on each polar plot corresponds to colour that the subject could not differentiate from the initial neutral grey colour, i.e. the polar plots depict colour vision scotomas. Colours outside the shaded areas can be differentiated and indicate residual colour discrimination. Four SN subjects produced colour vision scotomas with definite blue-yellow orientation axes; FF, GM, EC and DP (figure 4.06a and b). Many of the ARMD subjects demonstrated scotomas with a definite blue-yellow orientation axes (figure 4.07a and b).

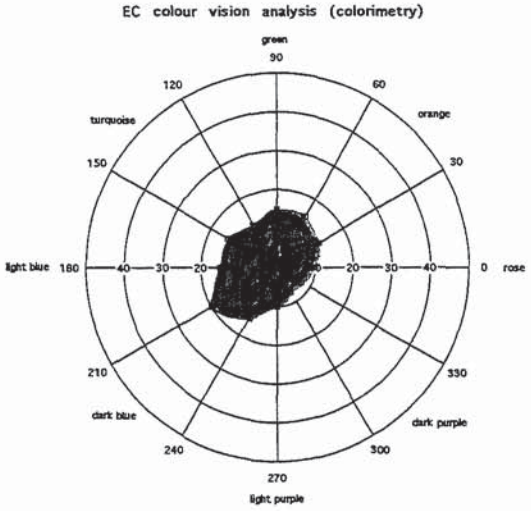
Analysis of the central 10-degree biocular visual field plot (Technical Note 1-Biocular Scotoma Analysis) for ARMD subjects and did not reveal any similarities in scotoma parameters.

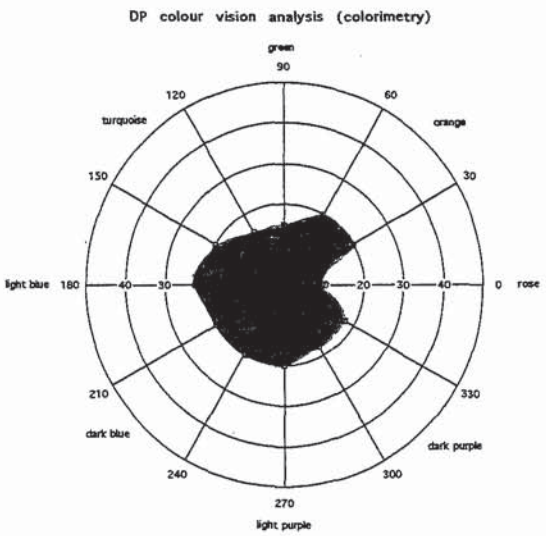
Figures 4.06a SN colorimetry plots

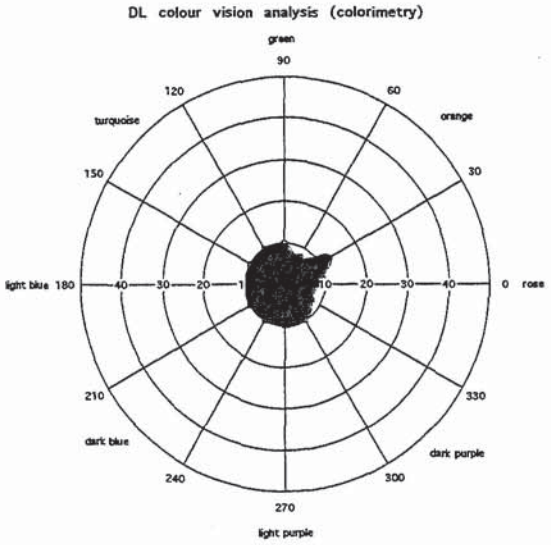




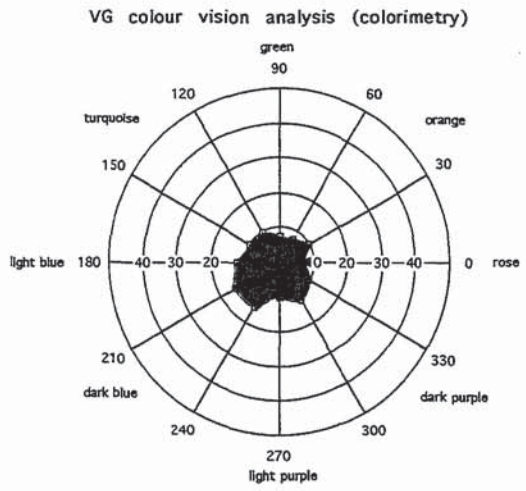


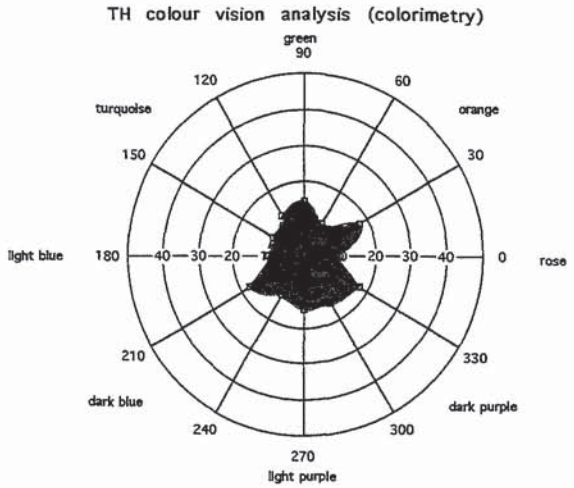


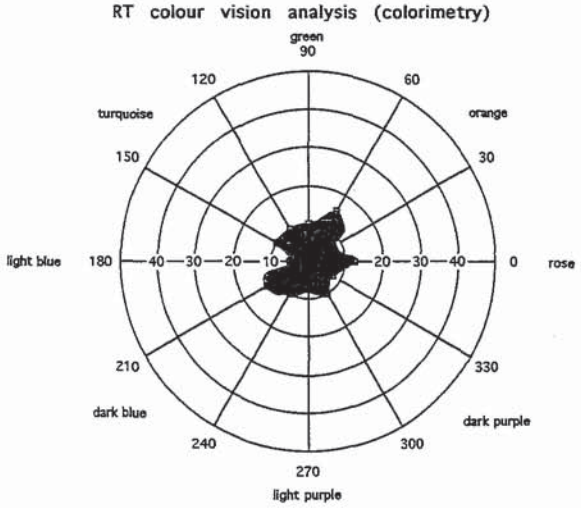


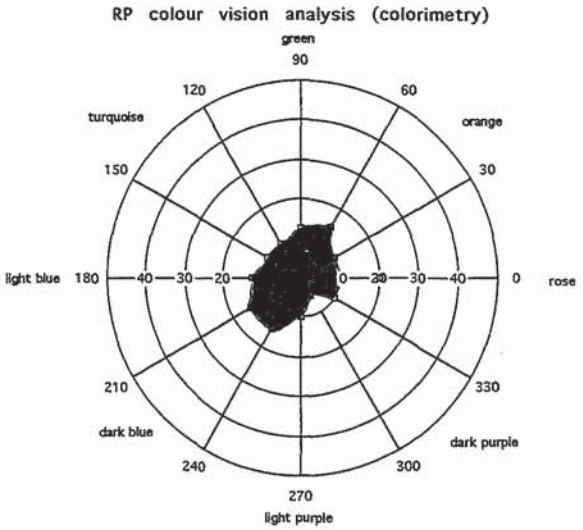


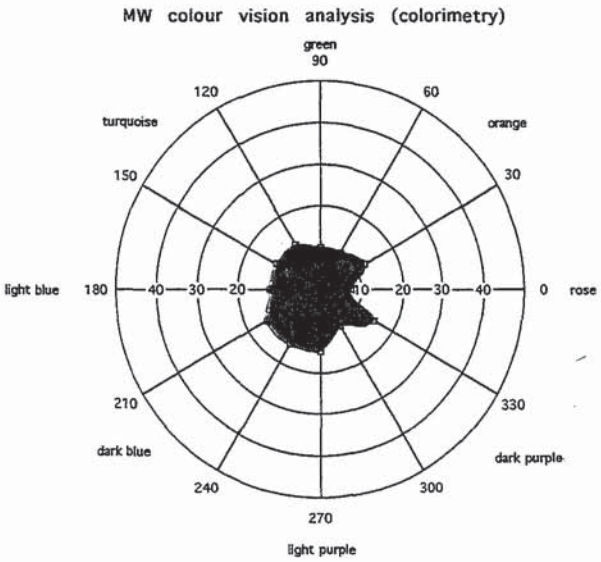
Figures 4.06b SN colorimetry plots











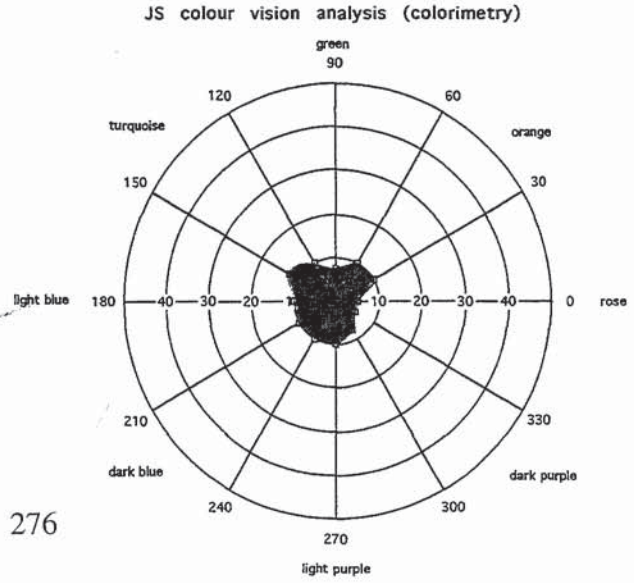
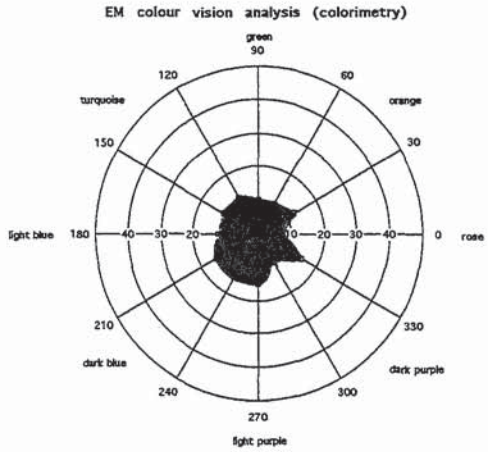
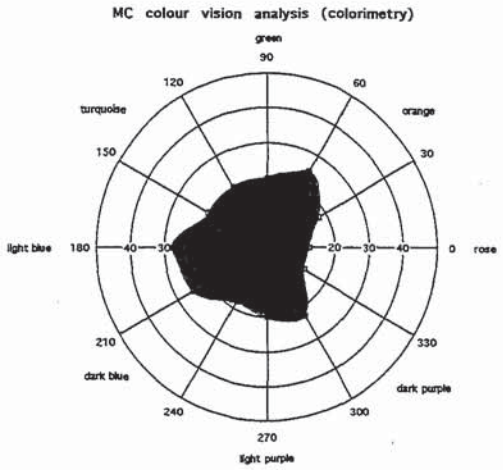
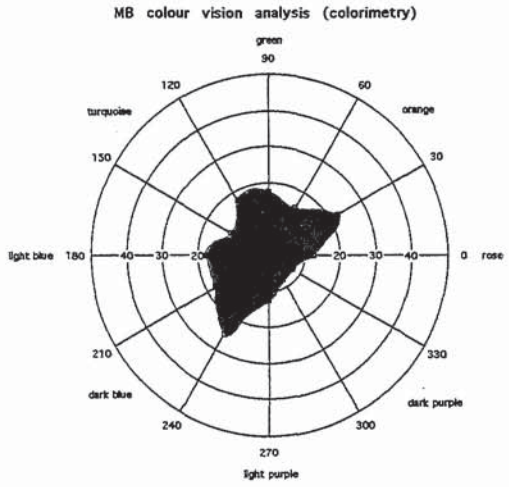
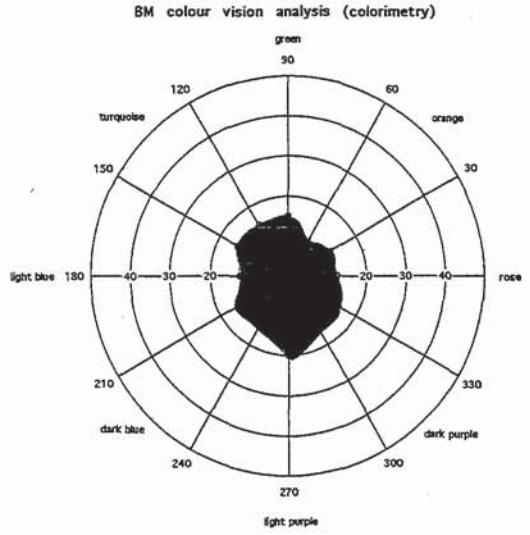


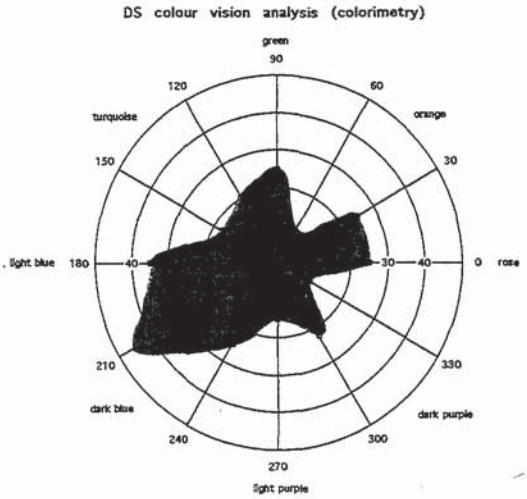
Figure 4.07a ARMD colorimetry plots

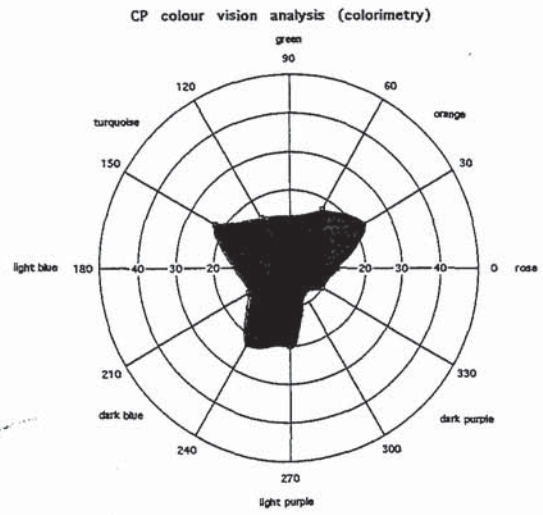






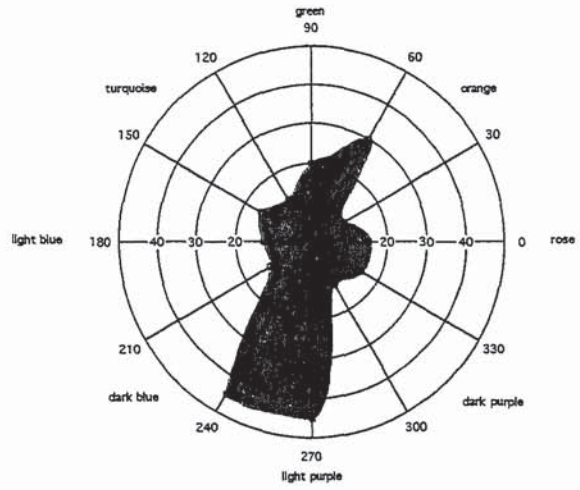




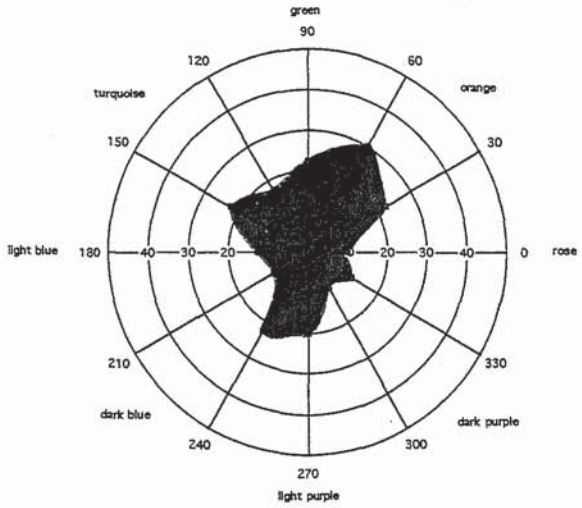


Figures 4.07b ARMD colorimetry plots

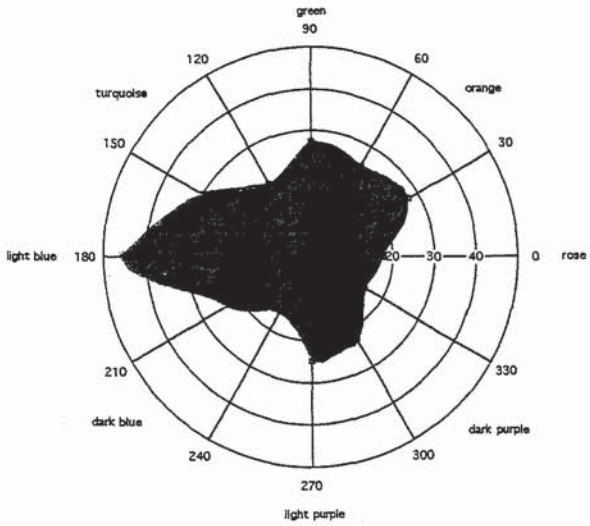
KH colour vision analysis (colorimetry)



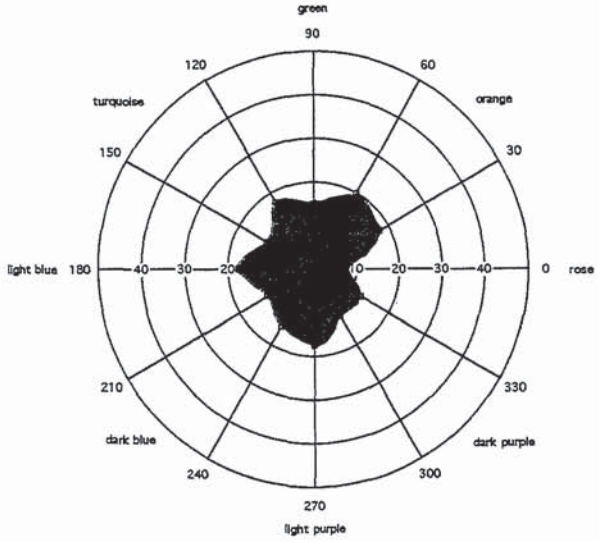
MS colour vision analysis (colorimetry)



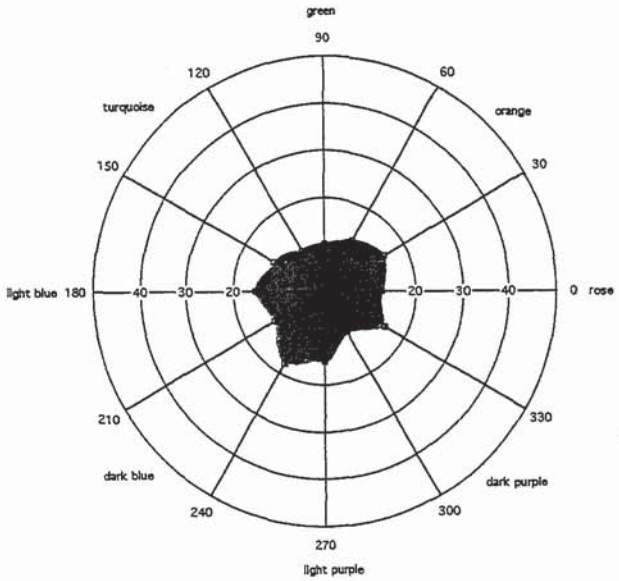
MJ colour vision analysis (colorimetry)



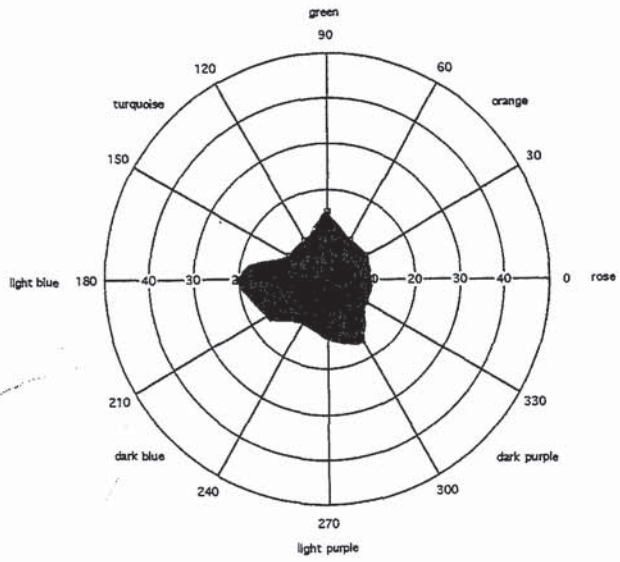
MH colour vision analysis (colorimetry)



GH colour vision analysis (colorimetry)



ID colour vision analysis (colorimetry)



Discussion

The PV-16 arrangement test indicated that none of the SN, but several of the ARMD subjects, had blue-yellow colour vision deficiency. The procedure for the PV-16 test was quickly understood by all subjects, it was easy to administer, and was repeated for those subjects who failed to produce a perfect score at the first attempt. Maximum completion time was seven minutes. ARMD subjects KH, and MC failed to produce a perfect score after two attempts, but only MC produced multiple confusion circle crossings when the test was repeated. Since this test assesses only a central nine to ten degree retinal area, these confusion colour axes provide information mainly on central retinal performance and very little on functional colour vision.

The Intuitive Colorimeter® colour vision analysis instructions (described under *Procedure*) were more difficult to explain and the test took longer to administer. A demonstration was conducted prior to the main testing session. However, unlike the PV-16 it was necessary to conduct the test once only for each subject. Maximum completion time was ten minutes. Four SN subjects produced colour vision scotomas with definite blue-yellow orientation axes. These results have three possible causes: they are erroneous; these subjects have a blue-yellow deficit possibly to yellowing of the crystalline lens (no subject had any clinically significant crystalline lens opacity or macular lesion); the PV-16 test is poor at detecting tritan defects in this type of subject and perhaps the D-15 or Farnsworth-Munsell 100 Hue test would be more appropriate. If this result was due to error it is unlikely that the confusion axes would all be in the blue-yellow orientation. A 60-degree retinal area was assessed by the colorimeter and therefore information provided is more likely to be of functional use.

Many of the ARMD subjects produced colour vision scotomas with definite blue-yellow axes of orientation, which would agree with that expected in ARMD. It is interesting that whereas only two ARMD subjects produced a tritan confusion axes with the PV-16 test, seven did so with the colorimeter. This could be due to the acquired blue-yellow dyschromatopsia phenomenon described by Bowman (1978), i.e. luminance with the colorimeter was much

lower than with the PV-16 test and therefore a blue-yellow defect was more likely to occur.

There are no obvious similarities in the biocular scotoma plots for those subjects that produced a blue-yellow colour confusion axis, in other words, blue-yellow confusion could not be related to any particular type of central field defect.

As well as providing useful information on retinal function, the polar plots can also be used to decide how to make the most of colour contrast in rehabilitation. Colours chosen from within the achromatic zone would not produce the most effective contrasts for an observer. One would expect colours chosen from a direction perpendicular to these band-shaped achromatic zones to produce the most effective chromatic contrasts for an observer. In a case where the achromatic zone is large and un-oriented, one can be certain that by choosing pairs of colours, one from within the achromatic zone and one outside it, the colours will be discriminable.

In some situations it would be useful to know whether an individual can utilise cues that depend on colour, rather than the functional status of a particular retinal region. In such circumstances, it may not be crucial how the stimulus is presented to the observer as long as the relevant information can be extracted from it. This approach might be particularly sensible in the evaluation of low vision observers.

Questions often arise as to whether chromatic cues can be incorporated into the design of displays and environment for such individuals to enhance their ability to perform various tasks that individuals with normal vision take for granted. Many conditions that result in low vision, however, also produce deficits in colour vision. Standard colour vision tests that utilise small test elements may underestimate the ability of low vision observers with central visual field defects to use colour cues. Bailey *et al.* (1982) tested low vision observers with a standard and an enlarged (eight times) Panel D-15 and reported fewer errors and faster times for observers with maculopathy with the enlarged test.

The information obtained from arrangement tests is crude and not readily related to practical situations relevant to the low vision observer. A better approach might be to measure chromatic discrimination directly. Use of an instrument such as the Intuitve Colorimeter® is more complex and takes longer, but a more accurate and useful measure of colour discrimination is obtained. The colorimeter determines colour vision under lighting conditions that are more likely to be found in the home environment of elderly people (Levitt, 1978; Silver *et al.*, 1978). Therefore, it may reveal subtle colour vision defects that could be missed by conventional arrangement tests that involve the use of brighter lighting. Information on colour discrimination can then be used to guide an individual as to what type of contrasts to use in order to improve daily living skills.

Conclusions

- Both the PV-16 and Intuitive Colorimeter® can be used to detect colour vision deficiency in ARMD.
- The PV-16 test is easy and quick to administer, but produces information limited to central retinal function only. In some circumstances it can be difficult to determine from the results whether the observer has normal or deficient colour vision.
- Testing with the colorimeter generally proved more difficult for the subjects, and took longer to administer but provided information on central and peripheral retinal function, which can be useful in low vision rehabilitation since this provides information on functional colour vision discrimination. This could be used to assist in improving daily living skills.
- Lighting conditions with the Intuitive Colorimeter® are more like that experienced by older people in the home environment and may reveal subtle colour vision loss, especially blue-yellow confusion, that may remain undetected with an arrangement test such as the PV-16.
- The Intuitive Colorimeter® is relatively more expensive (approximately 12 times) than the PV-16 test but can be used in other areas of optometric practice, i.e. the management of

Meares-Irlen Syndrome.

- The Intuitive Colorimeter® can be used to derive pairs of colours, that would optimise colour discrimination for ARMD subjects, on an individual basis.

TECHNICAL NOTE 1-BIOCULAR SCOTOMA ANALYSIS IN ARMD

Introduction

The traditional role of perimetry is to detect abnormalities, or monitor the integrity of the retina and higher visual pathways. Visual field analysis is rarely directed towards establishing functional information. Functional perimetry could have application to many aspects of low vision care including orientation and mobility training in RP, and reading rehabilitation in ARMD. Usually visual fields are assessed monocularly for each eye in turn, and then the effect of any scotoma on, for example reading, is estimated. However, in the real world most individuals read with both eyes open, even if the VA of one eye is severely reduced. Hence it may be more appropriate to determine the biocular visual field of people with ARMD and then estimate how any biocular scotoma may affect reading. The term biocular is preferred since binocular vision is not always present even if both eyes are open.

The Estermann program is the only biocular method currently used in eye care and measures the field available to the two eyes at once, at the single surface of the perimeter bowl. This is known as the binocular field map. This visual field analysis program is usually used to determine whether the observer has adequate binocular visual field to meet the UK legal driving standards. It analyses 75 degrees to either side of fixation in the horizontal, and 35 degrees above and 60 degrees below fixation and is therefore too gross a test for analysis of a central scotoma due to ARMD, as these tend to occur within the central 20 degrees.

Standard visual field analysis does not take into account that the overall effect of the scotoma will vary with, eye movements on reading, reading distance, and lighting conditions. Conventional visual field analysis is therefore of very limited use in the rehabilitation of reading in ARMD, where working distance and lighting conditions vary widely.

The Humphrey Visual Field Analyser has two programs available that could possibly be used

for individuals with ARMD in a rehabilitation context. The Estermann binocular field analysis (as discussed above) and the monocular macular threshold program, which allows analysis of the central eight degrees of visual field. The macular threshold program is not designed for use in a biocular manner and a literature search failed to reveal any published descriptions of its use in this way.

Aim

To determine whether the Humphrey 630 Visual Field Analyser macular threshold program can be used to evaluate the extent and depth of biocular central scotomas for subjects with ARMD.

Method

Subjects

See table 4.07 for subject age and threshold reading acuity details.

Procedure

Biocular central visual fields were assessed using a Humphrey 630 Visual Field Analyser, which has a background luminance of 10 cdm^{-2}, with its standard size target III (0.44 degrees arc diameter). The instrument was set up in the following manner. The blind spot check size was switched off (this is used to monitor the subject's fixation), subject name and age details were entered, and the macular full threshold program was selected from the main menu. Since the blind spot check size was switched off, subject reliability could not be monitored by means of fixation losses. However, the number of false positives and false negatives could be used to gain some information about observer reliability.

Table 4.07 subject age (years) and threshold binocular reading acuity

Subject	Age	Reading acuity
BM	87	N10
CP	80	N8
DS	70	N16
EH	78	N20
GH	84	N16
GS	81	N5
ID	81	N8
KH	77	N8
MB	80	N16
MC	84	N5
MH	87	N6
MJ	81	N6
MS	85	N4

Threshold reading acuity as measured with a Bailey-Lovie near word reading card at each observer's habitual reading distance. ARMD, mean age (years) 81, median 81, range 70 to 87, SD 4.60.

Each subject was instructed to place their chin on the rest and head against the bar and to look straight ahead at the yellow dot central fixation target in the centre of the bowl; all subjects stated that with both eyes open they could visualise this target. Each subject was asked to look at the fixation target at all times and to press the button on the handset when they saw a flashing spot of light on the bowl surface. As the subjects had both eyes open it was not possible to correct them for the instrument test distance (33 cm) by means of trial lenses using the incorporated single lens holder. Several subjects had bifocals and it was not possible to use these to correct for the working distance, and the use of trial lenses and trial frame may have created visual field artefacts. Therefore, all subjects were tested without any habitual near

refractive correction. Henson and Morris (1993) showed that with uncorrected refractive errors the threshold elevation is independent of eccentricity (within the central 21 degrees from fixation) and the variability of results did not increase. Therefore uncorrected refractive errors are unlikely to affect the sensitivity of threshold related, supra-threshold strategy to localised visual field defects.

The camera fixation monitor was activated and final head position adjustments made so that the middle of the subject's bridge was in the middle of the horizontal markers on the camera monitor and their inner canthii were just visible in the monitor screen. This was a gross compromise but it was the only method by which fixation could be monitored even approximately.

The system was demonstrated to each subject prior to the test session. They were constantly monitored for fatigue or head movements. All subjects completed the test without a requirement for a break.

Results

All 13 subjects successfully completed the test. See figure 4.08 for print outs of the visual field plots. The quickest completion time was 6 minutes 52 seconds and the slowest 8 minutes 32 seconds with the average being 7 minutes 55 seconds.

MACULA THRESHOLD TEST

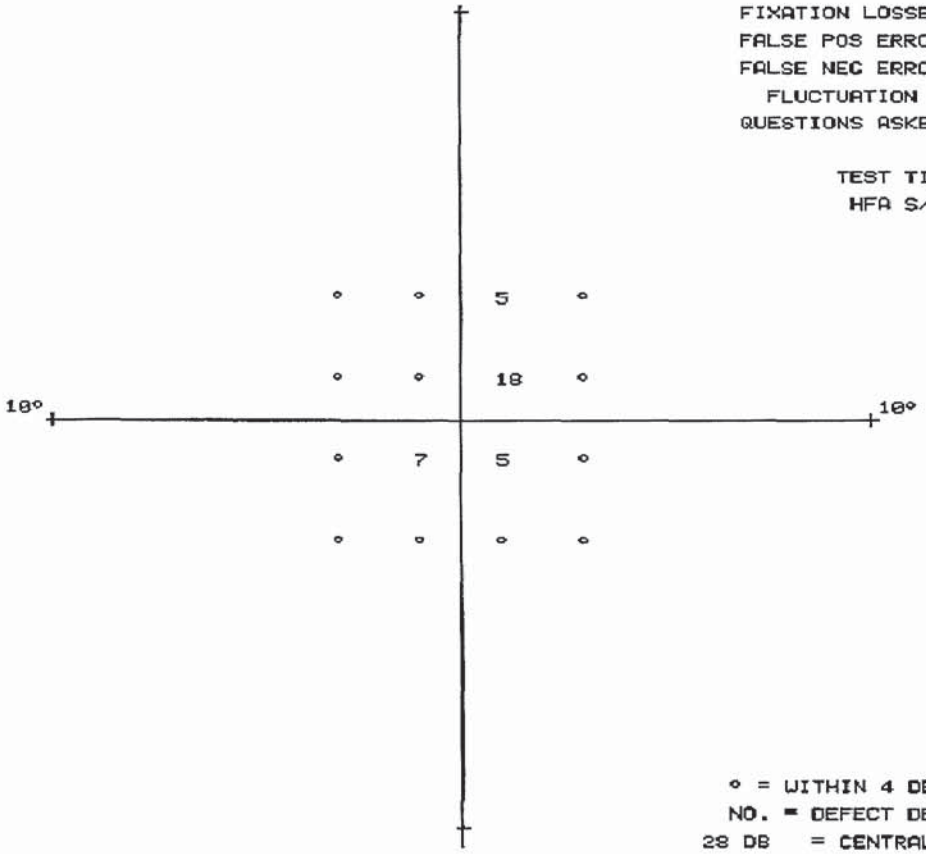
NAME BM RIGHT

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 11-12-10
DATE 07-08-98 TIME 12:13:09
PUPIL DIAMETER VA 20/100
RX USED 0 DS 0 DCX 0 DEG

FIXATION LOSSES 0/0
FALSE POS ERRORS 0/6
FALSE NEG ERRORS 0/6
FLUCTUATION 1.68 DB
QUESTIONS ASKED 220

TEST TIME 09:53
HFA S/N 630-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
28 DB = CENTRAL REF LEVEL

GRAYTONE SYMBOLS REV 8.0

SYM										
ASB	.8 – .1	2.5 – 1	8 – 3.2	25 – 10	79 – 32	251 – 100	794 – 316	2512 – 1000	7943 – 3162	≥ 10000
DB	41 – 50	36 – 40	31 – 35	26 – 30	21 – 25	16 – 20	11 – 15	6 – 10	1 – 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

MACULA THRESHOLD TEST

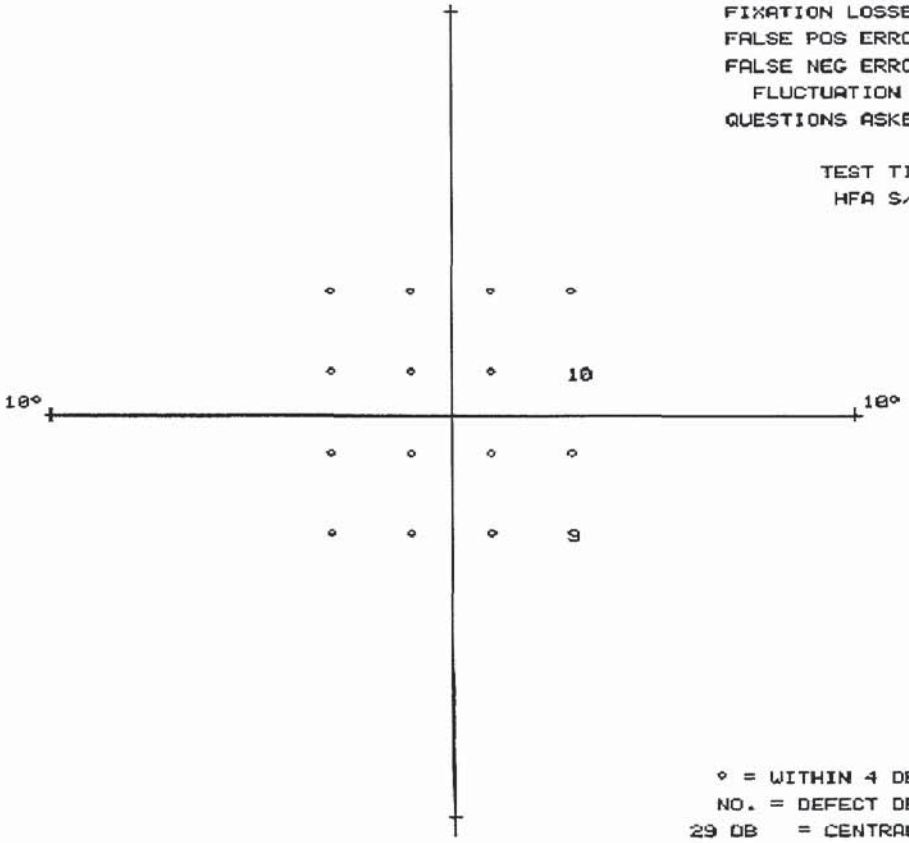
NAME CP RIGHT

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 29-07-18
DATE 04-09-98 TIME 16:37:57
PUPIL DIAMETER VA 20/200
RX USED DS DCX DEG

FIXATION LOSSES 0/0
FALSE POS ERRORS 0/5
FALSE NEG ERRORS 0/6
FLUCTUATION 2.32 DB
QUESTIONS ASKED 226

TEST TIME 06:53
HFA S/N 630-7009



◇ = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
29 DB = CENTRAL REF LEVEL

GRAYTONE SYMBOLS REV 8.0

SYM										
ASB	.8 – .1	2.5 – 1	8 – 3.2	25 – 10	79 – 32	251 – 100	794 – 316	2512 – 1000	7943 – 3152	≥ 10000
DB	41 – 50	36 – 40	31 – 35	26 – 30	21 – 25	16 – 20	11 – 15	6 – 10	1 – 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

MACULA THRESHOLD TEST

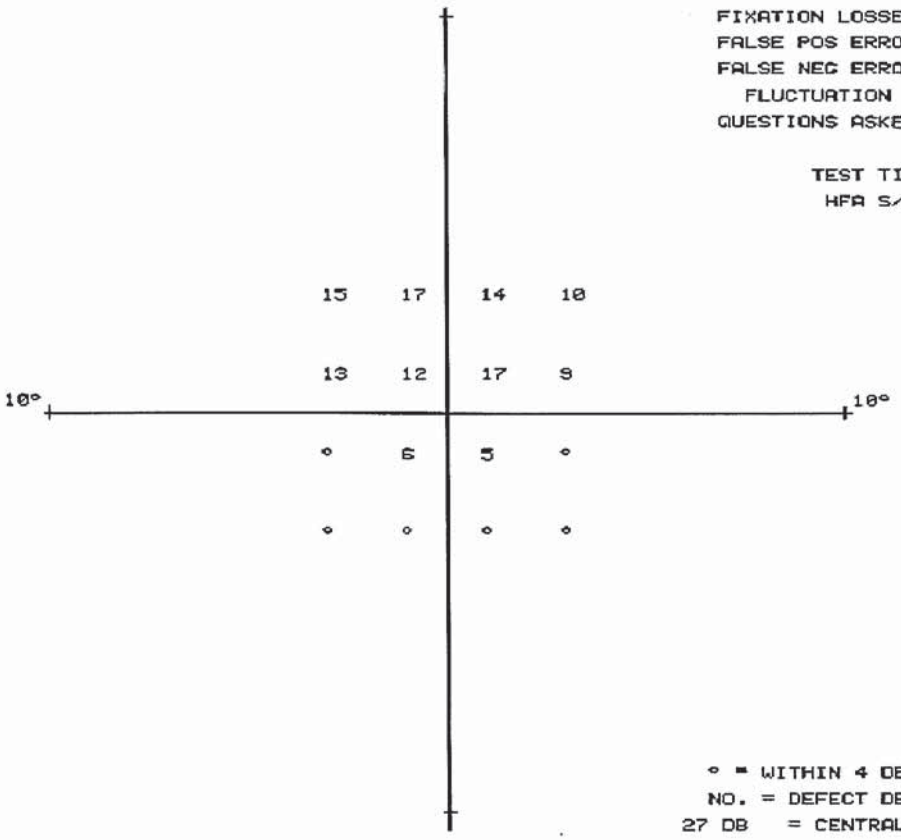
NAME DS **RIGHT**

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 12-09-28
DATE 23-10-98 TIME 12:45:36
PUPIL DIAMETER VA 20/400
RX USED DS DCX DEG

FIXATION LOSSES 0/0
FALSE POS ERRORS 0/8
FALSE NEG ERRORS 0/6
FLUCTURATION 3.22 DB
QUESTIONS ASKED 241

TEST TIME 07:51
HFA S/N 638-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
27 DB = CENTRAL REF LEVEL

GRAYTONE SYMBOLS REV 8.0

SYM									
ASB	.8 – .1	2.5 – 1	8 – 3.2	25 – 10	79 – 32	251 – 100	794 – 316	2512 – 1000	7943 – 3162	≥ 10000
DB	41 – 50	36 – 40	31 – 35	26 – 30	21 – 25	16 – 20	11 – 15	6 – 10	1 – 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

MACULA THRESHOLD TEST

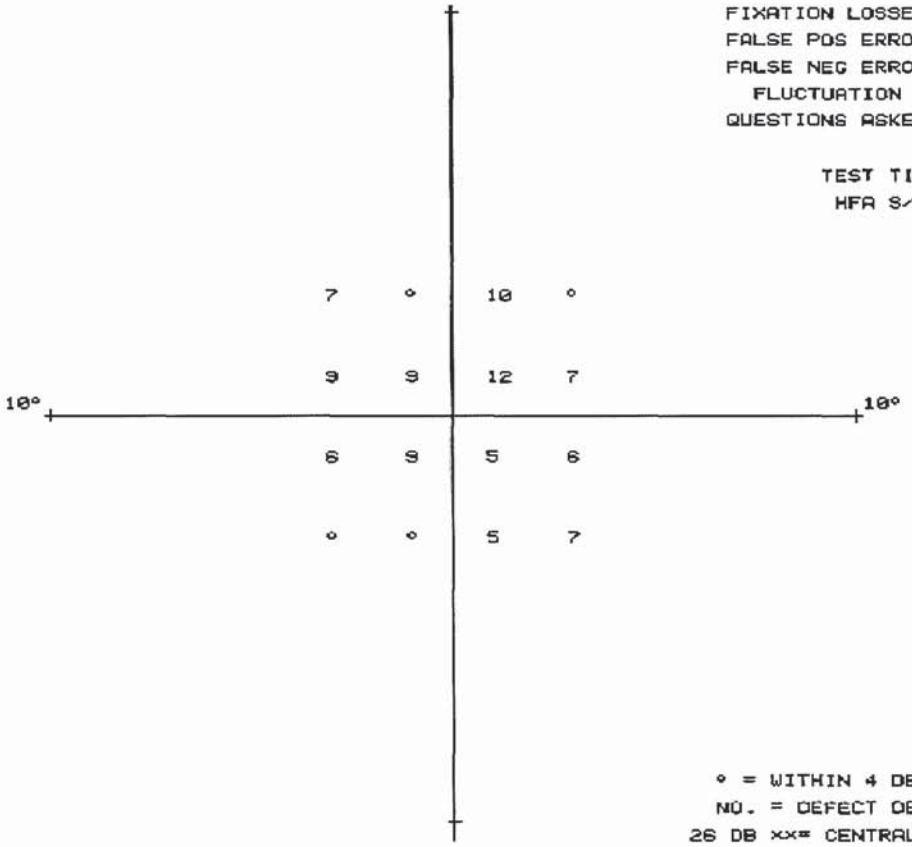
NAME EM RIGHT

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 08-03-20
DATE 11-09-98 TIME 15:45:10
PUPIL DIAMETER VA 20/100
RX USED DS DCX DEG

FIXATION LOSSES 0/0
FALSE POS ERRORS 1/3 xx
FALSE NEG ERRORS 1/6
FLUCTUATION 2.52 DB
QUESTIONS ASKED 237

TEST TIME 08:16
HFA S/N 630-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
26 DB xx= CENTRAL REF LEVEL

GRAYTONE SYMBOLS REV 8.0

SYM									
ASB	.8 .1	2.5 1	8 3.2	25 10	79 32	251 100	794 316	2512 1000	7943 3162	≥ 10000
DB	41 50	36 40	31 35	26 30	21 25	16 20	11 15	6 10	1 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

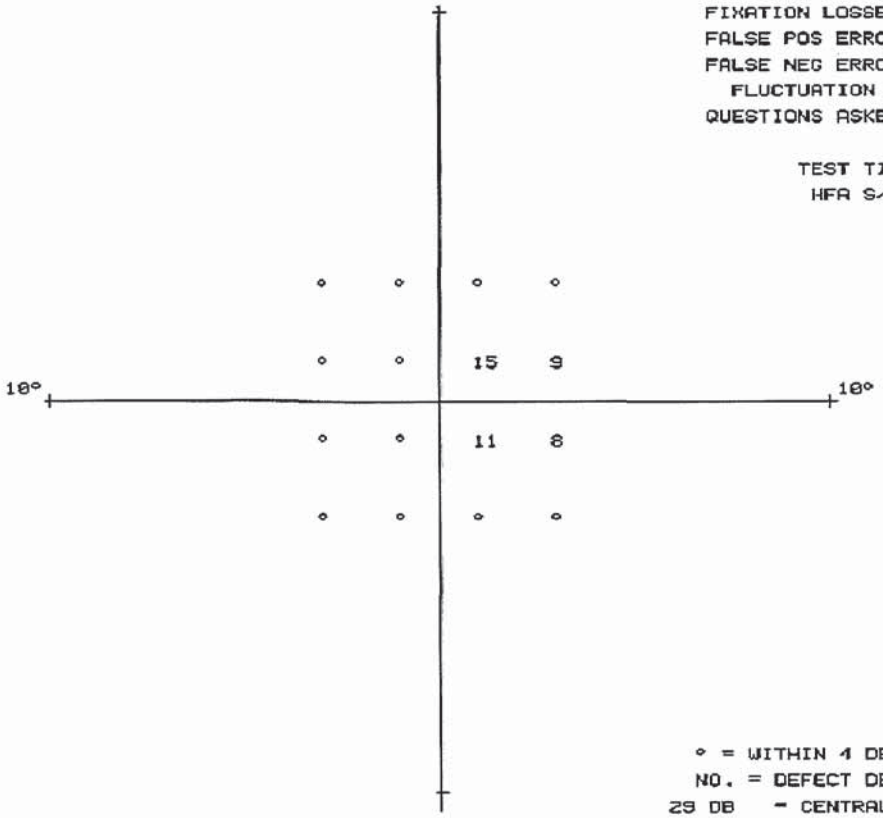
MACULA THRESHOLD TEST

NAME GH RIGHT

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF ID BIRTHDATE 25-12-13
FIXATION TARGET CENTRAL DATE 14-10-98 TIME 15:46:31
STRATEGY FULL THRESHOLD PUPIL DIAMETER VA 20/200
RX USED DS DCX DEC

FIXATION LOSSES 0/0
FALSE POS ERRORS 1/5
FALSE NEG ERRORS 0/7
FLUCTUATION 1.41 DB
QUESTIONS ASKED 251

TEST TIME 07:31
HFA S/N 630-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
29 DB = CENTRAL REF LEVEL

GRAYTONE SYMBOLS REV 8.0

SYM										
ASB	.0 – .1	2.5 – 1	9 – 3.2	25 – 10	79 – 32	251 – 100	794 – 316	2512 – 1000	7943 – 3162	≥ 10000
DB	41 – 50	36 – 40	31 – 35	26 – 30	21 – 25	16 – 20	11 – 15	6 – 10	1 – 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

MACULA THRESHOLD TEST

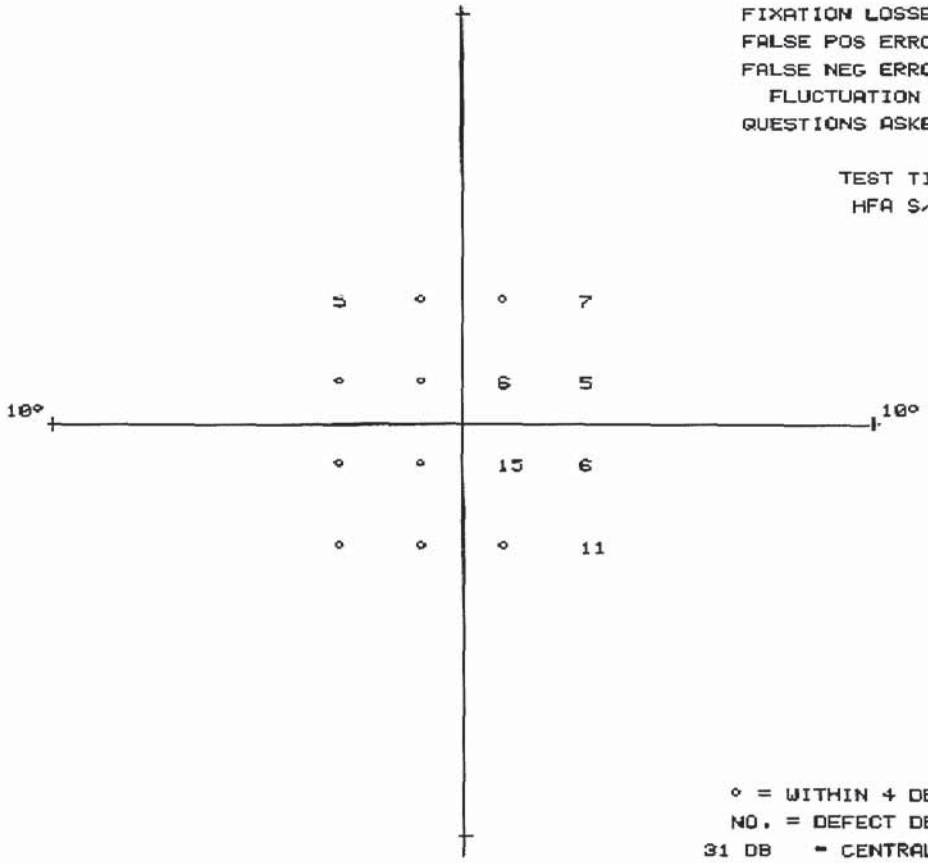
NAME CS RIGHT

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 28-09-16
DATE 02-12-98 TIME 19:08:07
PUPIL DIAMETER VA 20/400
RX USED DS DCX DEG

FIXATION LOSSES 0/0
FALSE POS ERRORS 1/4
FALSE NEG ERRORS 0/6
FLUCTUATION 2.06 DB
QUESTIONS ASKED 250

TEST TIME 07:47
HFA S/N 630-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
31 DB = CENTRAL REF LEVEL

CRAYTONE SYMBOLS REV 8.0

SYM									
ASB	.8 - .1	2.5 - 1	8 - 3.2	25 - 10	79 - 32	251 - 100	794 - 316	2512 - 1000	7943 - 3162	≥ 10000
DB	41 - 50	36 - 40	31 - 35	26 - 30	21 - 25	16 - 20	11 - 15	6 - 10	1 - 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

MACULA THRESHOLD TEST

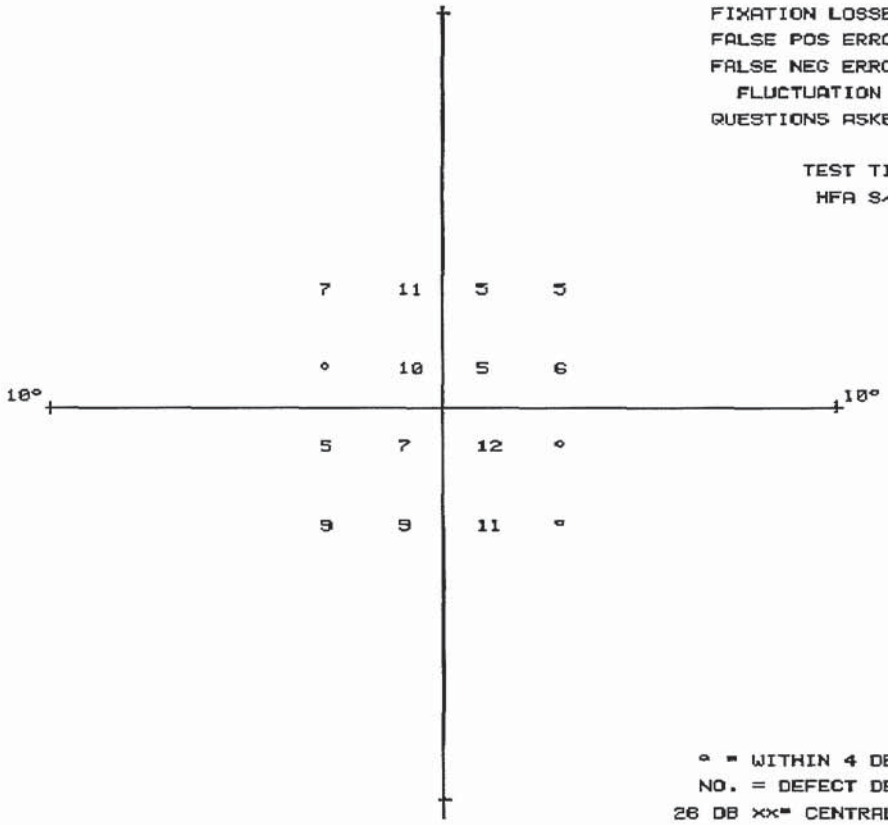
NAME KH RIGHT

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 26-06-21
DATE 04-09-98 TIME 13:02:16
PUPIL DIAMETER VA 20/400
RX USED DS DCX DEC

FIXATION LOSSES 0/0
FALSE POS ERRORS 1/8
FALSE NEG ERRORS 1/6
FLUCTUATION 3.76 DB
QUESTIONS ASKED 267

TEST TIME 08:50
HFA S/N 630-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
26 DB xx= CENTRAL REF LEVEL

GRAYTONE SYMBOLS REV 8.8

SYM										
ASB	.8 - .1	2.5 - 1	8 - 3.2	25 - 10	79 - 32	251 - 100	794 - 316	2512 - 1000	7943 - 3162	≥ 10000
DB	41 - 50	36 - 40	31 - 35	26 - 30	21 - 25	16 - 20	11 - 15	6 - 10	1 - 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

MACULA THRESHOLD TEST

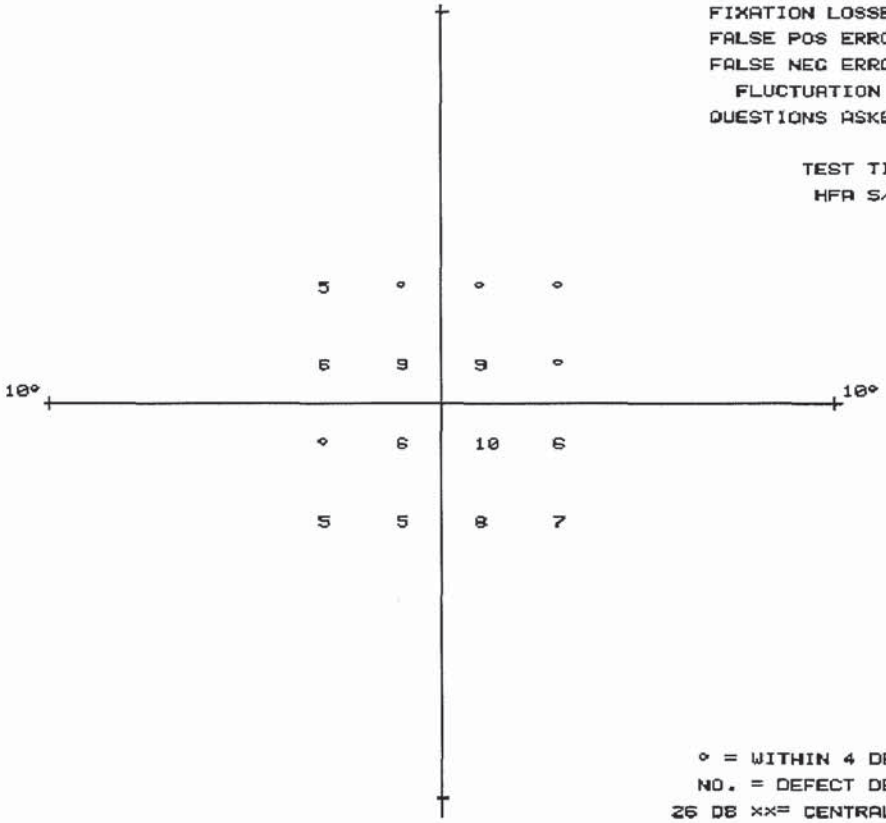
NAME MH **RIGHT**

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE III
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 26-08-10
DATE 14-08-98 TIME 13:01:47
PUPIL DIAMETER VA 20/100
RX USED DS DCX DEC

FIXATION LOSSES 2/17
FALSE POS ERRORS 0/8
FALSE NEG ERRORS 0/4
FLUCTUATION 2.92 DB
QUESTIONS ASKED 272

TEST TIME 07:47
HFA S/N 630-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
26 DB xx= CENTRAL REF LEVEL

GRAYTONE SYMBOLS REV 8.0

SYM									
ASB	.8 - .1	2.5 - 1	8 - 3.2	25 - 10	79 - 32	251 - 100	794 - 316	2512 - 1000	7943 - 3162	≥ 10000
DB	41 - 50	36 - 40	31 - 35	26 - 30	21 - 25	16 - 20	11 - 15	6 - 10	1 - 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

MACULA THRESHOLD TEST

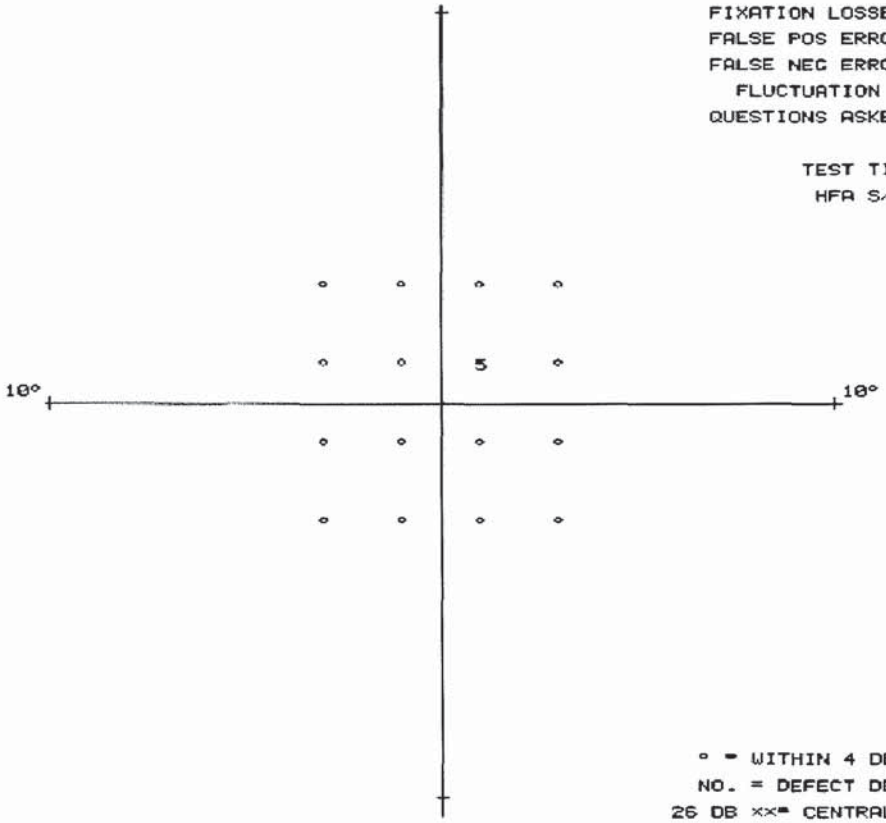
NAME MJ RIGHT

STIMULUS III, WHITE, BCKGND 31.5 ASB
BLIND SPOT CHECK SIZE OFF
FIXATION TARGET CENTRAL
STRATEGY FULL THRESHOLD

ID BIRTHDATE 18-12-16
DATE 07-08-98 TIME 14:35:10
PUPIL DIAMETER VA 20/100
RX USED 0 DS DCX DEG

FIXATION LOSSES 0/8
FALSE POS ERRORS 0/11
FALSE NEG ERRORS 0/6
FLUCTUATION 0.93 DB
QUESTIONS ASKED 228

TEST TIME 06:52
HFA S/N 630-7009



° = WITHIN 4 DB OF EXPECTED
NO. = DEFECT DEPTH IN DB
26 DB xx= CENTRAL REF LEVEL

CRAYTONE SYMBOLS REV 8.0

SYM										
ASB	.8 - .1	2.5 - 1	8 - 3.2	25 - 10	79 - 32	251 - 100	794 - 316	2512 - 1000	7943 - 3162	≥ 10000
DB	41 - 50	36 - 40	31 - 35	26 - 30	21 - 25	16 - 20	11 - 15	6 - 10	1 - 5	≤0

HUMPHREY INSTRUMENTS
A CARL ZEISS COMPANY

Discussion

Several subjects complained of postural and visual discomfort at the end of the test session but all successfully completed without the need for a break. The average time of just less than eight minutes to complete the test is relatively short and could probably be completed by many subjects with ARMD.

The visual field plots consist of a series of small horizontal oval targets which signify that the stimuli where logged within four decibels (DB) of the expected threshold as based on the age of the observer. The numbers correspond to extra intensity required for those particular retinal areas to enable the observer to detect the stimulus. The higher the number the greater the stimulus intensity.

In an attempt to relate biocular scotomas to reading performance a *post-hoc* analysis of the individual analyses for experiments 3, 5b and 7 was made. These were experiments in which some of the ARMD subjects had demonstrated an individual reading performance improvement of at least 20% when the coloured intervention result was compared to a no-colour intervention result. Visual field plots for these subjects were visually analysed for any obvious similarities. Subjects that showed at least a 20% improvement in reading performance in experiments 3, 5b and 7 are shown in table 4.08 and details of their central scotomas are given in table 4.09.

These visual field plots can be used to approximately determine how central scotomas affect the biocular visual field at a working distance of 33 cm, i.e. whether the defect is predominantly central or peripheral, right or left and inferior or superior. This is useful in a reading rehabilitation context in that a person with a biocular scotoma in the left field will have problems identifying the beginning of each word and also the start of a new line of text. Whereas a person with a scotoma affecting mainly the right side of the biocular field will have problems with the end of words but should be better at managing to locate the beginning of a

line. Subjects with scotomas that lie inferior or superior to the fovea should be most successful in reading rehabilitation. A person with a small but central scotoma may have problems identifying all words and may need to make more use of context.

Comparison of the biocular field plots for those subjects who did demonstrate at least a 20% reading performance improvement with one or more coloured interventions with those subjects who did not indicated that the former had relatively poorer visual fields, i.e. those who did not improve had more intact biocular visual fields.

Table 4.08 Individual ARMD subjects and reading performance improvement

Experiment	ARMD
3-gel filters	DS (blue 36% rr), KH (yellow 35% rr), MC (blue 28% rr and ND 83% rr), WH (ND 25% rr),
5b-tinted lenses	NJ (ND 23%)
7-luminaires	EM (standard tungsten 27% rr), MH (standard tungsten 53% rr), KH (compact fluorescent 35% rr and 25% ra), DS (standard tungsten 40% ra , DS (compact fluorescent 80% ra)

rr=reading rate; ra=reading accuracy

Table 4.09 details of biocular central scotomas for ARMD subjects

Subject	Comments on biocular central scotoma
DS	complete right and left superior loss with slight inferior central loss
EM	complete right and left central loss with moderate superior and inferior loss
KH	almost complete loss in all quadrants
MC	partial right superior and slight right central inferior loss
MH	complete central and right inferior loss with moderate left superior and inferior loss
WH	no visual field analysis was made for this subject

Current methods of assessment of functional loss from visual field analysis suffer from inadequate consideration of the third dimension. Most functional field defects produce reduced sensitivity to a volume of space and not merely to a portion of a two dimensional surface. The size and location of these volumes cannot be represented adequately in either monocular or binocular field maps, and hence assessments based on such maps will reflect spatial functional limitations inaccurately (Arditi, 1990).

Without modification, the ordinary visual field analysis is inadequate for low vision rehabilitation purposes for two reasons. First it depicts only the view from a single eye, whereas the typical observer uses the receptor surfaces of both eyes. The biocular visual field, which assesses visibility to points on the test surface with both eyes open, begins to address this problem, but that representation is also inadequate. Its most important failure is that it can depict but a single surface of visibility–that corresponding to the test distance. It does not indicate the visibility of objects displaced in depth from the convergence distance.

For example, as the proportion of the visual field affected by the scotoma depends on the working distance of the visual task even when the size of the macular lesion remains constant, therefore with a short working distance (for example when reading print) more of the field of view would be occupied by the scotoma compared to a longer working distance (for example when watching TV). Information gained on biocular scotomas in the way described in this study is limited in terms of reading rehabilitation since it relates to 33 cm, i.e. the fixation distance of the bowl. Many people with ARMD have a shorter working distance than this and therefore the biocular scotoma would affect a larger proportion of the visual field than the field plot would indicate.

A solution to this problem offered by Arditi (1990), relies on a graphic construct which depicts aspects of the field of view that are useful in delineating and testing hypothesis about visibility of objects in three-dimensional space on the basis of purely geometrical considerations. The

construct is called the volume visual field, and is defined as the set of loci in space from which light can impinge on either of the two retinas, given fixed eye positions. The volume visual field can be computed from two ordinary field maps by a computer program for any position of the eyes. It would be interesting to investigate the use of this program and this type of functional field analysis in the context of a clinically oriented low vision service, such as Birmingham Focus on Blindness Low Vision Centre.

Conclusions

- The Humphrey 630 Visual Field Analyser can be used to analyse the biocular visual field in subjects with ARMD.
- Many subjects complained of postural and visual discomfort and therefore greater care needs to be taken in the set up and the testing session may need to be split over two or three periods for some subjects.
- The analysis required each observer to have both eyes open during the testing and therefore the blind spot monitor had to be switched off. It proved difficult to monitor fixation either visually using the camera or mathematically using the fixation software.
- Used in this way none of the parametric analyses provided with the instrument can be utilised.
- Those ARMD subjects who demonstrated at least a 20% reading performance improvement with some of the coloured interventions had relatively more extensive biocular scotomas.
- An analysis involving evaluation of the volume visual field has been put forward by Arditi (1990) and this requires validation within the concept of a low vision service.

TECHNICAL NOTE 2-COMPARISON OF THE WILKINS RATE OF READING TEST® WITH THE BAILEY-LOVIE NEAR WORD READING ACUITY CARD FOR READING PERFORMANCE ANALYSIS IN LOW VISION.

Introduction

The ability to determine whether reading rehabilitation training is successful, or if one type of reading intervention is better than another type, often depends on the assessment of reading performance. Three aspects of reading can be measured to determine outcome or success; rate, accuracy and acuity. The premise being that a successful outcome of reading rehabilitation or intervention will produce an improvement in rate, accuracy or both and perhaps an improvement in reading acuity.

How should these reading parameters be measured? There are various charts available that provide information on near visual function. Passages of text are widely used for routine tasks such as assessing the effects of additional refractive power for reading. Quantitative assessment is possible using the Bailey-Lovie chart with its set of random words of decreasing size (Bailey and Lovie, 1980). Reading speed can be assessed by the MNREAD test, which is available on printed cards. This test provides a standard set of simple sentences with equal numbers of lines and characters, and with equal contextual difficulty. It can be used to determine the smallest print size that yields maximum reading speed and is considered to be of particular use in patients with low vision (Ahn and Legge, 1995).

The requirement for this series of experiments was a reading test that had several forms, which differed enough to prevent learning effects from repeated use under many different test conditions. This meant that tests with context had to be avoided because it is difficult to standardise context. The MNREAD test was not suitable because the number of different sentences was less than the number of test conditions used in most of the experiments, and therefore some of the sentences would have to be used more than once; also the sentences that

make up this chart are too short to be useful for this study.

Tests that required a high cognitive demand were avoided as most reading demands in ARMD are related to daily living skills and thus often have a high visual demand but a low cognitive demand. Charts were required which could be produced in a very small print size, in order to stress the visual system to its limit; subtle variations in reading performance with test condition were more likely to be detected using this type of assessment paradigm. Tests needed to be lengthy enough to obtain a meaningful result in terms of reading, but short enough to prevent excessive fatigue and observer discomfort.

Only two tests were commercially available that met some of the requirements discussed above; the Bailey-Lovie near word reading acuity card (Bailey and Lovie, 1980) and the Wilkins Rate of Reading Test® (Wilkins *et al.*, 1996).

Aim

The aim of this work was, by way of clinical observation and subjective comments, to highlight the advantages and disadvantages of the two charts and to make recommendations for future research and clinical usage.

Results

BAILEY-LOVIE NEAR WORD READING ACUITY CARD

As used in experiment 3 (gel filters) and 7 (luminaires).

Advantages

- Design more readily accepted by subjects, very few complained when reading from this chart.
- Shorter testing time and therefore less tiring, less confusing, and easier to find the beginning of the next line.

- Can be used to measure reading rate and accuracy and threshold reading acuity.

Disadvantages

- Task increases in difficulty down page since words become smaller, i.e. not a constant visual demand.
- Words of various length and difficulty used and therefore the cognitive demand is not constant when reading down the chart or when reading a different version of the same chart.
- Limited number of different versions available, therefore if used in an experiment with many test conditions, cards will have to be used repeatedly, which may lead to learning effects confounding the results.
- Not easy to reproduce and manipulate the word order on the chart, since size change and spacing between words is critical.
- Becomes dirty and worn with use and is expensive to replace.

WILKINS RATE OF READING TEST® (WRRT)

As used in experiment 4 (overlays), 5a (colorimetry), 5b (tinted lenses) and 6 (video-magnifier).

Advantages

- This test comprises familiar words, and therefore requires very little cognitive demand and only basic reading skills.
- There is a constant visual demand throughout the test as all the words are the same size and same words appear on each line.
- Observers are shown all words in the test prior to a testing session to aid familiarity.
- It can easily be reproduced in any font size and any number of words.
- Any configuration can easily be replaced if spoiled.
- Preferred from a research point of view as more flexible.

- Use of longer passages could be used to fatigue observers and provide information on whether an intervention might help in reading for pleasure.
- Can be used to measure reading rate and accuracy.

Disadvantages

- Several subjects complained that the text was difficult to follow as it 'did not make any sense', and was therefore confusing, stressful and more fatiguing than normal text. They often found it difficult to find the beginning of the next line, missed a line completely or lost their place within a line.
- Several subjects found the test too long and some could complete only half of the 150 words used.
- Not designed to measure reading acuity.

Discussion

One way of judging whether the outcome of an intervention has been successful is to measure performance without and then with, or before and then after using the intervention. Examples of interventions include eccentric viewing training, the provision of a magnifier or of tinted lenses. An intervention can be made in a clinical or research setting and outcome measures in both are important. A measure of reading performance can be used to determine whether the intervention has been successful and as discussed above there are three aspects of reading performance that can be used: rate, accuracy and acuity. These parameters can be measured singly or as a group.

When deciding which reading performance chart to use in order to measure these parameters several factors have to be considered. For example, will the test provide enough information to allow a determination of intervention outcome to be made, in a test session that can be completed in a comfortable time frame for the observer. Time factors are also logistically important for the clinician and researcher. Is the chart available in different versions to allow

the intervention to be repeated and to avoid learning effects? Is the chart readily available and of low cost for general use. Is the chart sensitive enough to detect change? This latter point will be further discussed in Chapter 5-Overall Discussion.

For a study that aims to investigate the effects of an intervention on survival or spot reading (for example food labels, medicine labels and prices in shops) then inducing fatigue is inappropriate and the Bailey-Lovie chart may be the best test since it is important to assess threshold reading acuity. If the effect of an intervention on sustained reading (for example reading a newspaper, magazine, book or recipes) were investigated then the WRRT would be more appropriate.

Both the Bailey-Lovie and the WRRT charts were found to be suitable for measurement of intervention outcome in low vision, but as reported above, both have disadvantages and advantages. These charts may well be used to measure the outcomes of eccentric viewing training, of magnifier use, or as described in this series of experiments to gauge the outcome of supplying tinted lenses, coloured filters or of local lighting.

The difficulty of gauging success is deciding on what amount of improvement can be determined to be a success. Rumney (1996) has advised the provision of new spectacles only if distance VA can be improved by two lines (two log units) on the Bailey-Lovie distance letter chart. A value of 20% improvement in reading performance was arbitrarily chosen in several of the experiments described in this series (Yolton *et al.,* 1995), but low vision individuals may consider a 10% or perhaps even 5% improvement to be of use. It may be necessary to resort to observer subjective reports as to whether the improvement is perceived as beneficial (further discussed in Chapter 5-Overall Discussion). So, even though the main thrust of this work has been in the use of objective tests, it may in some cases be necessary to use a combination of objective and subjective data. This is a contentious and controversial issue and one that will not be easily resolved.

Conclusion

The versatility of the WRRT probably makes it the best chart to use for an experiment that has many test conditions and requires information on reading rate and reading accuracy but not on reading acuity. Problems associated with fatigue may be overcome by reducing the number of words used. The chart can be used with observers who have poor word vocabulary.

The Bailey-Lovie near word reading acuity card is better used when the number of test conditions is approximately the same as the number of different cards that are available (approximately 10) and when information on threshold reading acuity and how reducing letter size affects reading speed is required. Observers need to have good word vocabulary.

Chapter 5- Overall Discussion

Introduction

This chapter will discuss in detail the findings from the coloured intervention experiments. Results from the binocular vision, luminaire, colour vision analysis and visual field analysis studies will be referred to in brief as they have already been described in their relevant chapters. The YN and SN groups are also included here but the emphasis is on the ARMD group.

As older people become less active, critical visual tasks such as prolonged reading may take on greater importance for recreation purposes, especially if vision is compromised by an ocular disease. In terms of low vision reading rehabilitation, it would be useful to know if a simple and easily available coloured intervention could be used to enhance reading performance in ARMD. Comparison of reading performance with and without a coloured intervention may address the issue of whether colour helps. If colour does help is it always the same colour in all subjects with ARMD. And which colour is it that helps?

This overall discussion is divided into two sections. The first describes experimental findings in detail and compares actual results to those expected intuitively. In the second section an attempt is made to relate findings to the visual system using a set of theoretical constructs derived from other studies.

DETAILED FINDINGS

As expected with a heterogeneous group of people with low vision, results were significantly different between subjects. Tables 5.00 to 5.05 summarise the findings from those experiments

that investigated the effects of coloured interventions.

These experiments were designed to determine whether coloured interventions have an effect on reading performance and attempted to detect change in outcome measures of reading rate and accuracy. Four analysis techniques were used to determine if there had been change in these measures; trend observation, ANOVA, Chi squared analysis and individual subject analysis. Results were also analysed to determine whether there was a reading rate versus accuracy trade-off, and learning or fatigue effects.

Table 5.00 summary of results experiment 2-effects of illumination varied in colour and intensity on reading performance in ARMD

Type of analysis	Results
ANOVA reading rate	YN>ARMD, SN>ARMD, YN=SN
ANOVA reading accuracy	YN=ARMD, SN=ARMD, SN>YN
Trends in the reading rate data	YN yellow and blue, and 25% ND
	SN blue and red, and higher TLT
	ARMD blue and green, and higher TLT
Trends in reading accuracy	YN yellow and blue
data	SN blue and green
	ARMD no obvious trend

Table 5.01 summary of results experiment 3-effects of five coloured gel filters on reading performance in ARMD

Type of analysis	Results
ANOVA reading rate	YN>ARMD, SN>ARMD, YN=SN
ANOVA reading accuracy	YN>ARMD, SN=ARMD, YN=SN
Chi squared reading rate	YN no gel filter third
Chi squared reading accuracy	YN yellow and red first
	SN green first
	ARMD yellow first
Individual reading rate	YN none
improvement	SN red 30%, yellow 31%
	ARMD blue 28% and 36%, ND 25% and 83%,
	yellow 35%
Individual reading accuracy	none
improvement	
Rate versus accuracy	YN 6.2%* SN 12.7%* ARMD 12.2%*
Learning/fatigue	none

*statistically significant at 0.05 confidence level

Table 5.02 summary of results from experiment 4-effects of Intuitive Coloured Overlays® on reading performance in ARMD

Type of analysis	Results
ANOVA reading rate	YN>ARMD, SN>ARMD, YN=SN
ANOVA reading accuracy	YN>ARMD, SN=ARMD, YN=SN
Chi squared reading rate	ARMD rose 7th and 8th, blue 9th and 10th, purple 11th
Chi squared reading accuracy	YN clear 1st, rose 1st, purple 1st, aqua 1st, yellow 1st, ND 1st, mint-green 1st, orange 1st, lime-green 1st SN clear 1st, ND 1st, mint-green 1st ARMD clear 1st, lime-green 1st
Individual reading rate improvement	YN lime green 40%, yellow 24%, rose 31%, blue 23%, grey 22%, mint-green 36%, pink 24% and 32% SN grey 37%, red 23% ARMD none
Individual reading accuracy improvement	none
Rate versus accuracy	YN 1.8%, SN 4.8%* ARMD 3.6%*
Learning/fatigue	none

*statistically significant at the 0.05 confidence level

Table 5.03 summary of results experiment 5b-comparison of the effects of various tinted lenses on reading performance in ARMD

Type of analysis	Results
ANOVA reading rate	SN=ARMD
	ARMD CPF>ND, CPF>IC, CPF=clear
ANOVA reading accuracy	SN=ARMD
Chi squared reading rate	ARMD CPF 1st
Chi squared reading accuracy	SN ND 1st
	ARMD clear 1st
Individual reading rate	SN CPF 37%
improvement	ARMD ND 23%
Individual reading accuracy	none
improvement	
Rate versus accuracy	SN 6.4% , ARMD 25.6%*
Learning/fatigue	none

*statistically significant at 0.05 confidence level

Table 5.04 Summary of results experiment 6-comparison of the effects of various video-magnifier screen colours on reading performance in ARMD

Type of analysis	Results
ANOVA reading rate	Green, yellow, grey, black>blue, red
ANOVA reading accuracy	Green, yellow, grey, black>blue, red
Chi squared reading rate	Grey 1st, yellow 3rd, green 4th, red 5th, blue 6th
Chi squared reading accuracy	Grey 1st, red 5th, blue 6th
Individual reading rate improvement	none
Individual reading accuracy improvement	none
Rate versus accuracy	ARMD 42.7%*
Learning/fatigue	none

*statistically significant at 0.05 confidence level

Table 5.05 summary of results experiment 7-comparison of the effects of various luminaires on reading performance in ARMD (luminaires)

Type of analysis	Results
ANOVA reading rate	SN>ARMD
ANOVA reading accuracy	SN>ARMD
Chi squared reading rate	ARMD compact fluorescent 1st and 2nd, no local light 3rd
Chi squared reading accuracy	ARMD cf 1st, no local light 1st
Individual reading rate improvement	ARMD standard tungsten 27% and 53%, compact fluorescent 35%
Individual reading accuracy improvement	ARMD standard tungsten 40%, compact fluorescent 25% and 80%
Rate versus accuracy	SN 5.3%, ARMD 28.6%*
Learning/fatigue	none

*statistically significant at 0.05 confidence level

ANOVA

Because of the presence of a central scotoma, intuitively the ARMD group were expected to have a lower reading rate and accuracy compared to the YN and SN groups. Also, because of physiological sub-clinical ocular and neurological age-related changes the SN group were expected to read slower and less accurately compared to the YN group. In other words, the result YN greater than SN, YN greater than ARMD and SN greater than ARMD for rate and accuracy was expected. Interestingly, only one of six ANOVAs followed this pattern. The reasons for this are unclear.

For experiment 2 (projection gels and random words) YN and SN rates were greater than ARMD rates, as expected, but YN rates equalled SN values. For accuracy YN equalled ARMD, SN equalled ARMD, but SN was greater than YN.

For experiment 3 (gel filters and Bailey-Lovie cards) YN and SN rates were greater than ARMD rates, but YN equalled SN for rate, results identical to those from experiment 2. The only ANOVA for which actual results matched the expected results was for accuracy, YN and SN greater than ARMD, and YN greater than SN.

For experiment 4 (overlays and WRRT) YN and SN rates were greater than ARMD rates, and YN equalled SN for rate as in experiment 2 and 3. For accuracy YN was greater than ARMD, but SN equalled ARMD and YN equalled SN.

For experiment 5b (tinted lenses and WRRT) SN equalled ARMD for rate and accuracy. Intuitively it was expected that the SN group would read faster and more accurately. ANOVA also highlighted a tinted lens effect for the ARMD group; the CPF (Corning photochromic filter) produced a higher reading rate than both the ND filter and the IC (Intuitive Colorimeter® lens), but CPF and clear filter performances were equal. This indicated that although the CPF was better than the ND and IC lenses (this may have been related to the higher transmission of the CPF) there was no significant difference between using this and a clear lens.

For experiment 7 (luminaires and Bailey-Lovie cards) SN rate and accuracy were better than the ARMD values, as expected intuitively.

Chi squared analysis

As in optics generally, the ocular optical system has a greater refractive effect on short wavelength light, i.e. the refractive effect of the optical media is greater for blue and green light than for red and yellow. Therefore, for an uncorrected observer with little or no remaining accommodative ability, blue and green light will form a clearer image on the retina for near targets than red or yellow light (chromatic aberration) (Sivak and Woo, 1983). However, for an observer wearing their optimum near refractive correction red and green

(duochrome test) should be in equal focus.

The experimental design and data for experiment 2 was too complex to allow Chi squared analysis and data were analysed for trends using a series of histograms. These suggested:

- YN subjects performed better with yellow and blue for rate and accuracy, and reduced illuminance for rate.
- SN subjects performed better with blue and red for rate and blue and green for accuracy and higher illuminance than the YN group.
- ARMD subjects performed better with blue and green for rate but there was no obvious trend for accuracy.

Chi squared analysis of the YN results from experiment 3 (gel filters) indicated a statistically significant ranking of third place for the clear filter for rate. For accuracy yellow ranked first for YN, green first for SN and yellow first for ARMD.

The only significant rankings from experiment 4 (overlays) were obtained for the ARMD results. Rose ranked 7th and 8th, blue 9th and 10th, and purple 11th for rate. In other words, these filters performed poorly for rate. Nearly all the overlays had a high ranking for YN accuracy (clear, rose, purple, aqua, yellow, ND, mint-green, orange, and lime-green). A possible explanation for this is that most of the YN subjects read at or near the accuracy ceiling of 100% with most of the overlays. This would indicate that the text size was too large or the words too easy or both, for this group of optometry undergraduates. Better results may have been obtained with smaller or more difficult text.

For the SN group statistically significant rankings were limited to mint-green, clear, and ND which all ranked first (arranged in order of statistical significance). This is interesting in that both a high (clear overlay) and low illuminance (ND overlay) condition produced high accuracy.

For the ARMD group statistical rankings occurred for clear and lime-green, both ranked first, (arranged in order of clinical significance) for accuracy.

In experiment 5b (tinted lenses and WRRT) the ARMD subjects produced the best rate with the CPF (Corning yellow) lens. The SN group had best accuracy with the ND filter (low illuminance) and the ARMD group with the clear filter (high illuminance).

Better rate occurred with black–on-grey text produced significantly better results, than black-on-yellow or black-on-green, which were in turn better than black-on-red or black-on-blue text in experiment 6 (video-magnifier). For accuracy black-on-grey was significantly best, while red and blue were significantly poor. It is possible that the results were confounded by differences in luminance contrast for the different screen colours, a design fault or an electronic malfunction of the particular video-magnifier used.

For rate in experiment 7 (luminaires and Bailey-Lovie cards) the compact fluorescent lamp ranked first and second for the ARMD group, interestingly followed by the ambient light only condition. Poorer reading performance with the daylight simulation lamp may have been due to its lower illuminance. For accuracy in the ARMD group the compact fluorescent lamp and the no local lighting conditions were equal first.

Individual subject analysis

As already described, for most of the experiments results without a coloured intervention were compared to those with a coloured intervention for each subject and a note made of those were an improvement of an arbritary 20% was identified.

For rate in experiment 3 (gel filters), some SN subjects improved by 30% with red and 31% with yellow, some ARMD subjects by 28% and 36% with blue, 25% and 83% with ND, and 35% with yellow.

For rate in experiment 4 (overlays), some YN subjects improved by 22% with ND, 23% with blue, 24% with yellow, 31% with rose, 36% with mint-green, 40% with lime-green, and 24% and 32% with pink. SN subjects improved by 23% with rose and 37% with ND. As in experiment 3 (gel filters) there were no improvements of this size in accuracy.

For rate in experiment 5b (tinted lenses), one SN subject improved 37% with the CPF and one ARMD 23% with the ND. As in experiment 3 (gel filters) and 4 (overlays) there were no improvements of this size in accuracy.

For rate in experiment 7 (luminaires) ARMD subjects improved 27% and 53% with standard tungsten and 35% with compact fluorescent; for accuracy there was a 40% improvement with the standard tungsten lamp, and 25% and 80% with the compact fluorescent lamp.

There are several possibilities as to what may have caused the discrepancy between expected and actual outcomes:

- Variability between subjects may have obscured the results, i.e. the statistical analysis did not have enough power for a 5% chance of detecting a certain percentage change, possibly because there were not enough subjects in the studies.
- Charts used to measure the reading parameters were not sensitive enough to detect change.
- The study groups did not behave as intuitively expected.

These are now discussed in turn.

Statistical power

Yolton *et al.* (1995) investigated the effects of tinted lenses on reading performance for a group of subjects with reading difficulty. They determined that the lenses might not have been beneficial for all subjects and searched the data for any individuals who had significant reading benefit and used a 20 % improvement cut-off. In view of the lack of data in the low

vision literature as to the level of reading improvement that would be considered useful by a person with low vision, the same 20% value was used as a cut-off in this series of studies.

Therefore with this requirement a coloured intervention could be described as worthwhile if it improved rate or accuracy by at least 20%. However, it is possible that because of the variability of the data, the number of observers used was not great enough for the ANOVA to detect a significant result, i.e. the power of the statistical analysis was too low.

The following equation can be used to calculate what percentage difference can be detected with a certain number of subjects used:

$$\text{Percentage difference detectable ('power')} = \frac{2C\sqrt{2}}{\sqrt{r}}$$

where C is the coefficient of variation and r is the number of subjects.

Table 5.06 shows the percentage difference detectable for each group as well as the number of subjects necessary for a 5% chance of detecting a mean percentage difference of 20%. The coefficient of variation used for this calculation was determined from the data obtained in each of the experiments conducted in this study.

Column 4 (number of subjects required to detect a mean 20% difference) indicates how many subjects would be required if the experiment were repeated assuming the same value for the coefficient of variation. These values are likely to be of use in further research, however, until studies are conducted to indicate what percentage improvement is useful to a person with low vision, it will be difficult to determine the appropriate number of subjects required.

Table 5.06 power calculations

Experiment	Group	Coefficient of variation	Percentage difference detectable ('power')	No. of subjects required to detect a mean 20% difference
Expt 3	YN rr	33.731	27.54	23
(gel filters)	**YN ra**	**1.732**	**1.41**	<1
	SN rr	**15.736**	**12.85**	5
	SN ra	3.256	2.66	<1
	ARMD rr	40.261	32.87	32
	ARMD ra	**9.668**	**7.89**	2
Expt 4	YN rr	25.427	20.76	13
(overlays)	**YN ra**	**3.768**	**3.08**	<1
	SN rr	28.373	23.17	16
	SN ra	**6.668**	**5.44**	<1
	ARMD rr	41.839	34.16	35
	ARMD ra	14.299	34.16	35
Expt 5b	SN rr	30.705	25.07	19
(tinted	**SN ra**	**16.897**	**13.80**	6
Lenses)	ARMD rr	42.953	34.78	37
	ARMD ra	**14.383**	**11.74**	4
Expt 6	ARMD rr	67.217	54.88	90
(video-mag)	ARMD ra	41.358	33.77	34
Expt 7	**SN rr**	**19.48**	**16.61**	8
(luminaires)	**SN ra**	**2.628**	**2.24**	<1
	ARMD rr	47.897	39.11	46
	ARMD ra	33.867	27.65	23

rr=reading rate, ra=reading accuracy

Figures in bold indicate those groups and experiments were the number of subjects used was sufficient to detect a 20% change or less.

Percentage difference detectable ARMD reading rate values are in the range of approximately 32% to 55%. This suggests that a statistically significant effect of coloured intervention on reading rate in ARMD for experiments 3-gel filters, experiment 4-overlays, experiment 5b-tinted lenses and experiment 6-video-magnifier, would only be found if reading rate increased by 32 to 55%. Since a beneficial effect might not have occurred for all subjects, this suggests some would have improved much more than the 5% thought to be individually significant by Wilkins (1994a) in children who demonstrated a preference for a coloured overlay.

Sensitivity of reading charts to detect change

Drifting text and RSVP (rapid serial visual presentation) techniques make use of a psychophysical approach to actively uncouple the link between visual and non-visual factors by using experiments based on within-subject comparisons on practised, motivated subjects, who act as their own controls. This reliance on within-subject comparisons poses significant barriers to the productive application of laboratory research to clinical practice.

The technique of RSVP involves subjects being asked to read aloud, single words that are rapidly presented one at a time on a TV. Effects of saccadic problems are thus negated since no eye movement is involved in this type of reading. Drifting involves reading lines of text that drift across the face of a TV monitor. The drift rate is increased from a low value until the subject makes a small number of errors. By this means the drift rate at which oral reading departs from 100% accuracy is determined. The transition from perfect reading (100% accuracy) to ineffective reading is sharp. From the transition drift rate the subjects reading rate is computed in words per minute as the product of the drift rate and the proportion of words read correctly. This method is used to find the reading rate as a function of the stimulus or subject variables under study (Legge *et al.*, 1985).

These procedures have the advantages of allowing easy experimental control of stimulus parameters and straightforward measurement of reading performance, and yield highly reproducible data. Moreover the reading of drifting text is similar to low vision reading as people with low vision typically scan text across the screen of a video-magnifier or through the field of a high-power optical magnifier.

However, everyday reading usually involves static printed text on a page. A major difference in the reading of static and drifting text is the pattern of eye movements, but there is a striking similarity between the two. Fine and Peli (1996) suggested that dynamic text displays may be more suitable than static printed text for readers with central field loss, such as in ARMD. This could be due to the elimination of the need to make a return sweep with the eyes from the end of one line of text to the beginning of the next, which would benefit readers who have difficulty controlling eye movements. Saccadic control is known to be more difficult for readers with ARMD (Whittaker *et al.,* 1991).

Recordings show that for drifting text the eyes fixate on a letter, track it across the screen through a distance of four or five character spaces, and then make a saccade back to pick up a new letter. Repetitions produce a pattern that resembles optokinetic nystagmus. The resulting sequence of retinal images is like that found for stationary text. There is a series of foveal fixations on letters, separated by saccades spanning a few letter spaces. Together these findings encouraged Legge and Rubin (1986) to believe that much of what has been learnt in studies of scanned text can be generalised to everyday reading.

Low vision clinicians have attempted to determine which clinical tests predict visual performance and which conditions optimise it. These studies tend to rely on between-subject design, which involves measuring the performance of a sample of low vision subjects. Variation in performance is then accounted for by a set of subject variables, such as VA and age. The objective is then to find clinical tests that accurately predict the performance of

everyday tasks such as reading. In this series of experiments, three types of word chart were used to calculate outcome measures for the effects of coloured interventions on reading rate and accuracy.

Results from experiment 2 differ considerably from that expected intuitively. This may be related to the chart that was used to measure reading performance (random, simple four-letter words). It is likely that this chart may not have been sensitive enough to detect change as suggested for example by YN equal to SN for rate, and YN and SN equal to ARMD for accuracy. This chart was constructed from new for use in this experiment and no reliability studies were conducted.

Results from subsequent experiments using the Bailey-Lovie cards are more in line with the expected; for experiment 3 (gel filters and Bailey-Lovie cards) results as expected apart from YN=SN for accuracy; experiment 7 (luminaires and Bailey-Lovie cards) as expected. Bailey-Lovie cards were specifically designed for low vision clinical and research use (Bailey and Lovie, 1980) and have been successfully used to detect change in reading performance (Bailey *et al.*, 1978). However, the literature search did not reveal any studies that demonstrated the validity and reliability of this chart.

Results from subsequent experiments using the WRRT charts are less in line with the expected when compared to those using the Bailey-Lovie cards, but more so than the random word cards; experiment 4 (overlays and WRRT) as expected apart from YN equal to SN for rate and SN equal to ARMD and YN equal to SN for accuracy; experiment 5b (tinted lenses and WRRT) SN equal to ARMD for rate and accuracy, neither as expected.

Wilkins *et al.* (1996) have shown that the WRRT is both reliable and valid, and predicted which normally sighted individuals, when offered a coloured overlay, would continue to use it. The test was found to be sensitive enough to reveal effects of coloured overlays even with as

little as two minutes of reading. Evans (1999) found that the WRRT can be used to distinguish between subjects with and without a decompensated phoria. Therefore, the WRRT seems reliable and sensitive enough to detect change. However, these studies used subjects without ocular disease and the test may be less sensitive for low vision subjects.

It is feasible to use both tests in low vision research and clinical work. As proposed in the discussion of technical note-1, the Bailey-Lovie may be used for subjects who are able only to spot read (reading for seconds) and the WRRT used for those who can read fluently (reading for minutes).

The study groups did not behave as expected intuitively

There are many factors that can affect reading performance including visual and non-visual processes. Examples of visual factors are reduced VA (especially at the reading distance), uncorrected refractive error and the presence of ocular disease. Examples of non-visual factors are reduced general motor control, age, and compromised higher level perceptual and cognitive processes.

Non-visual factors may have been responsible for difference between some of the actual and intuitively expected results. Several subjects in the YN group displayed a tendency to read as quickly as possible at the cost of accuracy to obtain a 'high score' in order to out perform their peers, despite instructions that emphasised the importance of accuracy. Older subjects seemed less likely to adopt this competitive attitude and were more concerned about not making mistakes. And although ARMD subjects consistently read at a slower rate than the SN group, they were often as accurate (experiment 2-projection gels and 4-overlays). This may indicate some type of compensation strategy adopted by ARMD observers, the mechanism of which is uncertain.

It is possible that these or other unknown factors may account for some of the negative and

unexpected results obtained in these studies.

Reading rate versus accuracy analysis

Coefficients of variation for rate and accuracy were compared for several experiments in order to determine if for any group there was a relationship between these two parameters, i.e. did some subjects read slowly and have good accuracy or did some subjects read quickly at the cost of accuracy. For most experiments there was a positive relationship between rate and accuracy; as one increased so did the other.

Data were assessed for the percentage of variation in reading rate attributable to the linear variation of reading accuracy and whether this value was statistically significant at the 0.05 confidence level. Subtracting this percentage from one hundred gave an indication of the variation attributable to other factors.

Percentage values for most groups are statistically significant but low. However, for the ARMD group in experiment 5b (tinted lenses), 6 (video-magnifier), and 7 (luminaires) the value is considerably larger at 25.6%, 42.7% and 28.6% respectively. This would indicate that a substantial percentage of the variation in reading rate can be attributed to the linear variation in accuracy and that there probably was a trade-off. Inspection of reading rate versus accuracy scattergrams suggested that there was good accuracy but poor rate, i.e. subjects in these groups read slowly but accurately.

It is difficult to determine whether these observers read slowly due to ARMD, and because they read slowly accuracy was high, or they read slowly in order to be more accurate. It is interesting to note that ARMD had less of an effect on accuracy, since many people with this ocular condition become frustrated with their low reading rate, and perceived poor accuracy. Data from these experiments may indicate that rate is predominantly affected, at least with text lacking context.

Learning and fatigue effects

Reading rate and accuracy values obtained before and after testing sessions were not found to differ significantly. This indicates that the results are unlikely to have been confounded by learning or fatigue, i.e. the results near the end of a session were not significantly different from those at the beginning and *vice versa* respectively. The coloured inventions were selected randomly during the test sessions and this would have helped avoid these effects.

THEORETICAL CONSTRUCTS

Introduction

Knoblauch and Fischer (1991) have asked: 'Why do low vision subjects perform poorly with coloured text?'. Legge and Rubin (1986) inferred that glare may be a critical factor limiting the performance of low vision observers reading coloured text. According to this theory, light from the background and the text may scatter to reduce the retinal contrast of the image. MacAdam (1949) proposed that coloured text of maximum contrast has a lower effective contrast than that of high contrast achromatic text. Another hypothesis is that low vision observers who have trouble reading text defined by colour contrast have lower sensitivity specifically to colour contrast, and that current colour vision tests may not be sensitive enough to pick up these deficits (Knoblauch and Fischer, 1991).

Knoblauch *et al.* (1991a) proposed that:

> 'Normal readers are able to read chromatic text as fast as achromatic text and suggested that lateral chromatic aberration of the optics of the eye introduced luminance transients in the retinal image at the borders of the characters, which would in effect outline the characters and increase their legibility. The poorer spatial resolution of many low vision observers would not permit resolution of these spatial transients, and their reading speeds would be limited by a system sensitive to colour contrast alone and this is thought to be less sensitive than systems responsive to achromatic contrast.'

Arditi and Knoblauch (1995) asked: 'What colour combinations result in the highest text readability?' They stated that some studies had found that the most important chromatic determinant of readability is the luminosity contrast component of the colour combination comprising the letters and background of the text display. In other words, for the standard observer, with standard spectral luminosity function, hue and saturation *per se* are irrelevant- the luminance contrast between the colours chosen for letters and background alone determines the readability. Relative to the standard observer however, most low vision patients have some colour defect, most likely acquired through ageing or disorders producing

spectrally non-uniform ocular media opacities or selective cone losses. These colour defects often result in luminosity functions that differ markedly from the standard observer. As a result, some colour combinations might produce higher effective contrasts and hence higher readability than others do for these observers.

It is not as yet clear which of the factors described above is critical in limiting reading performance of chromatic text by low vision observers or even whether a single factor can account for a performance decrement in all cases (Knoblauch and Fischer, 1991). Also, it must be remembered that these proposals apply to coloured text only and not to black text on a coloured background.

There is also an issue of idiosyncrasy and the use of mean responses from groups of subjects. One of the few things known about coloured filters in younger observers without ocular pathology is that different people need different ones. Wilkins (1994) suggested that this does not just affect people with non-ocular related reading difficulties and that about 10% of the entire population show a prolonged benefit from colour. So 10% of any sample should have an idiosyncratic colour preference which would reduce the chance of a significant effect of a certain colour on average in a group with ARMD. Even if there is not this background idiosyncratic effect of colour in the older population, it may be that colour helps people with ARMD, but for some reason one colour helps one person and a different colour helps another person (Evans, 1998).

There are five possible areas of the visual system where colour may have an effect:

- Ocular media-differential refraction due to chromatic aberration.
- Crystalline lens-differential scattering.
- Retinal photoreceptors-differential interaction with cones and the subsequent effect on innervational transmission of visual information.
- Retino-cortical pathways-differential interaction.

- Higher visual centres of the cerebral cortex-hyperexcitability of neurones.

CHROMATIC ABERRATION EFFECTS

Sivak and Woo (1983) pointed out that the eye has significant chromatic aberrations so that different wavelengths are focussed differently. They suggested that the colour that is best in focus (in their study a video display was used) depended on the interaction between accommodation, working distance and any correcting lenses that are worn. The optimum focus for near viewing in young observers was achieved with green. For older observers, the spectacle lenses used to focus for near affect the colour that is in best focus. For a presbyopic individual wearing lenses that are correctly focussed for the working distance yellow light should be in best focus.

On the other hand, Fagan *et al.* (1986) found that the latency of the P-300 electroencephalographic signal for normal observers was not affected by changing colour from green to amber and that the image could be out of focus by up to 2.00DS before effects were measurable.

Findings by Legge *et al.* (1990) suggested that chromatic aberration had little effect, and luminance contrast and colour contrast had separate and independent effects on reading rate for low vision observers, i.e. there was no evidence for additivity of luminance and colour effects.

Some of the results from this series of experiments differed from those found by Sivak and Woo (1983). From experiment 2 (projection gels) yellow and blue produced overall best reading performance for the YN subjects. For a young person with active accommodation, when focussing at near, less accommodative effort is required to focus green light than yellow light. Since blue has an even shorter wavelength than green even less accommodative effort is required and therefore blue light may be expected to produce the clearest focus and

subsequently the best reading performance.

It is difficult to explain the results with yellow light using the chromatic aberration theory. However, Hecht (1928) suggested that the natural peak spectral sensitivity of the retina is for yellow light and for a subject with an intact and functioning fovea (the YN and SN groups), yellow illumination should produce the best reading performance. Certainly in experiment 2 (projection gels) there was a trend for good reading rates with yellow for the YN group.

Surprisingly, YN results from experiment 3 (gel filters) differ from those of experiment 2 (projection gels) even though the experimental design was very similar. Yellow and red produced good reading performance, which is difficult to explain using the chromatic aberration construct. The performance of the yellow filter may be explained in terms of greater retinal sensitivity for yellow light. No meaningful data was obtained for this group from experiment 4 (overlays).

None of the older subjects were specifically corrected at near for chromatic aberration, and this may explain why overall reading performance in experiment 2 (projection gels) tended to be better with blue and green rather than red and yellow for both the ARMD and SN groups. However, this theory is confounded by the greater likelihood of short wavelength scatter in the older crystalline lens (see CRYSTALLINE LENS section). Interestingly, in experiment 3 (gel filters) the ARMD group performed best with yellow light. This may be explained in terms of reduced chromatic aberration blur or reduced intra-crystalline scattering, i.e. yellow light has a longer wavelength than blue and will be scattered less.

For experiment 3 (gel filters) red and yellow produced good results for two SN individuals, which would suggest no chromatic aberration effect, but perhaps a retinal sensitivity effect. For some observers with ARMD blue, yellow and ND gels produced an improved rate, which can be explained in terms of either chromatic aberration (blue) or retinal sensitivity (yellow).

The ND result is more difficult to explain, but may have been due to a glare effect despite the precautions that were taken in the experimental design to avoid glare.

For experiment 4 (overlays) most colours produced a good rate for YN subjects. Rose and grey yielded a good rate for two SN subjects, which again can be explained in terms of a retinal sensitivity and glare effect respectively. They were no individual effects for the ARMD subjects. And similarly from experiment 5b (tinted lenses) the CPF (Corning yellow) produced a good rate for one SN individual and the ND filter for one ARMD individual.

For experiment 7 (luminaires) two ARMD subjects displayed improved rate with the standard tungsten lamp (red bias) which would suggest a retinal sensitivity effect and one with the compact fluorescent lamp (blue bias) which suggested a chromatic aberration effect. One subject demonstrated improved accuracy with the standard tungsten and one with the compact fluorescent.

Interestingly, workers in the field of non-ocular acquired reading dysfunction have suggested that coloured interventions such as overlays and tinted lenses reduce the accommodative demand and thereby improve reading performance. Ciuffreda *et al.* (1997) investigated the effects of red, green, and blue tinted lenses, recommended to people with non-pathological, acquired reading dysfunction on sustained accommodation. They found no significant difference in the mean level of accommodation between filtered and non-filtered reading conditions.

CRYSTALLINE LENS EFFECTS

Legge and Rubin (1986) noted that optical imperfections in the ocular media mean that a localised point source of light within the visual field does not produce an equally well defined point image on the retina; instead a proportion of light is scattered. Light scatter and absorption by the ocular media are known to be important factors in both normal and low

vision. According to the Rayleigh-scattering formula, spherical particles that are small compared with the wavelength of light will scatter light with an intensity distribution that varies inversely as the fourth power of wavelength. Therefore, blue light is scattered more than red.

Legge and Rubin (1986) also noted that lenticular absorption is greater in the blue than in the red, even in the normal eye and that this difference increases with age. Eyes with cloudy media sometimes absorb more strongly in the blue than in the red. It is, therefore possible that selective absorption could result in wavelength specific effects on reading performance by reducing the effective retinal illuminance.

Shifts in the relative spectral sensitivity and reductions in retinal illuminance might have significant effects on reading. For example, if abnormal ocular media are optically more dense in the blue than in the red, then blue and red stimuli that are matched for normal photopic luminance will yield retinal images that are more intense in the red than in the blue. This difference might result in better reading performance for red stimuli. It is therefore important to know whether reading performance declines rapidly with target luminance. Reductions in luminance ultimately result in a shift from photopic to scotopic spectral sensitivity, i.e. increased sensitivity in the blue relative to the red. Therefore, an examination of the role of luminance in reading will also provide information on effects of change in relative spectral sensitivity.

For the older subjects in this series of studies there may have been a tendency for blue light scatter due to age-related yellowing and sub-clinical lens opacities. And, according to the Rayleigh scattering formula short wavelength light is more likely to be scattered and longer wavelength light is less likely to be scattered, therefore long wavelength light, e.g. red and yellow may produce a sharper retinal image than green and blue wavelengths. Consequently, red and yellow may produce a better reading performance than green and blue due to

scattering.

This does not seem to be the case in experiment 2 (projection gels) where both older groups performed well with blue and green. Results from experiment 3 (gel filters) are mixed; Chi squared analysis revealed a good rate with green for SN and yellow for ARMD, with the longer wavelengths producing some good SN individual effects. Both short and long wavelengths and reduced illuminance (ND filter) produced good ARMD rates.

Legge *et al.* (1990) asked: 'Why should colour contrast be more deleterious to low vision reading than to normal reading?'. Some of their subjects complained of glare when reading colour contrast text. Even subjects with clear media showed depressed reading with colour contrast. In earlier work these investigators had shown that subjects with cloudy media read white-on-black text faster than conventional black-on-white text because of the extra light scattered from both letters and background which probably diluted the retinal image contrast. They showed that glare effects in low vision are not restricted to subjects with cloudy media but are found widely in subjects with clear media and central field loss. Whatever the neural explanation in such cases, glare may play a role in explaining depressed reading with colour contrast. This may explain why some ARMD subjects performed better with ND filters in experiment 3 (gel filters) and 5b (tinted lenses).

RETINAL EFFECTS

By definition ARMD affects the central retina. Macular scotomas are specified by the spatial locations of the retinal areas and by the depth of the reduced light sensitivities of retinal areas compared with normally sighted sensitivities. The macula is where the greatest concentration of cones occurs, therefore ARMD can be described as a disease of the cone photoreceptors. Rods are distributed more peripherally and are unlikely to have a role in reading, as reading is usually undertaken in mesopic to photopic light conditions, when rods do not contribute to the output of the visual system.

It has been argued by Buchsbaum and Gottschalk (1983) (cited Wilkins, 1995) that signals from the photoreceptors in the eyes are combined into a luminance channel, conveying most of the information, and two colour difference channels, one red-green and the other yellow blue. Wilkins (1995) theorised that if one of the channels were selectively impaired by disease, the information transmission could be re-optimised by changing the relative output from the photoreceptors. Such a change could for example result from wearing tinted lenses, or some other type of coloured intervention, particularly if the colour was strong enough to overcome the effects of receptor adaptation.

Marc and Sperling (1977) showed that green (middle wavelength or M) cones are most numerous and red (long wavelength or L) cones makes up about one third of the total. The blue (short wavelength or S) cones are very sparse. These studies also showed that the three cone types are distributed in different concentrations throughout the retina. The S cones (blue) have the greatest variation in density with a maximum at two degrees, but only 3 to 4% of the total at an eccentricity of 0.5 degrees. The proportion is 20% at one degree, but by five degrees this has dropped to about 13%. They are distributed in an annular fashion with maximum density two degrees around the fovea. Red and green cone densities are maximum in the foveola.

Using adaptive optics and retinal densiometry, Roorda and Williams (1999) obtained photographs of the retina from two living human eyes. The proportion of L to M cones is strikingly different in the two male subjects each of whom had normal colour vision. The mean ratios for S, M and L cones were 1:5:20 and 1:9:10 at one degree nasal and one degree temporal to the fovea. The distribution of the sparse S cones is not significantly different from random in either subject. This suggested that the developmental mechanism used to space S cones in a regular non-random manner in humans is not seen near the fovea. The assignment of M and L cones is not significantly different from random in one subject but was significantly more aggregated than expected in a random mosaic for the other subject.

As discussed ARMD results in a central lesion of various dimensions, which may affect the S cones to a larger extent proportionally due to their central location, than the M and L cones, which have a relatively peripheral distribution. Intuitively, for a subject with a central scotoma with an angular subtense of greater than five degrees, most blue cones would be compromised.

Three ARMD subjects (EM, KH and MH) had a biocular visual field defect that was greater than five degrees in size, and thereby almost certainly resulted in extensive blue cone dysfunction. The other nine subjects who under went visual field analysis had smaller biocular defects. Interestingly, examination of the PV16 colour vision plots for these subjects revealed a probable blue-yellow confusion axis for KH only, whereas colour vision analysis with the Intuitive Colorimeter® revealed an obvious blue-yellow axis for KH, a moderate axis for MH and no axis for EM. Other ARMD observers with obvious blue-yellow confusion axes (CP, DS, GH MB, MC, MJ, and MS) had biocular scotomas that had an angular subtense of less than five degrees.

If greater numbers of M and L cones are more likely to be intact, medium and long wavelength light (green, yellow and red) may be expected to produce better reading performance than short wavelength light for ARMD observers. This did occur to some extent in experiment 2 (projection gels) with a trend for higher rate with green, experiment 3 (gel filters) greater reading accuracy with yellow, and experiment 4 (overlays) better accuracy with lime-green. Individual subject analysis for experiment 3 (gel filters) ARMD data highlighted two observers with improved rate when reading with blue light (one had moderate inferior retinal function to 2.5 degrees eccentricity and the other almost complete inferior and left biocular field) and one subject who read fastest with yellow (almost complete central five degrees scotoma).

Bullimore and Bailey (1995) theorised that high illuminance increased reading performance by reducing scotoma size. All their ARMD subjects showed some increase in scotoma area

with decreasing luminance, the median increase being 80% for a reduction from 100 to 1 cdm^{-2}. Some subjects showed quite dramatic changes in scotoma morphology. These subjects also showed marked reductions in word reading acuity and reading speed at lower luminances. The mechanism for this is unclear.

Brown and Lovie-Kitchin (1983) noted that the extent of scotoma is often larger when mapped using visual field analysis than the area of degeneration visible ophthalmoscopically.

Also, experience with SLO (scanning laser ophthalmoscope) macular perimetry has shown that macular areas with altered appearance, such as areas of retinal pigment epithelial atrophy or chorioretinal scarring, often have diminished or extinguished function, but the loss is not uniform. Grossly disturbed function was demonstrated in areas of retina that looked normal. The size, location and density of scotomas cannot be inferred from the ophthalmoscopic appearance of the macular (Fletcher and Schuchard, 1997).

Possibly a zone of partially compromised but surviving photoreceptors is activated by the increased light intensity, thereby innervational out put to the ganglion cells is increased and the visual centres involved in reading receive more visual information. In other words, the marked changes in VA and reading performance that often occur with increased illuminance in ARMD may be associated with subjects using retinal areas of different eccentricities for fixation or having reductions in perceptual span (the number of characters perceived in the field of view by an observer when fixing on one character) as a result of changes in scotoma size or configuration, i.e. a less peripheral zone of retina is made use of for reading, VA and therefore reading acuity will be greater, and a better reading performance is obtained.

A person with a central scotoma from a central sensory deficit is thought to choose (consciously or subconsciously) a preferred eccentric retinal area to perform the visual tasks that the non-functioning fovea used to perform. Thus, in an eye with a central scotoma

affecting all of the fovea, the development of one or more eccentric preferred retinal loci (PRL) naturally and reliably occur to perform the foveal visual tasks like fixation, reading and tracking. This concept of the visual system choosing an eccentric PRL or 'pseudofovea' for foveal visual performance functions has been noted primarily by the use of instruments like the SLO (Fletcher and Schuchard, 1997).

Lei and Schuchard (1996) showed that the position of the PRL can vary according to the brightness of the visual task. For their subjects with retinal neovascular membranes a bright target exhibited a PRL close to the scotoma and when the target brightness was decreased, the PRL retinal location shifted suddenly close to the largest relative scotoma. The PRL with bright light had a better visual acuity capability, while the PRL with dim light had better light sensitivity. This may explain why people with ARMD often read better with high intensity local light.

The major draw back of SLO studies on reading and ARMD is that all measurements are made under monocular conditions. Binocular reading is more complex than monocular reading. Most people with ARMD will read with both eyes open even if the vision in one eye is severely reduced, and will therefore be reading in a biocular if not binocular manner. The interaction of a lesion in each eye (or a lesion in one and healthy retina in the other) will create a reading condition entirely different from the monocular situation so often studied in SLO work.

RETINO-CORTICAL PATHWAY EFFECTS

Visual processing is considered to involve two parallel, albeit interlinked, visual pathways, the transient and sustained processing systems. The former is described as motion sensitive, while the latter channel as pattern or form sensitive (table 5.07). A difference in processing speed is thought to result in acquired reading dysfunction (not related to ocular pathology) for some people. Solan (1994) and Steinman *et al.* (1996) have provided the following summary.

The two systems originate in the retinal ganglion cells and extend, via the lateral geniculate nucleus (LGN), to the striate and extrastriate areas of the visual cortex. Their influence then projects to the parietal, temporal and sub-cortical areas of the brain with little or no cross-talk between them. The information carried in each pathway is kept separate by being transmitted through different cell types and different layers within the same areas, however the two systems do interact.

Two different types of ganglion and geniculate cells have been defined, M cells (magnocellular) and P cells (parvocellular). Both cell types are relatively smaller in the central retina and larger in the peripheral retina, but they form two distinct populations of cells. This duality is known to exist at the level of the ganglion cells but whether it exists even earlier, at the bipolar or horizontal cells in the retina, is not known. It is reasonably certain that the two components must both derive their inputs from the same rods and cones and that the marked differences in response properties must therefore depend on the way the photoreceptor inputs are combined (Livingstone and Hubel, 1988).

About 90% of the cells in the parvocellular layers of the lateral geniculate nucleus (LGN) are sensitive to differences in wavelength whereas cells in the magnocellular layers are not. The three types of cones in the primate retina have broad, overlapping spectral sensitivities and can be loosely termed red-, green-, and blue-sensitive, to indicate their peak sensitivities are in the long-, middle-, and short wavelength regions of the spectrum. Parvocells are wavelength selective because they combine these cone inputs so as to provide colour opponency. A typical parvocell may, for example, receive excitatory inputs to its receptive field centre from red cones only and inhibitory inputs to its receptive field surround from green cones only. Such a cell will be excited by long wavelengths (reds), inhibited by short wavelengths (blues and greens) and be unresponsive to some intermediate wavelength (yellow). Besides such red-on centre, green-off surround cells, other possibilities occur, most commonly red cones antagonised by green, and blue versus the sum of red and green (yellow).

In contrast to the colour selectivity of most parvocells, magnocells (and also the remaining 10% of the parvocells) sum the inputs of the three cone types, so that the spectral sensitivity curves are broad, and the response to a change in illumination is of the same type, either on or off, at all wavelengths. The magnosystem clearly combines the inputs from the red and green cones, but the contribution from the blue cones is so small that it is not clear whether the magnosystem receives any input at all from the blue cones. Also, magnocells are not completely broadband, in that their receptive field surrounds are often weighted toward the red.

M ganglion cells compromise 10% of the retinal ganglion cells and are distributed evenly across the retina. They have larger receptive fields compared to P cells (by a factor of two or three) and are more sensitive to high temporal and low spatial frequency (below one cpd) stimuli. M cells forward information to cells in the magnocellular layers (layers one and two) of the dorsal LGN, which are also large and have thickly myelinated axons that terminate in the visual cortex. P cells comprise 80% of the retinal ganglion cells and are more concentrated in the fovea. They have smaller receptive fields and are more responsive to low temporal and high spatial frequency (greater than 10 cpd) stimuli. The P cells forward information to cells in layers three through six, the parvocellular layers. Cells in the parvocellular layers are small and have thin, poorly myelinated axons that also terminate in the visual cortex. In general, the response characteristics of the M and P cells are similar to the attributes of the transient and sustained channels, respectively.

Information travels faster along large, highly myelinated axons, causing information from the M pathway to reach the visual cortex faster than information from the P pathway. Receiving information first from the M system and then from the P system allows the visual system to quickly locate objects and then to identify them.

Therefore retinal images are sampled at least twice by the visual system, but not in a

redundant manner. First, global, coarse form information is sampled by quickly analysing the low spatial frequency content of the retinal images in the M cell channel. Then the retinal images are sampled for the fine (local) detail by processing the higher spatial frequencies in the P cell channel. The M cell and P cell channels mediate the global-to-local mode of visual processing from the presence and location of the stimulus (M cell) to the processing of fine detail (P cell). In reading, first, word shape and size are sampled globally (M cell) in the field to the right of fixation prior to executing a saccadic movement. The succeeding foveation takes place for the processing of detail (P cell).

Interestingly the rate of neural processing within the transient (M cell) system increases as contrast decreases, and when the wavelength of light is short. Blue filters accommodate both of these conditions. Activity of the sustained (P cell) system is increased with high contrast, and when the wavelength of light is red.

Solan *et al.* (1997) confirmed a link between wavelength of light and eye movement efficiency in reading. Blue filters resulted in a significant decrease in the number of fixations and regressions and rate of reading in a group of children with non-ocular disease related acquired reading dysfunction when compared to a no filter condition. This finding broadened the concept of the (M cell) system deficit impacting on oculomotor efficiency.

Long wavelength cones input the inhibitory surrounds of M cells and this inhibits transient (M cell) transmission. Solman *et al.* (1995) theorised that the removal of red light from the input may increase transient activity by releasing the magnocellular pathways from tonic inhibition. Some of the effects of blue filters on reading for young subjects with good reading skills are consistent with the preposition that increased stimulation of the blue cones relative to the red and green cones reduces tonic inhibition in the magnocellular pathways and increases the level of the transient activity. This heightened level of transient information transfer would be expected to improve location accuracy (more efficient eye movements) and could lead to

increased reading performance.

Williams *et al.* (1991) provided evidence that showed that the efficiency of the magnocellular pathway decreased with red, as compared with the use of an equiluminant green or white background. In disabled readers (not related to ocular pathology) blue and grey overlays had equivalent effects on reading performance. It is unlikely however, that these were due to effects on different visual processing mechanisms produced by these two overlays. Although the use of short wavelength backgrounds has been found to increase the response magnitude and speed in transient channels, grey filters, by reducing stimulus luminance or contrast, may instead slow the response of sustained channels more than those of transient channels. Thus although the mechanisms may be different, the effects on reading performance of using blue and grey overlays in reading-disabled children are the same.

Normal readers, on the other hand, show reading gains only with the blue overlay, which may be due mainly to the increased magnitude of the transient response observed in visual processing of short-wavelength stimuli in normal readers, resulting in greater efficiency of visual processing. Reducing contrast however may not be expected to benefit normal readers, because the creation of a temporal separation is not likely to result in greater efficiency of visual processing.

Additionally Williams *et al.* (1991) found that the rate of processing in transient channels increases as wavelength decreases and also that red light enhances the activity of the parvocellular system, both for normal and disabled readers.

Theories linking a deficit in the parvo pathway with the effects of tinted lenses fail to account for the specificity issue, i.e. Irlen and Lass (1989) claimed and Wilkins *et al.* (1994) showed that a specific idiosyncratic tint is required for each individual. This may account some of the ARMD data obtained in this study.

Speculatively Wilkins (1995) has inferred that the aversive response to visual stimulation (including certain types of text) demonstrated by some people with reading difficulties may be due to more activity in the magnocellular pathways than the parvocellular, and that lenses that absorbed red light (in other words lenses coloured blue or green that transmit short wavelengths) reduced activity in the magnocellular pathways.

This is in direct contrast to Williams *et al.* (1991) and to Solman *et al.* (1995) who theorised that the removal of red light from the input may increase activity in the magnocellular pathway by releasing the pathway from tonic inhibition. Some of the effects of blue filters on reading for young subjects with good reading skills are consistent with the preposition that increased stimulation of the blue cones relative to the red and green cones reduces tonic inhibition in the magnocellular pathway and increases the level of the transient activity. This heightened level of transient information transfer would be expected to improve location accuracy (more efficient eye movements) and may lead to increased reading performance.

Also, as discussed in Chapter 1-Background and Research Rationale, Abramov and Gordon (1977) found that the peripheral retina of normal observers had an enhanced sensitivity to short wavelengths. Therefore, as people with central field loss probably use paramacular and peripheral retina to read, it may be advantageous for them to read with blue light. However, Legge and Rubin (1986) stated that although subjects with central-field loss must rely on peripheral vision to read, there is no evidence for the predicted advantage of blue over red. From their results they concluded that central-versus peripheral loss *per se* is not associated with any clear wavelength specific effects in reading.

Although it would be useful to directly transfer parvo- and magno-cellular theory to the low vision field it must be remembered that the reading situation in ARMD is complicated by the presence of central field loss. The parvocellular pathway is linked mainly to the central cones and the magnocellular to the cones and the rods throughout the retina. Since ARMD is a

disease of the central retina, the central cones and therefore the P cells are likely to be compromised to a greater extent than M cells. Hence, if the M cells (and therefore the magnocellular pathway) are stimulated with blue light this may improve both the neural processing rate and eye movement efficiency which may subsequently lead to better reading performance. Conversely, if the remaining P cells are preferentially stimulated with red light any deficit in the parvocellular pathway may be reduced to produce improved information through flow and therefore indirectly improve reading ability through better processing of detail.

Results from for the YN subjects from experiment 2 (projection gels) and 3 (gel filters) indicated better rate and accuracy with blue which may indicate a M cell effect on neural processing rate, eye movement efficiency or both.

For the SN subjects there was also a blue and green effect on reading performance, which suggested an M cell effect. However, there is also an improvement with red, which suggested a P cell effect on recognition of detail.

ARMD results from experiment 2 (projection gels) and 3 (gel filters), both group and individual, suggested an improved performance with blue light, a possible M cell effect. However, experiment 4 (overlays) highlights a poor performance for rate with a blue overlay. In experiment 7 (luminaires) the blue biased compact fluorescent lamp scored highly for group rate and also for one individual. However, the red biased standard tungsten lamp also produced some good individual results for rate and accuracy. In experiment 6 (video-magnifier) red and blue screens both performed poorly but this may have been due to a fault in the video-magnifier used.

Interestingly, the rate of neural processing within the transient (M cell) system is thought to increase with low contrast, and activity of the sustained (P cell) system is thought to increase

with high contrast. This theory may explain why some of the ARMD subjects performed better with reduced illuminance. These observers are likely to have an M-cell system that is functioning more efficiently than the P cell system due to factors discussed above. Therefore, if M-cell system neural processing is enhanced when contrast is reduced with ND filters, ocular movements and word location efficiency may improve, which could lead to better reading performance. This is conjecture but may be a more plausible explanation than the glare theory proposed above, since all the experiments were designed to reduce the possibility of glare to a minimum.

HIGHER VISUAL CENTRE EFFECTS

When questioned none of the subjects had any recollection of past difficulties or symptoms associated with Meares-Irlen Syndrome (perceptual distortions, visual discomfort and headaches when reading-often described as pattern-glare), and therefore it is unlikely that the colour effects demonstrated in these studies are confounded by this factor.

Wilkins and Neary (1991) noted that some people with reading difficulty benefited from the use of coloured overlays and tinted spectacle lenses; symptoms attributed to Meares-Irlen Syndrome were often reduced. Colours chosen by subjects were idiosyncratic. The reasons for this idiosyncrasy and the physiological basis for the benefits of coloured overlays and tinted lenses are uncertain and current theories are speculative. Wilkins *et al.* (1994) noted that in a double masked placebo controlled study of children with reading difficulties there was preponderance for subjects to chose blue and green shades.

Wilkins (1995) postulated that local cortical areas become hyperexcited when exposed to certain patterns of text. Coloured overlays and tinted lenses can be therapeutic and may change the pattern of excitation, which in turn could reduce perceptual distortions, visual discomfort or headache. Research has shown that some cortical neurones are tuned for wavelength or for colour appearance and none are indifferent to the spectral power distribution

of the stimulating light.

Wilkins (1995) inferred that the colour of illuminating light changes the pattern of excitation in the cortical network, since tinted lenses are thought to reduce seizure in some people with hyperexcitable cortical neurones (as in photosensitive epilepsy) the colour that is therapeutic changes the pattern of excitation in the cortical network so as to avoid local areas of hyperexcitability.

Yolton *et al.* (1995) measured the variation in eye movements when subjects with Meares-Irlen syndrome read with and without Irlen coloured overlays. Three subjects from 29 did have significant improvements in eye movements. It was not possible to demonstrate the benefits of the Irlen filters for the majority of subjects. Reasons for this might include:

- the possibility that the filter effects take time to develop and so were not detected when the subjects read short paragraphs
- filters benefit only a small proportion of persons with Meares-Irlen syndrome
- the eye movement detection equipment was not sensitive enough to detect improvements produced by the filters or
- the overlays do not have a significant effect on reading for most subjects.

The apparent improvements might have occurred because scores for the no filter condition used as baselines for the percentage change calculations happened to be artifactually low. To evaluate this possibility, the no filter data were compared with the clear filter condition. Both conditions yielded similar scores making it unlikely that the improvements were caused by artifactually low no filter scores. Finally, it was possible that these subjects truly derived significant benefits from the coloured interventions.

Yolton *et al.* (1995) found that some good readers benefited from a reduction in discomfort and distortion as much as those with reading difficulty, with the caveat that 'although the

apparent benefits of the coloured interventions for these subjects were intriguing the significance of the data must be interpreted with caution. Scores from the subjects could have represented the tail of a random distribution and thus might not signify a reliable improvement in reading performance, i.e. if they were tested again they would not show an improvement in reading produced by this filter'.

Some tentative data by Wilkins *et al.* (1994) indicated that people with reading difficulties tended to choose blue and green colours. The ARMD group in experiment 2 (projection gels) showed a trend to read well with blue and green illuminance, as did the two ARMD observers in experiment 3 (gel filters). However, the ARMD group performed poorly with the blue overlay in experiment 4 (overlays) but well with the lime-green overlay.

It is not possible to say whether some of the effects in this series of experiments were due to an effect in the higher visual centres, but it is unlikely because higher visual centre involvement is thought to occur only in those people with epilepsy, migraine or Meares-Irlen Syndrome.

SYNTHESIS

It is now possible to speculate on which of these theoretical constructs is most likely to provide a physiological basis for the reading benefit gained by some ARMD individuals from the use of a coloured intervention.

The effect is unlikely to be due to an improvement in P-cell parvocellular pathway neural processing as none of the experiments indicated an improvement with a red intervention. This is not surprising as the central retinal location of the P-cells makes them most likely to compromise in ARMD. However, it is possible that a red intervention may stimulate partially compromised P-cells and result in an improvement in near letter VA. Resolution ability of small letters rather than word recognition performance may be a better indicator of this type of effect.

Experiments 2 (projection gels) and 4 (overlays) indicated a benefit from a green intervention. This may indicate a mechanism at the retinal level, i.e. most S cones are located in the foveal and parafoveal areas and therefore a greater proportion of S cones is likely to be affected by ARMD than M cones which have a more general distribution pattern across the macular. This theory does not however, explain why blue interventions produced good reading performance in several of the other experiments.

Experiments 2 (projection gels), 3 (gel filters) and 7 (luminaires) all highlight a positive effect of a blue intervention. Either a magnocellular pathway or some other peripheral retina mechanism may explain this. A magnocellular pathway effect could result in more efficient eye movements and therefore better word localisation. In other words, perhaps the effect of a neural processing deficit in the parvocellular pathway created by central retinal cone dysfunction and impairing recognition of detail, may be compensated for to some extent by stimulation of a less compromised or perhaps even totally complete magnocellular pathway. This could lead to improved eye movements and better word localisation.

The peripheral retina of normal observers has an enhanced sensitivity to short wavelengths (Abramov and Gordon, 1977). Therefore, as people with central field loss may use parafoveal and peripheral retina to read, it may be advantageous for them to read with blue light from the point of improved word localisation rather than any improvement of reading acuity. Both theories are pure conjecture and could be inter-linked because of the close relationship between the peripheral retina and the magnocellular pathway.

Chapter 6- Conclusions, practical implications and further research

Introduction

This small sample of individuals with ARMD represents a subset of subjects whose life is disrupted by vision problems. It is not representative of all people with ARMD because there is a built in selection bias by referral to low vision rehabilitation services (Birmingham Focus on Blindness Low Vision Centre). Those seeking low vision rehabilitation are experiencing visual performance or task related functional difficulties and this study does not include stages of disease where significant lifestyle problems are not as likely to be encountered. The following conclusions and practical implications should only be applied to people in low vision rehabilitation programs and those complaining of functional difficulties in activities of daily living. This chapter also includes proposals for further research.

Conclusions

The literature review illustrated that many studies have demonstrated the positive effects of moderate to high illuminance on reading in low vision, albeit for some observers these effects were short lived. A few laboratory based studies that evaluated coloured interventions suggested that there is very little benefit to be gained from using colour to improve reading in low vision. However, recognition of every day objects, may be assisted with colour cues (Wurm *et al.* 1993). The author is unfamiliar with the literature examining the use of tinted lenses in driving with low vision.

The review in Chapter 1-Background and Research Rationale demonstrated that a substantial amount of research has produced equivocal results, which have failed to prove objectively any

consistent benefit of filters. The use of filters in low vision still remains controversial.

Some individuals with ARMD also have a BV anomaly. Tailored questioning and a modified BV assessment can be used to reveal symptoms and signs that may be partly attributable to a BV anomaly and not exclusively due to retinal disease. It is not possible to determine whether a BV anomaly was present before ARMD occurred or if it is present as a direct consequence of ARMD. From a clinical and rehabilitation point of view, acquiring this information will assist in the implementation of the most appropriate course of management. Optimisation of residual visual function for the individual's interaction with the environment with respect to rehabilitation, orientation and mobility is paramount for improved quality of life. In research it is important to be able to determine the aetiology of a prospective subject's symptoms in order to be able to draw the correct conclusions from the results obtained.

It was not possible to demonstrate any reading performance benefit from coloured interventions for the majority of subjects and no common characteristics (age, threshold reading acuity, type of scotoma) could be found for those subjects who showed improvement with the coloured interventions. It is better to design an experiment with as few variables as possible and preferably only one, to allow simple data analysis and a better chance of determining a clear outcome.

The results varied considerably across the experiments even though the design and nature of the studies was similar. Many of the actual results from this series of experiments differed from those expected intuitively. Reasons for this might include:

- Coloured intervention effects take time to develop and so were not detected when subjects read short blocks of text.
- Coloured interventions only benefit a small proportion of people with ARMD
- Variability between subjects may have obscured the results and the ANOVA did not have enough power for a 5% chance of detecting a certain percentage change, possibly because

there were not enough subjects in the study.

- The random word chart (experiment 2-projection gels) was probably unable to detect change in reading performance, but the Bailey-Lovie and WRRT charts were almost certainly sensitive enough to detect change.
- Coloured interventions do not have a significant effect on reading for most subjects.

The outcome of the raw data analyses was determined by the type of analysis method used. Three types of analysis were carried out; overall and individual group ANOVA, Chi squared analysis and individual subject analysis. Chi squared analysis of ranking frequencies proved to be a good method to determine effects. Actual results from Chi squared analysis were more in line with expected results when compared to those obtained from ANOVA.

None of the Intuitive Coloured Overlays® improved reading performance for the ARMD group as a whole or for any individual subject. This is perhaps not too surprising as Wilkins (1995) has theorised that the mechanism of the effect noted in subjects with Meares-Irlen Syndrome and migraine is probably of a cortical nature (peripheral effect) and that ARMD is a retinal photoreceptor disease (ocular –retinal effect) (Lightstone, 1997b). In the context of these findings it could be stated that the provision of Intuitive Coloured Overlays® to individuals with ARMD for use as a reading aid is at present inappropriate. The apparent failure of the overlays to produce improved reading performance is in contrast to the positive effect of some of the tinted lenses. The reasons for this are unclear.

The CPF450 did provide a reading benefit over the other filters but this may have been related to the fact that it had high transmission. This is borne out by the fact that the clear filter performed equally as well. As the clear lens performed equally well as the CPF450 for reading rate and the clear lens performed better than any other lens for accuracy it may be in the individual's best interest not to use any of the tested filters or lenses when reading. ANOVA suggested that there was no benefit gained in ARMD reading performance with tinted lenses

compared to a clear filter, Chi squared analysis indicated a reading rate was optimum with the CPF450. The results are therefore ambiguous.

The Intuitive Colorimeter® can be used in the low vision field with ARMD subjects, to determine the optimum colour for tinted lenses to produce the best reading performance. The reading task has to be short in length to avoid visual and postural discomfort and fatigue. The Colorimeter can also be used to determine colour vision discrimination ability for people with ARMD. However, from the data presented here it seems unlikely that tints determined by the Intuitive Colorimeter® are as useful for low vision reading with ARMD as the CPF450 or a ND filter.

No advantage was gained from using the coloured screen facility of the Eschenbach Optik ELG-01 Television Reader video-magnifier for the ARMD study group. No improvement in reading performance was gained from using any other video-magnifier screen-text combination than black text on a grey background. However, the results from the video-magnifier experiment may have been confounded by a fault with the system, and the difference in luminance contrast between the text and the background for the various screen colours. The results from this study are only applicable to ARMD subjects and to this particular brand of video-magnifier.

Some individuals with ARMD benefited from the use of increased local illuminance produced by either a standard tungsten or compact fluorescent lamp. The daylight incandescent tungsten lamp performed poorly compared to the standard incandescent lamp but it is not possible to ascertain whether this was due to the blue tint or because of the lower illuminance produced at the desk surface.

For all the experiments there was a positive relationship between reading rate and accuracy, i.e. as one increased so did the other. There was no reading rate versus accuracy trade-off and

no effects of learning and fatigue. In this study reading accuracy often produced a ceiling effect, i.e. 100% accuracy was achieved by many observers. For future research it may be adequate to use only one of these parameters as an outcome measure. Reading rate may be preferable, as it is less likely to produce such a ceiling effect. However, this may only apply to reading tasks that are simple and it is easy to be accurate.

Both the PV-16 and Intuitive Colorimeter® can be used to detect colour vision deficiency in ARMD. The PV-16 test is easy and quick to administer, but produces information limited to retinal function only and is usually used as a diagnostic tool. Testing with the Colorimeter generally proved more difficult for the subjects, and took longer to administer but may well provide information on retinal integrity, as well as colour vision discrimination, the latter often being of use in functional low vision rehabilitation. Lighting conditions with the Intuitive Colorimeter® are more like that experienced by older people in the home environment and may reveal subtle colour vision loss, especially blue-yellow confusion, that may remain undetected with an arrangement test such as the PV-16. The Intuitive Colorimeter® can be used to derive pairs of colours, that would optimise colour discrimination for ARMD subjects, on an individual basis.

The Humphrey 630 Visual Field Analyser can be used to analyse the biocular visual field in subjects with ARMD.

The Bailey-Lovie near word reading card and the WRRT are both useful in low vision research and clinical work. The Bailey-Lovie near word reading card can be used for clinical measurements related to rehabilitation of spot reading (short periods of reading, e.g. bills, medicine instructions, TV program guides) as well as in research when short periods of reading are evaluated. The card is better used when the number of test conditions is approximately the same as the number of different cards which are available and when information on threshold reading acuity and how reducing letter size affects reading speed.

Observers require at least a moderate word vocabulary.

The WRRT can be used to assess those people who are able to read fluently and when longer research evaluations are required in an attempt to fatigue the observer. The versatility of the WRRT probably makes it the best chart to use for an experiment that has many test conditions and requires information on reading rate and reading accuracy but not on reading acuity. Problems associated with fatigue may be overcome by reducing the number of words used from 150 to 75 per intervention. The chart can be used with observers who have poor word vocabulary.

It is difficult to work out the mechanism that is responsible for the success of some of the filters since some results can be explained by each of the theoretical constructs. Several experiments highlighted a positive effect of a blue intervention in ARMD reading. This may indicate a possible magnocellular pathway effect resulting in more efficient eye movements and therefore, better word localisation. Also, the peripheral retina of normal observers has been shown to be sensitive to blue light, and it may be advantageous for people using para- and peri-macular areas to read with a blue intervention. These two theoretical constructs could be linked since the peripheral retina and the magnocellular pathway are inter-related.

The question can be asked what improvement in reading performance would justify the purchase or supply of the intervention? One difficulty in gauging success is deciding on what amount of improvement can be determined to be a success. Rumney (1996) has advised the provision of new spectacles only if distance VA can be improved by two lines (two log units) on the Bailey-Lovie distance letter chart. A value of 20% improvement in reading performance was arbitrarily chosen in several of the experiments described in this series following work by Yolton *et al.* (1995). But low vision individuals may consider a 10% or perhaps even 5% improvement to be of use. Wilkins (1994) has shown that a 5% improvement in reading rate was a significant indicator in the continued voluntary use of coloured overlays

in a young population (without ocular disease).

Several of the studies described in this thesis reinforce the idiosyncratic nature of the provision of coloured and illuminance interventions to people with low vision. Provision of such an intervention should be by a low vision practitioner taking individual measurements and calculations, as there are no general rules. A person with ARMD cannot simply be recommended one type of general intervention without being tested. Previous research has also suggested (Cornelissen *et al.*, 1991) that it is in the person's interest to conduct individual subject analysis rather than group data analysis to determine if an intervention will be of benefit. People with ARMD should be advised to undergo formal objective testing.

It may still be necessary to resort to observer subjective reports as to whether any improvement is perceived as beneficial. So, even though the main thrust of this work has been in the use of objective tests, it may in some cases be necessary to use a combination of objective and subjective data. This is a contentious and controversial issue and one that will not be easily solved.

Practical implications

Attempts are often made to remediate reading difficulties associated with ARMD by magnification. This has inherent problems in that the field of view is decreased, and if magnification causes less than four letters to be seen in a single glance, then reading performance deteriorates (Legge *et al.*, 1985). Other forms of rehabilitation are required.

However, some claims for the success have yet to be justified. One low vision device manufacturer (A. Scweizer Optik, GmbH., 1996) provides a yellow and a blue filter with a one particular type of stand magnifier, in order to 'subdue the light, according to personal feelings'. There is little scientific evidence to confirm any benefit from these. Also, NoIR Medical Technologies (PO Box 159, South Lyon, MA 48178, USA) supply yellow and orange tinted

hand magnifiers.

The supply of Intuitive Coloured Overlays® as a reading aid to people with ARMD based solely on subjective observations may be considered as inappropriate. Individual objective assessment is required.

Reading performance is better with the CPF450 compared to an ND filter and an Intuitive Colorimeter® lens, but the same as with a clear filter. The provision of a CPF lens as an aid to reading with ARMD may be inappropriate.

The 60W daylight simulation incandescent tungsten lamp will probably not improve reading performance as much as high ambient lighting alone, or when combined with a 60W standard tungsten incandescent lamp, or a compact fluorescent lamp.

The Humphrey 630 Visual Field analyser with the blind spot monitor switched off can be use to plot the biocular visual field of people with ARMD. The field plot can provide rehabilitation use for either near vision or distance tasks depending on the program used.

The Intuitive Colorimeter® can quickly and easily plot out zones of poor colour discrimination. The plot may be used for rehabilitation purposes.

The universal prescribing of a particular coloured intervention for all people with ARMD is not supported by the literature or by the studies in this thesis. Some people with ARMD do seem to benefit from coloured interventions, but the optimal colour varies from person to person. Tests should rely on subjective preferences and objective testing, such as with the WRRT. A comprehensive range of coloured interventions should be used.

Further research

- Experiment 6 (video-magnifier) would be worth advancing with other types of video-magnifier.
- Experiment 7 (luminaires) could be repeated using a daylight simulation incandescent lamp with the same desktop illuminance as a standard incandescent tungsten lamp and a compact fluorescent lamp. This could provide useful reading information on the light *per se* rather than the illuminance produced by the lamp along with the use of a lower level of ambient lighting, more in accordance with that found in the real world.
- An analysis involving evaluation of the volume visual field has been put forward by Arditi (1990) and this requires validation within the concept of a low vision service.
- What percentage improvement in reading performance is subjectively or objectively found to be beneficial by a person with low vision in activities of daily living?
- Speculatively, mechanisms in the peripheral retina and magnocellular pathways have been put forward to explain the benefits of blue interventions found in some of the studies described here. Further work is required.
- Eye movement analysis during reading with blue and red lights in ARMD.

Glossary and abbreviations

ANOVA

Analysis of variance.

ARMD

Age-related macular degeneration.

Cpd

Cycles per degree.

BV

Binocular vision.

CPF

Corning photochromic filter.

CS

Contrast sensitivity.

CSF

Contrast sensitivity function.

CWPM

Correct words per minute.

Brightness

The subjective response to luminance in the filed of view dependent upon the adaptation of the eye.

Colour

The attribute of things that results from the light they reflect, transmit or emit in so far as this light causes a visual sensation that depends on its wavelengths.

Colour contrast

The difference in colour between the background and the text.

Colour constancy

The condition resulting from the process of colour adaptation whereby the colour of objects is not perceived to change greatly under a wide range of lighting conditions both in terms of colour quality and luminance.

Hue

The attribute by which colours are categorised with terms like blue, yellow, green, red and purple.

ICS

Integrated contrast sensitivity.

Illuminance

The luminous flux density at a surface, i.e. the luminous flux incident per unit area. This was formerly known as the illumination value. Units lux.

Illumination

The process of lighting.

Intensity

This is defined as the ratio (expressed as a percentage) of illumination of the test print after the illuminating light has passed through filters, to the illumination of the test print when the illuminating light did not passed through any filters.

Local(ised) lighting

Lighting designed to illuminate a particular small area, which usually does not extend far beyond the visual task.

Lamp

The term used by lighting engineers for an electric bulb.

Luminaire

The term used by lighting engineers to describe a light fitting or shade.

Luminance

Luminance is the physical measure of the stimulus which produces the sensation of brightness measured by the luminous intensity of the light emitted or reflected in a given direction from a surface element, divided by the projected area of the element in the same direction and has units candelas per square metre (cdm^{-2}).

Luminance contrast

The difference in luminance between the brighter and darker parts of a task.

MAR

Minimum angle of resolution.

ND

Neutral density.

PLS

Protective lens series

RSVP

Rapid serial visual presentation

Reading rate

Reading rate was calculated by noting the time taken (in seconds) to complete the reading task; this figure was divided into 60 and the result multiplied by the total number of words read correctly and expressed in terms of the number of correct words per minute (CWPM).

Reading accuracy

When the reading task consisted of words of the same size reading accuracy was calculated as a percentage of the total words correctly identified. When the reading task consisted of words that became progressively smaller reading accuracy was measured in terms of the percentage of words read correctly up to the subject's acuity threshold.

Reading performance

A combination term for reading rate and reading accuracy.

SLO

Scanning laser ophthalmoscope.

SD

Standard deviation.

TLT

Total light transmission.

Troland

Unit used to express a quantity proportional to retinal illuminance produced by a light stimulus. When the eye is viewing a surface of uniform luminance, the number of trolands is equal to the product of the area of pupil (m^2) and the luminance of the surface in cdm^{-2}.

VA

Visual acuity.

Weber's Law

This states that as the intensity of a stimulus increases the ability to detect a difference between the two levels of the stimuli decreases.

WRRT

Wilkins rate of reading test.

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Appendix 1-Raw data

Appendix 1.00-experiment 2 (projection gels) effects of illumination varied in colour and intensity on reading performance in ARMD raw data

YN reading rate (cwpm)

	12.5% transmission				12.5% transmission				50% transmission				100% transmission			
subject	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue
MR	84.61	71.88	39.53	70.35	65.00	95.81	94.02	73.64	65.66	96.19	29.66	89.22	58.91	76.33	52.50	72.63
RE	38.87	61.40	29.90	52.38	44.64	69.47	43.17	67.45	44.28	59.47	30.24	42.38	33.98	82.55	19.04	72.91
YL	93.69	118.22	56.58	54.37	83.77	105.65	52.68	82.62	80.72	117.55	65.64	55.41	70.20	92.43	58.56	101.77
AB	90.40	83.53	67.04	113.86	73.42	100.22	94.61	122.03	75.71	112.06	90.28	113.96	79.28	103.94	53.96	81.30
PW	97.83	93.62	91.09	95.57	76.36	88.73	80.76	91.73	98.76	96.98	63.89	76.27	91.92	100.07	68.18	105.19
SA	83.14	109.34	93.88	119.90	100	106.40	96.49	95.79	127.77	98.57	105.42	89.92	121.83	108.68	89.19	128.23
IC	75.91	69.07	66.90	72.89	91.21	78.72	91.09	77.08	75.91	73.87	65.74	72.89	49.37	78.37	73.34	97.56
AM	62.36	77.17	70.16	97.13	78.69	94.46	71.88	124.68	66.89	68.50	88.18	103.90	73.92	58.94	48.52	72.95
JC	47.67	53.84	66.47	72.82	75.67	56.53	80.31	69.60	57.20	56.53	80.05	61.77	51.16	55.02	68.22	71.13
JM	44.30	49.98	43.92	56.14	55.73	55.36	31.71	52.74	44.30	35.24	69.73	52.74	71.04	51.14	54.40	42.01

Appendix 1.00 contd experiment 2 (projection gels) raw data

SN reading rate (cwpm)

	12.5% transmission				25% transmission				50% transmission				100% transmission			
subject	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue
VS	40.00	50.77	53.33	42.00	50.77	60.00	72.63	57.60	75.79	44.00	57.60	138.00	81.50	72.12	45.00	83.65
EE	34.29	31.43	39.38	42.86	46.15	37.50	42.22	41.39	72.63	51.11	39.43	68.57	45.52	32.90	45.52	72.63
RA	80.61	83.48	67.98	84.20	79.63	77.18	59.82	69.63	84.81	72.75	70.97	69.63	75.08	83.48	67.98	84.19
JH	77.80	111.20	94.61	100	112.37	99.59	107.06	109.76	104.27	111.20	94.61	115.39	102.20	90.85	99.72	107.62
DB	71.71	58.32	62.31	70.45	75.31	64.03	61.07	72.29	83.77	68.02	73.97	69.03	77.71	76.12	77.42	78.30
LE	70.25	81.73	54.89	45.44	85.56	74.00	82.15	59.80	78.37	49.85	77.75	78.43	82.33	85.36	69.90	91.72
ME	91.03	88.58	99.79	81.49	84.61	90.34	83.99	106.90	82.81	103.15	105.18	106.90	87.96	101.77	113.48	86.59
JA	102.78	93.75	83.14	89.16	98.93	92.80	81.49	89.16	92.61	99.42	95.77	63.28	105.26	79.82	100.95	95.24
GC	40.16	44.52	48.27	43.85	38.21	47.01	47.32	49.16	46.07	52.61	46.71	48.91	59.26	53.39	46.14	50.51
BC	74.70	52.61	60.33	76.39	77.30	119.70	53.53	78.99	94.76	84.01	75.51	75.47	98.97	45.42	86.07	86.07

Appendix 1.00 contd-experiment 2 (projection gels) raw data

ARMD reading rate (cwpm)

	12.5% transmission				25% transmission				50% transmission				100% transmission			
subject	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue
EC	86.85	74.38	68.93	52.13	47.50	104.80	45.49	61.72	110.35	52.71	52.33	71.71	68.25	84.36	88.13	76.41
BP	20.00	11.13	43.13	30.64	26.96	29.94	31.43	35.39	24.92	37.30	40.81	33.13	30.59	47.47	31.81	35.05
VW	32.20	31.31	22.91	34.01	39.92	34.55	39.90	48.24	48.76	27.35	47.29	53.95	46.72	29.66	47.64	60.94
BH	48.03	33.57	39.54	41.24	48.76	39.30	51.51	52.45	53.45	43.31	55.05	48.60	49.46	49.29	58.32	54.48
MH	47.42	70.28	52.48	59.08	53.29	77.01	58.56	66.00	50.99	64.22	62.10	62.99	50.75	31.23	48.64	46.19
RR	53.95	43.88	47.12	47.64	46.08	48.37	43.22	45.47	39.42	49.23	62.94	45.58	38.01	39.93	56.12	53.37
VB	60.76	55.80	46.23	47.23	58.60	57.17	52.81	48.49	45.73	64.58	57.51	54.01	58.35	54.91	53.20	70.99
BM	31.97	40.70	39.60	41.05	52.83	35.78	43.14	49.77	47.07	54.82	60.23	51.45	44.06	37.10	60.00	43.94
FP	32.47	28.34	49.27	37.65	41.05	22.55	53.06	33.38	35.67	24.08	53.06	39.42	28.86	27.74	39.71	48.17
BM	73.51	67.71	60.66	82.47	75.04	73.58	74.60	59.53	72.36	85.92	69.87	82.33	59.33	73.09	64.92	75.49

Appendix 1.00 contd experiment 2 (projection gels) raw data

YN reading accuracy (%)

	12.5% transmission				25% transmission				50% transmission				100% transmission			
subject	red	yellow	green	blue	red	yellow	green	blue	red	yellow	green	blue	red	yellow	green	blue
MR	100	95.83	79.17	100	100	100	91.67	87.50	100	100	79.17	100	87.50	95.83	87.50	95.83
RE	79.17	87.50	70.83	83.33	83.33	91.67	87.50	91.67	83.33	83.33	75.00	79.17	79.17	91.67	70.83	100
YL	95.83	100	95.83	91.67	100	95.46	87.50	100	100	100	91.67	87.50	87.50	100	100	95.83
AB	100	75.00	100	95.83	91.67	95.83	100	100	87.50	100	100	95.83	91.67	91.67	87.50	83.33
PW	100	91.67	95.83	95.83	87.50	87.50	100	91.67	100	95.83	91.67	87.50	91.67	95.83	83.33	100
SA	100	100	91.67	100	100	100	91.67	91.67	100	95.83	95.83	91.67	100	100	91.67	100
IC	91.67	95.83	91.67	91.67	95.83	95.83	95.83	100	100	91.67	91.67	91.67	87.50	95.83	83.33	100
AM	100	100	95.83	91.67	100	100.00	87.50	100	95.83	91.67	100	100	100	100	87.50	100
JC	87.50	95.83	95.83	95.83	100	91.67	100	100	87.50	91.67	100	91.67	87.50	91.67	91.67	95.83
JM	83.33	91.67	95.83	95.83	87.50	100	87.50	91.67	87.50	91.67	100	87.50	100	100	83.33	87.50

Appendix 1.00 contd experiment 2 (projection gels) raw data

SN reading accuracy (%)

	12.5% transmission				25% transmission				50% transmission				100% transmission			
subject	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue
VS	83.33	91.67	100	87.50	91.67	100	95.83	100	100	91.67	100	95.83	98.61	94.40	100	99.01
EE	83.33	91.67	87.50	83.33	83.33	83.33	79.17	83.33	95.83	95.83	95.83	100	91.67	70.83	91.67	95.83
RA	95.83	100	100	100	95.83	95.83	95.83	95.83	100	95.83	100	100	95.83	100	95.83	95.83
JH	100	100	100	100	95.83	100	100	100	100	100	100	100	100	95.83	100	100
DB	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
LE	91.67	100	95.83	100	100	95.83	100	100	95.83	91.67	100	100	100	100	100	100
ME	95.83	95.83	100	100	100	100	95.83	100	100	100	95.83	100	100	95.83	100	100
JA	100	95.83	100	95.83	95.83	95.83	100	100	100	95.83	95.83	91.67	100	95.83	95.83	100
GC	100	95.83	100	95.83	100	100	100	100	100	100	100	100	100	100	100	100
BC	91.67	100	100	100	91.67	100	100	100	91.67	100	100	100	100	91.67	100	100

Appendix 1.00 contd experiment 2 (projection gels) raw data

ARMD reading accuracy (%)

	12.5% transmission				25% transmission				50% transmission				100% transmission			
subject	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue	rose	yellow	green	blue
EC	95.83	100	100	87.50	95.83	100	95.83	100	100	100	100	100	100	100	100	95.83
BP	100	75.00	95.83	100	95.83	95.83	100	100	100	100	100	91.67	100	100	91.67	95.83
VW	100	91.67	87.50	95.83	95.83	83.33	91.67	95.83	95.83	91.67	95.83	95.83	95.83	91.67	95.83	100
BH	100	91.67	95.83	87.50	95.83	100	95.83	95.83	100	100	91.67	100	91.67	95.83	100	100
MH	95.83	100	100	95.83	95.83	95.83	100	100	91.67	95.83	95.83	100	95.83	75.00	95.83	91.67
RR	100	91.67	100	95.83	100	100	95.83	100	100.00	100	100	100	91.67	91.67	100	100
VB	100	95.83	100	100	95.83	100	100	100	95.83	95.83	100	100	95.83	91.67	95.83	95.83
BM	87.50	95.83	70.83	91.67	95.83	91.67	87.50	95.83	95.83	100	100	87.50	91.67	87.50	100	91.67
FP	100	95.83	100	95.83	95.83	91.67	100	91.67	87.50	83.33	95.83	91.67	91.67	91.67	100	95.83
BM	100	95.83	100	100	95.83	100	95.83	95.83	100	100	100	100	100	91.67	100	95.83

Appendix 1.01 experiment 3 (gel filters)-investigation of the effects of five coloured gel filters on reading performance in ARMD raw data

YN	reading rate (cwpm)								reading accuracy (%)							
subject	none 1	none 2	average	rose	yellow	blue	green	ND	none 1	none 2	average	red	yellow	blue	green	ND
NH	81.10	116.42	98.76	92.83	96.11	102.82	85.86	105.52	97.50	97.50	97.50	98.60	91.30	98.60	98.60	100
KB	80.84	78.04	79.44	78.79	91.77	84.51	75.75	74.75	98.75	97.53	98.14	97.58	100	100	98.77	96.30
DS	79.83	83.35	81.59	76.12	79.36	100.00	100.00	79.37	100	100	100	100	100	100	100	98.77
NC	90.44	81.52	85.98	83.80	89.10	72.94	85.43	92.70	100	98.77	99.39	98.77	100	97.44	96.30	100
FR	69.35	74.78	72.07	67.91	67.46	66.71	69.11	70.46	96.00	97.33	96.67	100	97.33	98.61	100	100
AG	58.18	55.92	57.05	51.02	52.53	54.39	60.70	55.89	100	100	100	98.63	98.61	100	100	98.57
SB	67.28	66.86	67.07	66.39	66.82	69.14	67.78	59.68	98.61	100	99.31	97.33	100	97.30	98.61	95.95
AC	98.83	104.05	101.44	95.91	115.50	101.72	102.67	98.98	97.53	98.67	98.10	96.15	100	96.30	100	97.53
GF	107.98	218.45	163.22	212.82	214.13	122.57	129.43	118.94	100	100	100	100	100	100	100	100
LB	89.03	91.21	90.12	79.76	83.27	78.84	80.89	93.04	98.67	98.67	98.67	98.67	98.67	98.67	97.33	98.59
EM	61.07	60.57	60.82	69.40	70.31	56.97	68.70	59.58	97.37	98.72	98.05	98.67	97.33	93.33	94.67	96.05
RT	89.23	79.46	84.35	90.69	83.86	77.09	84.77	82.05	98.67	98.67	98.67	100	97.33	100	98.55	100

Appendix 1.01 contd experiment 3 (gel filters) raw data

SN	reading rate (cwpm)								reading accuracy (%)							
subject	none 1	none 2	average	rose	yellow	blue	green	ND	none 1	none 2	average	rose	yellow	blue	green	ND
RT	54.66	69.60	62.13	61.44	58.04	53.63	69.58	59.89	96.49	97.10	96.80	98.25	95.24	96.61	100	96.49
FF	74.27	60.32	67.30	64.38	61.44	65.66	76.78	68.88	96.83	95.52	96.18	93.65	93.65	95.24	96.83	98.41
EC	75.17	69.21	72.19	70.62	69.34	71.48	68.93	68.93	96.77	98.41	97.59	100	98.41	98.41	100	95.08
SL	60.23	68.29	64.26	63.56	66.85	69.58	53.87	65.10	100	100	100	98.41	100	100	100	100
DL	94.39	97.89	96.14	62.50	69.58	69.73	65.95	65.71	100	100	100	98.04	100	92.16	97.92	100
RP	66.34	61.68	64.01	54.90	52.34	52.41	64.66	57.47	98.25	100	99.13	87.50	88.89	100	100	100
GM	55.44	56.71	56.08	51.10	50.28	48.05	62.58	55.37	96.43	98.18	97.31	96.30	96.08	91.84	96.49	96.30
DP	75.05	70.68	72.87	70.84	70.15	71.12	69.27	70.90	96.77	98.18	97.48	100	98.41	100	100	96.72
MW	82.52	85.67	84.10	97.80	87.23	94.91	87.40	96.32	98.59	100	99.30	100	100	100	100	100
VG	71.02	72.01	71.52	71.36	76.49	67.78	65.93	70.54	92.19	96.89	94.54	100	100	98.41	98.49	98.55
EE	55.93	64.28	60.11	57.95	70.74	65.42	66.15	53.14	87.30	92.19	89.75	93.75	93.65	85.71	96.83	95.31
JS	67.27	70.17	68.72	59.36	72.35	72.09	61.84	72.83	98.61	96.89	97.75	98.61	100	100	95.95	98.55

Appendix 1.01 contd experiment 3 (gel filters) raw data

ARMD	reading rate (cwpm)								reading accuracy (%)							
subject	none 1	none 2	average	rose	yellow	blue	green	ND	none 1	none 2	average	rose	yellow	blue	green	ND
BM	37.61	46.23	41.92	39.42	44.76	45.77	38.75	44.78	92.31	88.37	90.34	79.55	86.67	92.31	75.00	43.21
MJ	63.31	69.53	66.42	57.10	65.97	59.97	64.09	66.06	100	100	100	100	100	100	100	100
MH	56.46	47.20	51.83	59.43	52.15	62.23	42.21	57.06	100	100	100	100	100	100	100	100
ID	65.79	66.98	66.39	73.86	71.78	70.80	61.27	70.19	100	100	100	100	100	100	100	100
KH	21.49	37.73	29.61	32.15	39.86	30.18	28.62	18.74	94.87	82.05	88.46	88.46	90.43	80.00	77.78	90.43
MB	17.43	19.74	18.59	13.58	10.68	11.94	11.22	19.94	85.19	85.19	85.19	92.59	74 07	85.71	80.00	90.48
MC	29.68	29.89	29.79	33.65	27.82	37.98	33.05	54.59	96.07	92.16	94.12	94.12	87.72	100	97.92	91.11
CP	27.76	36.98	32.37	33.02	27.51	28.41	29.19	31.88	97.50	97.22	97.36	97.50	92.68	87.89	91.11	100
MAS	31.56	25.56	28.56	27.93	25.14	28.76	23.21	24.94	100	100	100	100	96.97	100	100	96.97
WH	33.40	33.34	33.37	26.40	28.79	26.67	34.41	41.73	97.77	95.56	96.66	95.35	97.78	95.56	91.11	95.46
DS	41.83	46.65	44.24	38.71	30.20	60.00	45.49	31.97	95.56	87.76	91.66	95.35	97.78	95.56	91.11	95.46
NJ	45.66	52.79	49.23	33.47	36.78	46.95	42.16	43.82	88.89	100	94.45	81.48	92.59	96.30	100	96.30

Appendix 1.02 experiment 4 (overlays)-investigation of the effects of Intuitive Coloured Overlays® on reading performance in ARMD raw data

YN reading rate (cwpm)

subject	none 1	none 2	rose	pink	yellow	orange	mint	lime	grey	blue	aqua	purple	clear
LB	97.63	102.33	129.42	115.00	122.58	98.52	105.18	138.29	97.49	123.86	112.43	112.90	98.52
SD	137.96	141.66	125.51	135.16	134.19	133.69	133.93	137.13	123.02	126.89	81.92	139.91	136.80
FR	115.94	112.19	100.08	102.53	101.36	110.93	98.63	107.32	75.96	107.73	116.89	94.87	106.91
DS	119.52	155.74	144.79	132.95	150.35	134.44	144.26	133.53	124.32	124.67	148.56	131.25	146.53
NC	119.08	181.12	160.80	141.44	143.23	172.26	141.84	182.56	181.53	137.03	173.29	163.21	181.08
AC	158.53	162.19	172.18	166.51	160.83	161.41	166.67	157.64	160.46	169.06	115.39	149.47	165.99
NS	156.00	167.96	163.35	153.37	174.03	177.81	143.42	156.95	169.80	165.81	165.65	165.88	180.42
AG	82.16	97.68	83.87	114.37	88.24	89.24	117.85	91.40	105.25	106.11	88.70	84.87	86.64
SD	132.65	139.30	126.15	122.78	132.35	127.66	124.93	136.53	132.31	130.87	116.85	122.82	116.79
EM	91.04	99.44	81.95	100.97	90.23	92.52	74.92	94.71	89.28	80.59	83.00	97.00	81.71
NL	219.86	201.09	202.54	188.98	201.21	197.07	197.35	200.59	165.09	220.46	184.24	184.22	200.54
GF	157.34	181.27	187.15	165.37	186.45	194.93	172.08	182.56	176.86	187.50	170.80	177.97	179.03

Appendix 1.02 contd experiment 4 (overlays) raw data

SN reading rate (cwpm)

subject	none 1	none 2	rose	pink	yellow	orange	mint	lime	grey	blue	aqua	purple	clear
MW	176.13	209.60	189.55	203.80	198.19	181.93	177.20	212.16	197.07	179.25	196.59	189.31	201.98
VG	123.21	154.25	103.64	127.03	108.65	109.01	116.28	120.56	106.70	116.61	105.55	126.50	115.26
EE	104.41	93.88	88.46	94.70	87.44	92.38	85.94	80.25	94.70	92.71	78.19	83.36	93.74
JS	114.19	156.55	116.85	120.51	116.32	127.75	142.88	138.04	107.69	120.18	131.37	117.76	121.29
GM	86.12	101.97	95.48	90.08	98.57	99.38	91.60	94.61	97.80	96.95	97.49	94.11	101.25
RP	77.73	70.05	63.09	70.31	68.84	62.91	65.93	61.01	70.13	61.23	67.72	69.60	51.05
DL	98.97	92.50	93.49	77.63	91.91	74.64	94.20	90.90	60.25	90.53	89.58	78.82	110.47
SL	143.29	126.58	110.19	124.05	118.61	121.92	83.96	123.25	133.77	136.28	131.21	136.53	121.80
RT	120.77	119.00	108.33	111.25	119.39	103.28	113.69	106.61	102.50	100.92	115.85	118.38	115.33
EC	119.23	137.25	146.20	134.80	118.29	116.54	127.86	136.47	121.64	115.09	123.15	120.37	118.56
FF	136.15	120.24	98.22	116.17	96.07	95.20	92.83	122.60	124.13	100.04	106.36	99.86	114.98
DP	135.68	140.41	130.00	130.32	132.14	139.88	133.06	137.26	122.28	130.36	123.28	129.11	121.05

Appendix 1.02 contd experiment 4 (overlays) raw data

ARMD reading rate (cwpm)

subject	none 1	none 2	rose	pink	yellow	orange	mint	lime	grey	blue	aqua	purple	clear
BM	78.67	86.37	66.75	74.23	53.10	82.50	78.91	87.85	66.08	82.63	65.16	81.33	77.72
MJ	91.33	123.15	86.48	106.88	92.54	81.27	106.71	66.53	103.66	78.72	94.92	84.65	115.43
MH	134.55	166.48	163.86	132.72	149.97	148.70	141.63	130.57	141.66	139.76	142.47	154.06	149.23
ID	114.49	113.59	91.31	94.95	98.17	90.48	102.82	113.11	89.49	90.52	102.69	109.19	101.81
KH	101.56	112.15	91.71	100.95	88.02	84.31	96.49	107.26	96.48	100.27	83.14	63.05	116.19
MC	59.56	60.93	52.91	54.04	60.39	52.00	44.92	53.99	58.86	58.18	54.57	42.93	59.19
CP	56.55	61.74	59.11	59.57	55.31	54.87	61.35	58.32	59.95	61.64	62.75	60.96	58.66
EM	62.48	65.40	32.94	47.32	53.17	37.29	40.55	37.14	54.10	37.41	54.45	35.66	63.41
MS	42.63	59.60	61.13	53.45	54.17	51.77	46.99	58.96	111.26	50.20	53.85	59.53	54.53
GH	43.42	48.14	31.47	34.01	35.06	35.12	30.23	37.50	33.49	28.05	33.39	23.03	46.57
DS	35.97	69.08	61.49	48.51	70.37	58.98	61.32	65.99	37.46	47.49	48.54	33.95	57.14
WH	60.23	104.34	96.67	93.66	106.39	100.23	99.61	114.26	98.24	90.80	101.51	86.58	104.60

Appendix 1.02 contd experiment 4 (overlays) raw data

YN reading accuracy (%)

subject	none 1	none 2	rose	pink	yellow	orange	mint	lime	grey	blue	aqua	purple	clear
LB	98.52	97.04	98.52	97.04	99.26	98.52	98.52	97.78	95.56	99.26	100	97.04	100
SD	99.26	100	100	100	100	100	100	100	99.33	100	100	100	100
FR	100	99.33	99.33	100	100	100	100	100	100	100	99.33	98.00	100
DS	90.00	98.67	100	98.67	99.33	99.33	99.33	99.33	99.33	98.67	98.00	98.67	100
NC	100	100	100	100	98.67	98.67	99.33	100	100	99.33	99.23	98.67	99.33
AC	100	100	100	98.67	100	100	100	99.23	100	99.33	100	100	100
NS	96.67	98.67	96.67	98.67	99.33	98.67	96.67	98.67	99.33	96.67	100	98.00	99.33
AG	100	100	99.33	99.33	99.33	100	99.33	100	99.33	98.67	90.00	100	100
SD	100	100	98.67	100	100	100	100	100	100	100	100	100	100
EM	100	100	99.33	99.33	99.33	100	100	100	100	99.33	98.67	100	100
NL	98.67	98.67	99.33	98.67	100	100	99.33	98.67	94.00	98.67	100	99.33	100
GF	100	100	100	99.33	100	100	100	99.33	99.33	100	98.67	100	100

Appendix 1.02 contd experiment 4 (overlays) raw data

SN reading accuracy (%)

subject	none 1	none 2	rose	pink	yellow	orange	mint	lime	grey	blue	aqua	purple	clear
MW	100	100	100	100	100	100	100	100	100	100	100	100	100
VG	97.33	91.33	81.33	80.00	83.33	80.67	94.67	92.00	85.33	92.67	91.33	83.33	83.33
EE	94.67	93.33	95.33	96.67	97.33	93.33	93.33	93.33	96.67	94.67	98.67	93.33	96.00
JS	99.33	100	100	100	100	100	100	100	100	100	100	100	100
GM	84.67	96.67	97.33	98.00	98.00	100	88.00	95.33	97.33	97.33	98.00	98.00	100
RP	99.33	99.33	99.33	99.33	99.33	98.67	100	99.33	100	100	100	99.33	96.00
DL	96.00	99.33	95.33	95.33	93.33	92.67	96.00	94.00	87.33	92.67	94.67	94.67	97.33
SL	100.00	99.33	98.67	100	98.67	100	100	100	100	99.33	100	99.33	99.33
RT	88.00	90.67	90.00	69.33	96.00	91.33	95.33	90.67	85.33	81.33	95.33	94.67	85.33
EC	97.33	98.67	98.67	98.00	98.67	99.33	100	98.00	94.00	99.33	98.67	96.67	98.00
FF	86.67	93.33	79.33	79.33	92.00	85.33	80.00	86.00	89.33	87.33	79.33	79.33	92.00
DP	99.33	100	100	98.67	100	100	100	99.33	100	100	99.33	100	100

Appendix 1.02 contd experiment 4 (overlays) raw data

ARMD reading accuracy (%)

subject	none 1	none 2	rose	pink	yellow	orange	mint	lime	grey	blue	aqua	purple	clear
BM	98.00	97.33	95.33	98.67	88.67	97.33	97.33	98.67	92.67	96.67	88.67	98.00	96.67
MJ	98.67	100	99.33	100	99.33	99.33	100	94.00	100	98.67	100	100	98.67
MH	100	100	99.33	98.67	90.00	99.33	98.67	100	99.33	98.67	98.67	98.67	100
ID	87.33	78.00	68.67	66.67	64.67	68.67	68.00	76.00	66.00	84.00	76.67	78.67	79.33
KH	82.67	89.33	76.67	70.00	76.00	66.67	66.00	80.00	82.00	66.67	68.67	54.67	92.00
MC	89.33	98.67	98.00	96.00	100	89.33	92.66	88.67	98.67	98.00	99.33	93.33	98.67
CP	98.67	98.00	99.33	96.67	89.33	97.33	94.67	98.67	97.33	100	98.00	99.33	98.67
EM	93.33	89.33	85.33	88.00	92.00	70.67	84.00	66.67	90.67	88.00	92.00	81.33	92.00
MS	98.67	100	100	98.67	80.00	100	100	100	100	100	100	100	100
GH	80.00	93.33	77.33	78.67	77.33	74.67	60.00	81.33	78.67	57.33	77.33	42.67	74.67
DS	98.67	98.67	100	98.67	97.33	58.98	100	100	98.67	100	100	100	100
WH	90.00	98.00	96.67	94.00	97.33	95.33	98.67	98.67	96.67	96.00	97.33	97.33	99.33

Appendix 1.03 experiment 5a (colorimetry)-use of the Intuitive Colorimeter® in the assessment of reading performance with ARMD raw data

SN reading rate (cwpm) (saturation set at 20 for all hue angles)

hue angle	zero sat.1	zero sat.2	0	30	60	90	120	150	180	210	240	270	300	330
illuminance (lux)	204	204	195	165	150	135	125	145	186	235	263	268	250	225
EC	123.60	147.55	150.78	131.21	140.32	141.78	143.99	139.14	139.03	139.14	129.64	132.84	135.42	135.24
RP	112.39	68.05	85.03	79.65	77.74	79.76	80.93	76.49	79.16	78.37	72.28	71.45	73.12	76.58
FF	99.16	93.55	92.96	93.02	92.96	93.72	96.64	97.88	93.12	105.43	90.65	94.54	90.60	87.55
RT	126.27	118.77	137.77	118.75	108.59	110.25	109.54	107.06	108.39	121.12	104.85	111.30	129.92	122.11
EE	77.81	79.69	74.24	73.90	80.70	75.37	78.03	79.62	91.76	73.40	86.33	81.66	79.25	61.44
VG	98.04	112.79	112.79	112.13	98.34	115.01	100.99	117.01	115.83	118.50	114.64	105.78	111.55	109.78
JS	112.18	111.82	103.22	110.39	108.23	123.81	124.88	121.97	134.27	121.16	73.51	99.90	115.21	102.46
GM	74.99	80.50	52.62	75.30	77.59	83.07	87.01	82.34	89.18	83.65	81.36	68.79	65.47	73.38
MW	198.62	204.13	192.72	196.64	210.43	200.62	177.66	184.09	194.09	196.35	213.27	168.32	205.28	206.14
DP	133.31	137.53	143.21	135.34	144.02	133.94	137.43	133.88	133.42	138.30	137.13	132.04	127.35	129.70
DL	96.11	110.62	95.30	87.88	105.70	111.30	97.40	104.71	92.83	88.34	90.84	92.98	75.26	101.55
TH	106.04	121.94	121.94	114.51	119.46	114.32	109.15	125.23	123.29	122.10	119.39	118.65	121.35	112.25

Appendix 1.03 contd experiment 5a (colorimetry) raw data

SN reading accuracy (%) (saturation set at 20 for all hue angles)

hue angle	zero sat.1	zero sat.2	0	30	60	90	120	150	180	210	240	270	300	330
illuminance (lux)	204	204	195	165	150	135	125	145	186	235	263	268	250	225
EC	99.33	99.33	96.67	98.67	97.33	100	99.33	98.00	98.00	139.14	99.33	98.67	97.33	98.67
RP	99.33	98.67	100	98.67	98.67	99.33	89.33	98.67	100	99.33	99.33	100	99.33	98.67
FF	96.67	91.33	94.00	95.33	93.33	94.00	93.33	92.00	96.67	91.33	94.67	94.00	92.00	92.00
RT	85.33	94.00	86.00	95.33	95.33	80.67	94.00	95.33	75.33	88.00	92.67	94.67	84.00	92.67
EE	96.00	88.00	96.00	96.00	88.67	99.33	98.00	99.33	95.33	88.67	98.67	84.67	98.00	84.67
VC	98.00	94.00	96.00	98.00	91.33	97.33	92.00	98.67	84.00	87.33	114.64	96.00	93.33	96.00
JS	100	100	100	100	100	100	99.33	100	100	100	99.33	100	98.67	99.33
GM	96.00	98.00	90.67	87.33	98.00	99.33	87.33	88.00	98.67	84.00	88.00	95.33	78.67	95.33
MW	99.33	100	100	100	100	100	100	100	100	100	100	100	99.33	100
DP	98.67	100	91.33	100	100	98.67	100	98.00	97.33	99.33	100	100	100	99.33
DL	86.00	94.00	93.33	87.88	91.33	93.33	92.67	93.33	94.00	84.00	93.33	92.67	80.67	85.33
TH	88.00	98.00	98.00	99.33	98.00	98.67	86.67	100	100	100	99.33	98.67	98.00	100

Appendix 1.03 experiment 5a (colorimetry) raw data

ARMD reading rate (cwpm) (saturation set at 20 for all hue angles)

hue angle	zero sat.1	zero sat.2	0	30	60	90	120	150	180	210	240	270	300	330
BM	52.47	74.87	68.91	72.26	79.99	59.97	71.25	68.01	59.55	71.84	73.05	55.90	78.66	55.05
MJ	68.04	25.55	33.76	62.55	35.14	57.01	59.07	42.61	39.02	34.68	33.56	32.36	48.27	29.20
MH	87.48	115.04	112.78	82.19	116.41	98.25	106.84	115.70	115.20	125.07	107.04	94.54	88.98	92.52
ID	102.44	90.53	106.53	73.03	75.01	98.52	84.65	79.87	111.99	100.02	93.87	95.91	103.93	103.87
MC	40.36	55.00	68.23	48.81	63.98	54.07	65.02	57.20	48.32	62.39	65.44	63.05	33.47	54.97
CP	60.56	56.26	60.19	62.22	52.93	56.66	59.02	58.22	53.44	46.63	53.02	55.50	54.27	52.66
MB*	18.58	8.95	19.54	17.27	11.67	10.86	17.93	13.94	31.70	11.33	19.64	18.26	10.32	15.15
MS*	30.62	26.71	25.32	13.71	29.74	33.93	23.77	28.87	38.39	22.66	26.55	21.98	34.29	20.62
NJ	104.90	115.68	105.86	108.02	105.59	109.92	93.95	105.41	101.04	105.72	105.48	115.67	118.85	105.59
MAS	55.48	77.53	87.20	54.44	50.70	63.23	46.49	51.50	52.02	58.92	47.76	48.24	75.59	65.88
GS	62.58	90.98	70.61	72.96	86.60	88.71	58.13	74.57	83.96	73.70	81.04	92.81	80.73	89.92
WH	68.61	66.54	59.99	74.18	68.81	64.32	61.80	70.35	69.33	70.29	69.86	62.73	66.09	73.07

* these subjects fatigued and only managed to attempt the first 75 words from the total of 150 and reading rate has therefore been calculated from 75

Appendix 1.03 contd experiment 5a (colorimetry) raw data

ARMD reading accuracy (%) (saturation set at 20 for all hue angles)

hue angle	zero sat.1	zero sat.2	0	30	60	90	120	150	180	210	240	270	300	330
BM	98.67	99.33	96.67	99.33	98.67	98.67	71.25	95.33	95.33	98.00	96.67	96.00	98.00	99.33
MJ	100	48.00	63.33	98.00	61.33	98.00	100	80.00	75.33	62.00	68.67	62.67	97.33	60.67
MH	90.00	98.00	99.33	78.00	99.33	88.67	100	99.33	96.67	99.33	88.67	94.00	90.00	99.33
ID	92.00	87.33	78.67	76.67	86.00	86.00	98.00	84.67	85.33	84.67	78.67	86.67	78.67	88.67
MC	85.33	86.00	98.00	76.67	86.67	78.00	97.33	76.67	82.67	96.67	98.67	96.67	40.67	84.67
CP	90.67	89.33	99.33	87.33	85.33	96.67	59.02	98.00	93.33	98.67	94.00	96.67	86.67	97.33
MB*	88.00	4.00	82.67	74.67	66.67	78.67	85.33	40.00	100	76.00	62.67	76.00	48.00	84.00
MS*	93.33	78.67	76.00	56.00	76.00	58.67	48.00	76.00	80.00	45.33	76.00	73.33	80.00	93.33
NJ	88.00	70.00	87.33	79.33	87.33	78.67	79.33	68.00	68.00	78.67	69.33	68.67	68.67	68.67
MAS	77.33	98.67	98.67	94.67	73.33	96.00	73.33	73.33	76.00	94.67	92.00	48.24	94.67	96.00
GS	96.67	99.33	95.33	98	99.33	99.33	96.67	97.33	98.67	98.67	98.67	99.33	97.33	100
WH	94.67	93.33	90.00	95.33	92.00	92.67	91.33	98.67	92.00	95.33	94.00	88.67	96.67	96.67

*these subjects fatigued and only managed to attempt the first 75 words from the total of 150 and reading accuracy has therefore been calculated as a percentage of 75

Appendix 1.04 experiment 5b (tinted lenses)-comparison of the effects of tinted lenses on reading performance in ARMD raw data

SN	reading rate (cwpm)						reading accuracy %					
subject	none 1	none 2	CPF 450 TLT=68%	Intuitive Colorimeter® filter TLT [%]	ND TLT =50%	clear	none 1	none 2	CPF 450	IC filter	ND	clear
EC	128.91	145.54	125.35	113.86 (roseD3) [66%]	147.59	135.29	99.33	93.33	96.33	97.67	98.33	98.33
RP	67.89	63.70	81.89	61.57 (roseD3+C4) [53%]	31.87	61.22	99.33	100	99.33	99.67	100	99.67
FF	93.26	95.99	89.39	88.45 (blueE1+turquoiseC3) [28%]	88.29	80.48	89.67	90.67	88.00	88.33	88.33	79.00
RT	107.09	110.66	104.30	115.86 (rose D3+C4) [53%]	110.73	112.95	89.00	90.00	82.33	84.00	88.33	86.00
EE	87.21	72.92	75.13	83.78 (turquoiseD2+blueD2) [30%]	69.41	84.71	82.67	87.33	85.00	88.67	80.33	87.00
JS	123.32	118.59	119.43	87.43 (turquoiseD2+blueD2) [30%]	121.86	169.69	95.00	100	99.67	99.67	100	100
GM	57.11	81.99	48.93	36.61 (turquoiseD2+blueD2) [30%]	62.63	67.13	78.67	92.67	86.00	72.00	91.67	96.66
MW	139.61	130.05	133.48	100.61 (blueC3+E1) [32%]	130.97	143.84	99.33	99.33	99.00	97.00	99.33	99.67
DP	136.11	134.55	128.91	130.05 (yellowB4+greenB4) [74%]	133.64	138.29	94.67	99.67	93.67	99.00	99.33	99.33
DL*	87.21	103.50	112.72	99.41 (yellowC3+greenC3) [52%]	120.37	35.15	65.33	86.33	88.00	85.33	83.33	65.22
TH	114.77	112.50	120.72	107.54 (roseC4+purpleD3) [49%]	118.36	118.15	88.00	71.67	89.33	81.67	83.33	88.33
VG	134.53	93.01	122.28	97.84 turquoiseD2+E1) [17%]	128.44	126.71	97.00	86.67	88.33	92.67	96.67	84.00

Appendix 1.04 contd experiment 5b (tinted lenses) raw data

ARMD	reading rate (cwpm)						reading accuracy %					
subject	none 1	none 2	CPF 450 TLT=68%	Intuitive Colorimeter® filter TLT [%]	ND TLT=50%	clear	no filter 1	no filter 2	CPF 450	IC filter	ND	clear
BM	96.05	109.33	106.56	103.29 (yellowB4+greenB4) [74%]	76.66	89.87	99.33	99.33	98.67	98.00	96.67	88.00
MJ	122.97	129.74	104.84	101.21 (orangeD2+roseB5) [60%]	99.63	97.40	100	100	99.33	99.33	99.33	100
MH	166.48	162.52	162.89	119.53 (turquoiseD2+blueE1) [21%]	135.59	151.29	100	98.00	89.33	97.33	98.67	100
ID	113.59	116.10	102.12	93.51 (turquoiseE1+blueD2) [19%]	99.57	105.82	78.00	68.67	78.00	86.00	85.33	77.33
MB*	26.20	27.36	13.63	8.25 (turquoiseE1+blueD2) [19%]	12.80	19.96	93.33	84.00	62.67	37.33	77.33	85.71
MC	60.93	63.72	50.99	50.41 (roseD3+roseC4) [53%]	51.90	55.84	98.67	96.67	88.67	96.00	96.67	87.33
CP	61.74	53.20	60.36	58.28 (roseD3+roseC4) [53%]	51.53	55.90	98.00	88.00	60.36	96.00	98.67	99.33
MS*	35.54	56.56	59.87	39.60 (turquoiseE1+blueD2) [19%]	31.49	52.05	92.67	98.67	69.33	77.33	88.00	99.33
NJ	106.44	112.53	96.75	101.84 (purpleE2+blueC3) [33%]	104.18	84.82	88.00	76.67	78.67	77.33	77.33	84.67
MA	88.49	103.45	102.86	94.11 (roseD3+C4) [53%]	90.25	91.72	89.33	100	96.00	93.33	97.33	98.67
GS	134.64	137.28	134.58	122.40 (blueD2+purpleD3) [38%]	129.27	134.82	99.33	98.00	99.33	98.00	100	99.33
WH	93.96	92.43	86.92	80.94 (orangeD2) [66%]	84.77	76.74	96.67	94.00	97.33	96.00	95.33	94.67

*these subjects fatigued and only managed to attempt the first 75 words from the total of 150 and reading rate and reading accuracy has therefore been calculated from 75.

Appendix 1.05 experiment 6 (video-magnifier)-comparison of the effects of video-magnifier screen colours on reading performance in ARMD raw data

ARMD reading rate (cwpm)

subject	grey 1	grey 2	grey (ave)	red	yellow	green	blue	black
BM	123.38	124.77	124.08	48.78	89.18	105.95	43.11	111.87
MJ	109.81	141.24	125.53	37.27	121.59	101.39	32.14	124.36
MH	174.30	148.30	161.30	79.27	117.69	110.02	33.69	153.77
ID	129.36	117.71	123.54	67.64	119.08	109.92	47.69	106.34
KH	71.76	71.11	71.44	29.66	72.47	78.00	8.99	86.36
MB*	36.30	27.35	31.83	8.33	14.78	10.38	2.40	18.56
MC	63.53	60.28	61.91	28.34	55.24	42.86	1.99	49.40
CP	58.99	55.29	57.14	17.53	39.68	41.06	12.48	43.37
EM	65.38	86.96	76.17	25.25	53.19	55.47	41.54	53.65
MS	18.70	43.52	40.46	10.72	32.26	30.80	4.24	38.07
GH	57.04	67.27	62.16	36.52	54.74	59.52	35.03	53.61
DS	61.17	59.48	60.33	3.92	56.09	20.71	18.96	75.52

*this subject fatigued and only managed to attempt the first 75 words from the total of 150 and reading rate and reading accuracy has therefore been calculated from 75.

Appendix 1.05 contd experiment 6 (video-magnifier) raw data

ARMD reading accuracy %

subject	grey 1	grey 2	grey (ave)	red	yellow	green	blue	black
BM	99.33	74.67	87.00	74.67	93.33	98.00	74.67	98.67
MJ	100	100	100	74.67	100	98.67	76.67	100
MH	99.33	100	99.67	98.00	100	98.00	82.00	100
ID	96.00	98.00	97.00	85.33	96.67	96.67	68.00	94.67
KH	80.00	79.33	79.67	74.44	81.33	78.00	2.00	79.33
MB	84.00	64.00	74.00	5.33	20.00	26.67	1.33	61.33
MC	99.33	98.00	98.67	43.33	92.67	86.67	2.00	90.67
CP	100	90.00	95.00	57.78	93.33	94.00	32.97	85.33
EM	82.00	95.33	88.67	3.33	71.33	90.67	85.33	78.67
MS	94.00	80.00	87.00	64.67	98.67	88.00	6.00	100
GH	90.67	90.67	90.67	56.67	88.67	88.67	43.33	82.00
DS	90.00	99.33	94.67	1.35	98.00	92.67	5.63	100

Appendix 1.06 experiment 7 (luminaires)-comparison of reading performance with various luminaires in ARMD raw data

SN	reading rate (cwpm)						reading accuracy (%)					
subject	no local light 1	no local light 2	no local light (ave.)	compact fluorescent	standard tungsten	daylight tungsten	no local light 1	no local light 2	no local light (ave.)	compact fluorescent	standard tungsten	daylight tungsten
DP	84.96	84.77	84.87	74.29	84.02	77.39	100	100	100	100	100	98.51
EC	76.01	76.49	76.25	65.21	76.60	66.76	98.41	98.41	98.41	98.41	100	98.41
EE	53.46	68.69	61.08	61.87	60.80	46.36	98.49	77.27	87.84	94.74	96.83	93.65
FF	78.59	92.13	85.36	77.63	85.70	80.64	92.06	88.89	90.48	96.83	100	96.83
GM	56.92	51.61	54.27	55.94	61.57	56.84	98.41	95.00	96.71	100	100	98.25
JS	63.94	66.43	65.19	64.53	71.79	69.65	97.22	98.67	97.95	98.63	98.57	97.26
MW	90.14	102.91	96.53	97.83	96.08	100.93	100	100	100	100	100	100
RP	54.40	57.78	56.09	52.97	55.14	55.99	100	90.48	95.24	98.49	100	100
RT	73.41	69.20	71.31	64.00	63.68	61.91	100	100	100	100	98.55	98.61
TH	53.70	61.53	57.62	68.92	54.91	52.33	100	95.59	97.80	100	100	96.83
VG	67.78	66.89	67.34	63.01	65.48	61.91	100	96.83	98.42	100	95.46	96.83

Appendix 1.06 contd experiment 7 (luminaires) raw data

ARMD	reading rate (cwpm)						reading accuracy (%)					
subject	no local light 1	no local light 2	no local light (ave.)	compact fluorescent	standard tungsten	daylight tungsten	no local light 1	no local light 2	no local light (ave.)	compact fluorescent	standard tungsten	daylight tungsten
BM	33.95	39.82	36.89	33.55	30.26	32.17	92.31	87.18	89.79	84.62	83.33	88.57
CP	29.53	30.26	29.90	26.99	28.52	34.85	96.97	91.11	93.89	94.87	93.94	100
DS	23.49	23.05	23.27	21.14	27.14	29.99	100	100	100	100	100	100
EH	31.24	37.14	34.19	29.82	43.39	29.76	96.30	100	98.15	100	95.24	85.71
GH	19.33	35.38	27.36	20.18	15.97	20.51	90.48	74.07	82.28	64.29	66.67	73.91
ID	69.37	55.78	62.58	66.10	69.38	62.77	100	100	100	100	100	100
KH	24.39	25.76	25.08	33.75	19.34	28.42	89.24	82.05	85.65	93.33	87.18	92.86
MB	16.24	14.77	15.51	16.27	12.91	12.32	92.59	77.78	85.19	92.59	89.29	92.59
MC	28.30	31.85	30.08	32.55	28.25	25.14	93.33	98.04	95.69	94.12	96.36	93.75
MH	50.94	61.43	56.19	55.11	85.70	54.38	100	100	100	100	100	100
MJ	61.60	63.86	62.76	74.10	47.89	54.76	100	100	100	97.78	96.78	100
NJ	34.91	41.39	38.15	35.77	30.95	32.53	97.87	97.78	97.83	93.33	87.88	89.74

Appendix 1.07 experiment 8 (colour vision)-comparison of colour vision analysis in ARMD using the PV-16 arrangement test and the Intuitive Colorimeter® raw data

Intuitive Colorimeter® saturation settings SN

subject	0 (hue)	30	60	90	120	150	180	210	240	270	300	330
VG	7.5	10.0	7.5	7.5	10.0	10.0	12.5	15.0	15.0	10.0	12.5	10.0
EC	10.0	12.5	15.0	15.0	12.5	15.0	15.0	20.0	15.0	10.0	7.5	7.5
RP	20.0	10.0	15.0	12.5	10.0	10.0	12.5	15.0	15.0	10.0	5.0	10.0
FF	20.0	15.0	17.5	22.5	12.5	22.5	15.0	35.0	22.5	20.0	20.0	15.0
RT	12.5	7.5	15.0	10.0	10.0	10.0	5.0	12.5	10.0	7.5	10.0	7.5
EE	5.0	5.0	12.5	12.5	7.5	10.0	10.0	10.0	7.5	10.0	7.5	7.5
JS	5.0	10.0	10.0	7.5	10.0	12.5	10.0	10.0	10.0	10.0	7.5	5.0
GM	15.0	25.0	12.5	12.5	15.0	15.0	20.0	20.0	20.0	10.0	12.5	12.5
MW	7.5	12.5	10.0	10.0	12.5	12.5	12.5	15.0	15.0	15.0	10.0	15.0
DP	10.0	20.0	20.0	15.0	15.0	20.0	22.5	20.0	20.0	20.0	17.5	17.5
DL	7.5	12.5	7.5	10.0	10.0	10.0	7.5	10.0	10.0	10.0	10.0	7.5
TH	10.0	17.5	10.0	15.0	12.5	10.0	10.0	17.5	12.5	15.0	15.0	17.5

Appendix 1.07 contd experiment 8 (colour vision) raw data Intuitive Colorimeter® saturation settings ARMD

subject	0 (hue)	30	60	90	120	150	180	210	240	270	300	330
BM	12.5	12.5	10.0	15.0	15.0	15.0	12.5	15.0	15.0	20.0	15.0	15.0
MJ	17.5	27.5	25.0	27.5	20.0	30.0	45.0	22.5	15.0	25.0	22.5	15.0
KH	15.0	10.0	30.0	20.0	12.5	15.0	12.5	12.5	45.0	45.0	12.5	15.0
MH	7.5	17.5	20.0	15.0	17.5	12.5	17.5	12.5	15.0	17.5	12.5	12.5
ID	10.0	10.0	10.0	15.0	10.0	10.0	20.0	15.0	10.0	12.5	15.0	10.0
MC	12.5	17.5	25.0	20.0	20.0	20.0	27.5	25.0	17.5	20.0	22.5	12.5
MB	12.5	22.5	15.0	17.5	17.5	12.5	17.5	17.5	25.0	12.5	7.5	7.5
CP	12.5	22.5	17.5	7.5	15.0	22.5	10.0	12.5	22.5	20.0	7.5	10.0
EM	10.0	12.5	10.0	10.0	12.5	12.5	12.5	15.0	15.0	15.0	10.0	15.0
MS	10.0	22.5	30.0	22.5	17.5	22.5	12.5	10.0	22.5	20.0	10.0	12.5
GH	12.5	15.0	12.5	10.0	10.0	12.5	15.0	12.5	17.5	15.0	10.0	15.0
DS	25.0	25.0	10.0	25.0	20.0	17.5	35.0	45.0	25.0	15.0	22.5	10.0

Appendix 2-Intuitive Overlays

Intuitive Overlays® have been designed to be used for classroom or optometric use by children or adults with certain types of reading dysfunction. These overlays are also used to screen for those people who may benefit from the prescription of precision tinted lenses. They are manufactured using conventional printing techniques with specially prepared inks (Coates Lorrieux). They consist of ten A5 transparent plastic sheets, covering a wide range of chromaticity, have non-reflective surface, and result in minimal interference with the visibility of text beneath. The spectral reflectance function is even to reduce metamerism and the set of overlays and combination of overlays has an even distribution of chromaticities with equal CIE 1976 u', v' saturation (s_{uv}) and evenly spaced hue angles (h_{uv}). The colour names given to the overlays are coarse descriptions of the colour signified by the locations in colour space (Wilkins, 1994). In this study the overlays were used only singly and not in combinations.

Appendix 3-Intuitive Colorimeter® and Precision Tinted Lenses®

Light is produced by a powerful lamp and is shone through part of a disc made up of three coloured filters. These filters comprise three primary colours, red, green, and blue. The light is then mixed and falls on a test text, which the subject views through a window in the instrument. The disc containing the filters can be rotated or translated.

If the circular beam of light is shone exactly through the centre of the disc then the light is coloured by equal amounts of red, green, and blue and the resultant illuminant appears white. If the disc is moved sideways (translated) then the light becomes coloured, and as the disc becomes more eccentric in the beam the saturation (depth) of the colour increases. When the disc is rotated the colour (hue) changes.

There are four main controls to the instrument: two move the disc (translate and rotate), changing hue and saturation, a third control reduces the luminance by introducing ND filters and a fourth illuminates a standard white fluorescent light for comparison purposes. The Intuitive Colorimeter® allows the light that illuminates the test text to be changed gradually, systemically, and precisely through a very large range of colours.

An associated system of precision tinting has been developed which allows any colour in the colorimeter to be reproduced and specified. Precision Tints comprise CR39 lenses that have been dyed with seven primary dyes, which have smooth transmission curves. The smooth transmission curves have the advantage of reducing metamerism (the phenomenon whereby an object appears to change colour under different light sources). The seven colours that partly make up the Precision Tinting system are arranged at approximately equal angles on the diagram of human colour space.

Each colour in the trial set comes in a range of saturations. These have been arranged in a geometric progression so that a large range of densities can be obtained. Yet the density, like the hue, can be varied in very fine steps. By stacking the lenses on top of on another a very large range of colours can be obtained, even though only two dyes from the series are used. This gamut is increased further by the inclusion of ND and ultraviolet blocking filters.

Once an individual's optimum colour has been determined in the Intuitive Colorimeter® this can be matched precisely with the precision tints. The colour can then be checked under different lighting conditions so that the final lenses can be specified precisely.

When colorimetry is carried out in a dark room, the only colour that the subject can see is in the colorimeter, they have no reference colours in their field of view. For this reason they will adapt rapidly to the colour in the Intuitive Colorimeter® and be unaware of the precise colour of light that they are viewing. They might know for example that it is a blue or

green, but they will not know precisely what shade of blue or green it is (Wilkins *et al.*, 1992, Evans *et al.*, 1994a).

Appendix 4-British Ability Scales

Educational and clinical psychologists measuring cognitive function over a wide age range have used the British Ability Scales (BAS) as an objective and reliable resource. It consists of a series of subtests, which evaluate speed of information processing, reasoning, spatial imagery, perceptual matching, short-term memory, retrieval and application of knowledge including word reading. Observers are tested and their performance age is determined.

The word reading subtest was used in this project in order to obtain information on the reading age of the study subjects. The 16 words highlighted below are taken from the BAS. They were presented, in the form of a single-word vertical list, to the subjects who were asked to read each one out loud. Correct identification of all these words infers a reading age of at least 14.5 years. In the BAS these words are presented as approximately 14 to 36 point size and for some observers the smaller words had to be enlarged using a word processor and printer.

No other reading test was available that allowed older reading ages to be determined.

BAS word reading subtest

he, fish, out, running, dig, light, paper, sport, harvest, collect, guest, transparent, obscure, environment, divulge, criterion

Appendix 5-Daylight simulation tungsten incandescent lamps

Daylight Simulation lamps are tinted with a natural coloured blue glass, which simulates daylight (northlight). It is available in 60, 75, 100 and 150 Watts. Marketing literature provided by one distributor (Daylight Studios, 223a Portobello Road, London, W11 1LU, UK) states:

- The light emitted by these luminaires reproduces daylight conditions and allows true colour comparison and rendering at any time.
- Work can continue at any time of day or night, whenever natural light is insufficient, as simulated daylight alleviates eyestrain, allowing work to continue for longer hours and colours to be matched late into the evening.
- The colder simulated daylight achieves a much higher level of contrast than conventional tungsten lighting and is consequently much kinder and more relaxing to the eyes, the light is ideal for those involved with detailed or intricate work and these luminaires are recommended primarily as a close light source.
- Many people have found reading and working much easier with daylight simulation luminaires and this has been confirmed by initial tests conducted independently in the UK (not located by the literature search), the cool clear light is perceived as more relaxing than normal tungsten lighting.

See photograph 4.

Appendix 6-List of random words (159) used as test print for experiment 2 (projection gels)-effects of illumination varied in colour and intensity on reading performance in ARMD

GOOD	CAMP	MORE	FEAR	GUST	LESS
SOME	HAND	EACH	PEST	TIME	FIND
CLUE	FULL	EASE	TEST	WORD	SIZE
MIND	SPIT	USED	MORE	SEEN	DEAD
LAMP	TIME	RATE	TYPE	THAN	EYES
TYRE	RULE	WERE	THIS	MADE	STEP
THAT	MAIN	STOP	SPAT	HAVE	READ
WHEN	HIGH	DOWN	STEP	MIND	FORE
BALL	FOUR	MEAN	ONLY	NINE	BEST
MOST	ROOM	SONG	BLUE	SUNK	BULB
NEAR	FIVE	COPY	WORK	COME	SING
PLAN	HELP	LOVE	RISK	BEAN	BORE
FOUR	HAVE	WITH	MEAN	YEAR	SUNG
SANK	MUST	SOLO	MADE	MALE	MIST
FACT	FROM	MILD	BEEN	BORN	DIET
MAIL	BUST	DEAD	BILL	NEAT	SAID
POOR	BULL	LIVE	RICH	DAMP	SEEN
POOL	BIRD	LAKE	GOAT	CAME	SHIP
BEEN	BOAT	SIGN	EYES	RULE	ROOM
DIET	PEST	HAVE	MEAT	POST	BABY
FIRE	FILE	WORD	RATE	TEST	FIRM
HIGH	FORM	MIND	FLAT	BEST	FACT
PUSH	RUSH	CHIP	USED	FLOW	MENU
SAME	PAGE	OPEN	SPICE	DEEP	SHUT
MOVE	SHOP	LENT	BEER	FORT	BARN
FOOT	RULE	LOVE			

Appendix 7-Words from five different Bailey-Lovie near word reading acuity cards used in experiment 3 (gel filters)-investigation of the effects of five coloured gel filters on reading performance in ARMD and experiment 7 (luminaires)-comparison of reading performance with various luminaires in ARMD

Bailey-Lovie card 1

efficiency	card	nowhere	pain	kept
advance	enjoyed	pond	expressing	mess
occurrence	candles	productive	lost	tonight
leading	poor	distribute	chicken	undertaken
bolt	copy	resistance	crystal	characters
filling	sold	evening	wire	accordance
mood	highway	separately	port	revolution
battery	stories	continuous	plug	business
painted	glad	sank	conclusion	feature
tail	economy	vocational	news	photograph
boating	registered	sang	doctors	culture
statements	pole	occasions	fuel	musical
accurately	destroy	goal	crucial	dawn
possession	slim	foundation	village	advantages
talking	bowl	pick	containers	soldier
inspection	diet	achieve	nest	impressive
storage				

Appendix 7 contd

Bailey-Lovie card 2

answers	pink	securities	disease	luck
collection	navy	dynamic	additional	incredible
briefly	gate	veteran	encouraged	lane
historians	gold	carries	membership	bullets
edge	managed	attempting	stem	fine
remembered	crawled	stretch	procedures	desk
outdoor	fail	everywhere	biological	post
extreme	resolution	wars	skilled	formidable
growing	duty	impression	corners	send
rose	calculator	hostile	tiny	savings
illustrate	nineteenth	held	suburbs	expression
tons	permission	shelter	urge	personally
literature	optical	rent	concerning	weekend
lamp	bomb	expense	attributed	percentage
dirt	closing	citizen	stretching	nice
gulf	instant	containing	substances	cast
imagine				

Bailey-Lovie card 3

conditions	salt	outlook	bank	bell
motives	performing	glanced	pass	discipline
seconds	milk	opening	economical	stay
jump	associated	unhappy	observe	protection
path	core	awarded	conviction	reasonable
dogs	kitchen	engaged	whip	properties
consistent	towards	foot	considered	heat
passion	fabrics	confidence	sand	tray
submarines	similar	base	fiction	emphasized
atom	convenient	explain	stop	degrees
components	produce	ages	repeatedly	plot
experiment	portion	size	remarkably	tractor
background	contain	seal	laws	causing
delightful	approached	flat	protest	dedications
reverse	vote	subjective	pointed	blue
remembered	self	plainly	cuts	builder
scientists				

Appendix 7 contd

Bailey-Lovie card 4

daytime	loop	shut	careful	hate
settled	soft	pronounced	reached	aggressive
hall	journey	package	especially	deal
kind	accomplish	roughly	proceed	sigh
providence	tent	importance	trouble	busy
meaningful	require	hearing	traditions	legs
assumed	puts	structural	struggling	noticed
draw	assignment	easy	obliged	automobile
sheriff	span	remarkable	pure	lowered
classes	compromise	guys	artificial	monthly
hill	quietly	barn	associates	hope
tremendous	drawing	comparison	reading	fare
dull	equivalent	excited	eventually	concern
talk	laboratory	crop	periods	functional
beat	formula	ends	sixteen	discussion
beam	represents	project	shop	attacks
individual				

Bailey-Lovie card 5

belt	regardless	customs	help	restaurant
academy	abandon	supplement	park	vein
closely	newspapers	play	illness	ambassador
intense	hide	leadership	authorized	sharply
pipe	forests	rule	indication	sink
popularity	welcome	everything	rapidly	dome
sons	biggest	management	acceptance	pack
helping	join	express	companions	cope
unusual	petitioner	details	fish	succession
balance	drug	underlying	ugly	resolution
designs	opposed	soap	detectives	grip
distant	dictionary	pattern	prevailing	nose
beneath	spot	respective	dark	engagement
follows	open	figured	perception	younger
lean	throughout	figs	average	strengthen
gang	understand	replace	display	bond
adjustment				

Appendix 8.00 score sheet for experiment 4 (overlays)-investigation of the effects of Intuitive Coloured Overlays® on reading performance in ARMD

Name	**date**	**N size**
1a. come see the play look up is cat not my and dog for you to the cat up dog and is play come you see for not to look my you for the and not see my play come is look dog cat to up dog to you and play cat up is my not come for the look see play come see cat not look dog is my up the for to and you to not cat for look is my and up come play you see the dog my play see to for you is the look up cat not dog come and look to for my come play the dog see you not cat up and is up come look for the not dog cat you to see is and my play		**no overlay 1** **time** **no. correct** **no. incorrect** **cwpm** **accuracy**
1b. come see the play look up is cat not my and dog for you to the cat up dog and is play come you see for not to look my you for the and not see my play come is look dog cat to up dog to you and play cat up is my not come for the look see play come see cat not look dog is my up the for to and you to not cat for look is my and up come play you see the dog my play see to for you is the look up cat not dog come and look to for my come play the dog see you not cat up and is up come look for the not dog cat you to see is and my play		**no overlay 2** **time** **no. correct** **no. incorrect** **cwpm** **accuracy**
2. see the look dog and not is you come up to my for cat play not up play my is dog you come look for see and to the cat look up come and is my cat not dog you see for to play the my you is look the dog play see not come and to cat for up for the to and you cat is look up my not dog play see come you look see and play to the is cat not come for my up dog come not to play look the and dog see is cat up you for my and is for dog come see the cat up look you play my not to dog you cat to and play for not come up the see look my is the come to up cat my see dog you not look is play and for		**overlay** **time** **no. correct** **no. incorrect** **cwpm** **accuracy**

Appendix 8.00 contd score sheet for experiment 4 (overlays)

3. you is not come cat up look to play dog my the for and see
look for up and the play is dog cat not see to come my you
to not play come see look cat you for up the my is dog and
the look you dog is cat play see come to for and up not my
cat up to my the see and come dog for is you not look play
see and dog come cat is play the not look to up my you for
dog to cat the is you my see for up play come and not look
up my for and to come dog see look cat you is the play not
come you is see my for look to not the dog play cat and up
is the look to cat not and come play for you up my see dog

overlay
time
no. correct
no. incorrect
cwpm
accuracy

4. cat for the you not up my dog see to is come play look and
see you dog for is cat look play my the up and come not to
look cat see my and dog the play is come not for to you up
my see is the come play look for and up to cat you dog not
and you cat look to see not my dog the for come is up play
dog to and play up come you the not is cat look for my see
the play look cat see up come for my you and not is to dog
for to not you come play the look cat see is dog up and my
you dog and for up not see my cat is the play come to look
come not and to see you is play look up the cat dog my for

overlay
time
no. correct
no. incorrect
cwpm
accuracy

5. the cat up dog and is play come you see for not to look my
come see the play look up is cat not my and dog for you to
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
my play see to for you is the look up cat not dog come and
up come look for the not dog cat you to see is and my play
look to for my come play the dog see you not cat up and is
to not cat for look is my and up come play you see the dog

overlay
time
no. correct
no. incorrect
cwpm
accuracy

Appendix 8.00 contd score sheet for experiment 4 (overlays)

6. see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
for the to and you cat is look up my not dog play see come
you look see and play to the is cat not come for my up dog
look up come and is my cat not dog you see for to play the
and is for dog come see the cat up look you play my not to
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for
my you is look the dog play see not come and to cat for up
come not to play look the and dog see is cat up you for my

overlay
time
no. correct
no. incorrect
cwpm
accuracy

7. you is not come cat up look to play dog my the for and see
to not play come see look cat you for up the my is dog and
the look you dog is cat play see come to for and up not my
dog to cat the is you my see for up play come and not look
up my for and to come dog see look cat you is the play not
come you is see my for look to not the dog play cat and up
is the look to cat not and come play for you up my see dog
see and dog come cat is play the not look to up my you for
cat up to my the see and come dog for is you not look play
look for up and the play is dog cat not see to come my you

overlay
time
no. correct
no. incorrect
cwpm
accuracy

8. cat for the you not up my dog see to is come play look and
see you dog for is cat look play my the up and come not to
look cat see my and dog the play is come not for to you up
my see is the come play look for and up to cat you dog not
for to not you come play the look cat see is dog up and my
dog to and play up come you the not is cat look for my see
you dog and for up not see my cat is the play come to look
come not and to see you is play look up the cat dog my for
and you cat look to see not my dog the for come is up play
the play look cat see up come for my you and not is to dog

overlay
time
no. correct
no. incorrect
cwpm
accuracy

Appendix 8.00 contd score sheet for experiment 4 (overlays)

9. come see the play look up is cat not my and dog for you to
you for the and not see my play come is look dog cat to up
the cat up dog and is play come you see for not to look my
my play see to for you is the look up cat not dog come and
up come look for the not dog cat you to see is and my play
look to for my come play the dog see you not cat up and is
to not cat for look is my and up come play you see the dog
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
up come look for the not dog cat you to see is and my play

overlay
time
no. correct
no. incorrect
cwpm
accuracy

10. come not to play look the and dog see is cat up you for my
for the to and you cat is look up my not dog play see come
and is for dog come see the cat up look you play my not to
see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
you look see and play to the is cat not come for my up dog
look up come and is my cat not dog you see for to play the
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for
my you is look the dog play see not come and to cat for up

overlay
time
no. correct
no. incorrect
cwpm
accuracy

11. for the to and you cat is look up my not dog play see come
you look see and play to the is cat not come for my up dog
look up come and is my cat not dog you see for to play the
and is for dog come see the cat up look you play my not to
see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for
my you is look the dog play see not come and to cat for up
come not to play look the and dog see is cat up you for my

overlay
time
no. correct
no. incorrect
cwpm
time

Appendix 8.00 contd score sheet for experiment 4 (overlays)

12.you is not come cat up look to play dog my the for and see	**overlay**
to not play come see look cat you for up the my is dog and	**time**
up my for and to come dog see look cat you is the play not	**no. correct**
come you is see my for look to not the dog play cat and up	**no. incorrect**
cat up to my the see and come dog for is you not look play	**cwpm**
look for up and the play is dog cat not see to come my you	**accuracy**
the look you dog is cat play see come to for and up not my	
dog to cat the is you my see for up play come and not look	
is the look to cat not and come play for you up my see dog	
see and dog come cat is play the not look to up my you for	

Appendix 8.01-Score sheet for experiment 5b (tinted lenses)-Comparison of the effects of tinted lenses on reading performance in ARMD (YN and SN groups only)

Name **date** **N size**

1a. come see the play look up is cat not my and dog for you to
the cat up dog and is play come you see for not to look my
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
to not cat for look is my and up come play you see the dog
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
dog to you and play cat up is my not come for the look see
see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
look up come and is my cat not dog you see for to play the
my you is look the dog play see not come and to cat for up
for the to and you cat is look up my not dog play see come
you look see and play to the is cat not come for my up dog
come not to play look the and dog see is cat up you for my
and is for dog come see the cat up look you play my not to
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for

no tinted lens 1
time
no. incorrect
no. correct
cwpm
accuracy

Appendix 8.01-contd score sheet for each experiment 5b (tinted lenses)

1b. come see the play look up is cat not my and dog for you to
the cat up dog and is play come you see for not to look my
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
to not cat for look is my and up come play you see the dog
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
dog to you and play cat up is my not come for the look see
see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
look up come and is my cat not dog you see for to play the
my you is look the dog play see not come and to cat for up
for the to and you cat is look up my not dog play see come
you look see and play to the is cat not come for my up dog
come not to play look the and dog see is cat up you for my
and is for dog come see the cat up look you play my not to
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for

no tinted lens 2
time
no. incorrect
no. correct
cwpm
accuracy

Appendix 8.01 contd score sheet for each experiment 5b (tinted lenses)

2. you is not come cat up look to play dog my the for and see

look for up and the play is dog cat not see to come my you

to not play come see look cat you for up the my is dog and

the look you dog is cat play see come to for and up not my

cat up to my the see and come dog for is you not look play

see and dog come cat is play the not look to up my you for

dog to cat the is you my see for up play come and not look

up my for and to come dog see look cat you is the play not

come you is see my for look to not the dog play cat and up

is the look to cat not and come play for you up my see dog

cat for the you not up my dog see to is come play look and

see you dog for is cat look play my the up and come not to

look cat see my and dog the play is come not for to you up

my see is the come play look for and up to cat you dog not

and you cat look to see not my dog the for come is up play

dog to and play up come you the not is cat look for my see

the play look cat see up come for my you and not is to dog

for to not you come play the look cat see is dog up and my

you dog and for up not see my cat is the play come to look

come not and to see you is play look up the cat dog my for

tinted lens

time

no. incorrect

no. correct

cwpm

accuracy

Appendix 8.01 contd score sheet for each experiment 5b (tinted lenses)

3. the cat up dog and is play come you see for not to look my
come see the play look up is cat not my and dog for you to
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
my play see to for you is the look up cat not dog come and
up come look for the not dog cat you to see is and my play
look to for my come play the dog see you not cat up and is
to not cat for look is my and up come play you see the dog
dog to you and play cat up is my not come for the look see
see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
for the to and you cat is look up my not dog play see come
you look see and play to the is cat not come for my up dog
look up come and is my cat not dog you see for to play the
and is for dog come see the cat up look you play my not to
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for
my you is look the dog play see not come and to cat for up
come not to play look the and dog see is cat up you for my

tinted lens
time
no. incorrect
no. correct
cwpm
accuracy

Appendix 8.01 contd score sheet for each experiment 5b (tinted lenses)

4. you is not come cat up look to play dog my the for and see

to not play come see look cat you for up the my is dog and

the look you dog is cat play see come to for and up not my

dog to cat the is you my see for up play come and not look

up my for and to come dog see look cat you is the play not

come you is see my for look to not the dog play cat and up

is the look to cat not and come play for you up my see dog

see and dog come cat is play the not look to up my you for

cat up to my the see and come dog for is you not look play

look for up and the play is dog cat not see to come my you

cat for the you not up my dog see to is come play look and

see you dog for is cat look play my the up and come not to

look cat see my and dog the play is come not for to you up

my see is the come play look for and up to cat you dog not

for to not you come play the look cat see is dog up and my

dog to and play up come you the not is cat look for my see

you dog and for up not see my cat is the play come to look

come not and to see you is play look up the cat dog my for

and you cat look to see not my dog the for come is up play

the play look cat see up come for my you and not is to dog

tinted lens

time

no. incorrect

no. correct

cwpm

accuracy

Appendix 8.01 contd score sheet for each experiment 5b (tinted lenses)

5. come see the play look up is cat not my and dog for you to
the cat up dog and is play come you see for not to look my
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
to not cat for look is my and up come play you see the dog
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
dog to you and play cat up is my not come for the look see
see the look dog and not is you come up to my for cat play
not up play my is dog you come look for see and to the cat
look up come and is my cat not dog you see for to play the
my you is look the dog play see not come and to cat for up
for the to and you cat is look up my not dog play see come
you look see and play to the is cat not come for my up dog
come not to play look the and dog see is cat up you for my
and is for dog come see the cat up look you play my not to
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for

tinted lens
time
no. incorrect
no. correct
cwpm
accuracy

Appendix 8.01 Score sheet for experiment 5b (tinted lenses)-Comparison of the effects of tinted lenses on reading performance in ARMD (ARMD group only)

Name	**date**	**N size**
1a. come see the play look up is cat not my and dog for you to the cat up dog and is play come you see for not to look my you for the and not see my play come is look dog cat to up dog to you and play cat up is my not come for the look see play come see cat not look dog is my up the for to and you to not cat for look is my and up come play you see the dog my play see to for you is the look up cat not dog come and look to for my come play the dog see you not cat up and is up come look for the not dog cat you to see is and my play dog to you and play cat up is my not come for the look see		**no tinted lens 1** **time** **no. incorrect** **no. correct** **cwpm** **accuracy**
1b. come see the play look up is cat not my and dog for you to the cat up dog and is play come you see for not to look my you for the and not see my play come is look dog cat to up dog to you and play cat up is my not come for the look see play come see cat not look dog is my up the for to and you to not cat for look is my and up come play you see the dog my play see to for you is the look up cat not dog come and look to for my come play the dog see you not cat up and is up come look for the not dog cat you to see is and my play dog to you and play cat up is my not come for the look see		**no tinted lens 2** **time** **no. incorrect** **no. correct** **cwpm** **accuracy**
2. see the look dog and not is you come up to my for cat play not up play my is dog you come look for see and to the cat look up come and is my cat not dog you see for to play the my you is look the dog play see not come and to cat for up for the to and you cat is look up my not dog play see come you look see and play to the is cat not come for my up dog come not to play look the and dog see is cat up you for my and is for dog come see the cat up look you play my not to dog you cat to and play for not come up the see look my is the come to up cat my see dog you not look is play and for		**tinted lens** **time** **no. incorrect** **no. correct** **cwpm** **accuracy**

Appendix 8.01 contd score sheet for experiment 5b (tinted lenses)

3. you is not come cat up look to play dog my the for and see
look for up and the play is dog cat not see to come my you
to not play come see look cat you for up the my is dog and
the look you dog is cat play see come to for and up not my
cat up to my the see and come dog for is you not look play
see and dog come cat is play the not look to up my you for
dog to cat the is you my see for up play come and not look
up my for and to come dog see look cat you is the play not
come you is see my for look to not the dog play cat and up
is the look to cat not and come play for you up my see dog

tinted lens
time
no. incorrect
no. correct
cwpm
accuracy

4. cat for the you not up my dog see to is come play look and
see you dog for is cat look play my the up and come not to
look cat see my and dog the play is come not for to you up
my see is the come play look for and up to cat you dog not
and you cat look to see not my dog the for come is up play
dog to and play up come you the not is cat look for my see
the play look cat see up come for my you and not is to dog
for to not you come play the look cat see is dog up and my
you dog and for up not see my cat is the play come to look
come not and to see you is play look up the cat dog my for

tinted lens
time
no. incorrect
no. correct
cwpm
accuracy

5. the cat up dog and is play come you see for not to look my
come see the play look up is cat not my and dog for you to
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
my play see to for you is the look up cat not dog come and
up come look for the not dog cat you to see is and my play
look to for my come play the dog see you not cat up and is
to not cat for look is my and up come play you see the dog
dog to you and play cat up is my not come for the look see

tinted lens
time
no. incorrect
no. correct
cwpm
accuracy

Appendix 8.02 score sheet for experiment 6 (video-magnifier)-comparison of the effects of video-magnifier screen colours on reading performance in ARMD

Name **date** **N size**

1a. come see the play look up is cat not my and dog for you to — **grey screen 1**
the cat up dog and is play come you see for not to look my — **time**
you for the and not see my play come is look dog cat to up — **no. incorrect**
dog to you and play cat up is my not come for the look see — **no. correct**
play come see cat not look dog is my up the for to and you — **cwpm**
to not cat for look is my and up come play you see the dog — **accuracy**
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
dog to you and play cat up is my not come for the look see

1b. come see the play look up is cat not my and dog for you to — **grey screen 2**
the cat up dog and is play come you see for not to look my — **time**
you for the and not see my play come is look dog cat to up — **no. incorrect**
dog to you and play cat up is my not come for the look see — **no. correct**
play come see cat not look dog is my up the for to and you — **cwpm**
to not cat for look is my and up come play you see the dog — **accuracy**
my play see to for you is the look up cat not dog come and
look to for my come play the dog see you not cat up and is
up come look for the not dog cat you to see is and my play
dog to you and play cat up is my not come for the look see

2. see the look dog and not is you come up to my for cat play — **screen colour**
not up play my is dog you come look for see and to the cat — **time**
look up come and is my cat not dog you see for to play the — **no. incorrect**
my you is look the dog play see not come and to cat for up — **no. correct**
for the to and you cat is look up my not dog play see come — **cwpm**
you look see and play to the is cat not come for my up dog — **accuracy**
come not to play look the and dog see is cat up you for my
and is for dog come see the cat up look you play my not to
dog you cat to and play for not come up the see look my is
the come to up cat my see dog you not look is play and for

Appendix 8.02 contd score sheet for experiment 6 (video-magnifier)

3. you is not come cat up look to play dog my the for and see
look for up and the play is dog cat not see to come my you
to not play come see look cat you for up the my is dog and
the look you dog is cat play see come to for and up not my
cat up to my the see and come dog for is you not look play
see and dog come cat is play the not look to up my you for
dog to cat the is you my see for up play come and not look
up my for and to come dog see look cat you is the play not
come you is see my for look to not the dog play cat and up
is the look to cat not and come play for you up my see dog

screen colour
time
no. incorrect
no. correct
cwpm
accuracy

4. cat for the you not up my dog see to is come play look and
see you dog for is cat look play my the up and come not to
look cat see my and dog the play is come not for to you up
my see is the come play look for and up to cat you dog not
and you cat look to see not my dog the for come is up play
dog to and play up come you the not is cat look for my see
the play look cat see up come for my you and not is to dog
for to not you come play the look cat see is dog up and my
you dog and for up not see my cat is the play come to look
come not and to see you is play look up the cat dog my for

screen colour
time
no. incorrect
no. correct
cwpm
accuracy

5. the cat up dog and is play come you see for not to look my
come see the play look up is cat not my and dog for you to
you for the and not see my play come is look dog cat to up
dog to you and play cat up is my not come for the look see
play come see cat not look dog is my up the for to and you
my play see to for you is the look up cat not dog come and
up come look for the not dog cat you to see is and my play
look to for my come play the dog see you not cat up and is
to not cat for look is my and up come play you see the dog
dog to you and play cat up is my not come for the look see

screen colour
time
no. incorrect
no. correct
cwpm
accuracy

Appendix 8.02 contd score sheet for experiment 6 (video-magnifier)

6. see the look dog and not is you come up to my for cat play	**screen colour**
not up play my is dog you come look for see and to the cat	**time**
for the to and you cat is look up my not dog play see come	**no. incorrect**
you look see and play to the is cat not come for my up dog	**no. correct**
look up come and is my cat not dog you see for to play the	**cwpm**
and is for dog come see the cat up look you play my not to	**accuracy**
dog you cat to and play for not come up the see look my is	
the come to up cat my see dog you not look is play and for	
my you is look the dog play see not come and to cat for up	
come not to play look the and dog see is cat up you for my	

Appendix 9.00 -Supporting published work

RUNDSTRÖM, M. M. AND EPERJESI, F. Is there a need for binocular vision evaluation in low vision? (1995). Ophthalmic and Physiological Optics. **15**, 525-528.

EPERJESI, F., FOWLER, C. W. AND KEMPSTER, A. J. (1995). Luminance and chromatic contrast effects on reading and object recognition in low vision: A review of the literature. Ophthalmic and Physiological Optics. **15**, 89-114.

EPERJESI, F., FOWLER, C. W. AND EVANS, B. J. W. Tinted lenses and low vision: A review of the literature. (Submitted for review to Ophthalmic and Physiological Optics).

ARMSTRONG, R. A., SLADE, S.V. AND EPERJESI, F. The application of analysis of variance (ANOVA) to clinical data from experiments in optometry. (Accepted for publication in Ophthalmic and Physiological Optics).

EPERJESI, F. Reading performance in age-related macular degeneration (ARMD) with various reading luminaires. (Submitted for review to Journal of Visual Impairment and Blindness).

Presentations

RUNDSTRÖM, M. M. AND EPERJESI, F. (1994). Is there a need for binocular vision evaluation in low vision? Poster presented at the American Academy of Optometry, San Diego.