The correction of borderline
refractive and heterophoric anomalies

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ABSTRACT

The core function of optometrists is the prescribing of spectacles in order to alleviate symptoms and improve visual function. Most commonly, the spectacles are used to correct refractive errors and, less frequently, they are also used to correct a decompensated heterophoria. Whilst identifying and diagnosing a marked refractive error or decompensated heterophoria is relatively straightforward, the management of marginal or borderline cases is much more difficult, for there is no clear cut-off point between normality and abnormality. The literature search in this thesis reveals a lack of evidence-based research on the criteria for determining when a refractive or prismatic correction is required.

The aim of the present research was to investigate at what point optometrists currently decide to prescribe spectacles in borderline cases, and to see if current prescribing habits relate to the advice given in the literature. Further aims were to investigate whether the correction of borderline refractive errors and decompensated heterophoria improves reading performance, and to investigate any association between an improvement in reading performance and symptoms.

A practitioner survey was given to practitioners attending CET events during 2001 and to the UK Optometry E-mail discussion list. A wide variety of prescribing criteria were reported from the 37 respondents, and the presence of symptoms greatly influenced the decision to prescribe. Practitioners reported that their likelihood of prescribing when symptoms are present exceeded 50% for: horizontal aligning prism of $\geq 1.5\Delta$, vertical aligning prism $\geq 1.0\Delta$, hypermetropia of $\geq +0.75$, reading additions of $\geq +0.75DS$ and astigmatism of $\geq -0.75DC$. For asymptomatic patients, practitioners' likelihood of prescribing exceeded 50% for: reading additions of $\geq +1.50DS$ and astigmatic corrections of $\geq -1.50DC$. In the absence of symptoms, optometrists would not regularly correct any degree of hypermetropia or aligning prism up to the limits of the survey.

In a prospective clinical trial, 58 subjects with decompensated heterophoria and 208 subjects with borderline refractive errors had their reading performance assessed with the Wilkins Rate of Reading Test both with the refractive or prismatic lens in place and with a placebo control lens using a double-masked randomised design. Analysis of the data indicated that prescribing prism for decompensated exophoria of 2Δ, a reading addition of +1.00DS and correcting oblique cylindrical errors is likely to result in an improvement in reading performance. Correlations between symptoms and the change in reading performance with small refractive or prismatic corrections were very weak.

It is concluded that the correction of borderline decompensated heterophoria and refractive errors can improve rate of reading. Guidelines are suggested for the correction of these anomalies that are based on the present data on visual performance, as well as the literature on the effect of these anomalies on symptoms.

Keywords: low refractive errors, heterophoria, hypermetropia, presbyopia, astigmatism, symptoms

to my family

LYNETTE, TERENCE and CHERYL O'LEARY

"For your unending love, support and belief"

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CHAPTER 1   INTRODUCTION

1.1   BACKGROUND

A survey of spectacle prescribing by The Ministry of Health in 1962 showed that eighty nine percent of the population in the UK has a refractive error of at least 0.50DS (Rabbetts, 2007, p422) and the correction of refractive errors remains the principal activity of most optometrists. Heterophoria is also ubiquitous, and as it is the most common binocular anomaly (Simons and Grisham, 1987), is often detected, diagnosed and treated during a routine eye examination (Evans, 2009, p241). Whilst identifying and diagnosing a refractive error or heterophoria is relatively straightforward, the management of these conditions is much more difficult, as not all refractive errors or heterophoric anomalies require correction. As a result, optometrists have to regularly decide whether a refractive error or heterophoria requires correction or treatment. These decisions are generally straightforward if a large anomaly is present, but become much more difficult in marginal or borderline cases, for there is no clear cut-off point between normality and abnormality.

Several authors have questioned whether correcting small amounts of ametropia is clinically beneficial. Stewart-Brown (1985) investigated spectacle prescribing among 10-year-old children. She found that 10% of the 13,871 children tested had been prescribed spectacles, but that 20% of these children had no 'visual acuity defects' (6/6 distance and near), and that a further 15-20% had visual acuities of 6/9. She acknowledged that some of these cases would have a sound clinical reason for prescribing other than a decrease in visual acuity, but concluded that the over prescription of spectacles to school children was common. A similar point has been made in an Australian paper, which was particularly critical of the prescribing of low plus lenses (Robaei et al., 2006).

It might be thought that if patients did not need spectacles that they were prescribed then they would not wear them, but an interesting study by Cholerton (1955) may question this. Cholerton prescribed plano spectacle lenses to 11 patients under the age of forty with low refractive errors who were complaining of eyestrain and headache during periods of prolonged reading. After three months of wearing the glasses, seven (64%) reported an improvement in symptoms, suggesting that the glasses acted as a placebo. Nathan (1957) investigated this point further by taking careful histories of 17 consecutive patients attending with asthenopic symptoms (symptoms associated with the use of the eyes (Evans, 2009, p369), typically headache, eye fatigue, eye pain, photophobia and eyestrain) and low refractive errors. He diagnosed eight (47%) of them as having 'ocular neurosis' based on fear about the health of their eyes, and in all eight subjects the symptoms disappeared within a month without any treatment. Symptoms for the remaining subjects were attributed to fatigue (24%), systemic and ocular health problems (17.6%) and accommodative insufficiency (5.9%). The symptoms were found to be caused be 'faulty glasses' in only one subject (5.9%), although he does not describe in what way the glasses were 'faulty'. In conclusion, Nathan suggests that taking a very thorough history is essential in any case of low refractive error, and that although prescribing glasses often relieves the symptoms, this is rarely justifiable or ideal.

The following chapters (chapters 2 to 7) will give an overview of the definition, incidence and prevalence of borderline heterophoria and refractive error, and will review any guidance given on their management.

CHAPTER 2   DESCRIPTION AND DEFINITION OF REFRACTIVE ERRORS

2.1   AN OVERVIEW OF REFRACTIVE ERRORS AND THEIR MEASUREMENT

When the light entering an unaccommodated eye from a distant object is sharply focussed on the retina, the eye is classified as being emmetropic. If the light is not sharply focussed, the eye is said to have a refractive error, or an error of refraction (Rabbetts, 2007, p67). Spherical refractive errors occur when the eye's refractive system is symmetrical about the optic axis, but the axial length of the eye and its focal length do not coincide. This results in myopia or hypermetropia. Astigmatism occurs when the refractive system is not symmetrical and therefore an object does not form a point image on the retina (Rabbetts, 2007, p85).

The two main methods of determining the refractive error of an eye are retinoscopy and subjective refraction. Either one or a combination of both techniques can be used. The details of both of these techniques are outside the scope of this thesis, but a good review can be found in chapter four of *Clinical Procedures in Primary Eye Care* (Elliott, 2007).

2.2   MYOPIA

2.2.1   Definition

The *Dictionary of Optometry and Visual Science* (Millodot, 2009, p240) defines myopia as the refractive state in which images of distant objects are focussed in front of the retina when accommodation is relaxed. As a result distance vision is blurred. The term myopia is also known in layman's terms as 'short-sightedness'. It is measured in Dioptre Spheres (DS) and is identified by a minus sign when written (e.g. -0.50DS).

2.2.2 Classification

Myopia can be classified in many ways, for example according to age of onset (juvenile onset or adult onset) or by the degree of myopia (low, medium or high). The vast majority of myopia is acquired in either the late teenage years or in adulthood. A myopic prescription of up to -3.00DS is considered to be low and myopia of -6.00DS or more is classified as high. Medium myopia is any value in between (Millodot, 2009, pp240-241).

Another important classification is whether the myopia is physiological or pathological. Physiological myopia is much more common than pathological myopia and occurs when there is a failure in correlation between the power of the lens and cornea and the length of the eye. It is associated with the growth process and stabilises when growth has been completed usually at the end of the teenage years.

Pathological myopia is associated with retinal and choroidal degeneration. It occurs most commonly in myopia exceeding -8 to -10DS and continues to progress during adulthood. It can lead to an uncorrectable decrease in visual acuity (Millodot, 2009 p241).

2.2.3 Incidence & prevalence

The incidence of myopia is defined as the number of new cases divided by the number of people in a population over a specified period of time, usually one year (Millodot, 2009 p166). The prevalence is defined as the number of cases of a condition that are present in a particular population at a given time (Millodot, 2009, p293).

Comprehensive epidemiological studies can take a long period of time to produce due to the amount of data generated. A search of the literature shows that the most recent epidemiological study of refractive errors and prisms throughout the U.K. was undertaken by the Ministry of Health in 1962. This survey was sent to every Health Authority in England and Wales, who were asked to provide the details of every hundredth O.S.C.2 (Ophthalmic Services Committee) form submitted for payment. A random sample of 21,042 single vision and 4,114 bifocal lenses was obtained representing about 0.25% of the annual demand at that time. Rabbetts' (2007, p422) review of this survey found that 23.1% of the glasses prescribed were for a myopic prescription of greater than -0.25DS. This is slightly more than that reported by Tassman (1932), whose review of 10,153 cases from the refraction clinic of a hospital in the U.S. showed that 17% of the glasses prescribed were for myopia of least -0.75DS. Millodot (2009, p240) states that the percentage of myopia in Caucasian populations is 24% to 28%, but he does not give any details as to the origin of his data or the criteria used.

2.2.4   The effect of myopia on visual acuity

Even a small amount of myopia can result in a decrease in visual acuity. Elliott (2007, p33) states that for low myopic errors, every -0.25DS of myopia results in a reduction of one line of acuity on a traditional Snellen chart when viewed at 6m. Rabbetts (2007, p104) provided guidelines as to the visual acuity expected for different amounts of myopia (and this broadly agrees with Elliott (Table 2.1)).

Table 2.1 The reduction in vision associated with myopia (amended from Clinical Visual Optics by Rabbetts 2007, p104)

Amount of Myopia (DS)	Snellen Visual Acuity
small	6/6
-0.50	6/7.5
-0.75	6/9
-1.00	6/12
-1.50	6/18
-1.75	6/24
-2.25	6/36
-2.50 to -3.00	6/60

2.2.5   The effect of myopia on reading performance

Near visual acuity is rarely affected in myopia as the text can simply be brought closer to make it clearer. This may be the main reason why myopia does not appear to affect reading development (Grisham and Simons, 1986). However, the literature review undertaken by Grisham and Simons (1986) only reviews studies investigating the correlation between myopia and vision development in children. As it does not include any studies which investigate whether reading performance is reduced in adults with myopia, it is possible (although unlikely) that myopia may have an effect. There has even been some suggestion that myopia improves reading performance, but further research in this area is needed.

2.2.6   Symptoms and myopia

Blurred distance vision with clear near vision is highly suggestive of a myopic refractive error (Brookman, 1996a, p3). However other symptoms have also been reported. Daum et al. (1988) found that Visual Display Terminal workers with small amounts of myopia (from -0.50 to -1.50DS) were significantly more likely to have symptoms of eyestrain ($p<0.04$) and slow refocus ($p<0.04$) than those with emmetropia or hypermetropia when the data was analysed using Kruskal-Wallis nonparametric analysis of variance. Although the authors do not suggest any explanation as to why those workers with small amounts of myopia had significantly more symptoms than emmetropes, convergence insufficiency subsequent to reduced accommodation may be a possible cause. Interestingly, workers with myopia also had the earliest onset of symptoms and the longest duration of symptoms. Another common problem reported by patients with myopia is frontal headache, which may occur as a result of squeezing the eyelids together in an effort to see more clearly (Elliott, 2007, p83).

As even small amounts of myopia can result in a decrease in visual acuity, spectacles are usually prescribed to improve vision. As the purpose of this thesis is to investigate the management of borderline refractive errors and heterophoria where there is doubt as to whether to prescribe glasses or prisms, the management of myopia is not discussed further. A good review on prescribing glasses for children with myopia can be found in chapter four of *Paediatric Optometry* by Harvey and Gilmartin (2004)

2.3   HYPERMETROPIA

2.3.1   Definition

Hypermetropia occurs when distant objects are focussed behind the retina when accommodation is relaxed (Millodot, p157). It is known in lay terms as long-

sightedness and can cause blur for both near and far objects. Like myopia, it is measured in Dioptre Spheres, but is identified by a plus sign when written (e.g. +0.50DS).

2.3.2   Classification

There are two important components to hypermetropia: the amount of hypermetropia that is manifest, and the amount that is latent. Most people under the age of 55 have the ability to accommodate: that is to steepen the shape of the focussing lens within the eye by altering the tonus of the ciliary muscle. This ability enables the image to be brought closer to the retina, and reduces the amount of hypermetropia present. The amount of hypermetropia that is compensated for by accommodation is known as latent hypermetropia. If the patient habitually uses accommodation to reduce their hypermetropia, the full amount may not be detected at a routine eye examination. Cycloplegic drops are then needed to relax the ciliary muscle, in order to determine the amount of latent hypermetropia present. Manifest hypermetropia is the amount of hypermetropia that is not compensated for by accommodation, and is the amount that is apparent during a routine refraction without cycloplegia (Millodot, 2009, p157).

2.3.3   Incidence and prevalence

The reported prevalence for hypermetropia varies considerably, depending on a variety of factors, such as the age group studied, whether cycloplegia was used and the author's definition of hypermetropia.

The distribution of refractive error in the general population is shown in Figure 2.1. This distribution differs significantly from a normal distribution (shown by the dashed line) due to the large number of subjects who are within one dioptre of emmetropia. It

can also be seen that hypermetropia is more prevalent than myopia. However, the data is taken from young males in the military, and the entrance criteria regarding vision is likely to result in an underestimation of larger refractive errors.
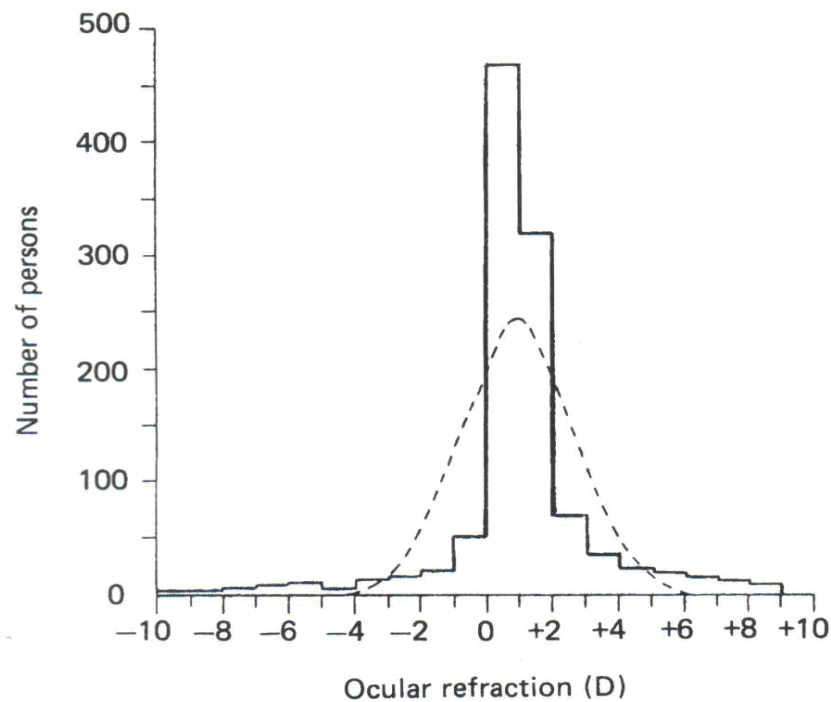
Figure 2.1 The distribution of refractive error in 2066 young adult males. A normal distribution curve (dashed line) is superimposed. Graph from Rabbetts (2007, p426). Original data from Sorsby et al., 1960.

The most comprehensive data on refractive errors was provided by a Ministry of Health survey in 1962 which investigated the power of lenses prescribed through the supplementary Ophthalmic Services. Rabbetts (2007, p422) describes the data from this survey, which showed that 65.4% of the UK population at this time had hypermetropia of over +0.25DS (Table 2.2). However, it should be noted that only glasses that had been prescribed on the N.H.S were included in the data, and that as good vision in uncorrected hypermetropia is generally maintained for longer than in uncorrected myopia (see 2.3.4), hypermetropia is likely to be under-represented. As a result the percentage of hypermetropia in the general population is likely to be higher than 65.4%.

Table 2.2. The prevalence of hypermetropia in the general population (amended from Rabbetts 2007, p422)

Power (DS)	+0.37 to +0.50	+0.62 to +1.00	+1.12 to +2.00	+2.12 to +4.00
Prevalence (%)	7.0	14.6	19.9	17.5

A similar figure of 66.4% was found by Tassman (1932) who examined the records of 10,153 patients prescribed glasses at the refraction department of a hospital in the U.S. The majority (65%) of the refractions were taken after cycloplegia, and hypermetropia was defined as any refractive error greater than 0.50DS.

There is evidence that the prevalence of hypermetropia in adulthood increases with age. Hirsch (1958) classified refractive errors of over 1.12DS as being hypermetropic, and found that the number of subjects with hypermetropia aged 55 to 59 was twice the number aged 45 to 49, and there were three times as many aged over 70. In the 45 to 49 year-old group hypermetropia was present in 16.3% of the subjects compared to 47.9% of the subjects aged over 75. These values are lower than the prevalence reported by Rabbetts (2007, p422) and Tassman (1932), however the results of this study may be questionable due to the analysis of the data. The equivalent sphere for each eye was determined and then the two values averaged to obtain the amount of hypermetropia for each subject. Although the refractive error in each eye is often similar this is not always the case, and by averaging the refractive errors of the two eyes, a subject with +1.00DS in one eye and -1.00DS in the other, will be incorrectly classified as having no refractive error.

Logan et al. (2005) determined the non cycloplegic refraction of 373 University students from Bradford and Aston Universities with an infrared open-field autorefractor (mean age 19.55 years ±2.99, range 17-30 years). They found that 18.8% of white students and 17.3% of the British Asian students had a mean spherical equivalent hypermetropic refractive error of at least +0.50DS.

Whilst Logan looked at the prevalence of hypermetropia in adults aged 17 to 30, and Hirsch (1958) at the prevalence of hypermetropia in adults over 40, Ip et al. (2008) examined Australian schoolchildren by autorefraction with cycloplegia. They defined hypermetropia as any refractive error of +0.50DS or over, but did not consider hypermetropia to be 'significant' until a value of +2.00D was reached. They found the prevalence in children to be much higher as hypermetropia of at least +0.50D was present in 93.7% of six year olds and 70.1% of twelve year olds. For moderate hypermetropia (≥+2.00DS) the prevalence fell to 13.2% and 5% respectively.

A few studies have investigated whether hypermetropia is affected by gender.

In their paper on the development of refractive errors into old age, Haegerstrom-Portnoy et al. (2002) looked at the refractive errors of 569 Californian patients from 62 to 90 years of age, and defined hypermetropia as any positive refractive error above zero dioptres. They found that males had less hypermetropia than females for both the right and left eyes for both the spherical error (RE $p=0.01$ and LE $p=0.02$) and equivalent sphere (RE $p=0.004$, LE $p=0.01$). Ip et al. (2008), also found that moderate hypermetropia (≥+2.00D) was significantly higher among girls in the 6-year-olds age group compared to boys (15.5% vs. 10.9%, $p= 0.005$).

In summary, most authors agree that hypermetropia of at least +0.50 is common with a prevalence of between 16% and 93.7%, is more prevalent in children than adults, and is more common in females compared to males.

2.3.4   The effect of hypermetropia on visual acuity

The effect of hypermetropia on visual acuity is difficult to predict because of the ability of the eye to use accommodation to make the image clearer. As accommodation declines with age, visual acuity is more likely to be reduced in adults than in children. Millodot (2007, p157) states the likely effect on visual acuity for increasing amounts of manifest hypermetropia (see 2.3.2 for definition), and his table is summarised below.

Table 2.3 The reduction in vision associated with manifest hypermetropia (amended from the Dictionary of Optometry by Millodot, p157)

Amount of Hypermetropia (DS)	Snellen Visual Acuity
+0.50	6/9
+0.75	6/12
+1.00	6/18
+1.50	6/24
+2.00	6/36
+2.50	6/60
+3.50	6/90
+4.50	6/120

Rabbetts (2007, p75) explained that the blur circles produced by an unaccommodated hypermetropic eye were dependent on pupil size, and the amount of refractive error. Rabbetts shows that an uncorrected error of 0.75D for typical pupil sizes would give a Snellen acuity of 6/12. As a patient with this acuity could be beyond the legal limit for driving in the UK, which Drasdo and Haggerty (1981) found to be approximately equivalent to $6/9^{-2}$, it would be reasonable to suggest correcting hypermetropia of 0.75D or above, for drivers who are presbyopic.

2.3.5   The effect of hypermetropia on reading performance

It seems logical that uncorrected hypermetropia may be associated with a decrease in reading performance due to the increase in accommodative effort required. Symptoms such as eyestrain, visual fatigue and near blur during prolonged vision seem to support this belief. A book held at a working distance of 40cms would produce an accommodative stimulus of 2.5 dioptres, and it can be seen from Figure 2.2 that the accommodative response to this stimulus is typically 2D (i.e there is an accommodative lag of 0.5D; see Evans, 2007b, p31 for more details). Most children and many adults will have adequate accommodative reserves to comfortably overcome this accommodative demand. However, although blur is the primary stimulus to accommodation, many other factors can influence the accommodative response. For example, when reading a page of text, spatial frequency, contrast, the diameter of the pupil and the illumination of the text are also all likely to influence the accommodative response (Ciuffreda and Kenyon, 1983), and these factors may contribute to the symptoms reported by patients with uncorrected hypermetropia.
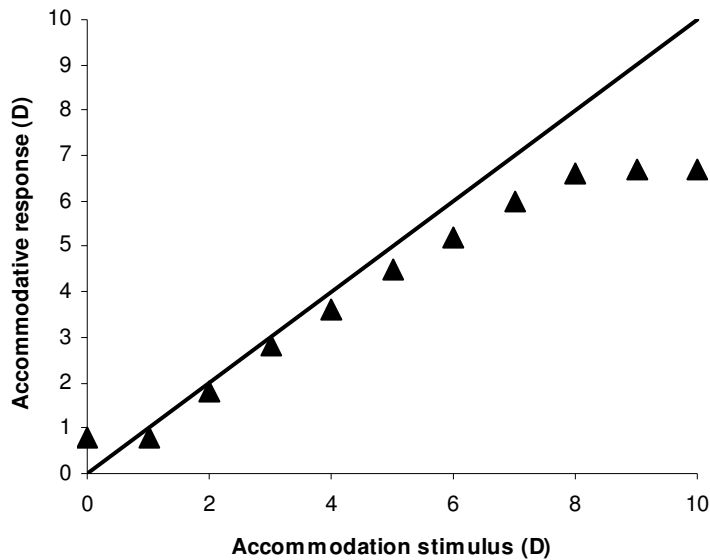
Figure 2.2 Static accommodative stimulus-response curve for typical adult. The diagonal line represents the unit ratio (or 1:1) line. The black triangles represent the accommodative response to increasing accommodative stimuli. Redrawn from Ciuffreda and Kenyon, 1983.

An interesting literature review was undertaken by Grisham and Simons (1986) exploring the relationship between refractive errors and reading performance. The authors found that whilst several studies support the theory that hypermetropia contributes to poor reading performance, some of the studies do not. They conclude that significant uncorrected hypermetropia appears to be a factor contributing to poor visual performance, but that the results are not unequivocal due to methodological flaws. They add that the literature does not address the question of how much uncorrected hypermetropia is considered to be significant.

Other studies that have investigated the effects of hypermetropic corrections on visual performance have been by behavioural optometrists. In these studies (reviewed by Press, 1985), the physiological benefits of small plus prescriptions are investigated, and one of the authors reviewed (Pierce) found the rate of reading to be significantly faster with a +0.50DS lens compared to a plano lens. This lens was prescribed based on

guidelines produced by Skeffington (see Barrett, 2009 for an overview), using criteria not widely used in the U.K.

2.3.6   Symptoms and hypermetropia

In their study on symptoms in visual display terminal operators with small refractive errors, Daum et al. (1988) found that people with hypermetropia (+0.50 to +0.75) did not have significantly more symptoms than those with emmetropia, and had fewer symptoms than people with myopia. This is surprising as prolonged VDU use requires sustained accommodation, and as patients with hypermetropia use some of their accommodation in order to overcome their refractive error, it might be expected that they would have most symptoms. However, it has been shown that accommodation is not precise, and that in fact most people under-accommodate by about +0.75DS when focussing on a near object. This under-accommodation (known as the lag of accommodation) would mean that patients with hypermetropia of +0.50 to +0.75 may not actually be accommodating any more than if they were emmetropic.

In contrast, Carlson (1996, p49) argues that uncorrected hypermetropia often causes difficulty with near work, particularly as the patient ages and the amount of accommodation available decreases, often between the ages of 20 and 40.

 2.4   ASTIGMATISM

2.4.1   Definition

The Dictionary of Optometry and Vision Science defines astigmatism as the difference in power between the principal meridians of the eye (Millodot, p35). It is a refractive error in which the image of a point object does not form a single point, but forms two focal lines at different distances from the optical system, generally perpendicular to

each other. In a clinical setting, it is usually measured in Dioptre Cylinders (DC). But in research studies astigmatism can also be stated as a scalar measurement (Harris, 2000; Harris, 1996; Rabbetts, 1996; Harris, 1994), a vector measurement (Haegerstrom-Portnoy et al., 2002) or as a Fourier measurement, and astigmatism is sometimes expressed in these forms for quantitative analyses. However, there is disagreement over the calculations required for each of the methods above, resulting in different authors using a variety of formulae in order to analyse the astigmatic component of a refractive error. This causes difficulty when comparing the results of different studies.

When issuing a prescription for glasses, the prescription can be written in two forms: the plus cylinder form and the negative cylinder form. Spectacle lenses that have the cylinder ground on the front surface (plus cylinder lenses) produce different spectacle magnification in one meridian to the other. This difference does not occur in lenses with the cylinder worked on the back surface (minus cylinder lenses) and so from about the mid 1960's minus cylinder lenses have been the preferred prescribing form (Guyton, 1977). The minus cylinder form will therefore be used throughout this thesis.

As well as describing astigmatism in terms of the difference in power between the principal meridians, it can also be described in terms of the overall refractive power and in terms of axis direction.

2.4.1.1   Classification of astigmatism based on underlying refractive error

When astigmatism is referred to in terms of the overall refractive error, it is classified as simple, compound or mixed. Simple astigmatism occurs when one principal meridian of the eye is emmetropic and the other myopic or hypermetropic. Astigmatism in which the two principal meridians of an eye are either both hypermetropic or myopic, is

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known as compound astigmatism, and mixed astigmatism is that in which one principal meridian is hypermetropic and the other myopic (Millodot, 2009, p36).

2.4.1.2 Classification of astigmatism based on axis direction

Astigmatism can also be classified according to the direction of maximum power (axis). With-the-rule astigmatism (also known as direct astigmatism) occurs when the refractive power of the vertical (or near vertical) meridian is the greatest. When the refractive power of the horizontal meridian is the greatest, astigmatism is considered to be against-the rule (also known as inverse or indirect) (Millodot, 2009, p36). Most authors and practitioners classify astigmatism as with-the-rule if the negative axis is at $180° \pm 15°$ and against-the-rule when it is at $90° \pm 15°$. Oblique astigmatism encompasses astigmatism at any other axis.

2.4.2 Incidence and prevalence

The most recent large scale epidemiological study of astigmatic corrections in the U.K. was by the Ministry of Health in 1962. Bennett (1965) reviewed the cylindrical corrections in 7594 single vision lenses prescribed for distance use and found that 73% of the corrections were for astigmatic errors of 1.00DC or less and another 16% for corrections between 1.25DC and 2.00DC. A review of the same survey was made by Rabbetts in 2007 (Rabbetts, 2007, p423). He analysed the prescriptions of single vision lenses for distance or reading and found that two thirds of the prescriptions issued had an astigmatic element. One half of the cylinders prescribed were 0.25 or 0.50DC, a quarter were 0.75DC or 1.00DC and less than 1% had cylinders over 4.00DC (Table 2.4).

Table 2.4. The prevalence of astigmatism in the general population and the distribution of astigmatic corrections (amended from Rabbetts, 2007 p423).

Cylindrical power (DC)	0.25 to 0.50	0.75 to 1.00	1.25 to 2.00	2.25 to 3.00
Prevalence in general population (%)	34.6	17.7	9.8	3.8
Percentage of astigmatic corrections (%)	50.9	26.0	14.4	5.6

A similar finding was made by Tassman (1932) who examined the records of 10,153 patients examined in the refraction clinic of the Wills Hospital in the U.S., mostly (65%) under cycloplegia. Tassman found that 68% of all the glasses prescribed included an astigmatic component. However, no information is given as to the criteria used to classify a refractive error as astigmatic.

Howland et al. (1978) suggest that the prevalence of astigmatism in infants is approximately eight times that found in adults. The researchers carried out photorefraction (an objective method of determining the refractive error) on 93 infants (birth to 12 months) and found that 63% had at least 0.75 dioptres of astigmatism compared to only 8% of the 26 adults tested by the same method. However, the photorefraction measurements were taken without cycloplegia, and a study by Fulton et al. (1980) indicates that non cyloplegic refractions may overestimate the prevalence. In their study Fulton et al (1980) investigated the cycloplegic refraction of children during the first three years of their life, in order to determine if astigmatic or spherical error could predict esotropia or amblyopia. They examined the consecutive records of 5042 patients attending an ophthalmology department who were full term and were free from any ocular abnormalities apart from esotropia or amblyopia. Data were taken from the right eye of each patient, and subjects were classified as having astigmatism if the difference in power between the principal meridians was at least -1.00DC. When the

non-cycloplegic retinoscopy measurements were examined, the prevalence of astigmatism in children up to the age of three was found to be 45%, but this percentage dropped to 19% for cycloplegic retinoscopy measurements.

Dobson et al. (1984) found the prevalence of astigmatism in children to be slightly higher. They examined children seen at the Children's Hospital Medical Center in Boston between 1968 and 1978 and undertook cycloplegic refraction on the right eye of all children aged between birth and 9.5 years of age, who had no ocular or systemic abnormalities at the time of the examination, and who had an astigmatic error of at least 1.00DC in either eye. They found that 281 out of the 979 children (28.7%) with no ophthalmological or neurological problems had at least one dioptre of astigmatism.

Other authors have found the prevalence of astigmtism in children to be much higher, at between 70 and 90%, For example, Gwiazda et al. (1984) refracted 1000 children from birth to six years old and found that out of 81 children under one year old, 62 (76.5%) had an astigmatic refractive error of at least -1.00DC. The children were refracted without cycloplegia using the near retinoscopy technique (where the child fixates the retinoscope light in an otherwise dark room). Howland and Sayles (1984) used a different technique (photorefraction) to examine 312 infants and young children aged from birth to six year old, in Tompkins County, New York State. They also found that 70% of infants up to the age of twelve months had astigmatism in one eye of at least one dioptre of astigmatism. However by the age of four, this figure had dropped to one in ten (10%). The authors followed up this study with a longitudinal study of 26 infants, which also showed that the amount of astigmatism decreases over the first three years of life.

The highest prevalence reported in the literature is by Logan et al. (2005) who determined the non cycloplegic refraction of 373 University students (aged 17-30 years) from Bradford and Aston Universities with an infrared open-field autorefractor. They found that 90% of the students had astigmatic errors of 0.75DC or less. The astigmatic errors found ranged from 0.25DC to 2.50DC (mean -0.55DC ± 0.51DC).

Harvey et al. (2006) performed non cyloplegic autorefraction on 1327 Native American schoolchildren in the first to eighth grade (i.e. aged six to twelve years old). They found that 42% of the children had at least 1.00DC of astigmatism in one eye, and that the astigmatism was entirely with-the-rule. In contrast, Ip et al. (2006) examined 1462 Australian children by cycloplegic autorefraction, and found that only 202 (15%) had astigmatism of at least 1.00DC.

A North American population survey (Vitale et al., 2008) defined astigmatism as a cylinder of 1.00DC or greater in the eye with the higher astigmatism and found that the prevalence of astigmatism increased with increasing age. For ages 20 through 39 years, 40 through 59 years, and 60 years and older, prevalence estimates were 23.1% (95% CI, 21.6%-24.5%), 27.6% (95% CI, 25.8%-29.3%), and 50.1% (95% CI, 48.2%-52.0%), respectively. All measurements were taken using an autorefractor without cycloplegia.

Interestingly, a review of the studies above indicates that the prevalence of astigmatism reported in studies using cycloplegia (mean prevalence 32.7%) is noticeably less than the prevalence reported in studies which measured the amount of astigmatism without cycloplegia (mean prevalence 47.6%). Unfortunately some of these studies do not state the age range of the subjects who took part, as it is known that the amount of astigmatism is higher at birth and decreases as we age (Howland and Sayles, 1984). It is

therefore possible that subjects in the non cycloplegic studies had a lower mean age than those subjects tested with cycloplegia, however this is unlikely as cycloplegic refractions are more often performed in younger children than older children, and are rarely performed in adults. The explanation may therefore be due to unstable accommodation in the absence of cycloplegia, causing fluctuations in the refractive error being measured along each meridian.

A summary of the prevalence of astigmatism in shown in Figure 2.3. The reported prevalence of astigmatism is between 8% and 90% and is generally higher in infants and children than in adults. Most authors classify a refractive error as astigmatic when the error reaches -1.00DC.
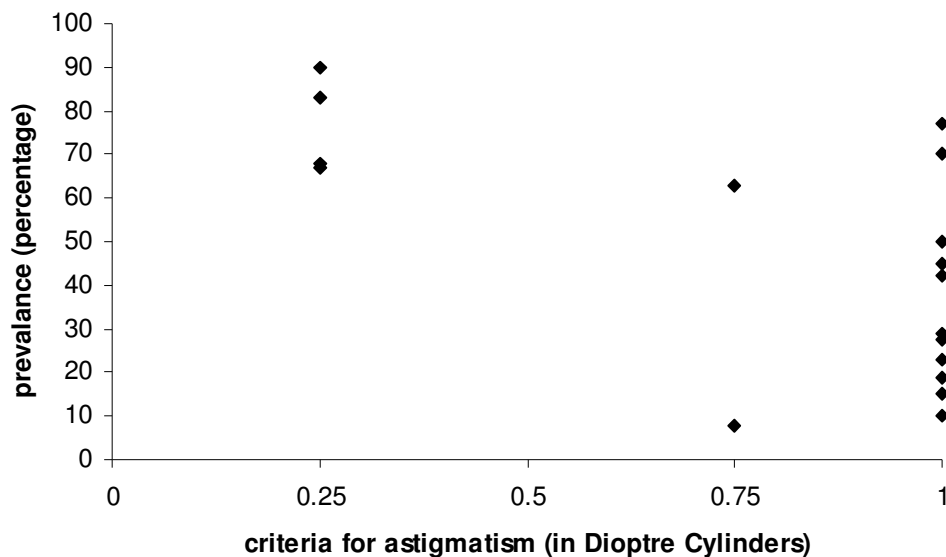
Figure 2.3 The prevalence of astigmatism according to the criteria used.

Although there is a lack of information in the literature regarding the prevalence of simple, mixed and compound astigmatism, several studies have looked at the prevalence of astigmatism in terms of the axis.

Bennett (1965) analysed the Ministry of Health Survey from 1962. All the cylindrical corrections were recorded in plus cylinder form, with any astigmatic correction within 15 degrees of the vertical being classified as with-the-rule, and any axis within 15 degrees of the horizontal as against-the-rule. All other directions were classified as oblique. Overall, there was a slight predominance of with-the-rule astigmatism (37.8%), with against-the-rule (30.4%) and oblique (31.8%) being found in similar amounts. However, the results showed that was a change in the proportion of cylinder axis when the cylindrical power exceeded 2.00DC. For astigmatism under 2.00DC each cylindrical axis represented just over a third of the total amount, but for powers of 2.00DC and above, there was a marked increase in with-the-rule astigmatism (58% of the total) and a decrease in astigmatism that was against-the-rule (17% of the total).

Dobson et al. (1984) investigated the prevalence of with-the-rule, against-the-rule and oblique astigmatism in children seen at the Children's Hospital Medical Center in Boston between 1968 and 1978. Cycloplegic refractions were taken from the right eye of all children aged between birth and 9.5 years of age, who had no ocular or systemic abnormalities at the time of the examination, and who had an astigmatic error of at least 1.00DC in either eye. They found that in children under the age of three and a half, against-the-rule astigmatism (90°±15°) was two and a half times more common than with-the-rule astigmatism (180°±15°), whereas in children over five and a half years of age, with-the-rule astigmatism was three times as common as against-the-rule astigmatism. The authors acknowledged that their sample was likely to be heterogeneous in nature due to the different reasons for each child attending the eye clinic, and therefore also undertook retinoscopy measurements on a subset of children who attended for the same reason: suspected poor vision or poor performance at school.

Again, the prevalence of against-the-rule astigmatism was much higher in the younger group of children. Longitudinal data was obtained from 11 of the 43 children who were under 18 months at their first examination, after a single follow up period of between five and 11 years. The examiner taking the cycloplegic examination at this follow up appointment was blind to the results of the first examination. Several interesting points emerged from the longitudinal data. Against-the-rule astigmatism was present in all but one of the subjects at the original appointment, but only six of the 22 eyes (27%) had an astigmatic error of greater then one dioptre at the follow up and these eyes had the same axis direction as when originally measured. The authors conclude from the longitudinal data that children with against-the-rule astigmatism of a dioptre or more in infancy do not develop with-the-rule astigmatism in childhood. However, they also acknowledge that the cross-sectional data shows that the predominant astigmatic axis changes from against-the-rule to with-the-rule. The authors suggest that the difference between the results of the cross-sectional and longitudinal results may be because the children who show large amount of against-the-rule astigmatism in infancy are not the same children who have large amounts of with-the-rule astigmatism at school age.

The tendency for childhood astigmatism to be against-the-rule has also been demonstrated by several other authors. For example, Gwiazda et al. (1984) examined 1000 children under six years of age and found that before four and a half years of age, most of the astigmatism was against-the-rule and after that age most was with-the-rule. A similar results was found by Howland and Sayles (1984) carried out photorefraction on 312 children aged from birth to six years old in New York State and found that in the most astigmatic eye of infants up to two years of age, the majority of astigmatism was against-the-rule, followed by oblique and then with-the-rule, in a ratio of 15:9:1. Interestingly, when they carried out photorefraction on a group of 159 infants from the

city of Seattle they found that although the overall prevalence for astigmatism was similar to the New York group, the ratio for each type of astigmatic axis was different with less against-the-rule astigmatism and more oblique. However, this difference was not significant when tested with a Chi square test (Chi Square =1.02, p>0.3).

Abrahamsson et al. (1988) followed 299 children with one dioptre of astigmatism or more in at least one eye, from the age of one year until the age of four years. In each case the right eye was used for the measurements, and the initial measurements showed that 272 of the 299 children examined (91%) had against-the-rule astigmatism (minus cylinder at 90°±15°), 18 (6%) had with-the rule (180°±15°) and only 10 (3%) had oblique astigmatism. The astigmatic axis did not change significantly (no more than 15°) for any of the subjects. The authors state that for infants the predominant form of astigmatism is against-the-rule, but for schoolchildren it is with-the-rule, despite the fact that none of the children in their study had a change of axis. The authors therefore agree with Dobson et al. (1984) in their conclusion that it is likely that the astigmatic cases with negative axis 180° (with-the-rule), are probably children who acquire their astigmatism at the age of three to four years or later.

Other authors have investigated whether there is a change in astigmatic axis with aging. In their paper on the progression of refractive errors into old age, Haegerstrom-Portnoy et al. (2002) found that the percentage of subjects manifesting with-the rule astigmatism of at least one dioptre decreased from approximately 7% in the lowest age group (aged 65 years and under, mean age 62) to approximately 3% in the oldest age group (85 and over, mean age 89). The percentage of subjects with against-the-rule astigmatism increased from approximately 8% to approximately 48%, and the percentage of oblique astigmatism increased from approximately 6% to approximately 19%. It should be

noted that this was a retrospective study where the refractions were determined by different practitioners, and this may increase the variability of the findings. In addition, each astigmatic measurement was converted into three vectors: a spherical vector and two cross cylinders, one at 0° and one at 45°, and therefore the criteria for classifying an astigmatic correction as oblique differed from other papers using more traditional methods.

Ferrer-Blasco et al. (2008), restrospectively reviewed the records of 2654 patients attending an eye clinic in Spain, and also found that astigmatism progresses with age, becoming against-the-rule from about the age of 60.

It is possible that the shift in astigmatic axis from with-the-rule to against-the-rule in old age may be the result of lid changes. Lid tension has been shown to decrease with age (Hill, 1975), and it has been proposed that the decrease in tension reduces the pressure on the cornea, with a resulting change in corneal toricity. However this belief is disputed by Vihlen and Wilson, 1983 who used a tensiometer to measure lid tension and a keratometer to measured corneal toricity on 100 subjects aged between 20 and 80 years old. Although their results confirmed that lid tension decreased with age, they found no correlation between lid tension and corneal toricity.

The reported prevalence of oblique astigmatism in the Ministry of Health review is surprising as it is much higher that that reported in other studies (3% for children to 19% in old age). It is not clear why this should be the case, although it is possible that it is due to the difference between the populations being sampled. The Ministry of Health survey obtained its data from spectacle prescriptions issued by optometrists and ophthalmic medical practitioners, whereas Dobson's data were taken from hospital

outpatients. In addition in all but two studies, (Haegerstrom-Portnoy et al., 2002, and Ferrer-Blasco et al., 2008, the subjects were children, whereas data from The Ministry of Health survey were taken from both adults and children (although the age range was not stated).

Other factors such as gender and distance refractive error may also affect the prevalence of astigmatism. Haegerstrom-Portnoy et al. (2002) converted the astigmatic errors of 569 Californian patients aged from 62 to 90 into vector components. Their results showed that males had larger amounts of primary astigmatism, whereas there were no differences in the oblique astigmatic component. Primary positive astigmatism (with the rule) of 1.00DC or more was found in 2.8% of males and 5.4% of females, whereas primary negative astigmatism (against the rule) of 1.00 D or more was found in 32.8% of males and 24.2% of females.

Slataper (1950) measured the astigmatic error of a cross section of patients at several ages and found that the average astigmatic error differed between myopia and hypermetropia. Patients with hypermetropia had an average of 0.83 DC and those with Myopia, 0.62 DC. The study also showed that there was little change in astigmatic error throughout life.

2.4.3   The effect of astigmatism on visual acuity

The effect of an uncorrected astigmatic error on visual acuity is complex and depends on the magnitude of the error, the type of error, and the axis of astigmatism. Visual acuity measurements also tend to more variable with astigmatism due to increased variability in the relative legibility of different letters. Millodot (2009, p35) states that visual acuity in astigmatism is reduced by approximately one line for every 0.25DC.

Rabbetts (2007, p104) however, suggests astigmatism produces less reduction in visual acuity: approximately one line for every 0.50DC (Table 2.5). Rabbetts bases his prediction on calculations of blur circles in patients with myopia or manifest hypermetropia with pupils of about 4mm diameter, but Millodot does not state the source of his guidelines. Visual acuity is likely to be worse for patients with larger pupils, and better if the pupils are smaller. These guidelines suggest that an astigmatic error of between 1.25DC and 2.00DC may reduce visual acuity below the legal standard for driving.

Table 2.5 The reduction in vision associated with astigmatism

Astigmatism (DC)	Snellen Vision (Millodot)	Snellen Vision (Rabbetts)
0.25	6/6	6/6
0.75	6/9	-
1.00	-	6/7.5
1.25	6/12	-
1.50	-	6/9
1.75	6/18	-
2.00	-	6/12
2.50	6/24	-
3.00	-	6/18
3.50	6/36	6/24
4.00	-	6/36
4.50	6/60	-
high		6/60

Harvey et al. (2006) attempted to define the effect of astigmatism on visual acuity by experimental means. They performed non-cycloplegic autorefraction on 1327 Native American school children from the first (age 6) through to the eighth (age 12) grade, and measured visual acuity using a LogMAR chart. Although there was a significant correlation between the amount of astigmatism and the uncorrected visual acuity the effect on visual acuity was less than that reported by either Millodot or Rabbetts, with each dioptre of astigmatism resulting in an additional one logMAR line reduction in uncorrected visual acuity. However, Harvey et al. (2006) do not state the type of

astigmatic error and as the population examined in the study are young and were examined without cycloplegia, it is likely the type of astigmatic error would have influenced the visual acuity results. Subjects with compound hypermetropic astigmatism (see section 2.4.1.1) can accommodate to reduce their refractive error and improve visual acuity, as can subjects with mixed astigmatism although to a lesser extent. In compound myopic astigmatism however, accommodation is unlikely to be of help, and therefore there is likely to be a greater reduction in visual acuity.

Congdon et al. (2008) prescribed spectacles to 810 South African children aged 6 to 19 years old, and found that those children with astigmatic errors of at least 0.75DC had a significantly greater improvement in visual acuity with their spectacles than those with astigmatic errors of less than this. The authors also investigated spectacle compliance with an unannounced visit between four and 11 months after the glasses were prescribed and surprisingly found that spectacle compliance was not related to the amount of visual improvement or the initial level of vision.

Other authors have found that the affect of astigmatism on uncorrected visual acuity is dependant on the direction of astigmatism (the astigmatic axis), and therefore cannot be predicted on the magnitude of astigmatism alone.

Rabbetts (1996) stated that an astigmatic error causes half the blur of a spherical error of the same magnitude. He also found that oblique astigmatic blur has a greater effect on Snellen acuity than a horizontal or vertical blur. This is likely to be because most letters in the English language are composed of vertical and horizontal lines (Figure 2.4).
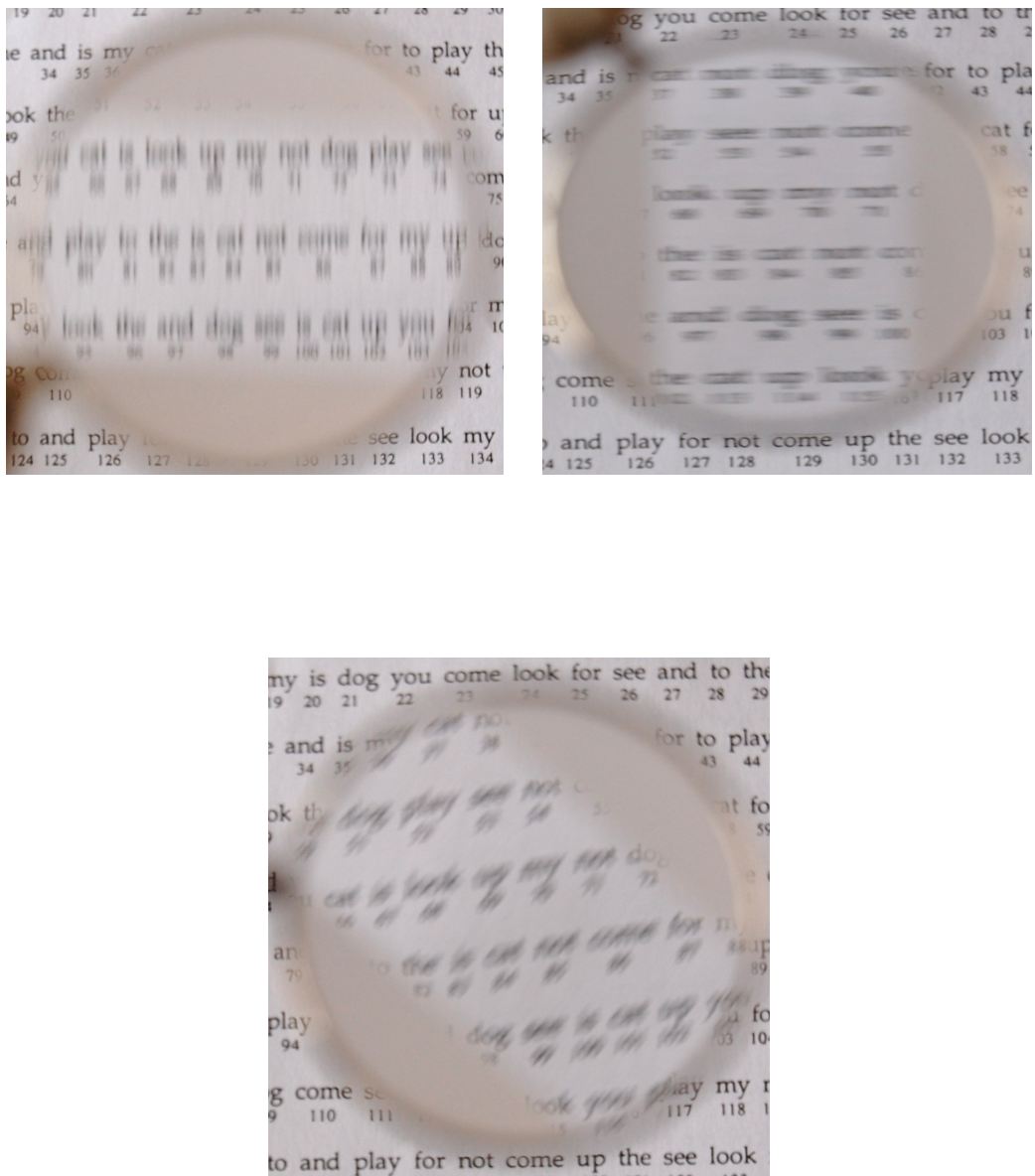
Figure 2.4. The effect of a +2.00 cylindrical lens on a page of text. Top left: with-the-rule. Top right: against-the-rule. Bottom photo: Oblique

Guidelines provided by Brookman (1996a, p5) on the expected visual acuity reduction from uncorrected astigmatism, also indicate that oblique astigmatism causes a greater reduction in acuity than with-the-rule (Table 2.6). Brookman states that against-the-rule astigmatism results in more blur than with-the-rule, but not as much as that produced by oblique astigmatism.

Table 2.6 The reduction in vision associated with different astigmatic axis (adapted from Brookman, 1996, p5)

Oblique astigmatism (DC)	With-the-rule astigmatism (DC)	Snellen visual acuity
-	0.50	6/7.5
0.75	1.00	6/9.5
1.00	1.50	6/12
1.50	2.00	6/15
1.75	2.50	6/20
2.25	3.00	6/30
2.75	3.50	6/45
3.50	4.50	6/60
4.25	5.50	6/75
5.00	6.25	6/90

2.4.4   The effect of astigmatism on reading performance

There is still debate as to whether uncorrected astigmatism affects reading performance. A review of the literature by Grisham and Simons (1986) found that there have been only a few studies investigating whether astigmatism is associated with poor reading performance in children, and most of these had low subject numbers. The results of the studies were mixed, with some studies finding a decrease in reading performance, some finding no association, and one study finding that uncorrected astigmatism resulted in an improvement in reading performance. Grisham and Simons (1986) report that none of the studies analyse the data with regards to astigmatic axis or associated refractive error, and as these factors contribute to the effect on uncorrected acuity, further research in this area is needed.

2.4.5   Symptoms and astigmatism

Several symptoms have been reported in patients with astigmatism and these include headache, blur, ghosting, eyestrain, squinting and asthenopia (Grisham and Simons, 1986, Capone, 1996). Capone (1996, p75) attributes these symptoms to prolonged 'squinting' (facial frown) which in turn leads to muscle fatigue, and suggests that symptoms are more prevalent in astigmatism over -2.00DC.

Asthenopia may be present in small astigmatic errors if enough accommodation is available to place one of the focal lines onto the retina. This can cause the accommodation to become unstable, resulting in symptoms. Larger amounts of astigmatism may actually cause fewer symptoms (although more blur) as the vision is too poor to cause fluctuations in accommodation as neither focal line can be brought into focus (Rabbetts, 2007, p103).

A study by Ip et al. (2006) however, suggests that astigmatism alone may not be the cause of a patients symptoms. They investigated whether there was a correlation between children reporting eye strain and the presence of eye disorders and found that only 18 out of the 220 (8.2%) children reporting symptoms had astigmatism of ≥1.00DC.

The literature shows that many authors believe there is a link between migraine headaches and refractive errors (Harle and Evans, 2004). Harle and Evans (2006) conducted a masked case control study to determine whether four aspects of refractive error (one of which was astigmatism) were correlated with migraines. Migraine sufferers were referred from local GPs' practices and the London Hospital Neurology

unit specialising in migraine headaches. All subjects had been diagnosed with migraine and met the International Headache Society diagnostic criteria. These subjects were age and gender matched with a control, with a total of 25 subjects in each group (21 females and 4 males, aged 33.2 to 41.8 years old). For the statistical analysis the astigmatic errors were converted into a scalar measurement using Humphrey's principle of astigmatic decompensation, where the cylindrical power C is represented as a combination of two obliquely crossed cylinders, Co at axis 0° and C45 at axis 45° and the data from the two eyes were averaged. Compared with the control group, the migraine group had higher degrees of astigmatic components, both subjectively (C, $p = 0.03$; C(0), $p = 0.03$; C(45), $p = 0.05$) and objectively (C, $p = 0.01$; C(0), $p = 0.01$; C(45), $p = 0.05$) when tested with the Mann-Whitney U test.

Akinci et al. (2008) compared the prevalence of refractive errors in patients with headache and a control group. The refractive errors of 1153 adolescents were obtained by autorefraction: 310 patients with headache and 843 controls. The refraction was obtained without cycloplegia for all the patients aged ten or over, and with cycloplegia for those patients under the age of ten. The authors found that the prevalence of astigmatism was statistically significantly higher in the headache group compared to the control ($p<0.0001$, t-test).

2.5 PRESBYOPIA

2.5.1 Definition

Presbyopia is a condition in which the accommodative ability of the eye is insufficient for near work, due to aging (Millodot, 2009, p 292). Accommodation allows the eye to focus at closer working distances and is a result of an involuntary increase in the positive power of the eye due to a change in shape of the crystalline lens. The lens

hardens as the eye ages, and the ability of the eye to accommodate at close working distances decreases. Presbyopia can be found in combination with myopia, hypermetropia, astigmatism and emmetropia.

2.5.2   Incidence and prevalence

Presbyopia is an inevitable condition that occurs in every eye at it ages. As a result the reported prevalence will increase as the age of the population studied increases, until the prevalence reaches 100%.

As a subject gets older, they are increasingly likely to need a prescription for presbyopia, and Bennett's (1965) analysis of the Ministry of Health data, showed that the most commonly prescribed reading addition was for +2.50DS (Table 2.7).

Table 2.7. The percentage of time each reading addition is prescribed.

Reading addition (DS)	Less than +1.00	+1.00	+1.25	+1.50	+1.75	+2.00	+2.25	+2.50
Prevalence (%)	2	4.3	4.2	8.2	9.3	17.3	16.2	20.3

The onset of presbyopia varies from person to person, but generally occurs between the ages of 42 and 48 years in temperate climates such as the U.K. (Millodot, 2009 p292). The age of onset will depend on a combination of the amplitude of accommodation, gender (Pointer, 2002) and the visual demands of the patient (Kurtz, 1996, pp147-148). These factors are discussed in more detail in section 5.2.1.

2.5.3   The measurement of presbyopia

Presbyopia is corrected by prescribing additional plus power for reading on top of the patient's distance correction. This extra power is termed the 'reading addition'. Generally the reading addition required increases as the patient gets older and their

accommodative ability decreases. However, as the reading addition increases, there is also a decrease in the range of clear vision available through the glasses. There are several different ways of determining the correct reading addition, and these methods are reviewed in section 5.2.2.

2.5.4 The effect of presbyopia on visual acuity

The primary symptom of presbyopia is difficulty with near vision, and a drop in near visual acuity is inevitable. Presbyopia only affects near visual acuity, and distance visual acuity is unaffected.

2.5.5 Symptoms and presbyopia

A patient's first visit to an optometrist is often prompted by symptoms related to presbyopia. These are likely to include blurred vision when reading, difficulty in maintaining clear vision at close working distances, having to hold things further away when reading and difficulty with changing focus. Obstfeld (1998, p466) notes that patients with presbyopia do not normally complain of asthenopia, but rather the smallness of print and poor lighting. Kurtz (1996, p148) cautions that symptoms caused by presbyopia manifest solely for near work, and that if similar symptoms also exist for distance, then uncorrected hypermetropia should be suspected

2.6 EMMETROPISATION

Although most children are born with a refractive error, this commonly reduces over the first few years. This process is known as emmetropisation, and is thought to be due to a biofeedback mechanism which coordinates the growth of the optical components within the eye (Millodot, 2009, p113 and p382).

This biofeedback mechanism may be stimulated by visual blur, and therefore there is an argument that correcting refractive errors in young children will disrupt the normal development of the eye. As a result some authors caution against prescribing glasses to young children unless there is a risk of strabismus, amblyopia or a reduction in acuity (Viner 2004, p24).

Emmetropisation occurs rapidly during the first five years of life. Viner (2004, p24) states that at birth most children have hypermetropia and astigmatism with a refractive error of approximately +2.50, but that by the age of five years this refractive error has reduced to about +0.50DS. Ruddick (2004) adds that the most rapid decline in hypermetropia occurs between six months and two years of age, and that emmetropisation is essentially complete in over 80% of children by the age of one.

Astigmatism is also commonly found in infants, with a mean value of 1.00DC (Ruddick, 2004), but which can sometimes be as high as 2.50DC (Viner, 2004), before this also reduces rapidly over the first few years of life. There is debate over the correction of astigmatism in infants as some authors believe the correction of astigmatism impedes emmetropisation, and others believe that uncorrected astigmatism causes meridional amblyopia (a reduction in vision along a particular axis, uncorrectable after a certain age by glasses)

Atkinson et al. (1980) examined the prevalence of astigmatism in children and its progression, by the photorefraction of children in three different age groups: under six months (N=20), 17 to 20 months (N=22), and 33 to 39 months (N=20). The youngest group provided longitudinal data and had their astigmatic error measured at least twice (some were measured a third time) between 9 and 24 months of age. The other two

groups provided cross-sectional data. For the longitudinal study the mean astigmatic error between the two eyes was calculated for each child before analysis, whereas for the cross sectional study, the measurement was taken from the eye with the largest astigmatic error. Nineteen of the 20 subjects (95%) aged under six months had either with-the-rule or against-the-rule astigmatism at their initial measurement, with oblique astigmatism found in the remaining subject. The initial magnitude of astigmatism ranged from 0.75DC to 3.25DC, but had reduced in all but one subject by the time the second and third measurements were taken. It this subject the amount of astigmatism initially increased, before it also reduced to 0.50DC by the age of 22 months. Only three subjects still had an astigmatic error of over 0.75DC after 18 months of age, and one of these was the subject who initially had oblique astigmatism. The cross-sectional data taken on children aged 17 to 20 months showed that 20 out of the 22 children (91%) had astigmatic errors of 0.75DC or less. This value increased to 95% (19 out of 20) in the group aged between 33 and 39 months old. The authors conclude that the prevalence of astigmatism falls rapidly in the second year of life, and is down to adult levels by 18 months. They also suggest that early oblique astigmatism may cause problems for the corrective mechanism. The longitudinal astigmatic data were taken as an average measurement from both eyes, and therefore a large change in astigmatism in one eye may mask the change in the other, however, the authors state that only two of the infants had a difference of more than 0.75DC between the eyes, and therefore averaging the astigmatic errors is unlikely to have had an affect on the results.

The results of Gwiazda et al. (1985) also suggest that oblique astigmatism may impair the emmetropisation process within the eye. They investigated the development of visual acuity in infants with astigmatism of one dioptre or more using a preferential

looking test and found that the average acuity for horizontal, vertical and oblique gratings all continued to improve up to the end of the study (when the infants reached one year old), but that the acuity for the oblique gratings increased more slowly in comparison to the acuity for the horizontal and vertical gratings. However, the authors concluded that there was no evidence for the development of meridional amblyopia during the first year of life.

Abrahamsson et al. (1988) cautioned against correcting astigmatism in children under the age of four. They followed 299 children with astigmatism of at least one dioptre in either eye from the age of 1 until the age of 4 and found that both the magnitude and prevalence of astigmatism decreased throughout the four years of the study. Between the ages of one and two, the astigmatism vanished in one sixth of the infants, and by the age of four, one third of the patients had a purely spherical refraction. They also found an association between astigmatism and anisometropia, where the children with anisometropia of one dioptre or more were more likely to have astigmatism of at least 1.5DC. Those patients who had anisometropia at the age of one year showed both emmetropisation and conversion of astigmatism to a spherical refraction, but those patients with anisometropia at the age of four only showed emmetropisation, but <u>no</u> conversion of astigmatism.

Dobson et al. (2003) however, advise that astigmatism found prior to 3 to 5 years of age should be corrected to prevent amblyopia. They measured the best corrected acuity in children aged 3 to 5 years using horizontal and vertical gratings and Lea symbols to measure the acuity and found that for children with myopia and mixed astigmatism, meridional amblyopia was present due to reduced acuity for the horizontal gratings. Children with hyperopic astigmatism had reduced acuity for both the horizontal and

vertical gratings and all the children had reduced recognition acuity when tested with the Lea symbols.

The importance of axis direction was also demonstrated by Abrahamsson and Sjostrand (2003) who investigated the prevalence of amblyopia in children with oblique astigmatism. The children were selected for the study at one year of age from a general health screening programme, and were assigned into two groups: orthogonal (180 or 90° ±15°) or oblique (all other axes) astigmatism according to the most emmetropic axis. Amblyopia was defined as a difference in visual acuity of at least 0.1 log unit and the results showed that oblique astigmatism significantly increased the risk of developing amblyopia (p=0.0024). There was no increase in risk of amblyopia in children with orthogonal astigmatism.

Harvey et al. (2007) investigated the correction of astigmatism over 0.75DC in children aged under the age of eight, and in those aged eight and over. The 310 Native American children with astigmatism had a significantly reduced initial mean best visual acuity compared to the 446 non astigmatic children. However after wearing their correction for six weeks, the children with astigmatism showed a significantly greater improvement in mean best-corrected visual acuity (0.08 logMAR unit; approximately 1 line), compared to the children without astigmatism (0.01 logMAR unit). The visual acuity improvement was not dependent on whether the children were under or over eight years of age or whether they had previously worn glasses. The children's visual acuity was checked again after a year of wearing glasses, but there was no further improvement, and the mean best-corrected visual acuity in the children with astigmatism remained worse than in the children without astigmatism.

A review of the above literature on the emmetropisation of astigmatism suggests that the risk of meridional amblyopia depends on the astigmatic axis, with oblique astigmatism much more likely to cause meridional amblyopia than other types of astigmatism.

2.7   THE DEFINITION OF BORDERLINE REFRACTIVE ERROR

Refractive errors are continuous variables with no clear 'cut-off' point between normality and abnormality, and therefore controversy surrounds the point at which a refractive error should be corrected, particularly in the case of low refractive errors.

Several authors believe the normal refractive limit of the eye to be +0.50D. Both Tassman (1932) and Jackson (1932) defined emmetropia as being +0.50D or less, a view also held by Nathan (1957) who stated that small errors are usually taken as being any ametropia not exceeding +0.50D in either principal meridian. However, Hirsch (1958) defined emmetropia as any refractive error of less than +1.12D, and Millodot and Millodot (1989) as a refractive error between -0.24D and +0.61D.

However, other authors have found it more difficult to define emmetropia. Adamson and Fincham (1939) found that there is a physiological tolerance to ametropia of between +0.25 and +0.50D without any compensatory change in accommodation: they also reported that perceptual tolerance (the amount by which the accommodation varies for a given object distance without blur) can be as high as 1.25D in some subjects. In addition, Cholerton (1955) reminds us that the spherical aberration of the eye may be greater than 0.50D, and that chromatic aberration can amount to 0.85D. Further work on the accommodative efficacy of the eye was done by Cooper et al. (1987). They used Monocular Estimation Method (MEM) retinoscopy to measure accommodative lag and

found that the mean accommodative lag was +0.35D with a standard deviation of 0.35D. This technique provides an objective measurement of the accuracy of the focussing system of the eyes. The patient fixates a reading card held at their normal reading distance and retinoscopy is performed form the same position with lenses placed in front of the patient's eye until the retinoscopic reflex is neutralised. Further details can be found in Elliott, 2007, pp 194-195.

CHAPTER 3   A REVIEW OF THE REFRACTIVE MANAGEMENT OF

                    HYPERMETROPIA

3.1   INTRODUCTION

The foregoing literature review (see section 2.3.3) indicates that hypermetropia is the most commonly encountered refractive error (Carlson, 1996, p50), and yet arguably it provides the most difficulty when deciding whether to prescribe glasses. This is because many people with hypermetropia subconsciously use their accommodative ability to overcome their refractive error, and even when a large amount of hypermetropia is present, good visual acuity may still be maintained. In these cases a borderline correction for hypermetropia may be considered if the patient has symptoms associated with close work, or if there is a large esophoria (see section 6.2 for a definition), esotropia or the risk of amblyopia (Lyons et al., 2004). Patients with hypermetropia can be reluctant to wear their glasses, particularly if their vision without glasses is as good as their visual acuity when glasses are worn.

3.2   PREVIOUS REVIEWS

When deciding whether to give a prescription for hypermetropia several factors need to be considered. These include symptoms, age, and the patient's visual demands.

Carlson (1996, pp50-55) gives detailed advice on prescribing glasses for hypermetropia, and splits the guidelines into two sections: those for adults and those for children. She suggests that the most important consideration for pre-presbyopic adults is the presence (or absence) of symptoms. As distance visual acuity is rarely reduced, the first reported symptom is likely to be increasing difficulty with near work as the amount of

accommodation available decreases, and Carlson advises prescribing glasses to adults between the ages of 20 and 40 when asthenopic symptoms are present. Conversely, she adds that when there are no asthenopic symptoms, no functional problems and when good visual acuity is maintained, then a correction for hypermetropia is not required. Unfortunately she does not state what these 'functional problems' may be, but it is likely that she is referring to amblyopia or strabismus. Latent hypermetropia is often uncovered as the amount of accommodation decreases and the hypermetropic correction may need to be increased over a number of successive visits. Carlson suggests that as a result, patients worry that the glasses are making their eyes worse and that optometrists need to reassure the patient that this is not the case.

Advice on how much hypermetropia to correct is also provided by Carlson (1996), and in adults this involves prescribing as much plus as possible without causing distance blur. She states that +1.50DS is often the minimum amount of hypermetropia that optometrists prescribe, although she suggests that lower amounts require correction when asthenopic symptoms, esophoria, esotropia or accommodation-convergence anomalies are present.

It is much more difficult to assess whether a hypermetropic refractive error is causing symptoms in children and Carlson admits that many young children are unable to identify or articulate any symptoms they have. As preventing strabismus and associated amblyopia is a priority in younger children, she divides her advice on the provision of hypermetropic glasses to children into two groups: children under the age of six years old, and children who are older. She explains that as bilateral refractive amblyopia is a risk for children under the age of six, that any hypermetropia of +2.50DS or more should be corrected. Cycloplegic refraction should be undertaken in any child with

esotropia, esophoria or a reduction in visual acuity that cannot be improved with spectacles, and Carlson recommends prescribing the full amount of heterophoria found. Carlson warns that older children have more complex visual needs and are unlikely to wear glasses that blur their distance vision. Therefore a post cycloplegic refraction should also be undertaken and the amount prescribed should be the maximum amount of plus tolerated without interference to distance vision. She suggests that a near add be prescribed in the form of a bifocal if extra plus is needed to control significant esophoria or esotropia at near. Finally, Carlson adds that although the minimum amount of plus prescribed to children by optometrists is often +1.50DS, as for adults, spectacles for smaller hypermetropic errors should be prescribed when asthenopic symptoms are present.

3.3 THE CORRECTION OF HYPERMETROPIA IN CHILDREN

The vast majority of optometrists registered in the U.K. are members of The College of Optometrists. The College of Optometrists produces guidelines on professional conduct as part of its Code of Ethics, and these state that the correction of hypermetropia of less than +0.75DS is unlikely to be beneficial in children under the age of 16, and that small plus prescriptions should only be given when there is a clear clinical reason for doing so. These reasons include: low amplitude of accommodation, low fusional reserves, oculomotor balance problems at distance or near, and poor general health. It is interesting that these reasons are restricted to clinical signs and no mention is given to the presence of symptoms, unlike in most other studies and books, although it could be argued that the above abnormalities would be likely to cause symptoms.

Other authors have investigated whether correcting hypermetropia in young children prevents strabismus or amblyopia and have mainly concentrated on pre-school children

(e.g., Ingram et al., 1985; Anker et al., 2004; Lyons et al., 2004; Shea and Gaccon, 2006). In these papers the 'normal' refractive limit for hypermetropia is often considered to be +2.00DS (Ingram et al., 1985) and children are asked to wear spectacles until their refractive error drops below this amount.

In the absence of any risk factors for strabismus or amblyopia, the amount of hypermetropia present before glasses are prescribed tends to be much higher. Miller and Harvey (1998) surveyed 491 AAPOS (American Association for Pediatric Ophthalmology and Strabismus) members to establish their prescribing recommendation for non-strabismic children. They found that 50% of respondents would correct +4.00DS of hypermetropia and 75% would correct +4.50DS in children aged between 4 and 7. Only 25% said they would correct hypermetropia of +3.00 DS.

3.4   THE USE OF LOW POWERED PLUS LENSES

The prescription of low powered plus glasses was advocated by Pierce (cited in Press, 1985). He found that prescribing +0.50DS resulted in a significantly faster reading rate than plano, and in certain subjects also increased comfort. He also found that a small plus prescription reduced physiological activity (reduced heart rate, respiration rate, basal resistance level of the skin, and electrical activity of skeletal muscle). However, the distance ametropia was not corrected, and the difference in magnification was not controlled. As a positive lens will have greater magnification than a plano lens, this increase in magnification may have contributed to the faster reading rate. Therefore we cannot conclude that the refractive correction alone was beneficial in Pierce's study.

In his review of the physiological effects of low powered plus lenses, Press (1985) cited several authors who warned against inappropriate correction of small amounts of hypermetropia. One such author was Greenspan, who found that although performance

for near tasks significantly improved when wearing plus lenses up to a critical power, that there was a subsequent decrease in performance when this critical power was exceeded. He found this critical power to be approximated by the subject's binocular lag of accommodation as found by dynamic retinoscopy (retinoscopy undertaken with the subject fixating an accommodative target held close to the retinoscope), but admitted that this was not the case for all subjects. From these studies Press concluded that low powered plus lenses were beneficial to some subjects, but that no single clinical measurement could predict the appropriate power.

3.5 CONCLUSIONS AND PRESCRIBING GUIDELINES

The advice on prescribing for borderline hypermetropia can be broadly split into two schools of thought. The first advises that spectacles be prescribed only if symptoms are present or if there is likely to be a detriment to visual function (such as strabismus or amblyopia). These authors suggest that any hypermetropia be corrected if symptoms are present even if it is a small amount, and that the full amount of hypermetropia found should be prescribed in cases where there is a risk of strabismus or amblyopia. The second, more controversial, school of thought is that small hypermetropic corrections have a positive effect on physiological activity such as cardiac function, muscle function and respiration rate, and therefore hypermetropic corrections as small as +0.50DS have a beneficial effect, even in the absence of symptoms. However Press' (1985) review of these studies showed that the improvement in physiological activity was only small, and that the improvement may have occurred as a result of postural changes induced by the plus lens. Therefore more studies are needed before definite conclusions can be formed.

The literature indicates that for adults and children over the age of six, optometrists tend to prescribe corrections for hypermetropia of +1.50DS and over when found, but would not usually correct less than +2.50 in younger children. Ophthalmologists in the U.K. would not generally correct hypermetropia of less than +2.00DS, which is less than the minimum amount corrected by ophthalmologists in the U.S.A who would generally correct only less than +4.50 if there was a risk of strabismus or amblyopia.

CHAPTER 4   A REVIEW OF THE REFRACTIVE MANAGEMENT OF

ASTIGMATISM

4.1   INTRODUCTION

Astigmatism is a common cause of blurred vision and asthenopia (Capone, 1996, p75) and therefore there is a need to identify and correct any astigmatism that is likely to cause symptoms or reduce visual performance. However, although most authors agree that the prevalence of astigmatism in the general population and especially children is very high, the point at which it becomes clinically significant is more debateable.

4.2   PHYSIOLOGICAL ASTIGMATISM

Gullstrand (in Helmholtz's Treatise on physiological optics, 1924) stated that the limit of normal astigmatism in the eye was 0.5DC, and The Dictionary of Optometry (Millodot, 2009, p35) defines physiological astigmatism as any astigmatism up to and including -0.75DC. This suggests that any astigmatism of -1.00DC or greater is clinically significant and indeed many studies on astigmatism use the value of -1.00DC for the inclusion criterion as detailed below, however this value seems to have been taken arbitrarily.

A criteria of 1.00DC has been used in studies investigating the relationship between astigmatic errors and meridional amblyopia (Fulton et al.,1980 and Abrahamsson and Sjostrand, 2003) prevalence of astigmatism (Howland and Sayles, 1984, Haegerstrom-Portnoy et al., 2002 and Ip et al.,2008), and the effect of astigmatism on vision (Harvey et al., 2006) and Robaei et al., 2006). Subjects have also been classified patients as having astigmatism when their cylindrical correction reached 1.00DC in studies

investigating the correlation between refractive errors and stereoacuity (Robaei et al., 2007) and headaches (Akinci et al., 2008).

4.3   PREVIOUS REVIEWS

Both Hirsch (1963) and Walton (1950) found very little change in the amount of astigmatism during the school years. Hirsch's data were taken from the Ojai longitudinal study of refraction, where 167 children had their refraction measured by retinoscopy twice a year for 8 years. Walton's study was also longitudinal, the results being taken from individual patient records at an optometric practice. From his findings, Hirsch suggested correcting astigmatism of a dioptre or greater if found before the child enters school at the age of 4. This value is twice the power (0.50DC) that Gullstrand recommended should be corrected (Gullstrand, quoted in Helmholtz's Treatise on Physiological Optics 1924 p382), but less than the values found in Miller and Harvey's 1998 study. They surveyed 491 AAPOS Members, and found that only 50% would correct astigmatic errors of 1.50 DC and above for children aged between 4 and 7. This value increased to 75% when the astigmatic error reached 2.00 DC.

In patients with astigmatism, the unaided vision is dependent upon the type of astigmatism present. In simple and compound myopic astigmatism, the distance vision cannot be improved by accommodation, and therefore the unaided acuity will be approximately the same as it would be for spherical ametropia of the same mean ocular refraction. However, in simple and compound hypermetropic astigmatism, patients can accommodate to partially improve image clarity. Therefore the blur circle is approximately half the size of that produced by the same amount of spherical ametropia (Rabbetts, 2007, p92). This suggests that in these cases optometrists should only be correcting astigmatism when it reaches twice the amount of the spherical ametropia that

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they would correct. However, this prediction relates to acuity only, and exceptions might occur if astigmatism was causing asthenopia. For example some small astigmatic errors may result in almost normal acuity, but if either focal line can temporarily be focussed onto the retina, accommodation is unstable, and asthenopic symptoms could result.

Shea and Gaccon (2006) attempted to identify the magnitude of refractive error likely to lead to amblyopia, and concluded that astigmatism of less than -1.75DC did not impair visual acuity in three and four year olds.

4.4 ASTIGMATIC AXIS

Many authors have found that the axis of astigmatism greatly influences its effect on the visual system, independently of the astigmatic power, and therefore the axis of astigmatism also needs to be taken into consideration when deciding whether to give an astigmatic correction. Rabbetts (2002, pp83-86) investigated the relationship between the axis of astigmatism and the orientation of the line viewed. He explained that the least amount of blur occurs when the astigmatic axis and orientation of the line are coincident and the maximum amount of blur occurs when they are perpendicular to each other. As most of the letters in the English language have a dominant vertical element, people with against-the-rule astigmatism (corrected by a negative cylinder axis 90°) would experience more blur than those that have with-the-rule astigmatism (corrected by a negative cylinder axis 180°) (see Figure 2.4.). This may be an explanation for Gullstrand's (from Helmholtz Treatise on Physiological Optics 1924) finding that inverse (against-the-rule) astigmatism produced more symptoms than twice the same amount of direct (with-the-rule) astigmatism. Another possible explanation may be found in the ability to squeeze the eyelids together ('eyelid squinting') to reduce the

vertical palpebral aperture. As previously stated, in with-the-rule astigmatism the axis of astigmatism is at 180º and the astigmatic power is perpendicular to the axis at 90º. Squeezing the eyelids together will reduce the palpebral aperture and therefore also reduce the blur in the vertical meridian. However, the astigmatic power in against-the-rule astigmatism is found in the horizontal meridian, and therefore squeezing the eyelids together will have little effect on reducing blur. Both Hirsch (1963) and Gullstrand (cited in Helmholtz Treatise on Physiological Optics 1924) suggest correcting against-the-rule astigmatism as low as 0.50 dioptres, as it may produce asthenopic symptoms, even if visual acuity is unaffected, but only correcting with-the-rule astigmatism if it reaches 1.00DC.

For those individuals with oblique astigmatism, the blur is even greater (Rabbetts, 2007, p85), possibly because they are unable to squeeze their eyelids together to improve their vision unlike patients with against-the-rule and with-the-rule astigmatism (Capone, 1996, p77). Authors such as Ball (1982, p44) therefore suggest that correcting small amounts of oblique astigmatism may significantly improve vision.

This advice is echoed by Viner (2004, p25) who warns that oblique cylinders are likely to cause meridional amblyopia in children if left uncorrected, and therefore oblique cylinders as small as -1.00DC should be corrected if found at any age. She advises correcting other types of astigmatism when they reach -1.50DC.

4.5   ASTIGMATIC DISTORTION

Spatial distortion is a common problem when prescribing glasses for astigmatism. This distortion causes flat surfaces to appear warped and vertical lines tilted.

An excellent paper by Guyton (1977) explains the source of cylindrical distortion, discusses adaptation processes and provides comprehensive guidelines as to how to minimise it. He explains that the unequal spectacle magnification of the retinal image in the different meridians results in the image appearing to be distorted. This effect is at its greatest when the astigmatic axis is oblique, when each dioptre of oblique cylindrical power produces about 0.4° of tilt. This is rarely a problem monocularly, but under binocular conditions even small amounts of tilt can cause significant problems with spatial awareness. For example, if a patient with one dioptre of symmetrical astigmatism at an oblique axis views a vertical object 3 meters away, the retinal images of the object will be tilted towards each other at the top by 0.4° in each eye. This amount of spatial distortion is unlikely to be noticed under monocular conditions, but when viewed binocularly the object will theoretically appear to be tilted towards the patient by 35°.

Guyton continues by describing the two adaptation processes: physiological and interpretative. He suggests that physiological adaptation involves a form of rotational anomalous retinal correspondence, and as that as the ability to develop anomalous retinal correspondence is better in children, this may explain why children often adapt more easily to large cylindrical prescriptions than adults. Adults mainly use interpretative adaptation, gained from monocular perspective clues, but this adaptation may take a few days.

Capone (1996, p75) also advises that symptoms are more likely if the astigmatism present is high or if the axis is oblique, and that patients with small astigmatic errors and young children (under the age of 10), should adapt to the distortion fairly quickly.

Guyton and Capone both advise that cylindrical distortion should not prevent the use of astigmatic lenses, but have provided guidelines for their prescription.

Guyton (1977) suggests that:

1. Children are given the full astigmatic correction.

2. In adults, try the full astigmatic correction first, but with warnings and advice about the possible distortion.

3. To minimise distortion, use minus cylindrical lenses and minimise vertex distances.

4. Check that the distortion is due to the cylindrical correction by occluding one eye. As distortion from an astigmatic correction only occurs in binocular conditions, the distortion should disappear when one eye is occluded.

5. If necessary reduce the distortion by rotating the axis towards 90° or 180° degrees, or towards the old axis. Reduce the cylinder power if necessary using a cross-cyl (a lens with a minus cylinder ground on one side, and a plus cylinder on the other, with the two axes located 90° apart) and adjust the sphere.

6. If distortion still persists consider contact lenses.

Capone (1996, p76) advises that:

1. Children should be given the full correction to prevent meridional amblyopia and counselled about the time it will take to adapt.

2. Children should be encouraged to wear their glasses full-time to aid the adaptation process.

3. For adults, the practitioner needs to take note of the patient's personality. The full prescription should be given to 'laid back' patients who notice an

improvement in visual acuity with the new prescription or who have symptoms with their old glasses. Patients who are more anxious or critical are more likely to experience problems with spatial distortion, and a partial prescription is advisable.

4.6 CONCLUSIONS AND PRESCRIBING GUIDELINES

Both the magnitude and axis of astigmatism need to be taken into consideration when deciding whether to correct a borderline astigmatic error. Most authors suggest that oblique astigmatism is most likely to cause blur and also has the highest risk of causing meridional amblyopia, and as a result even small amounts of astigmatism should be corrected when found. For with-the-rule and against-the-rule astigmatism, the age of correction is important. It is not necessary to correct astigmatism less than two dioptres in children under the age of four, but for older children cylindrical corrections of -1.50 may be given. For adults with astigmatism, against-the-rule is likely to cause more blur and symptoms than with-the-rule, and therefore it is advisable to correct amounts as low as -0.50. With-the-rule astigmatism benefits from correction when it reaches -1.00DC.

CHAPTER 5   A REVIEW OF THE REFRACTIVE MANAGEMENT OF
              PRESBYOPIA

5.1   INTRODUCTION

Deciding when to prescribe a first reading addition is one of the most common decisions encountered in optometric practice. However, it is not always an easy decision and non-tolerance can arise from prescribed reading additions of an inappropriate magnitude. In the Optometric Centre of Fullerton (Southern California College of Optometry), 17.5% of rechecks (appointments to investigate a spectacle non-tolerance) over a year were due to reading additions that were either too strong or too weak (Hanlon et al., 1987).

5.2   PREVIOUS REVIEWS

5.2.1   When to prescribe

As presbyopia is inevitable, all patients will eventually require a presbyopic correction of some sort, even if this simply involves the removal of glasses when reading for patients with myopia. The most important consideration for optometrists is therefore when to prescribe a first presbyopic correction, and Kurtz (1996, pp149-154) believes that several factors will influence this decision. The most obvious factor is the patient's habitual working distance. Different tasks are performed at varying distances and as a result will require different amounts of accommodation. The typical working distance and accommodation for various tasks is illustrated in Table 5.1.

Table 5.1 Typical working distance and accommodative demand for various tasks (measurements from Kurtz, 1996, p151)

Task	Working distance (cm)	Accommodation (D)
Stockmarket reports/telephone directories	30	3.0
Newspapers and books	40	2.5
Knitting	50	2.0
VDU	60	1.7
Music (in an orchestra)	70	1.4

The age of onset of presbyopia will also depend on the patient's stature: patients with shorter arms require a correction earlier than those with longer arms, and many optometrists will have experience of patient's complaining that their 'arms are too short'. Other patients will report that pulling their distance glasses down their nose makes near tasks easier, and Kurtz (1996, pp152-153) explains that this is due to lens effectivity (the change of vergence as light travels from one point on its path to another). In patients with spectacles for myopia, the stimulus to accommodation declines as the vertex distance of the spectacles increases. This can delay the need for a presbyopic correction, and in general a smaller reading addition is needed in myopia than in hypermetropia. Further explanation of lens effectivity is outside the scope of this thesis, but further information can be found in *Bennett and Rabbett's Clinical Visual Optics*, pp 10, 137-138.

Pointer's (2002) retrospective review of 816 routine patient records showed that the first reading addition was prescribed over a large range of ages. The youngest patient

prescribed their first reading addition was 38 years of age and the oldest was 55 years of age. There was also a wide range of prescribed initial reading addition prescribed: the smallest being +0.50DS and the largest +2.00DS. It has long been believed that females require their first reading addition earlier than males, and this was confirmed by Pointer who found that females required their first reading addition approximately one year earlier than males. However, he suggests that the difference in age may be because males with near vision difficulty postpone having an eye examination for longer than females, rather than any physiological difference due to gender. He also found that females require a higher initial reading addition than males, particularly if they are under 40 years of age ($p=0.002$), and suggested that this may be because females have, on average, shorter arms than males, and consequently have a shorter working distance.

Several other authors have also found that females require a higher reading addition than males of the same age, but that the mean difference was very small. Hofstetter (1949) reviewed the reading addition prescribed to patients aged between 39 and 69 by six different optometrists He found that the reading additions given to females were consistently higher than those given to males in all the age groups by about 0.12DS.

Kragha and Hofstetter (1986) analysed the information provided by 577 optometrists in North and Central America regarding the reading addition they typically prescribe for patients aged 45 to 60. Their results also showed that reading additions given to females were significantly higher than males when tested with a two tailed t-test ($p<0.05$), but the mean difference was less than that recorded by Hofstetter (1949) at 0.05 to 0.06DS. As the mean difference remained the same across all the age groups, the authors concluded that it was more likely to be attributable to a difference in stature rather than

the age of onset, and would be equivalent to females holding reading material 8mm closer than males.

5.2.2   Methods of determining the reading addition required

There are several methods available to the practitioner when deciding the magnitude of reading addition to prescribe.

In the Binocular Cross Cylinder method, a cross cylinder (+0.50/-1.00x90) is placed before the patient's eye, and extra plus power is added until both the vertical and horizontal lines on a cross cylinder grid appear equally clear. The amount of plus power added is then prescribed as the reading addition.

In the NPA (negative relative accommodation)/PRA (positive relative accommodation) method, the reading addition prescribed is modified to ensure balance between the negative and positive fusional reserves. The patient wears their distance correction, and any additional plus power to enable them to see one or two lines larger than their best near acuity on the near point card. Negative relative accommodation is then measured by adding plus lenses binocularly until the letters become blurred. These extra lenses are then removed, and minus lenses are added until the letters are blurred to measure the positive relative accommodation. The reading addition is then adjusted so that both the NRA and PRA are equal.

A reading addition can also be prescribed based on the amplitude of accommodation. With this technique the push up method is used to measure the amplitude of accommodation and the reading addition prescribed is a proportion of that value. In the push up method, a near target (such as a line of text) is brought closer to the patient's

eyes until it becomes blurred. The amplitude of accommodation is then calculated as the inverse of this distance (in metres). For example, if the near point was 10 centimetres (0.10 metres), the amplitude of accommodation is calculated as 1 divided by 0.10, giving a measurement of 10 dioptres (Elliott, 2007, p191). This method of determining the reading addition assumes that no more than a half to two thirds of the total amplitude of accommodation can be used without asthenopic symptoms, but there is debate as to how much accommodation should be left in reserve. Millodot and Millodot (1989) attempted to establish this amount by measuring the amount of accommodation present with the optimal reading addition in place, and found that most patients used half of their available accommodation. However the amount used was statistically higher in females (who only left a third in reserve) than males (who left half in reserve) and also decreased significantly with age. This method is not suitable for patients over the age of 55 as their accommodation amplitudes are reduced to virtually zero and all that will be measured is depth of focus.

The simplest method of determining a reading addition is based on the patient's age, with the practitioner referring to a table with age-related norms. This approach is supported by the work of Hofstetter (1965) and Charman (1989) who demonstrated that accommodation decreases linearly with age, reaching zero at about the age of 47. They advise that after this age it is not accommodation that is being measured, but depth of focus. The main limitation of this approach is the assumption that accommodation decreases at the same rate in all people. As this is not the case, prescribing a reading addition based on age-matched norms, may result in the incorrect power being prescribed.

Hofstetter (1949) looked at the reading addition prescribed to the patients of six optometrists, and the method used for determining the addition given. He found that there was only a very small difference in the reading addition prescribed by all six of the optometrists despite the fact that several different methods of determining the prescription were used. He also noted that for each patient age group, there was a large spread of reading additions prescribed, and concluded that most practitioners do not prescribe based on age, but based on another technique.

Hanlon et al. (1987) compared the above four methods of prescribing a reading addition in 37 patients who were returning for a recheck due to problems with their reading prescription. They found that prescribing a reading addition based on the patient's age accounted for the fewest errors (14%) and the Binocular Cross Cylinder method accounted for the most errors (61%). From their findings they developed prescribing guidelines, which suggested prescribing additions only of 1.00D and over. This is in agreement with several other authors who have also provided guidelines based on age (Table 5.2).

Table 5.2 Suggested reading addition based on the patient's age

Age (Years)	Addition required (Dioptre Spheres)		
	Kragha and Hofstetter (1986)	Hanlon et al. (1987)	Borish (1975)
40		1.00	—
45	1.25	1.25	0 – 1.00
50	1.78	1.62	1.00 –1.75
55	2.12	1.87	1.50 – 2.25
60	2.34	2.12	1.75 – 2.50
65	—	—	—
70	—	—	—

Elliott (2007, p133) suggests that, in routine practice, the first reading addition tried should be based on the patient's age as it provides a useful starting point, in the same

way that retinoscopy provides a starting point for a subjective refraction. However, he then advises modifying and refining the reading prescription with other methods, such as using +0.25DS and -0.25DS confirmation lenses, and checking the range of clear vision.

The working distance, pupil size, and the available accommodation that patients can comfortably use, will also vary from one individual to another. For these reasons, the empirical approaches outlined in the studies reviewed above are at best a starting point, and will never replace the need for careful refractive testing. Similarly, the use of formulae to assist in relating the available accommodation to working distance in order to determine the required reading addition (e.g., Borish, 1970, pp179-182; Rabbetts, 2007, pp131-132) should also be considered a starting point.

5.3 CONCLUSIONS AND PRESCRIBING GUIDELINES

The literature shows that there is considerable variation in the initial reading addition prescribed by practitioners. This variation is demonstrated by Pointer (2002) who investigated the relationship between gender, the age at which a reading addition is first required and the power of the initial add. His results showed that the most common initial addition required was +0.50DS (37.5% of males and 35% of females), but that in some cases the initial reading addition prescribed was as high as +2.00DS. Ball (1998) also states that the smallest reading addition prescribed is +0.50DS, but this is disputed by Kurtz (1996, p146 and p156) who claims that reading additions of less than +0.75DS are rarely prescribed, and by Hofstetter (1949) who found that practitioners rarely prescribe reading additions of less than +1.00DS. However, Kragha and Hofstetter's (1986) survey of bifocal prescribing practices showed that the mean add prescribed to patients aged 45 was approximately +1.25D.

There are many different factors to consider when prescribing a first presbyopic correction and also many different techniques used to determine the correct reading addition. This makes it difficult to provide definitive guidelines for the correction of presbyopia, but typically the first spectacles prescribed tend to be for reading additions of between +0.50D or +1.00D.

CHAPTER 6   DESCRIPTION AND DEFINITION OF HETEROPHORIA

6.1   DEFINITION

Heterophoria occurs when the two eyes have a tendency not to be directed towards the point of fixation in the absence of an adequate stimulus to fusion (Millodot, 2009, p152). This deviation of the eyes only occurs when they are dissociated (either by covering one eye or distorting the image to prevent fusion) in contrast with strabismus when the eyes are misaligned under normal viewing conditions (Evans, 2007b, p4).

Heterophoria can be classified clinically according to the direction of the deviation, the distance at which it occurs (usually either at 6m or 40cms) and by whether the heterophoria is compensated (Evans, 2007b, p6).

6.2   CLASSIFICATION

A lateral deviation under dissociation is termed horizontal heterophoria. This deviation is classified as an exophoria when the visual axes are divergent when dissociated, and an esophoria when the visual axes converge on dissociation (Evans, 2007b, p6).

A vertical heterophoria occurs when the visual axes are vertically misaligned when the eyes are dissociated. If the right eye is higher than the left, the deviation is termed a 'right hyperphoria' and if the left eye is higher, a 'left hyperphoria' (Evans, 2007b, p6). Some authors still use the term hypophoria to describe a deviation of the eye downwards on dissociation of the eyes. As a heterophoria is a binocular condition, a right hyperphoria is usually the same as a dissociated deviation of the left eye downwards, and a right hypophoria is equivalent to a left hyperphoria. As a result the

term hypophoria is now falling into disuse, and therefore the terms right or left hyperphoria will be used throughout this thesis, unless quoted from another author.

Clinically the most important aspect of a heterophoria is whether it is compensated (Evans, 2007b, p7). A decompensated heterophoria is one of the most common binocular vision anomalies and is generally considered to be a heterophoria that is causing symptoms or having a detrimental effect on binocular vision. There are many ways of assessing whether a heterophoria is compensated but unfortunately there is no single test that will provide a conclusive diagnosis in all cases. Compensation is returned to in more detail in section 6.6.

6.3 INCIDENCE AND PREVALENCE

The reported incidence and prevalence of heterophoria in the literature varies depending on how the heterophoria has been measured and classified, but is generally believed to be high, as detailed below.

6.3.1 Horizontal heterophoria

The distribution of horizontal heterophoria at near (Freier and Pickwell, 1983) is shown in Figure 6.1 and the distributions of horizontal aligning prism at near for symptomatic and asymptomatic patients (Pickwell et al., 1991) is shown in Figure 6.2.
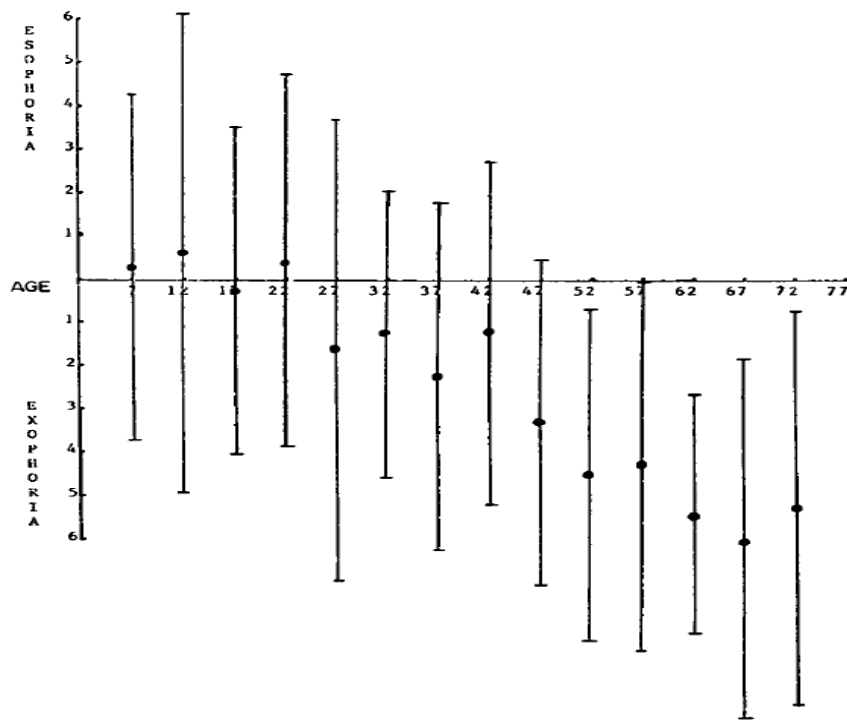
Figure 6.1 The distribution of heterophoria in near vision (Δ) with increasing age (years) is shown by the dots. One standard deviation on each side is indicated by the lines. Freier and Pickwell (1983).
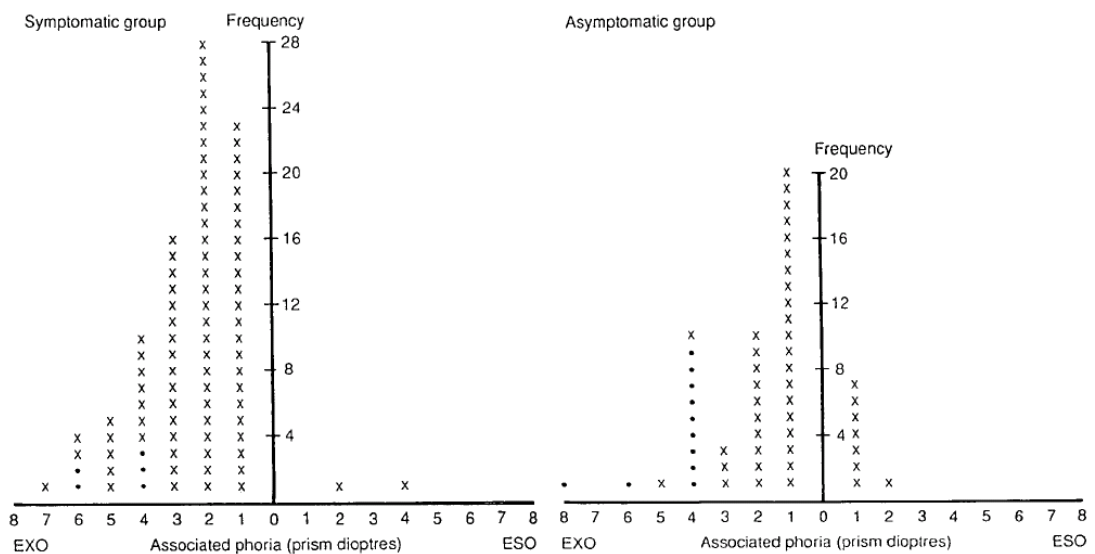
Figure 6.2. The distribution of near aligning prism measurements for symptomatic and asymptomatic subjects. Those with zero readings have been omitted (Pickwell et al. 1991).

Considering the prescribing of horizontal prisms, the prevalence of horizontal prism is generally higher than vertical prism as shown in Bennett (1965). Out of the total sample of 21042 single vision lenses, 580 contained horizontal prism of at least 0.25Δ (2.8%), and 98% of the horizontal prisms prescribed were for powers under 3.25Δ. More

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detailed information about the number of times each prismatic power was prescribed is shown in Table 6.1.

Table 6.1 The percentage of time practitioners prescribe horizontal prism (original data from Bennett, 1965)

Prism Power (Δ)	0.5	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Number of times prescribed	67	24	263	0	90	2	102	0	6	2	25
Prevalence (%)	0.32	0.15	1.25	0	0.43	0.01	0.49	0	0.03	0.01	0.12

6.3.2   Vertical heterophoria

A literature search (keywords [vertical OR hyper*] AND [heterophoria] AND [distribution OR norms OR population] revealed no publications describing the distribution of vertical heterophoria in the general population. However, Rabbetts (2000) states that 'Vertical heterophorias are much smaller [than horizontal], seldom more than 1Δ and rarely more than 2Δ'.

Considering the prescribing of vertical prisms, the only two papers that reviewed the records from a broad range of subjects from a variety of backgrounds were by Bennett (1965) and Rabbetts (2007, p422) who analysed the results of a Ministry of Health Survey into NHS prescribing undertaken in 1962. Even then, the data only included information on glasses actually prescribed, and therefore does not include subjects who had not had an eye examination or those people with very small refractive errors where glasses were not required. As a result, their analysis is likely to underestimate the prevalence of small refractive errors or aligning prism. Bennett's (1965) analysis of the data indicates that the prescription of vertical prism in the general population is very low, as vertical prisms of at least 0.25Δ were only prescribed in 258 out of the 21042 single vision lenses (1.2%) in the study. However, 94% of the vertical prisms prescribed

were under 3.25Δ. A more detailed summary of the prescription of vertical prism can be found in Table 6.2.

Table 6.2 The percentage of time practitioners prescribe vertical prism (original data from Bennett, 1965)

Prism power (Δ)	0.5	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Number of times prescribed	61	13	90	0	30	1	42	0	3	0	15
Prevalence (%)	0.29	0.06	0.43	0	0.14	0.005	0.20	0	0.01	0	0.07

6.3.3　　　　　Distance heterophoria

Distance heterophoria is reported as being more common in adults than children, with the reported prevalence varying between 3% and 76%. Morgan (1944) reviewed clinical data published before 1944 in an attempt to establish 'norms' for various visual functions and states that 76% of subjects had a distance heterophoria between 1 prism dioptre (Δ) esophoria and 3Δ exophoria, with the mean value being 1Δ exophoria. Unfortunately he does not state which tests were used to obtain these values, but in the paper he advocates the use of the Maddox Rod test to control accommodation and minimise the effect of peripheral fusion, and it is therefore possible that this was the test reviewed.

Dowley (1990) measured the distance dissociated heterophoria (see section 6.5.1 for the definition) of 925 symptom-free subjects using a Maddox Rod technique and found that 625 (68%) had a heterophoria of at least 1Δ.

However, Walline et al. (1998) performed cover tests on 1495 children and found that distance heterophoria of at least 2Δ was only present in 3% of the children.

6.3.4   Near heterophoria

It has previously been noted that esophoria at near is rare (Jenkins et al., 1989). Yekta et al. (1989) measured the dissociated heterophoria, aligning prism and fixation disparity (see 6.6.4 for definition) for near vision in 187 subjects. There were only six subjects with esophoria and these were all under the age of 40. However, Walline et al. (1998) demonstrated that there is a convergent shift in the amount of near heterophoria in children as they grow older. At the age of about five (Kindergarten) the prevalence of near exophoria and esophoria was 31.8% and 6.7% respectively. However at the age of about 11 (fifth grade) the prevalence of exophoria at near had decreased to 21% and the prevalence of near esophoria had increased to 12.2%.

6.3.5   Decompensated heterophoria

There is a variety of reported prevalence for decompensated heterophoria in the literature, and this is likely to be related to the differing criteria used to classify the heterophoria as decompensated. The methods available to assess compensation will be discussed in more detail in section 6.6, however most studies quoting incidence and prevalence values of decompensated heterophoria broadly classify the heterophoria as decompensated based on a combination of symptoms, and clinical signs.

Several authors have reported the prevalence of decompensated heterophoria as approximately 20%. Hokoda (1985) found that symptomatic general binocular dysfunction was present in 21% of 119 patients under the age of 40 and Pickwell et al. (1991) found that 18% of patients attending for a routine eye examination have signs and symptoms suggesting a decompensated heterophoria. Similarly, 22% of the subjects had vergence disorders and symptoms in Montes-Mico's (2001) study of 1679 pre-

presbyopes, and Karania and Evans (2006) found a similar figure of 20% in their study of 105 subjects aged between 8 and 71 years old.

However, Stidwill (1997) found the prevalence of decompensated heterophoria to be much lower at only 4.86 per 1000 (0.5%) in his review of the records of 60,000 patients aged six or over attending for a routine eye examination over a period of 15 years. This difference may be attributable to the fact that subjects were classified as having a decompensated heterophoria if they had an aligning prism on either the near or distance Mallett fixation disparity test on two separate occasions, compared to the other authors above, who only tested the subjects once.

6.4 PHYSIOLOGICAL HETEROPHORIA

A physiological heterophoria is a heterophoria that is deemed to have occurred as part of the normal function of the binocular vision system.

6.4.1 Heterophoria and aging

Exophoria is common in near vision and increases with age. The increase in near exophoria occurs as a result of under-convergence as the fixation distance decreases (Freier and Pickwell, 1983). Snydacker (1963) indicated that the amount of near exophoria increases by about 1.5Δ for every 20 years of age, and Sheedy and Saladin (1975) found that near heterophoria for subjects with absolute presbyopia (over 55 years) increases to between 8Δ and 10Δ of exophoria from the norm of 3Δ for non-presbyopic subjects

Although there is a trend towards increasing near exophoria with aging, several authors have shown that distance heterophoria is independent of age (Freier and Pickwell, 1983, Dowley, 1990 and Walline et al., 1998).

As the distance heterophoria remains largely static, and the near heterophoria changes towards increasing exophoria over time, the difference between the distance and near heterophoria also increases, and this difference is termed physiological exophoria. Freier and Pickwell (1983) measured the distance and near dissociated heterophoria on 663 patients attending for a routine eye examination and found that physiological exophoria first becomes apparent at the age of 20 years, and continues to increase throughout life to reach a mean value of 5Δ in the researchers' oldest age group of 75 and over.

6.4.2   Proximal and accommodative convergence and the effect on near
             heterophoria

Both proximal and accommodative convergence can influence the near heterophoria, because of the accommodative/convergence relationship. For example, young patients with myopia often exhibit a near esophoria when first given a refractive correction. This is because when uncorrected, excess proximal convergence was used instead of accommodative convergence. Similarly, a newly corrected presbyope will often have a large near exophoria. Again, this is because before the presbyopic correction they would have been using a large amount of accommodative convergence, and little proximal convergence. When wearing their new glasses, the accommodative demand is considerably reduced and without the proximal convergence, an exophoria results (Carter, 1963). Both these conditions reduce rapidly within a few days of wearing the

new glasses, and may be considered a physiological heterophoria (see section 7.4 for details about vergence adaptation).

6.5 MEASUREMENT OF HETEROPHORIA

Heterophoria can be measured under conditions of complete dissociation of the eyes, and also when only part of the visual field is dissociated. Confusingly, this second method of heterophoria measurement using partial dissociation is often termed the associated heterophoria. As the term heterophoria implies dissociation (it is a deviation that only occurs during dissociation of the eyes, even if it is only partial dissociation) the term 'associated heterophoria' is a contradiction. Therefore the International Standards Organisation has proposed replacing the term with 'aligning prism' (Evans, 2007b, p75). As a result the term aligning prism is now in widespread use and for the purposes of this work the term aligning prism will be used, unless quoting an author using another term.

6.5.1 Dissociated heterophoria

Dissociated heterophoria is defined as a deviation from the orthovergence position that occurs when no fusionable contours are provided. (Otto et al., 2008). It is revealed by methods that produce complete dissociation such as the cover test, the Maddox rod test, the modified Thorington test, the von Graefe's test (Millodot, 2009, p152; Evans, 2009, p246), and the Maddox Wing.

The cover test is an objective test that can be used to both measure the amount of heterophoria and assess the compensation (see section 6.6.3). The Clinical Practice Survey by The College of Optometrists in 1998 (Stevenson, 1999) revealed it to be the most common technique used to assess heterophoria, and it is the only clinical test that

can distinguish between a heterophoria and a strabismus. One eye is covered for approximately two seconds whilst the patient fixates a letter on a chart. If the uncovered eye moves to take up fixation, a diagnosis of strabismus is made. The occluder is then removed and if there is movement of the covered eye, and a strabismus was not present, a diagnosis of heterophoria is made. The magnitude of the heterophoria is measured by adding prisms in front of the eyes until the eye movement is eliminated. One of the test's main advantages is that it can be performed at any fixation distance.

In the Maddox rod test, one eye views a spot of light unaided, and the other through a Maddox groove consisting of a series of high powered cylinders that make the spot appear as a streak. Prisms are then added until the streak appears to go through the spot of light to determine the magnitude of the heterophoria. A variation of this test is the flashed Maddox rod technique, where the Maddox rod is only shown for a very short period of time (typically 0.25 seconds by the use of a photographic shutter). Another useful variation of this test, used for vertical and cylotorsional deviations, is the double Maddox rod test. This consists of two Maddox rods of the same colour. The lenses are placed one before each eye with their axes vertical so that two horizontal lines are seen. A vertical deviation is revealed by a separation of the lines, and cyclodeviations by tilting of one or both of the lines. A disadvantage to tests using the Maddox Rod is that the stimulus to accommodation is not controlled when used at close working distances.

A Maddox rod is also used in the modified Thorington test. In this test the Maddox rod is placed before one eye, whilst the patient views of spot of light shone through a hole in a card. The card contains rows of horizontal and vertical numbers, calibrated in prism dioptres for the appropriate distance, and the magnitude of the heterophoria is recorded as the number that the patient reports the streak of light to be going through.

In Von Graefe's test dissociation is achieved by using a prism that is too large to be fused and whose axis is orthogonal to the direction of the heterophoria being measured (e.g. to measure a horizontal heterophoria a 10Δ base-up or down would be placed before the eye to cause vertical diplopia). The patient then views a single isolated letter one line larger than the visual acuity in their worst eye, and horizontal prisms would be introduced until the two diplopic images were vertically aligned.

The Maddox Wing (Figure 6.3) causes dissociation by a septum, with one image viewing an arrow and the other a tangent scale. A disadvantage to this test is that the testing distance is fixed. Apart from the Maddox Wing test, dissociation tests above can be carried out at 6m and for the reading distance. More detailed descriptions of these tests can be found in optometric textbooks (Evans, 2007b, p68, and Evans, 2009, p246).

Figure 6.3 The Maddox Wing

There are several other types of dissociation test available such as Scobee's test and haploscopic devices such as the synoptophore. They are not widely used in routine optometric practice in the U.K. and so are not discussed in detail here.

All the above tests are subjective, and the measurements can be influenced by the degree and duration of dissociation and will vary as the stimulus to accommodation changes. As a result the various techniques will produce different results making it difficult to interpret the findings. The measurement of dissociated heterophoria alone is of little help in assessing whether a heterophoria is compensated (Yekta et al., 1989) and whether it needs treating and it is doubtful if dissociated techniques are the best way of spending time in a routine eye examination (Evans, 2007b, pp68-69). Nonetheless, the measurement of the degree of dissociated heterophoria may be useful in some cases, such as for monitoring whether a deviation is changing. Another occasion when this measurement is useful is when quantifying the relationship between the dissociated heterophoria and the opposing fusional reserves, in the assessment of compensation (see section 6.6.5).

6.6   ASSESSMENT OF COMPENSATION

6.6.1   Magnitude of heterophoria

Several authors have stated that the magnitude of dissociated heterophoria is a poor predictor of symptoms (Sheard, 1931), and research has found no statistically significant relationship between these two variables for horizontal heterophoria (Yekta et al., 1989).

Jenkins et al. (1989) used receiver operating characteristic curves (see section 11.10.1 for a description) to investigate the cut-off value that would predict whether patients had symptoms due to decompensated heterophoria. They found that for dissociated heterophoria measurements there was no cut-off point that would distinguish those subjects with symptoms from those without.

Ip et al. (2006) investigated whether eyestrain symptoms in children were related to visual anomalies and found that symptoms were surprisingly rare in children with a near exophoria of over 10Δ. Out of the 1740 children examined only 35 (2.0%) had a near exophoria of more than 10Δ and no esophoria of over 10Δ at near was seen. Only 5 of the 35 (14.3%) children with over 10Δ of exophoria at near had symptoms of eyestrain, and this group represented 2.3% of the total of 220 children with eyestrain symptoms. The authors calculated that a near exophoria of over 10Δ had a sensitivity of 0.14 (and a specificity of 0.85) in identifying those children with symptoms, and this suggests that the magnitude of near exophoria is a poor indicator of heterophoria compensation.

6.6.2   Symptoms

A decompensated heterophoria usually causes symptoms, but may occasionally not cause symptoms if suppression occurs (Evans, 2007b, p62). Symptoms associated with decompensated heterophoria can be divided into three categories: visual (blur, diplopia, distorted vision), binocular factors (difficulties judging distances, monocular comfort, difficulties changing focus) and asthenopia (headache, aching eyes, sore eyes) (Evans, 2009, p244). Jenkins et al. (1989) also suggested that headache, distorted vision and poor reading performance can be an indicator of decompensation.

Carter (1963) believed that patients with significant asthenopia almost always have a decompensated heterophoria, but added that symptoms are more likely in vertical heterophoria compared to horizontal, and in esophoria compared to exophoria. He attributed this to the different amounts or vertical, divergent and convergent fusional reserves.

Jenkins et al. (1989) found that symptoms in general are very common. They asked subjects to fill in a symptom questionnaire, and found that the symptomatic group was 75% larger than the size of the asymptomatic group. However, although the presence of symptoms is an indicator for decompensation, it should not be looked at as the only factor. Many of the symptoms found in decompensated heterophoria can also be attributable to other conditions, and it can be difficult to determine their origin. Symptoms are also often vague, and as a result are rarely reliable indicators of an intervention's benefit (Cholerton, 1955; Nathan, 1957 and Ball, 1982). It is therefore recommended that practitioners carry out further clinical tests and combine their results to help confirm whether symptoms are attributable to a decompensated heterophoria (Evans, 2007b, pp 86 and 91).

6.6.3   Cover test recovery

The cover test is often considered to be a quick and useful way to assess compensation during a routine eye examination (Evans, 2007b, p23). After the diagnosis of heterophoria has been made, the recovery of the eyes to their original position should be observed.   A smooth and quick recovery indicates that the heterophoria is fully compensated, whereas decompensation is likely if the recovery is slow and hesitant. The recovery of the cover test can be graded further from 1 to 5 as described in Table 6.3. However, although the speed of recovery may be useful in assessing compensation, there appears to be little evidence in the literature to support this, and further research is indicated.

Table 6.3 Cover test recovery grading. Reproduced with kind permission from Professor Bruce Evans.

Grade	Recovery
1	Rapid and smooth
2	Slightly slow/jerky
3	Definitely slow/jerky but does not break down into a strabismus
4	Slow/jerky and breaks down with repeat covering, or only recovers after a blink
5	Breaks down readily after 1-3 covers

6.6.4   Fixation disparity

In normal binocular vision, the fovea of one eye corresponds with a small area centred on the fovea of the other eye. This area is called Panum's area and allows the eyes to be deviated by a very small amount (less than 0.25Δ) without loss of fusion (Evans, 2007b, p73). Fixation disparity occurs when the image in one eye does not fall on the corresponding point in the other, but still falls within Panum's area (Millodot, 2009, p99). The amount of prism needed to correct a fixation disparity is much less than the amount of dissociated heterophoria and has been termed the aligning prism or associated heterophoria (Millodot, 2009, p152; Otto et al., 2008).

In fixation disparity tests, part of the visual field is dissociated whilst the rest of the visual field is fused with a fusion lock. The dissociation is achieved by cross polarisation (e.g. Mallett fixation unit, Sheedy disparometer) or a septum (e.g. Turville infinity balance test).

Fixation disparity is not always a stable measurement, as demonstrated by Mitchell and Ellerbrock (1955) who found that an individual's horizontal fixation disparity measurement can vary considerably over time. They analysed their data using t-ratios and found a statistically significant difference in the fixation disparity measurements on the same subject, when measured just four months apart. However, this finding was obtained using a fixation disparity test without a fusional lock. Tests that have a fusion lock give more reliable data (reviewed by Evans, 2007b). This may explain the better repeatability obtained by disputed by Dowley (1989), who found that the fixation disparity measurements taken from 10 subjects using the near Mallett Unit had a mean difference of less than 0.5Δ. Each subjects had their fixation disparity measured on ten separate occasions over a 40 day period using the same Mallett Unit. Vertical fixation disparity measurements have been found to be more stable, and Rutstein (1992) found that the slope of a vertical fixation disparity curve changed very little from morning to evening, and from month to month.

Fixation disparity can be considered to be either physiological or abnormal. The first belief assumes that a small amount of fixation disparity represents an error in the eye's alignment and provides feedback to help control vergence. This belief is supported by Saladin and Sheedy (1978) who found that many asymptomatic subjects have been found to have a fixation disparity. However, these measurements were taken on the Sheedy disparometer, which has been found to be inconsistent (Dowley, 1989), especially with unobservant subjects and children, and to have a significant learning effect (Pickwell et al. 1988). This is likely to be due to the lack of a central fusional lock, which results in viewing conditions that are unlikely to represent natural viewing conditions where central fusionable contours are always present (Sheedy, 1986). In

addition Carter (1964) found that fixation disparity measurements taken with only peripheral fusion contours are larger than measurements obtained with foveal fusion contours present, and that fixation disparity also reduced rapidly (over two to three minutes) in the presence of foveal fusion, but not when only peripheral contours were used. Pickwell suggests that this is because there is less movement of the Nonius lines when a fusional lock is used close to fixation, as Panum's fusional areas are smaller closer to the fovea than in the periphery As a result the fixation disparity values found on the Sheedy disparometer are typically greater than those found on the Mallett unit (Pickwell et al., 1988).

The second school of thought is that any fixation disparity is a sign of stress and should be corrected. The theory behind this belief is that the cortical response is significantly greater when the monocular receptive fields are superimposed very precisely, and evidence is provided by studies in the UK using the Mallett Unit which showed that fixation disparity is uncommon in asymptomatic subjects (Jenkins et al., 1989). A key component of the Mallett fixation disparity test is the inclusion of a good foveal and peripheral fusion lock which makes viewing conditions more closely resemble normal reading. These attributes improve the stability of results and the ability of results to predict symptoms (Karania and Evans, 2006). However it should be noted that, unlike the Sheedy Disparometer, the Mallett unit does not actually measure the amount of fixation disparity, but rather the amount of prism needed to correct it (known as the aligning prism). Mallett argued that as his fixation disparity test was carefully designed to have good foveal and peripheral fusion locks, the presence of a fixation disparity indicates that the heterophoria is decompensated and the aligning prism identifies the uncompensated portion of the binocular anomaly (Mallett, 1964).

In addition to facilitating the diagnosis of decompensated heterophoria, the Mallett fixation disparity test is also a useful tool for prescribing for this condition and this will be explored in more detail in section 7.3. A good review of fixation disparity measurement and its interpretation can be found in Carter (1980).

Fixation disparity measurements can also be analysed in terms of 'fixation disparity curves' where the degree of fixation disparity is plotted against increasing amounts of prism placed before the eye. The curves produced are mainly sigmoid in shape and can be broadly split into 4 different types. The curves can be used in the assessment of compensation, as it has been shown that if the habitual fixation disparity lies in the flattest part of the curve, the heterophoria is likely to be compensated (Sheedy and Saladin, 1978). Plotting these curves requires equipment that measures the actual amount of fixation disparity such as the Sheedy Disparometer, which is not widely used in the U.K. It is also very time consuming, typically taking 10-20 minutes (Despotidis and Petito, 1991) although this is disputed by Pickwell et al. (1988) who completed fixation disparity curve measurements on both experienced and inexperienced subjects in less than 5 minutes. However it is rarely used in routine eye examinations. A good review of these types of curves and their interpretation can be found in Despotidis and Petito (1991).

6.6.5   Fusional reserves

Fusional reserves are a clinical measure of the ability of the vergence system to control a heterophoria. Prisms are gradually added before each eye until the patient reports blur (blur point) and then diplopia (break point). The prisms are then gradually removed and the recovery point is taken as the point where single vision is restored. Base-in prisms are used to measure the divergent fusional reserves, and base-out prisms used to

measure the convergent reserves. Vertical reserves can also be measured. Fusional reserve measurements can vary considerably depending on the speed and symmetry with which the examiner increases the prism demand, and the targets used. The influence of accommodation can also vary and some patients do not report a blur point (Evans, 2007, pp69-70). The fusional reserves can be used to assess whether a heterophoria is decompensated, and both Percival and Sheard have developed criteria to aid in this assessment.

6.6.5.1   Percival's criterion

In Percival's criterion, Donders' line (or the demand line) should lie within the zone of comfort, which is the middle third of the total range of relative convergence (to the blur points). If the criterion is not met, appropriate prisms, spherical lenses or visual training can be used, to shift the demand point within the zone of comfort (Millodot, 2009, p82).

Sheedy and Saladin (1978) found that Percival's criterion was the best predictor for symptoms in subjects with a near esophoria. However this applied only when the rule was applied to the fusional reserve break point and not when used with the blur point.

A major criticism of Percival's criterion is that no reference is made to the actual heterophoria of the subject, and for this reason it has been criticized by several authors (Millodot, 2009, p82).

6.6.5.2   Sheard's criterion

Sheard's criterion is a rule to establish whether a patient is going to experience discomfort in binocular vision. It states that the amount of heterophoria should be less than half the opposing fusional vergence in reserve. If the criterion is not met,

appropriate prisms, spherical lenses or visual training can be prescribed. For example, if a patient has 10Δ of exophoria, the positive fusional vergence should be at least 20Δ to satisfy this criterion (Millodot, 2009, p82).

Worrell, Jr. et al. (1971) found that subjects with distance esophoria, and presbyopic subjects with near exophoria, preferred prisms prescribed according to Sheard's criterion compared to no prism. However Sheard's criterion was not helpful for prescribing prisms for pre-presbyopic subjects or for subjects with exophoria at 6m. Sheard's criterion was also found to be the best discriminator between symptomatic and asymptomatic subjects with exophoria when compared with measurements of dissociated heterophoria and fixation disparity (Sheedy and Saladin, 1977). However, the symptomatic subjects in this study were already known to have a horizontal heterophoria and therefore the results may not be applicable to the general population as a whole. The authors addressed this problem in a later study (Sheedy and Saladin, 1978) where the subjects for both the symptomatic and symptomatic group were taken from the same population (third year optometry students). The results again showed that Sheard's criterion was the best predictor of near symptoms in exophoria. However the questionnaire designed to classify patients as being symptomatic or asymptomatic was vague. Patients were asked if they had asthenopia, but the term asthenopia was not defined. Although the subjects were optometry students and were likely to understand the meaning of 'asthenopia', asthenopia covers a broad range of symptoms, and it is possible that the term was interpreted differently by each subject. In addition, the subjects were asked how often asthenopia occurred and were given the options of: always, quite often, once in a while or seldom. Again no definition of these terms was given (e.g. once a week) and one subject's interpretation of 'quite often', is likely to be different from another person's interpretation.

Mallett (1964) cautioned against assessing heterophoric compensation by measuring the opposing fusional reserves. He highlights the fact that fusional reserve measurements can vary depending on the test method, target used, the speed of movement and the subject's ability to concentrate, making the results too variable to be useful. He added that as the measurement of the first reserve would almost certainly influence the measurement of the opposing reserve, that using Percival's or Sheard's criteria would also be unreliable unless an inconveniently long interval was left between the two measurements.

6.6.6   Other signs of decompensation

Other signs of decompensation include foveal suppression, reduced binocular visual acuity and a reduction in stereoacuity. These adaptations usually occur if the heterophoria has been decompensated for a long period of time, although the literature does not give any details as to how long this time period actually is.

Longstanding fixation disparity is frequently accompanied by foveal suppression, which may act as a compensatory mechanism to prevent symptoms in a decompensated heterophoria (Evans, 2007b, p82). In cases of foveal suppression, the patient will use a parafoveal fusional lock, and as Panum's areas are larger in the periphery, the fixation disparity measured will also be larger (Evans, 2007, p78).

Pickwell (1977) interviewed the Polatest's (see section 7.3) creator Herr H.J. Haase who suggested that in long-term fixation disparity, a form of anomalous correspondence can develop. He explained that this adaptation was different from that seen in strabismus, as it only occurs under binocular viewing conditions, and named this sensory adaptation

'correspondence disparity'. In most cases of correspondence disparity there would be no misalignment of the monocular markers on a fixation disparity test. The patient may be asymptomatic (although Haase disputes this), but if disparate correspondence is present, visual acuity may be reduced (Lie and Opheim, 1985).

Jenkins et al. (1994) investigated the relationship between distance binocular and monocular visual acuities in 20 patients attending an optometric practice for a routine eye examination, with a fixation disparity of at least 2Δ on the Mallett Unit. They demonstrated that uncorrected aligning prism of 2Δ or more resulted in a reduction in binocular visual acuity, whereas no reduction in binocular visual acuity was found in those subjects without a fixation disparity.

When a heterophoria is decompensated or is associated with central suppression or amblyopia the stereoscopic perception may be reduced (Rutstein et al., 1994). Tests of stereoacuity can be divided into those which use true random dot stimuli (e.g. TNO test and Randot test) and those which use contours (e.g. Titmus Wirt circles test). Although patients with decompensated heterophoria may exhibit stereoacuity on the contoured tests, the level of stereoacuity is likely to be reduced (Evans, 2009, p244).

6.6.7   Aligning prism (associated heterophoria) verses dissociated heterophoria

Both dissociated heterophoria and aligning prism have been recommended as indicators for prismatic correction in the case of asthenopia, but recently tests for 'aligning prism' have been preferred, because the stimulus for aligning prism appears to be more natural, in that both eyes are presented with more natural viewing conditions (Mallett, 1964). Another limitation of dissociation tests is that, with a large slightly paretic heterophoria

(where there is restriction of movement in one direction), the eye may make a secondary movement of elevation in abducting or adducting. This is not likely to be a problem with the fixation disparity test (Evans, 2007, p67).

Yekta et al. (1989) investigated if there was any correlation between aligning prism and dissociated heterophoria and symptoms in 187 subjects aged between 10 and 69. The results of the study indicated that dissociated heterophoria is not related to symptoms in either pre-presbyopic or presbyopic subjects, and this was confirmed with an unpaired t-test. The authors therefore concluded that the measurement of dissociated heterophoria is not an appropriate test to use in routine eye examination in the assessment of compensation. However, those subjects with symptoms had a significantly larger aligning prism measurement and fixation disparity in both age groups, and therefore measurements of aligning prism and fixation disparity are likely to be much more useful indicators of compensation.

Otto et al. (2008), measured dissociated heterophoria and aligning prism in 20 subjects using the same fixation target to ensure that the accommodative demands were the same. They found a significant difference between the two measurements (p<0.01): in eleven subjects the amount of aligning prism found was greater than the dissociated heterophoria, and for four subjects the amount of aligning prism found was lower. The dissociated heterophoria and aligning prism measurements were similar for the remaining five subjects. They also measured the 'comfortable prism' which is the prism chosen by the subjects themselves as being the most comfortable when viewing the same target under normal binocular conditions. Although they claim that this prism was chosen 'under natural viewing conditions', the subjects performed the test in low illumination and were required to rest their chin in a support with their head against a

bar. In addition, it is likely that viewing the target through a rotary prism would have restricted the field in one eye. These factors are not present in normal everyday viewing, and therefore this casts doubt on the validity of their results and conclusions regarding the 'comfortable prism'. Surprisingly, all the subjects required a 'comfortable prism', which raises doubts about the use of this technique in a clinical setting. Although the test condition for aligning prism is commonly regarded as being more natural than that for dissociated heterophoria, the amount of aligning prism found was not closer to the comfortable prism than the dissociated heterophoria measurement under this particular experimental set up.

6.7   CORRECTION/MANAGEMENT OF DECOMPENSATED HETEROPHORIA

The main interventions for correcting or managing decompensated heterophoria are discussed below in the order they would normally be considered

6.7.1   Removing the cause of decompensation

Heterophoria can become decompensated for a variety of reasons, and if this cause can be established, it should then be removed or corrected wherever possible.

One cause of decompensation is a decrease in sensory fusion. This may be the result of visual loss from a pathology such as a cataract (Evans, 2009, p244) or simply be from an uncorrected refractive error. Carter (1963) therefore recommends correcting any large previously uncorrected refractive error to improve sensory fusion, before considering other methods of treatment. Another common cause of decompensation is a change in working conditions, such as an increase in close work. Again changes should be made to improve the working environment if possible (such as better lighting or work station set up) before other treatments are considered.

However, some causes are more difficult to eliminate. These include debility (from tiredness or illness) or emotional stress (e.g. from school exams) (Evans, 2009, p244). In these cases other forms of treatment (such a refractive or prismatic modification) may be more appropriate, but may only need to be given on a temporary basis until the initial cause of the decompensation has been resolved.

6.7.2   Refractive modification

In pre-presbyopic patients, exophoria can be reduced by the use of minus powered lenses, and esophoria by plus powered lenses, and treatment of heterophoria by refractive modification is often tried before the prescription of prisms.

Mallett (1964) advises that refractive modification be given in preference to prisms to young (pre-presbyopic) patients with esophoria, although he does not specify the reasoning for this advice. He cautions that in esophoria, the maximum amount of extra plus power given should not exceed the dioptric working distance, as any amount greater than this will cause the patient to work at a closer distance which may increase the esophoria. He suggests that in these cases the remaining fixation disparity should be corrected with prisms. He also recommends refractive modification be given in preference to prisms in young patients with exophoria and a slip on the Mallett unit of up to -3.00DS. This is due to his belief that refractive modification succeeds in the elimination of the exophoria over the period of a few years. He notes that his personal preference is to prescribe prisms if more than -3.00DS is required, possibly because greater amounts of minus power may be too great an accommodative demand.

6.7.3 Eye exercises

Orthoptic exercises are often successful in the treatment of horizontal heterophoria, particularly for near exophoria. As a result they are often used to treat heterophoria in preference to prismatic correction (Carter, 1963).

Sheedy and Saladin (1978) suggest that exercises may be considered the treatment of choice for exophoria as the positive fusional reserves (used to help control exophoria) respond better to eye exercises than negative fusional reserves (used to help control esophoria).

However, orthoptic exercises are less successful in treating vertical heterophoria. Rutstein et al. (1988) found that 5 hours of vertical vergence training on a synoptophore over a period of 4 weeks did not improve the vergence amplitudes, although it did result in a flatter vertical fixation disparity curve.

6.7.4 Prisms

Although it is generally believed that the previously discussed methods are the best ways to treat decompensated heterophoria, there are cases where prisms may become the first choice of treatment. Prisms are often used to treat decompensated heterophoria in older patients, as their vergence adaptation is very limited (Gray, 2008), and prism adaptation (a return of the heterophoria to its original value after the prism has been in place for a few minutes, see section 7.4) is very unlikely (Winn et al., 1994). Prisms may also be considered when the patient is in ill-health or if the patient does not have the time or motivation to undertake orthoptic exercises (Evans, 2007b, p105).

Mallett (1964) suggests that prisms are more appropriate than refractive modification for all patients with presbyopia due to their reduced accommodation, and for younger patients with exophoria who would require a refractive modification of over -3.00DS. This opinion seems to be based on personal experience rather than published research.

6.7.5   Surgery

Surgery is rarely used to correct decompensated heterophoria, but may be considered when other forms of treatment have failed. In his interview with Pickwell (1977), Herr Haase reported that surgery may be the best option for patients where a high prism (e.g. over 20Δ) is indicated on the Polatest and with severe symptoms. However Pickwell argues that orthoptic exercises should be tried first. In addition, Evans (2007, p107) reminds us that decompensated heterophoria should be referred for further investigation if the cause is suspected to be pathological.

CHAPTER 7   A REVIEW OF THE PRESCRIBING OF PRISMS FOR

HETEROPHORIA

7.1   INTRODUCTION

The previous chapter shows that heterophoria is a very common binocular condition

that does not always require correction. It is generally believed that a heterophoria only

requires treatment if it is causing symptoms or if the binocular status is likely to

deteriorate if it is not treated (Evans, 2007b, p53; Evans, 2009, p244). The methods

available to treat heterophoria have been briefly discussed in section 6.7, and this

chapter will look at the use of prisms in more detail.

7.2   PREVIOUS REVIEWS

Gray (2008) reviewed several measures of assessing binocular function with the aim of

identifying which method was the most useful for assessing heterophoric compensation:

dissociated heterophoria, fixation disparity, aligning prism and fusional vergence

reserves. He concluded that no single test will perfectly identify that a heterophoria is

decompensated, and that there is a lack of evidence-based research to establish which of

the above methods is the most reliable in determining the magnitude of prism required.

7.3   DETERMINING THE AMOUNT OF PRISM TO PRESCRIBE

There are a variety of opinions concerning the role of prisms in correcting heterophoria,

and many authors have attempted to provide guidelines for their use. The advice varies

from correcting the full amount of heterophoria found, to providing no correction at all.

This disagreement may be due in part to the differing methods of quantifying the

heterophoria and of assessing whether it is compensated. Pickwell (1977) noted that the

degree of fixation disparity measured depends on the size and nature of the binocularly seen parts of the test, the extent of any peripheral lock and the size of the monocularly seen parts of the test and their position relative to the central binocular lock. He added that when designing a fixation disparity test, the factors above need to be adjusted so that fixation disparity is only revealed in those cases where the degree of decompensation is such that it will give rise to symptoms. As previously mentioned (section 6.6.4) the Sheedy disparometer does not fulfil these requirements, and therefore is rarely used as a method for prescribing prisms in the U.K.

Many of the tests used to assess whether a heterophoria is decompensated can also be used to determine the amount of prism to prescribe. For example the prism power required can be determined as that which produces a quick and smooth recovery on the cover test (Evans, 2007b, p105).

One of the tests used most commonly for prescribing prism in the U.K is the Mallett unit (Karania and Evans, 2006). Mallett (1964) asserted that the refractive modification or prismatic lens that just eliminates a fixation disparity on the Mallett unit is the minimum correction that is necessary to correct the decompensated portion of the heterophoria. A small double-masked randomised controlled trial by Payne et al. (1974) confirmed that prisms prescribed with the Mallett unit were consistently preferred by patients to spectacles without prism and that the Mallett unit was a more useful tool for prescribing prism than Sheard's criterion.

Another method of determining the amount of prism to prescribe is the Polatest, which is widely used in Germany. This test consists of a series of five targets to assess the heterophoria: one with a peripheral fusion lock (to investigate motor compensation),

two with central fusional locks (to detect fixation disparity and determine the aligning prism) and two stereotests. Pickwell (1977) reviewed the Polatest, and concluded that some of the motor and sensory adaptations identified by the Polatest, such as disparity correspondence, cannot be detected by any method widely used in Britain. Lie and Opheim (1985) explain that when all 5 tests can be corrected by a single prismatic power then disparate fusion is present. However, if stronger prisms are required to align the markers on the tests with a central fusional lock, than disparate correspondence is present. The inventor of the Polatest Herr Haase has a large number of case studies in which prisms have been prescribed using the Polatest, and he reports (in Pickwell, 1977) that symptoms were only relieved when the disparity correspondence was completely eliminated by prismatic correction. This can result in prisms as high as 20Δ being prescribed, although it should be noted that German optometrists are not allowed to undertake any orthoptic treatment, and Pickwell suggests that in the U.K. orthoptic exercises would be used in preference to high powered prisms. Lie and Opheim (1985) prescribed prism to 43 symptomatic subjects with heterophoria for full-time wear using the Polatest to determine the amount of prism required. After correction, the number of reported symptoms had reduced by 86%. Although a great deal of information can be gained with the Polatest, the amount of time taken to fully complete the test during a routine eye examination may be the reason why it is not widely used in the U.K.

7.4   VERGENCE ADAPTATION

Some of the controversy regarding the prescription of prisms has originated because of vergence adaptation (also known as prism adaptation): where the heterophoria returns to its original value after the prism has been in place for a few minutes. The term vergence adaptation will be used throughout this thesis unless directly quoted by another author. Adaptation to prisms occurs in most patients with normal binocular vision (Evans,

2007b, p106), and is likely to be part of a vergence feedback system. Schor (1979) explains that there are two separate control mechanisms for fusional vergence: a fast-acting mechanism to reduce binocular disparity, and a slow-acting mechanism to reduce disparity vergence. He suggests that the fast-acting mechanism triggers the slower mechanism, which cannot operate on its own. The purpose of vergence adaptation may therefore be to maintain an amount of heterophoria or fixation disparity in order to stimulate this fast-acting fusional system (Crone and Hardjowijoto, 1979). However, Despotidis and Petito (1991) advise that this multiphasic adaptation only applies to horizontal prisms and that vertical adaptation seems to only have one speed rather than a fast and slow component. They explain that vertical fixation disparity curves form a straight line rather than the typical sigmoid shape of horizontal fixation disparity curves (Figure 7.1), and that patients either have normal vertical adaptation or none at all.
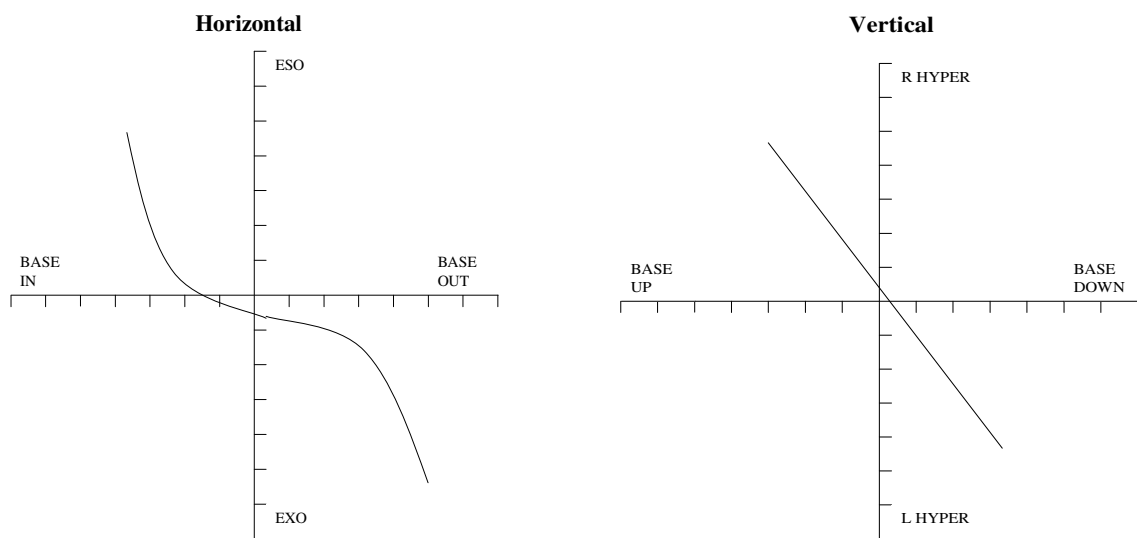
Figure 7.1 Typical fixation disparity curves

Rosenfield (1997) acknowledged that patients with binocular vision symptoms are likely to have poor vergence adaptation, but advised that this be checked before prisms are prescribed. He suggested placing the prism under consideration in a trial frame, and

then asking the patient to read through the lenses for approximately twenty minutes. The heterophoria should then be re-measured through the prism, to see whether it has returned to its original value (i.e. to check whether vergence adaptation had occurred). Gray (2008) suggests refining this technique by measuring the aligning prism (rather than the dissociated heterophoria) before and after the patient has worn the prism for ten minutes. However, Surdacki and Wick (1991) warn that vergence adaptation can sometimes take longer than twenty minutes and that it can take longer to uncover latent heterophoria that may not be apparent on routine clinical testing. They measured the aliging prism of seven symptomatic subjects after twenty four hours of occlusion and found that this revealed vertical heterophoria that was not present during routine clinical testing. Furthermore, prescribing prism based on the aligning prism found after the occlusion period, resulted in an elimination of the symptoms. However, there were no placebos used in this study and it is therefore possible that the reduction in symptoms was simply due to a placebo effect. It can also be argued that although measuring the aligning prism after a period of occlusion may uncover latent hyperphoria, that it does not represent the eyes habitual state under natural viewing conditions.

7.4.1   Horizontal adaptation

Complete vergence adaptation to horizontal prism was demonstrated by Carter (1965). He measured the distance dissociated heterophoria of nine asymptomatic subjects with normal binocular vision using the flashed Maddox rod technique (see section 6.5.1). The most base-in prism that could be fused by the subject was then worn for 30 minutes whilst the subject read or looked about the room before another heterophoria measurement was taken. Further heterophoria measurements were taken using the same technique for a variety of prism powers ranging from 10 base-in to 32 base-out. The amount of prism used and the number of measurements taken varied between the

subjects depending on the maximum amount of base-in that could be fused. For eight of the subjects (89%) the heterophoria measurement after adaptation to any magnitude of base-in or out prism was the same as the initial measurement taken with no prism in place. The same experiment was also undertaken on thirteen subjects, but using fixation disparity measurements rather than dissociated heterophoria measurements. In eleven of the subjects (35%) complete adaptation to both base-in and base-out prism occurred within fifteen minutes, with the majority of the adaptation occurring in the first 5 minutes.

Several authors have found that vergence adaptation differs depending on the fixation distance, and Carter (1963) argued that vergence adaptation occurs to lessen the demand on fusional convergence at distance fixation, even if this results in an increase in the amount of heterophoria present at near.

Henson and North (1980) found that the mean adaptation of subjects with normal binocular vision to base-in (requiring divergence) and base-out prisms (requiring convergence) at four meters was asymmetric, with the adaptation occurring much more quickly to the latter. However at a closer working distance of 50cms, the adaptation became symmetrical, although there was considerable variation in the adaptation process between individuals. The flash Maddox rod technique was used for both studies.

Mitchell and Ellerbrock (1955) measured vergence adaptation using fixation disparity at a closer working distance of 40cms and found that again the response was asymmetric, but that at this distance the adaptation was quicker for base-in prisms than for base-out. They suggest that poor adaptation for forced convergence at near is due in part to the

accommodation/convergence relationship. For example, many subjects will tolerate blurred vision in order to maintain fusion. However the authors provide only a few details as to the methods used in their study. They do not report what strength of prisms were worn, or for how long the subjects wore the prisms. There is also no mention of how many measurements were taken.

Henson and North (1980) suggest that the reversal of asymmetry from distance to near is a result of the frequency of each type of disparity. They state that convergent disparities are more common in the distance and that therefore the convergent adaptation is more efficient. Conversely, divergent disparities are more common at near, and as a result divergent adaptation occurs more quickly. They also suggest that as the adaptation occurs so quickly and asymmetrically, it is unlikely to have developed to deal with the gradual change in orbital mechanics that occur with age.

7.4.2   Vertical adaptation

It has been shown that vertical and horizontal vergence adaptation occur independently, and that vertical adaptation is often more effective than horizontal. North and Henson (1981) found that for subjects with abnormal binocular vision or symptoms, vertical adaptation remained intact even when the horizontal adaptation was deficient. Despotidis and Petito (1991) explain that vertical adaptation can be predicted from fixation disparity curves: patients with a flat slope are likely to adapt to prism, unlike patients with steep slopes. Vertical heterophoria is generally believed to be more likely to cause symptoms than horizontal heterophoria due to the smaller vertical fusional reserves. Ogle and Prangen (1953) investigated the rate of vergence adaptation in seven subjects to 2Δ base-up and down prisms, by measuring the amount of fixation disparity

over a period of time. They found that adaptation for both was normally complete within three to seven minutes.

7.4.3 Vergence adaptation in patients with abnormal binocular vision

The presence and amount of vergence adaptation varies considerably between individuals (Henson and North, 1980) with some subjects fully adapting within a few minutes, and others not adapting at all. Several authors have suggested that vergence adaptation or orthophorization, is deficient in heterophoria (Crone and Hardjowijoto, 1979).

Carter (1963) suggests that vergence adaptation is dependent on good sensory fusion. He found that recovery to base-out prism took much longer (eight hours or more) when sensory fusion is prevented, but only took 15 to 20 minutes when sensory fusion is present. He concluded that most patients with a large distance heterophoria or significant asthenopia have defective vergence adaptation, and that those individuals without the fusion adaptation ability will obtain relief from being prescribed prisms to reduce the demand on their fusional convergences. However, he did not state how large the distance heterophoria needed to be to indicate a defective adaptation system, and did not provide details of the experiment from which he developed this belief.

Lie and Opheim (1985) also expressed doubt that vergence adaptation occurs in subjects with heterophoria and with visual symptoms, due to poor sensory fusion. They equate vergence adaptation to latent hypermetropia and suggest that when heterophoria is present, there is accumulation of basic tonus of the extra-ocular muscles. This accumulation of tonus keeps the true position of the eyes partly latent, even when in the absence of fusion. As a result the amount of prism required may increase as the full

amount of the latent deviation is uncovered, a process which practitioners may interpret as the patient 'eating the prisms' (Lie and Opheim, 1985). However, Carter (1963) warned practitioners to be wary of repeated increases in prism, and advised practitioners that if repeated increases in prism are needed, they should only be prescribed if symptoms still exist.

A study by North and Henson (1981) investigated horizontal and vertical vergence adaptation using the flashed Maddox rod technique in 15 subjects with abnormal binocular vision or asthenopia. They found that the horizontal adaptation was often only present in one direction, but that the adaptation was not related to whether the original heterophoria was esophoric or exophoric. They also found that several subjects adapted differently to prisms at distance and near working distances, and that there was a relatively slower adaptation rate for near working distances.

However, the findings of North and Henson (1981) were not replicated by Dowley (1990) who compared the prism adaptation in subjects with orthophoria and symptom-free subjects with heterophoria with a flashed Maddox Rod technique. He found that the subjects with exophoria had a significantly reduced base-out prism adaptive response when compared with those with orthophoria, but a normal base-in adaptive response. Conversely, subjects with esophoria showed a reduced base-in prism adaptive response, but a normal base-out adaptation. He concluded that heterophoria itself occurs because of a failure of the prism adaptation process, and that although some prism adaptation does occur in heterophoria that it becomes saturated, and is therefore less efficient than in orthophoria. It should be noted that although the methods used were similar to North and Henson, the subject group was different as his subjects with heterophoria were asymptomatic, unlike those used in North and Henson's study.

All the above studies looked at the relationship between dissociated heterophoria and vergence adaptation, and it has already been shown that the magnitude of dissociated heterophoria is a poor predictor of compensation (see section 6.6.1). North and Henson (1981) investigated whether there is a relationship between fixation disparity (detected using the Mallett unit) or poor fusional reserves (measured using rotary prisms) and abnormal vergence adaptation. They found little correlation between the variables and concluded that the presence of a fixation disparity or reduced fusional reserves could not be used to predict whether a patient would adapt to any prism prescribed. However this conclusion was based on the results from only a few subjects (4 subjects in the case of the fixation disparity data), and therefore further research in this area is indicated.

7.4.4 Vergence adaptation and age

Vergence adaptation is unlikely in older patients, as their vergence adaptation is virtually zero. Therefore, eye exercises for older patients are less likely to be successful (Winn et al., 1994).

In conclusion, vergence adaptation is a normal physiological process in asymptomatic subjects with normal binocular vision in the presence of sensory fusion. However it has been shown to be defective in patients with abnormal binocular vision, in patients with symptoms associated with vision, and in older people. It has also been claimed that vergence adaptation is less effective in near vision than for distance vision, and is more effective at reducing exophoria than esophoria (Carter, 1963).

There have only been a few studies that have given advice on the amount of prism to prescribe for heterophoria. One notable study was by Jenkins et al. (1989) who used receiver operating characteristic (ROC) curves to identify the best criteria for predicting symptoms in subjects with heterophoria. The subjects were selected from patients attending optometry clinics in Iran and the U.K, and were split into two age groups: those aged under 40 (197 subjects, 137 symptom-free and 60 with symptoms), and aged 40 and over (69 subjects, 41 symptom-free and 28 with symptoms). The ROC curves showed that there was no value of dissociated heterophoria that would adequately distinguish between those subjects with symptoms and those without. However, the aligning prism measurements found on the Mallett unit were more useful. In the under 40's group, a criterion of 1Δ of aligning prism had a sensitivity of 0.75 and a 1-specificity (false alarm rate) of 0.22 in identifying those subjects with symptoms. This would mean using a criterion of 1Δ would correctly identify 75% of those patients with symptoms and incorrectly identify 22%. For the group aged 40 and over, the best criterion was 2Δ which had a sensitivity of 0.64 and a false alarm rate of 0.29. A limitation of this study is that it does not distinguish between exophoria and esophoria, although the authors admit that almost all the subjects in the study had exophoria.

Mallett (1964) advised that a horizontal aligning prism of 1Δ or over should be prescribed if it eliminates a slip on the Mallett unit. He adds that if the slip is only in one eye, the prism should be prescribed for the same eye up to the value of 3Δ. If the amount of prism required to correct the slip is greater than 3Δ, then the prisms should be split unequally with the larger prism again being prescribed for the eye with the slip. Mallett does not state how this advice is arrived at although it is likely that it is based on

personal experience. He believes that any slip on the Mallett unit is indicative of a decompensated heterophoria.

Carter (1963) advises the use of base-in prism for symptomatic subjects with exophoria at both distance and near, and where there is an excessive demand on the positive fusional reserves. Base-out prism is suggested for symptomatic subjects with esophoria at both distance and near, and where there is an excessive demand on the negative fusional reserves.

A literature review on the association between binocular vision anomalies and reading difficulty was undertaken by Simons and Grisham (1987). They concluded that there was consistent evidence that near exophoria and fixation disparity were related to reading problems.

This finding is disputed by Sheedy et al. (1988) who found that introducing vergence inducing prisms of up to 12Δ did not significantly affect reading speed on 10 subjects with normal binocular vision. However subjects with abnormal binocular vision may respond differently, and therefore these results cannot be applied to subjects with decompensated heterophoria.

7.6 THE CORRECTION OF VERTICAL HETEROPHORIA

The prescription of vertical prism in subjects with symptoms is widely accepted (Carter, 1963) as most authors and practitioners believe that even a small vertical heterophoria will result in symptoms (Mallett, 1974) due to smaller fusional amplitudes. This view, together with the low prevalence of vertical heterophoria, probably explains why there have been few studies investigating the use of vertical prisms.

Carter (1963) recommends that any vertical heterophoria accompanied by symptoms should be corrected with prism, even if the amount of heterophoria is very small.

Giles (1965, p191) suggested that vertical heterophoria of 1Δ and over should be corrected, and Mallett (1964) advised correcting vertical aligning prisms of 0.5Δ or over when found on the Mallett unit. However this advice was anecdotal rather than based on published research.

Walsh (1946), (cited by Borish, 1970, p871) suggested an upper limit for prescribing vertical prism of 6Δ. He believed that prisms over 6Δ could not be successfully incorporated into glasses as they would produce too much distortion, and that in these cases surgery would be a better option.

Ogle and Prangen (1953), however, disputed the view that vertical heterophoria should be corrected at all. They measured the amount of vertical heterophoria and the fusional reserves of eight subjects and found that after wearing 6Δ of vertical prism for a few hours, the heterophoria and vertical fusional reserves had almost returned to their original values. This suggests that the visual system maintains a 'resting' vertical heterophoria, which persists even after the original heterophoria has been corrected. However, Ogle and Prangen's subjects had normal binocular vision and it has since been shown that although subjects with normal binocular vision can readily adapt to prisms, those with abnormal binocular vision have deficient vergence adaptation (see section 7.4.3).

Overall most authors agree that it is beneficial to correct vertical heterophoria of 0.5Δ or over, however there is still disagreement over the amount of prism to prescribe.

Several methods have been proposed for detecting and measuring vertical heterophoria (Evans, 2007b, pp 65-85, 133-136), and this may account for differences of opinion as to the amount of prismatic correction needed. It is also important to remember that any new vertical heterophoria may be due to pathology, and that patients should be referred for further investigation if motility indicates a new or changing extraocular muscle paresis.

7.7 PRISMS AND SPATIAL DISTORTION

Carter (1963) reminds us that prisms affect the retinal image, causing spatial distortion and asthenopic symptoms, particularly in the case of prisms that force negative fusional convergence in near vision. He suggests that the maximum amount of prism (in any direction) that can be prescribed without the introduction of symptoms is 2Δ. However he admits that this advice is anecdotal, and that many patients will quickly adjust to the optical effects of prisms greater than this amount.

7.8 CONCLUSIONS AND PRESCRIBING GUIDELINES

Heterophoria is a common condition that can be considered normal for one person, yet abnormal for another, even when the same magnitude of heterophoria is found. The lack of a clear distinction between normal and abnormal heterophoria makes the decision as to whether to treat a heterophoria a difficult one, and this is reflected in the large number of studies that have attempted to address the problem, and the conflicting advice given.

It has been shown that the magnitude of heterophoria is a poor indicator as to its compensation, and other measurements such as fixation disparity and aligning prism are more useful.

7.8.1 Horizontal heterophoria

The literature gives a wide variety of advice on the use of prisms to correct horizontal heterophoria and this varies from correcting the full amount of heterophoria found, to providing no correction at all. This disagreement may be due in part to the differing methods of quantifying the heterophoria and of assessing whether it is compensated, and the differing methods used make it difficult to draw any conclusions from the literature search. In addition although most studies looked at whether it was beneficial to correct a horizontal heterophoria, only one investigated the actual amount that should be corrected: 1Δ and over for patients aged 40 and under, and 2Δ for those over 40 years of age (Jenkins et al., 1989).

7.8.2 Vertical heterophoria

Some heterophoric conditions are unlikely to respond to orthoptics and relieving prisms are more appropriate. Hyperphoria is of this type and in decompensated hyperphoria prism relief is more usual. Although the literature shows that whilst most authors advocate correcting vertical heterophoria, there have been no clinical studies investigating at what point the intervention becomes beneficial.

CHAPTER 8   HYPOTHESES

8.1   SUMMARY OF REVIEW CHAPTERS AND IMPLICATIONS FOR RESEARCH

8.1.1   The correction of borderline refractive errors

After the diagnosis of ametropia is made, the optometrist needs to decide whether

spectacles would be of benefit to the patient. Brookman (1996a, p9) suggests that there

are several indications for prescribing spectacles and these include: an improvement in

visual acuity, elimination of symptoms of asthenopia, enhancement of visual efficiency,

prevention or slowing of the progression of ametropia, prevention of secondary

anomalies, protection and safety, and vocational and non work related needs. In the case

of a borderline refractive error, the first three factors are likely to be the most relevant.

8.1.1.1   Visual acuity

There is little debate over whether glasses should be prescribed in cases where the

refractive error causes a significant reduction in visual acuity. The primary aim of

spectacles is to optimise vision, and as visual acuity can be measured easily and

accurately for most patients, it is quickly apparent whether glasses will result in an

improvement in vision. However, borderline amounts of ametropia are likely to have

only a minimal effect on visual acuity. This is especially true in the case of

hypermetropia and astigmatism where accommodation can be used to compensate for

the small refractive error (Brookman, 2006b, p125).

Stewart-Brown (1985) analysed the visual acuities of 1475 ten year old children who

had been prescribed glasses, and found that 516 (35%) did not have any significant

visual deficit (no definition of significant visual deficit is given). Although she

acknowledged that some of the glasses would have been prescribed to correct accommodative strabismus, she concluded that the majority are likely to have been prescribed for other reasons, and that in the absence of an improvement in visual acuity, it was debatable whether these glasses were really necessary. However the study did not give any definition of the classification of mild or marked defects, and also did not state any of the actual refractive errors. Therefore, some of the children classified as having mild visual defects may have had a high amount of hypermetropia, anisometropia or even amblyopia.

If the correction of borderline refractive errors does not improve visual acuity, then there may be other reasons why glasses are prescribed. These reasons may include the improvement of symptoms, or an improvement in visual performance that does not bring about a change in acuity as suggested by Brookman (1996a, p9). Unlike visual acuity, it is much more difficult to determine whether a refractive correction will result in an improvement in these two factors, making the decision to prescribe much more difficult.

8.1.1.2   Symptoms

Some authors believe that even small refractive errors can cause symptoms. Brookman (1996a, pp3-4) states that small and moderate uncorrected refractive errors are often the cause of asthenopic symptoms, particularly when associated with prolonged visual tasks. He even suggests that it should be assumed that the uncorrected refractive error is the cause unless clinical findings suggest otherwise. Ball (1998, p74) also advises that 'visual unease' can be caused by minor amounts of uncorrected ametropia in one eye. He distinguishes this symptom from blurred vision, as the patient normally reports good binocular vision, but reports that their vision is uncomfortable.

However, authors also admit that in small refractive errors, symptoms are often vague, transient and unspecific (Brookman, 1996b, p125). Both Elliott (2007, p146) and Brookman (1996b, p127), advise that small refractive corrections should only be corrected if there are symptoms that can be linked to visual activities or prolonged close work and only if the subject gives consistent and reliable responses.

Other authors such as Ball (1988) advise against correcting small refractive errors on the basis of vague eye discomfort or headache, when there are no clinical signs to justify a prescription. In these cases it is likely the correction would act as a placebo, and only relieve the symptoms for a short time. This placebo effect has been demonstrated by Cholerton (1955) who prescribed plano glasses to 11 pre-presbyopic subjects with refractive errors of less then 0.75D in either principal meridian, and with symptoms of eyestrain or dull headache after periods of prolonged near work. He found that after three months, the symptoms had improved in seven (64%) of the subjects.

It is difficult to identify a reason why small refractive errors should cause asthenopic symptoms, when larger refractive errors may not. Cholerton (1955) suggested that the cause of the asthenopia lies with the ciliary muscle. He believes that the muscular and emotional tensions produced by fatigue result in a disturbance of the physiological balance between the sympathetic and parasympathetic pathways, and that vasomotor disturbances cause an over-activated ciliary muscle, with referred pain felt in the frontal and occipital regions of the head. In his review on small errors of refraction, Nathan (1957) described the theory that small errors cause strain on the visual adjustment mechanisms, whilst larger refractive errors are too large to excite compensation of the ciliary muscle, and simply result in blur. He also suggested that in some cases the

symptoms may be caused by ocular neurosis based on a fear of impaired vision or blindness, and advised that only thorough history taking can identify these patients.

8.1.1.3   Reading performance

Reading performance is complex, and can be affected by many factors including aptitude, attitude, adequate instruction, fatigue and the validity and reliability of the testing equipment used (Grisham and Simons, 1986). It is therefore difficult to design a study which controls for all of these factors, and this may be why relatively few studies have investigated the effect of small refractive errors on reading performance. Although most of the studies reviewed by Grisham and Simons suggest that uncorrected hypermetropia may adversely affect reading performance, they all have methodological flaws. Very few used controlled randomised trials or any statistical analysis, and none of them controlled for a practice effect or used a placebo. Therefore expectation of the results may have been a confounding factor. In addition, none of the studies reviewed addressed the question of how large the refractive error needs to be before it affects reading performance.

A more recent study by Chung et al. (2007) investigating the effects of dioptric blur on reading performance attempts to address some of these problems. Reading speed was addressed using eight different versions of the MNREAD Acuity chart to control for any learning effect. The pupil diameter was also controlled by the use of mydiatics (drops to dilate the pupil) and a 3mm artificial pupil. They found that dioptric blur up to two dioptres only had a minimal effect on the maximum reading speed, but that the maximum reading speed was reduced by 23% when the blur increased to three dioptres. Print size was also found to be a factor as the reading speed increased with increasing print size for all levels of dioptric blur. However, this only occurred up to a certain print

size and then remained constant at the maximum reading speed. Again, the practice effect was no controlled and no placebo was used.

This builds on previous work by Legge and colleagues, which shows that reading speed is remarkably immune to image degradation. For example, reading speed is relatively unaffected by changes in font size or contrast, unless these are very extreme (Legge et al., 1987).

8.1.2 The correction of heterophoria

Heterophoria at near is common, partly due to physiological processes, and not all heterophoria needs correcting. As heterophoria is unlikely to reduce visual acuity, there are only two main reasons to provide a prismatic correction: elimination of symptoms, or an improvement in task performance. If a heterophoria is causing symptoms or is interfering with task performance then it is likely that the description of decompensated heterophoria is appropriate. The diagnosis of decompensated heterophoria will now be discussed.

8.1.2.1 Diagnosis of decompensated heterophoria

A search of the literature shows that there are numerous methods that can be used to investigate whether a heterophoria is decompensated. There is considerable debate as to which method is best, but there appears to have been only one published work that has evaluated the sensitivity and specificity of a test for decompensated heterophoria and has compared this with other methods (Jenkins et al., 1989). These authors used the Mallett fixation disparity test and found that, for pre-presbyopic patients, a criterion of 1Δ or more of horizontal aligning prism had a sensitivity of 75% and a specificity of

78% for predicting symptoms at near. For patients with presbyopia the criterion increased to 2Δ, with a sensitivity and specificity for detecting symptoms of 64% and 71% respectively.

There is far less information in the literature on the effect of a decompensated heterophoria on visual performance. A interesting study by Sheedy et al. (1988) showed that vergence inducing prism had a greater effect on tasks requiring depth perception compared to tasks that did not. Ten subjects (five male and five female, aged 22 to 30) with normal binocular vision undertook four tasks (in a random order) whilst wearing base-in prisms of 4Δ, 8Δ and 12Δ, and also with base-out prisms of the same magnitude. Two of the tasks involved depth perception: inserting wooden pointers into straws tilted at varying angles and threading coloured beads onto a thread in a specified sequence. The other two tasks required good visual acuity, but only minimal depth perception: reading a Bailey-Lovie near word chart, and counting the number of a specified letter within a paragraph displayed on a VDU. Analysis of the data with a t-test showed that there was a significant reduction in performance in the tasks requiring depth perception with 8Δ and 12Δ base-in or out. However performance was only marginally affected in the two tasks that did not require depth perception, and the decrease in performance was only statistically significant through 12Δ base-in prisms.

The problem of deciding when to correct a borderline refractive error was identified over 50 years ago by Cholerton, and yet the question still remains unanswered. The literature review in chapters three, four, five and seven, reveals a lack of evidence-based research on the criteria that should be used by eye care practitioners in deciding when and to what extent to correct borderline refractive errors and binocular vision anomalies. This lack of objective research may explain why there is such a variety of advice in

optometric texts. Much of this advice is also essentially anecdotal, and might be characterised as "clinical received wisdom". In this age of clinical governance, it is increasingly important that optometrists can demonstrate that the prescription of glasses is based on guidelines established with evidence based research.

8.2 SCOPE AND AIMS OF THE PRESENT RESEARCH

The literature review shows that there is a wide variety of opinion regarding the correction of borderline refractive errors and heterophoria. Most of this advice seems to be based on either the predicted improvement in visual acuity calculated from optical formulae or from anecdotal findings relating symptoms to small amounts of ametropia and heterophoria. It has been shown that spectacles are prescribed for three main reasons: to improve visual acuity, to relieve symptoms and to improve visual performance. Visual acuity is easy to assess, and much research has been undertaken regarding the association of symptoms with small refractive and binocular anomalies, with only a weak relationship found. However, less attention has been given to establishing whether the correction of a refractive error or heterophoria would improve reading performance, what at what magnitude of error this effect might occur. As today's lifestyle is visually demanding, this is an area that requires further investigation.

The first aim of the research described in this thesis was to investigate at what point optometrists currently correct refractive errors, and the second was to see if current prescribing habits relate to the advice given in the literature. This was achieved by a questionnaire identifying the prescribing philosophies reported by optometrists. The third aim was to investigate whether the correction of borderline refractive errors and heterophoria improves visual performance, using a visually demanding reading task.

Finally, statistical analysis was used to investigate any association between an improvement in reading performance and symptoms.

8.3   HYPOTHESES

The following hypotheses were investigated in the present research:

1. Optometrists follow published guidelines when prescribing for borderline refractive errors.

2. Optometrists follow published guidelines when prescribing prismatic correction for heterophoria.

3. Optometrists are more likely to prescribe for a borderline refractive error in patients with symptoms.

4. Optometrists are more likely to prescribe a prismatic correction to patients with symptoms.

5. The correction of low degrees of hypermetropia ($\leq$+1.75DS) results in an improvement in visual performance at a rate of reading task.

6. The correction of low/moderate degrees of astigmatism ($\leq$-2.00DC) results in an improvement in visual performance at a rate of reading task.

7. The correction of low degrees of presbyopia ($\leq$+1.50 Add) results in an improvement in visual performance at a rate of reading task.

8. The correction of decompensated horizontal heterophoria with prism results in an improvement in visual performance at a rate of reading task.

9. The correction of decompensated vertical heterophoria with prism results in an improvement in visual performance at a rate of reading task.

10. Subjects with symptoms have a greater improvement in visual performance than asymptomatic cases, when borderline refractive errors or decompensated heterophoria are corrected.

CHAPTER 9   STUDY ONE: INVESTIGATION OF THE CRITERIA USED

WHEN PRESCRIBING BORDERLINE OPTOMETRIC

INTERVENTIONS.

9.1   AIMS OF THE STUDY

There were three aims of this study: to investigate the criteria that are used by practitioners in determining whether to correct these borderline anomalies, to investigate how these relate to published guidelines, and to identify if there is a need for further research into the efficacy of borderline optometric interventions. The results of study one have been published in Ophthalmic and Physiological Optics, (O'Leary and Evans, 2003) and this paper is reproduced in Appendix 4 of this thesis.

9.2   METHODS

Two approaches were considered in order to determine current prescribing practice: a review of the records from one practice over the period of a few months, or a questionnaire to be sent to several practitioners. Reviewing the records has the advantage of giving an objective measurement of the actual interventions prescribed, but would only represent the views of a few optometrists in one location. Sending out a questionnaire would reach a much wider range of optometrists in different geographic areas and with a variety of training and experience, and therefore this second method was chosen. A disadvantage of using a questionnaire is a potentially low response rate, and to try and improve this, the questionnaire was simplified as much as possible in order to make it easy to follow and quick to complete.

9.2.1   Practitioner survey

9.2.1.1   Questionnaire design

The questionnaire (Appendix 1) asked questions about when optometrists would prescribe for various categories of refractive error (e.g., hypermetropia) and binocular vision anomalies (e.g., hyperphoria). In designing the questionnaire, the literature review was used to set the ranges of corrections in each category. For the binocular vision anomalies, slightly different criteria were used for horizontal and vertical heterophoria. For horizontal heterophoria, practitioners were asked to report when they would prescribe prism for fixation disparities detected with a Mallett unit, whereas for vertical heterophoria the method used to detect the heterophoria was not specified. The reason for the difference between the two questions is because the literature review indicates that horizontal heterophoria is common (see section 6.3), and only needs to be corrected when decompensated (see section 7.1). As Mallett unit is one of the tests most commonly used tests in the U.K. to assess compensation (Karania and Evans, 2006), this test was specified in the questionnaire. However, vertical heterophoria is less common and is often corrected or referred when detected without any further tests of compensation being undertaken (see section 7.6).

The instructions included in the questionnaire stressed that the most relevant "other factors" did not come into play. For example, the instructions for the questions relating to prescribing criteria for spherical refractive errors stated that the cases would have astigmatism under -0.75DC (See Appendix 1). This information was added to simplify the questionnaire, and to ensure that the answers related just to the relevant category.

The first version of the questionnaire was piloted to a small sample of optometrists, to ensure that the instructions were clearly understood. The received feedback led to

several improvements in the questionnaire design. In particular, the pilot questionnaire showed that it was easiest for practitioners to imagine that they were reviewing their prescribing habits over the last four months.

Initially, in an attempt to keep the design simple, the pilot version did not include information about symptoms. However, many optometrists found it very difficult to complete the questionnaire without this information, and so for the final version each category was sub-divided into sections for patients with symptoms and those without. The final version is reproduced in Appendix 1 (although the introduction section of the questionnaire mentions eye exercises, in the interests of brevity these were not referred to in the questions).

9.2.2 Subjects

The questionnaire was sent by e-mail to all members of the UK Optometry E-mail Discussion List, which is hosted at Manchester University. A copy was also given to all delegates at the 2001 American Academy of Optometry (British Chapter) conference, and at other U.K. CET conferences during 2001. The Optometry E-mail Discussion List has 300 members, but the dynamics are such that a few of the members regularly post e-mails, some occasionally post e-mails, and the majority receive the e-mails but do not take part in any discussions. Therefore, the number of active members of the mailbase is considerably less than 300 but the precise number cannot be ascertained.

9.3 STUDY ONE: RESULTS AND DISCUSSION

Questionnaires were received from 38 eye care practitioners, although some practitioners did not complete the answers to every category (e.g. they may not have answered the question regarding correcting asymptomatic astigmatism). The data were

used in the analysis if the optometrist had filled in answers for all the powers for that particular anomaly.

For the analyses, graphs were plotted showing the percentage of presentations at which each refractive error or binocular vision anomaly would be corrected. As the data did not follow a normal distribution, the median and upper and lower inter-quartile values for each category were calculated. The median value is the middle value of a ranked group of results and therefore, if the majority of the values were 100%, the median could also be 100% even if there were a large range of responses. The quartiles describe the range of the responses; with the upper quartile being the value above which 25% of the results lie, and the lower quartile the value below which 25% of the results lie.

9.3.1   Horizontal heterophoria

Complete data were available from 37 practitioners regarding prescribing for symptomatic patients with heterophoria and from 36 practitioners regarding patients without symptoms. A large range of criteria was reported when deciding whether to correct a horizontal heterophoria under 4Δ. This was particularly apparent for patients with symptoms, as shown by the large interquartile ranges. For those patients with symptoms, practitioners would prescribe prisms of 1.5Δ and over 55% of the time (Figure 9.1). This result is not dissimilar to that of Jenkins et al. (1989) who found that it was beneficial to prescribe an aligning prism of 2Δ and over for patients older than 40, and 1Δ for younger patients. However, the results showed that some of the sample of practitioners would prescribe any amount of prism found, and others none at all. For patients without symptoms most practitioners would not prescribe any prism, at least up to the maximum of 3.50Δ in this survey.

Horizontal heterophoria
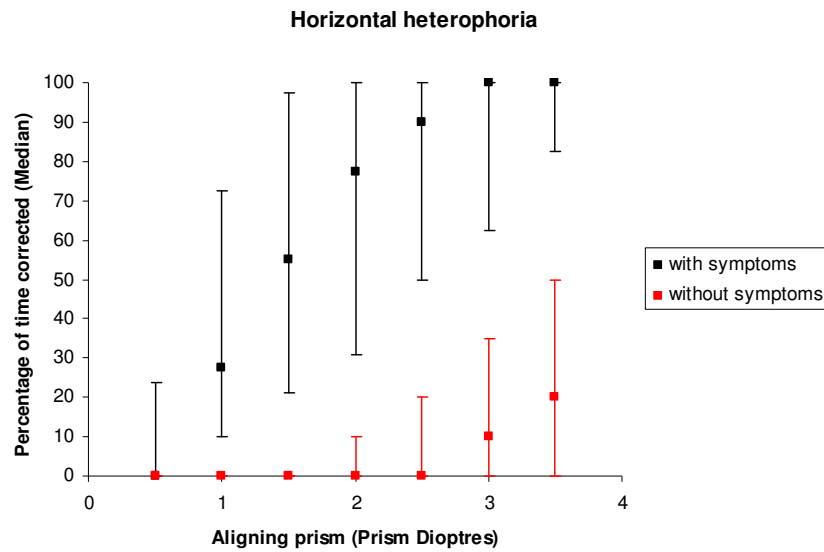
Figure 9.1 A comparison of the percentage of time a practitioner would correct an anomaly if symptoms were present (black points) compared to patients without symptoms (red points). The x-axis shows the magnitude of the anomaly. The y-axis shows the percentage of time that practitioners reported correcting the anomaly when seen in their practice over a 4-month period. The figure shows the median, and upper and lower inter-quartile values of all the results.

9.3.2   Vertical heterophoria

There was less variation in the reported criteria used to correct vertical heterophoria. Data were available from 35 practitioners regarding patients with symptoms and from 36 practitioners regarding patients without symptoms. The practitioners surveyed would prescribe virtually every time they found a vertical heterophoria of 1Δ or greater in patients with symptoms (Figure 9.2) which is consistent with Giles' (1965, p191) recommendation, but would only prescribe 50% of the time for patients without symptoms if the deviation reached 3Δ.
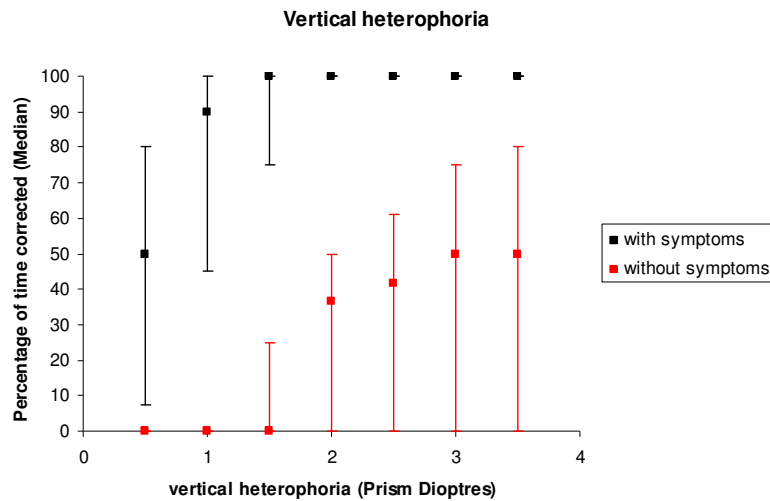
Figure 9.2 A comparison of the percentage of time a practitioner would correct an anomaly if symptoms were present (black points) compared to patients without symptoms (red points).

9.3.3   Hypermetropia

For hypermetropia, completed data were available regarding subjects with and without symptoms from 37 and 36 practitioners respectively. Practitioners report that they would prescribe +0.75DS only 50% of the time to symptomatic patients (Figure 9.3). This value increased to 90% when the refractive error reached +1.00DS. None of the practitioners surveyed would regularly prescribe less than +2.00DS if no symptoms were present. This outcome is slightly lower than the amount suggested in the literature review (see section 3.5) which indicated most optometrists would only correct hypermetropia of +1.50DS and above.
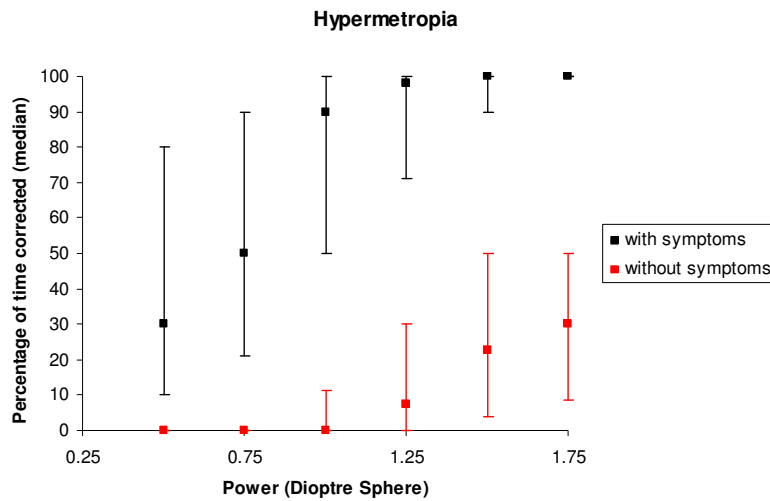
Figure 9.3 A comparison of the percentage of time a practitioner would correct an anomaly if symptoms were present (black points) compared to patients without symptoms (red points).

9.3.4   Presbyopia

For presbyopia, 38 practitioners completed the questions regarding patients with symptoms and 36 completed the questions about patients without symptoms. The results showed that for presbyopia where symptoms are present, practitioners would prescribe an addition of +0.75DS or above 80% of the time (Figure 9.4). This value of +0.75DS is lower than both Kragha and Hofstetter's (1986) recommendation of +1.25DS and the suggestion of +1.00DS by Hanlon et al. (1987). Nonetheless, it is higher than the value of +0.50DS found in Pointer's (2002) study. However none of these papers mentioned whether any of the subjects had symptoms relating to presbyopia. In the absence of symptoms, in the current study practitioners would only prescribe a reading addition of +1.50DS 60% of the time.
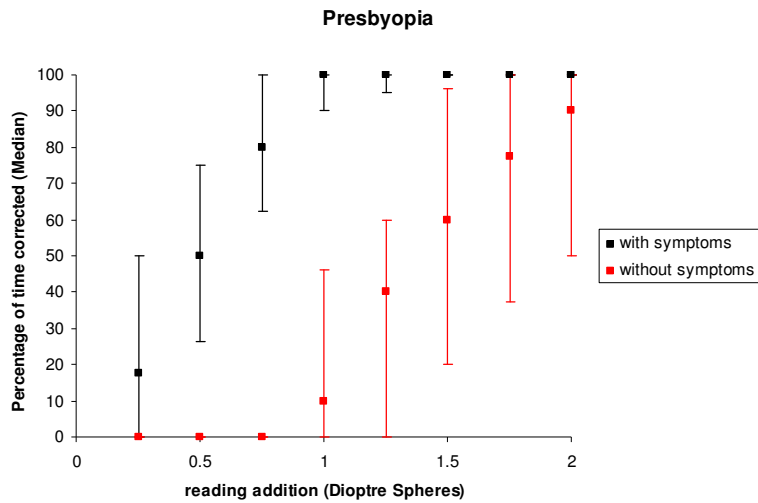
Figure 9.4 A comparison of the percentage of time a practitioner would correct an anomaly if symptoms were present (black points) compared to patients without symptoms (red points).

9.3.5   Astigmatism

Thirty seven practitioners completed the questions about patients with astigmatism and symptoms, and 36 completed the questions about patients with astigmatism and without symptoms. For symptomatic patients, the practitioners surveyed would prescribe cylinders of -0.75DC 60% of the time (Figure 9.5). In the absence of symptoms, practitioners would correct astigmatism of -1.50DC and above, 70% of the time. Few authors have considered the presence of symptoms when giving guidelines as to when to prescribe a cylindrical correction, preferring instead to consider the patient's age, and the astigmatic axis. This finding of -0.75DC for symptomatic patients of mixed age is slightly higher than Gullstrand's (as cited by Helmholtz, 1924) recommendation of –0.50DC. However it is lower then Hirsch's (1963) suggestion of –1.00DC for children of school age.
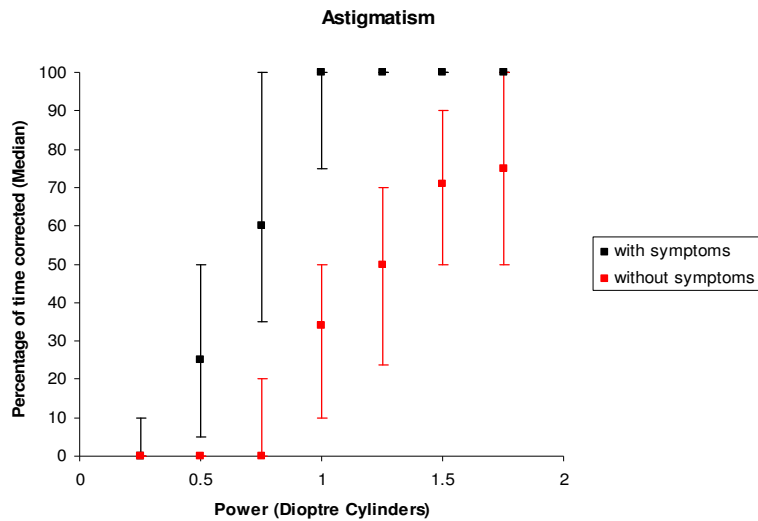
Figure 9.5 A comparison of the percentage of time a practitioner would correct an anomaly if symptoms were present (black points) compared to patients without symptoms (red points).

9.4 CURRENT PRESCRIBING CRITERIA

Finally, the data were analysed to find a 'cut-off point' where the majority of the practitioners surveyed would correct the anomaly. This point has been taken to be the degree of anomaly that was corrected, on average, over 50% of the time that it was seen. These 'cut-off points' are summarised in Table 9.1.

Table 9.1 This table shows the 'cut-off' point for each category. This is the refractive or prismatic power that the practitioners sampled would correct more than 50% of the time that it is seen. The dash indicates that these practitioners would not prescribe any of the powers in the questionnaire more than 50% of the time that they are seen. The maximum values on the questionnaire are also given to help interpretation.

	Hz aligning prism (Δ)	Vt heterophoria (Δ)	Hypermetropia (DS)	Presbyopia (DS)	Astigmatism (DC)
Max. value on questionnaire	3.5	3.5	+1.75	+2.00	-1.75
With symptoms	**1.5**	**1.0**	**+1.00**	**+0.75**	**-0.75**
Without symptoms	_	_	_	**+1.50**	**-1.50**
Literature guidelines	1.5	1.0	+0.75	+0.75	-1.00
No. of respondents (with/without symptoms)	34/36	35/36	37/36	38/36	37/36

9.5   THE IMPORTANCE OF SYMPTOMS

As the literature search and the pilot questionnaire showed that symptoms are a vital factor when deciding whether to prescribe, the data were reviewed to identify the value of each category for which there is the greatest influence of symptoms on the prescribing criteria (Table 9.2). For example, the respondents would have prescribed for +1.00D of hypermetropia, 92.5% of the time if there were symptoms, but 0% of the time had there not been symptoms.

Table 9.2 For each category the table gives the value for which there is the greatest influence of symptoms on prescribing criteria. The bottom two rows show what proportion of practitioners would have prescribed for each criterion if patients reported or did not report symptoms respectively.

	Hz aligning prism	Vt heterophoria	Hypermetropia	Presbyopia	Astigmatism
Value	3Δ	1.5Δ	+1.00DS	+0.75DS	-1.00DC
With symptoms	100%	99.5%	92.5%	80%	100%
Without symptoms	7.5%	0%	0%	0%	33%

9.6 STUDY ONE: CONCLUSIONS

It is clear from the data that there is an enormous variation in the criteria that different practitioners use in deciding when to prescribe. The results also show that the presence of symptoms is of vital importance to practitioners in deciding whether to prescribe across all five categories. For symptomatic patients, the results generally follow the guidelines found in the literature for all five categories, however this is not the case for asymptomatic patients, where the values found were much higher than suggested in the literature. Table 9.2 shows how important symptoms can be in influencing the prescribing decision. For the most extreme example in this table, (1.5Δ of vertical heterophoria), practitioners would have prescribed 99.5% of the time if there were symptoms, but 0% of the time had there not been symptoms.

The large range of reported prescribing criteria and the importance placed on symptoms may explain some cases where a patient is told that they need a refractive correction by one practitioner, but not by another. If the patient reported symptoms to the first practitioner but not to the second then this could completely alter the individual practitioner's advice on whether a correction was required. It is therefore particularly important to thoroughly question and record symptoms and history at the start of any

optometric examination, as recommended by Nathan (1957) and indeed in all optometric texts and teachings that have been encountered.

Clearly, symptoms are especially important in conditions such as hypermetropia and heterophoria, where visual acuity may be little affected by anomalies that may nonetheless produce asthenopia. Indeed, Ball (1982, p38) warned against prescribing optical corrections in the absence of symptoms.

However, in addition to symptoms, there are many other factors that need to be taken into consideration when deciding whether to correct a refractive or binocular vision anomaly. For example: the patient's age, occupational and recreational requirements, and any relevant previous history including the current spectacles. The information about these factors was not included in the questionnaire, in an attempt to keep the questionnaire simple in order to increase the response rate. In addition, the questionnaire did not indicate whether the entire refractive finding would be given, or whether only a partial amount would be prescribed.

Although the sample size was modest, many of the practitioners in this sample were attending CET meetings, and it could be hypothesised that those practitioners who do not attend CET meetings are more likely to prescribe based on habit and previous experience than based on recent research and contemporary instrumentation (e.g., Mallett unit). It is therefore possible that the results may have actually underestimated the range of refractive and binocular vision anomalies that are corrected. This variation is demonstrated in the large range of responses in some categories, particularly in the absence of symptoms, and this finding may be due, at least in part, to the fact that the advice given in the literature is confusing and conflicting. In the absence of coherent

guidelines, optometrists must use other criteria when deciding whether to prescribe. Several factors are likely to influence this decision and these may include past experience, different undergraduate training, and commercial pressures. Many practitioners will ask the patient whether they notice an improvement with the correction in place, before deciding whether to prescribe. This approach may be advantageous, in that every patient is an individual and obviously not all patients will fit into a set of published guidelines. However optometrists should also be aware of the danger of prescribing based on habit, rather than on the best available evidence.

Over the years, substantial attention has been given to improving the consistency of referrals and diagnosis of ocular disease: yet far less attention has been given to improving the consistency of the prescription of spectacles. In this age of clinical governance, it has become even more important to show that clinicians are all working to the same guidelines, and that these have been established by evidence-based research. To achieve this it would be useful to establish with tests of visual performance at what point an intervention becomes beneficial. Yet, most of the conditions surveyed in the current study would only have a minimal effect on visual acuity, and therefore other methods need to be considered. Measures of dynamic visual function, such as rate of reading, may be more appropriate and this will be the subject of the main study.

CHAPTER 10 STUDY TWO: THE EFFECT OF BORDERLINE PRISMATIC AND REFRACTIVE CORRECTIONS ON THE RATE OF READING AND THE RELATIONSHIP WITH SYMPTOMS.

10.1 AIMS OF THE STUDY

The results of study one revealed that practitioners use a wide variety of criteria when deciding whether to prescribe, and that in the absence of evidence-based guidelines, practitioners' decisions on when to intervene are often based on symptoms, which can be an unreliable indicator of whether an intervention will be helpful. A search of the literature (chapters 2 to 7) shows that the current prescribing guidelines are conflicting and rarely based on clinical research. The aim of study two was therefore to determine at what point correcting a small heterophoria or borderline refractive error improves performance at an objective measure of dynamic visual function: the Wilkins Rate of Reading Test (WRRT). The data for the heterophoria groups have been published (O'Leary and Evans, 2006; reproduced in Appendix 4 of this thesis) and a manuscript describing the results for the refractive error groups will be submitted for publication shortly.

10.1.1 Symptoms

The optometrists' survey in study one investigated the criteria used by optometrists in correcting borderline refractive and heterophoric anomalies, and showed that the presence or absence of symptoms is pivotal in the decision as to when to prescribe. In addition, the literature review revealed that several authors such as such as Giles (1965, p191) advocate that heterophoria should only be corrected if symptoms are present and that many of the symptoms of uncorrected refractive errors are non-specific (Ball, 1982,

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p111; Brookman, 1996a, p2; and Brookman, 1996b, pp 124-125). Therefore a second aim of study two was an attempt to identify any relationship between symptoms and the WRRT results.

10.2   SUBJECTS

Subjects were selected from patients attending a community optometric practice for routine eye examination. The practice is a busy independent practice in a town centre with a cross section of patients that is likely to be typical of primary eyecare practices in the UK. All patients meeting the inclusion criteria (Table 10.1) were given a full eye examination (Evans, 2007b, p12), including tests of ocular health (ophthalmoscopy, pupil reactions, visual fields, and, in patients over the age of 35 years, tonometry), refraction (including monocular and binocular visual acuities at distance and near), and binocular co-ordination at distance and near. The distance tests of binocular co-ordination were cover test and horizontal and vertical Mallett aligning prism and those at near were ocular motility, near point of convergence, amplitude of accommodation, Maddox wing test, horizontal fusional reserves, Randot shapes and circles stereoacuity and the Mallett foveal suppression test.

Table 10.1 Inclusion criteria for the subjects in study two.

> **Inclusion Criteria**
>
> *Vertical heterophoria*
> - Any age
> - Any spherical refractive error
> - Subjective cylinder less than or equal to -0.50DC in at least one eye.
> - Vertical aligning prism on near Mallett Unit or near vertical heterophoria on dissociation tests of $\geq 0.50\Delta$
>
> *Horizontal heterophoria*
> - Any age
> - Any spherical refractive error
> - Subjective cylinder less than or equal to -0.50DC in at least one eye.
> - Horizontal heterophoria that may be decompensated (either a near Mallett Unit horizontal aligning prism $\geq 0.5\Delta$, or poor cover test recovery)
>
> *Hypermetropia*
> - Subjective refraction reveals the least astigmatic eye to have astigmatism of less than or equal to -0.50DC
> - Aged 40 years or under
> - Retinoscopy or subjective refraction in the least hypermetropic eye, of +0.75DS to +1.75DS inclusive
>
> *Presbyopia*
> - Subjective cylinder in the least astigmatic eye of less than or equal to –0.50DC
> - Aged 35-60 years inclusive
> - Subjective reading addition of between +0.50DS and +1.50DS
>
> *Astigmatism*
> - Any age
> - Astigmatism found subjectively in the least astigmatic eye of between –0.50DC and -1.75DC inclusive

Every patient meeting the inclusion criteria was invited to return for a research appointment, unless they also met one of the exclusion criteria listed in Table 10.2. Subjects were only allocated to one category, and if a subject met the inclusion criteria for more than one of the groups being examined, then they were placed in the highest category in Table 10.1 for which they were eligible. This method was an attempt to maximise numbers in each group, as the top condition in Table 10.1 (vertical heterophoria) has the lowest prevalence and was therefore hardest to recruit for, and the

bottom condition had the highest prevalence and was therefore easiest to recruit for. All subjects gave informed consent to their participation in the study. The study was approved by the Research and Ethical Committee of the Department of Optometry and Visual Science at City University, and it conformed to the tenets of the Declaration of Helsinki.

Table 10.2 Exclusion criteria for the subjects in study two.

<table>
<tr><td align="center">**Exclusion Criteria**</td></tr>
<tr><td>

All groups
- Patients who cannot read
- Patients whose binocular visual acuity when wearing the intervention or control lens was not good enough to be able to read the text on the Mallett Unit surrounding the fixation disparity test or the text in the WRRT (which are both N9 in size)
- Patients with central visual field loss (within 25°)
- Patients with nystagmus
- Patients attending solely for contact lens aftercare
- Patients with incomitant deviations (as an abnormal head position may confound results)
- Patients with induced astigmatism (e.g. from contact lenses)

Heterophoria groups
- Patients with strabismus

</td></tr>
</table>

10.2.1   Heterophoria group

Subjects in the vertical heterophoria group could be any age, and had a subjective cylinder in the least astigmatic eye of less than or equal to –0.50DC and a vertical aligning prism on the near Mallett Unit or near vertical heterophoria on dissociation tests of ≥ 0.50Δ. Subjects with astigmatism of greater than -0.50DC were excluded from all the groups (apart from the astigmatism group) to ensure that subjects were unlikely to have meridional amblyopia that could have influenced their perception of lines of text (see section 2.4.3). As the results of study one indicated that 50% of optometrists would correct 0.5Δ of vertical aligning prism in symptomatic patients (Figure 9.2), this value

was used as the minimum amount of vertical heterophoria for the inclusion criteria in this group.

For the horizontal heterophoria group, subjects again could be any age, had a subjective cylinder in the least astigmatic eye of less than or equal to –0.50DC, and had a horizontal aligning prism on the near Mallett Unit, or a poor cover test recovery. The Mallett unit and cover test were chosen to assess compensation, as the literature shows that they are widely used throughout the U.K. (Karania and Evans, 2006 and Stevenson, 1999) for this purpose. The literature review (see section 7.8.1) and the results of study one indicate that a wide range of criteria are used in the correction of horizontal heterophoria (see section 9.3.1) with some optometrists reportedly correcting any aligning prism found, and others none at all. Therefore a value of 0.5Δ was again used as the minimum amount of horizontal heterophoria for the inclusion criteria in this group.

Although the inclusion criteria for the vertical and horizontal categories are similar, the vertical group includes patients with a vertical heterophoria seen on dissociated testing, and for the horizontal group, patients with poor cover test recovery. This difference in inclusion criteria is due to several factors. Firstly, detecting vertical heterophoria using a cover test is difficult (Evans, 2007b, p26). This is because vertical fusional reserves are small and as a result the amount of hyperphoria is also either very small, or breaks down into a hypertropia. As the amount of vertical heterophoria seen on a cover test is likely to be very small, gauging the cover test recovery can be difficult. In addition, any amount of vertical heterophoria is considered to be suspicious, so in practice it only needs to be detected and dissociation tests are considered to be the best method for this. Conversely, horizontal heterophoria is common, and as the size of the deviation is not

helpful in the assessment of compensation (see 6.6.1), other methods of assessment such as the cover test need to be used.

10.2.2   Refractive error groups

For hypermetropia, subjects were aged 40 or under, had a subjective cylinder in the least astigmatic eye of less than or equal to –0.50DC, and a retinoscopy or subjective refraction in the least hypermetropic eye, of +0.75 to +1.75DS inclusive. The lower value of +0.75 was chosen, as the results of study one showed that this was the minimum amount of hypermetropia that optometrists would regularly correct (see 9.3.3). Previous studies have shown that ophthalmologists in the U.K consider the 'normal' refractive limit for hypermetropia as +2.00DS (Ingram et al., 1985), and children are asked to wear spectacles until their refractive error drops below this level. Therefore the upper limit of our inclusion criteria was set at +1.75DS.

Subjects in the presbyopia group were aged from 35 to 60 years inclusive, had a subjective cylinder in the least astigmatic eye of less than or equal to –0.50DC and a subjective reading addition of between +0.50 and +1.50DS. The lowest value of +0.50 was chosen as the literature review indicated that this was the most common initial reading addition required (see section 5.3). Although the questionnaire in study one (see Appendix 1) asked optometrists about their prescribing practices for reading additions of up to +2.00, the upper limit for the inclusion criteria in study two was set at +1.50, as subjects requiring higher additions may not have been able to read print of N9 size as required in this study.

For the astigmatic group, subjects could be any age and had a subjective astigmatism in the least astigmatic eye of between –0.50 and –1.75DC inclusive. The literature review in section 4.6 indicated that astigmatism is generally corrected when it is between -0.50DC and -1.75 depending on age and astigmatic axis. The results of study one (see section 9.3.5) fell in between the values reported in the literature and therefore the literature values were used for the inclusion criteria.

10.2.3   Control group

All patients who did not meet either the inclusion or exclusion criteria were included in the control group. Some of the control participants had an aligning prism but did not meet the inclusion criteria because they had astigmatism over 0.50DC. An overview of the characteristics of the control group is shown in Table 10.3.

Table 10.3. Descriptive statistics of the control group

	Number of subjects (Max. 40)
Gender	
Male	17
Female	23
Refractive status	
Hypermetropia	25
Myopia	11
Astigmatism	32
Presbyopia	23
Aligning prism	
Horizontal	13
Vertical	3

	Maximum	Minimum	Median	Mean	Interquartile range
Age (years)	80	5	52	44	13 to 67
Horizontal aligning prism (Δ)	2	0.5	1	1.04	1 to 1
Vertical aligning prism (Δ)	1	0.5	0.5	0.67	0.5 to 0.75
Hypermetropia (DS)	+8.75	+0.25	+1.00	+1.39	+0.25 to +1.50
Myopia (DS)	-3.75	-0.25	-1.50	-1.77	-1.00 to -2.63
Astigmatism (DC)	-2.50	-0.25	-0.50	-0.63	-0.25 to -0.75
Reading addition (DS)	+2.75	+1.50	+2.50	+2.23	+2.00 to +2.50

10.3   OPTOMETRIC TESTING OF VISUAL PERFORMANCE

The main method currently used by optometrists to measure visual performance is visual acuity, typically evaluated using a test chart. In the UK, Snellen charts are most commonly used for checking distance acuities, and a near point chart used for reading, despite both charts having significant drawbacks (McGraw and Winn, 1993; Bailey and Lovie, 1976; Wolffsohn and Cochrane, 2000; Evans and Wilkins, 2000). For example,

with most near point charts the words can easily be guessed from the context of the passage and the surrounding words.

In modern societies, perhaps the most commonplace demanding requirement for the visual system is reading text. Typically, people wish to read text as quickly and as accurately as possible and they expect optometric interventions to help them with this. Rather than using acuity tasks that obtain a threshold based on angular resolution, it is hypothesised that it is clinically more relevant to obtain a threshold based on the rate of reading detailed text.

10.3.1   Wilkins Rate of Reading Test

Wilkins et al. (1996) developed the Wilkins rate of reading test (WRRT). The WRRT (Figure 10.1) employs small, crowded, text including 10 of the most commonly occurring words in the English language (e.g., to, for, and, but, see, the). The test is therefore relatively independent of reading skill and does not assess linguistic or semantic factors. In visual terms, the test has been made particularly demanding by reducing the horizontal spacing between words and printing the text in a small typeface. The text consists of words arranged in random order and the participant is instructed to read them out loud as quickly as possible for maximum accuracy, with the score taken as the number of words correctly read in one minute. The WRRT results are repeatable (Wilkins, 2002) and would appear to be very dependent on dynamic visual skills and to require sustained binocular single and clear vision.

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
is you dog for not cat my look come and up to play see the

Figure 10.1 A passage from the Wilkins Rate of Reading Test.
Image kindly provided by Professor Arnold Wilkins.

The WRRT was originally developed to assess the effect of coloured filters on reading in children with reading difficulties (for a review, see Wilkins, 2002), where it has been shown that the coloured filter is likely to be beneficial if there is an improvement in the rate of reading of >5% (Kriss and Evans, 2005). Children who show a significant initial improvement in rate of reading with a coloured overlay are likely voluntarily to use an overlay for prolonged periods (Wilkins et al., 1996; Jeanes et al., 1997), indicating a benefit during everyday reading. As the WRRT has been developed to assess the effect of coloured filters on the rate of reading, its sensitivity to refractive errors and decompensated heterophoria is unknown. However, if an optometric correction for a refractive or orthoptic anomaly would be likely to help symptoms, in particular to make prolonged and/or detailed visual tasks more comfortable, then it is hypothesised that the WRRT could be used to identify the benefit from the intervention. Additionally, if an optometric intervention is likely to bring about an improvement in visual performance during everyday tasks (e.g., in office-based activities) then it seems likely that such a benefit could be identified as improved performance at the WRRT.

10.4   METHODS

10.4.1   Mallett Unit

The Mallet unit is commonly used in the U.K. in the detection and management of decompensated heterophoria (see sections 6.6.4 and 7.3). In view of the large body of research supporting the Mallett Unit fixation disparity test (Payne et al., 1974; Pickwell et al., 1987a; Pickwell et al., 1987b; Pickwell et al., 1987c; Dowley, 1989; Jenkins et al. 1989; Pickwell et al. 1991; Heravian-Shandiz et al., 1993; Jenkins et al., 1994a; Mallett and Radnan-Skibin, 1994; Jenkins et al., 1995), it was decided to use this test both in the inclusion criteria and to determine the active intervention, described below as the "prescribed prism".

10.4.2   Prescribed prism

For heterophoria, the prescribed prism used was the total aligning prism found to eliminate a fixation disparity on the near Mallett Unit. The precise instructions that are given to the patient with this test have a significant effect on the result (Karania and Evans, 2006). The procedure used incorporated the questions recommended by Evans (2007b, pp 76-77) and validated by Karania and Evans (2006). This procedure is detailed in Figure 10.2.

Can each eye resolve OXO? → No → cannot test → **poor V/A**

Yes

Show FD test without visor

"Can you see both green lines, one above and one below the X, and are both green lines *exactly* in line, one straight above the other?" → No → cannot test → **unreliable px / visual conversion reaction**

Yes

Insert visor, px read line of text, show FD test

"Are both green lines (one above & one below the X) present all of the time?"

Yes | No

"Are both green lines ever present at the same time?"

Yes | No → cannot test → "Which one disappears, or do both disappear?" → **transient/altern./constant R/L/B suppression**

"(When both lines are present) Are the two lines exactly lined up?"

No | Yes

"Does one or both green lines ever move to one side?" → No → **no fixation disparity**

Yes

"Does just one line move or do both?" → **RE FD / LE FD / BE FD**

"Do(es) the line(s) that move(s) go to the left, right, or equally often to both sides?" → equal → **binocular instability** → try 0.5 ▲ in, then out

more to one side → **eso/exo fixation disparity**

introduce/add 0.5 ▲ in/out as appropriate → **Aligning prism**

Figure 10.2 A flow chart illustrating the procedure and questions followed when measuring the subject's fixation disparity using the Mallett Fixation Disparity Unit. Amended from an image kindly provided by Professor Bruce Evans

The subject was asked to hold the Mallett unit at their normal reading distance. (S)he was then asked to look at the OXO on the left side of the Mallett unit, used to measure horizontal aligning prism (Figure 10.3, left) and asked whether they were able to see both lines above and below the X, and also whether they were exactly aligned. If they were not aligned without the visor, the test was ended and the subject excluded from the study. The polarised visor was then introduced and the room illumination increased to compensate for the drop in visibility through the visor. The subject was asked to read a line of text surrounding the OXO before being directed to look straight at the central X, and was questioned as per the flow chart above. Depending on the clinical test results with the Mallett fixation disparity test, the aligning prism was prescribed in front of one eye or both eyes (Mallett, 1964). The first prism introduced was 0.5Δ, followed by 1Δ and then in 1Δ steps until the Nonius lines were completely aligned and stationary. The subject was asked to look at the central X throughout, and was allowed to view the OXO chart with the prism for as long as needed to make a decision about the position of the lines. Several steps were taken to minimise the risk of disrupting binocular vision during the testing: trial case prisms were used instead of a prism bar, the number of prism changes were minimised, and participants were asked to read some text with each new prism to stabilise binocular vision and accommodation before any measurement was taken. The first prism that resulted in stable and aligned Nonius lines was taken as the aligning prism measurement. If the Nonius lines did not stabilise with any prismatic power, then the subject was excluded from the study. No participants were excluded for this reason. The subject was then asked to repeat the procedure on the OXO target on the orthogonal OXO target to measure the vertical aligning prism (Figure 10.3, left).
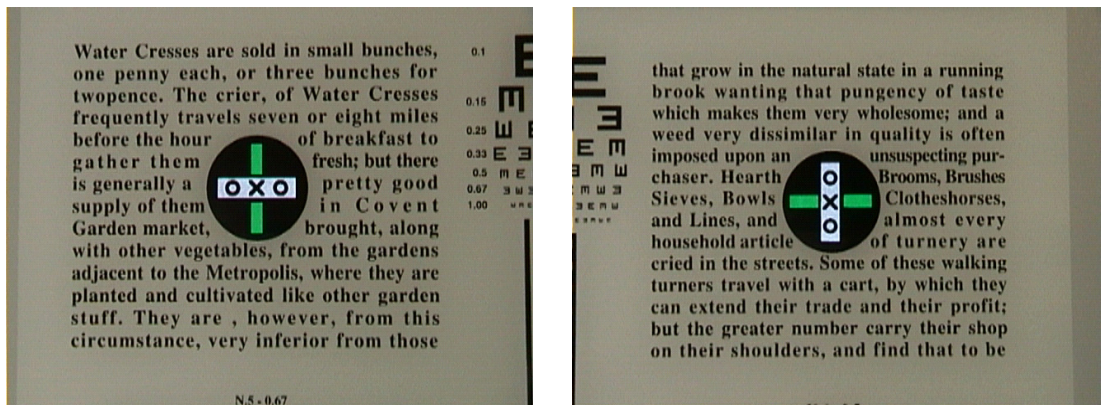
Figure 10.3. A photo of the OXO targets found on the near Mallett Unit.

For the astigmatism group and the presbyopia group, the prescribed lens used was the strength found on the final subjective refraction during the subject's routine eye examination. For the hypermetropia group, the prescribed lens used was taken as the lower power of either the non-cycloplegic retinoscopy or the non-cycloplegic subjective refraction. The literature suggests that cycloplegic refractions are indicated if there is a reduction in acuity, poor stereopsis, poor accommodation, a history of strabismus, amblyopia or high hypermetropia, manifest strabismus or esophoria that is unstable (Viner, 2004, pp 22-23). The same author suggests that cycloplegia is of little benefit in a symptom free, co-operative child with no abnormal findings. As the purpose of this thesis was to provide guidance for borderline refractive corrections encountered in everyday optometric practice, it was more useful to use the non-cycloplegic refractive findings. This issue is discussed further in section 13.3.5.

10.4.3   Control lenses

For exophoria and hyperphoria, plano size lenses were used as a control, and for esophoria a standard plano trial lens. Plano size lenses are (also known as iseikonic lenses) are afocal lenses that alter the magnification of an object (Rabbetts, 2007, p281).

When people view objects through base-in prisms they typically perceive the object as being increased in size (the SILO phenomenon; see section 12.1.1). The size lenses that were used as a control for exophoria had no refractive or prismatic power, but gave the same magnification as the prescribed lens being tested. Although the literature describes how to calculate the spectacle magnification produced from spherical lenses (Jalie, 1994, pp469-480), no publications were found describing the calculation of the perceived magnification associated with prismatic lenses. Therefore, the size lenses were assessed by five adult trained observers who had a fairly typical range of refractive corrections and binocular vision status, to determine which size lens most closely matched the perceived magnification produced by each prismatic lens used. The observers viewed a line on the distance and near Snellen charts through the prismatic lens, and then immediately compared this with each size lens. The results were unanimously agreed upon, and are shown in Table 2. The size lenses selected for the exophoria group and given in Table 10.4 were also used for the vertical heterophoria group. For esophoria, plano trial lenses were used rather than size lenses, in view of the SILO phenomenon (see section 12.1.1).

Table 10.4 The size lenses used as a control lens for exophoria (base-in), esophoria (base-out) and vertical heterophoria (base-up and down).

Prismatic power	Size lens used
Base-in, up and down	
0.5 1 2 3	1 (no 0.5 size lens available) 1 2 3
Base-out	
All powers	Plano lens

For hypermetropia and presbyopia plano size lenses were used as a control, and the reasons for this are explained below.

The size lenses used as a control for the hypermetropia and presbyopia groups had no refractive or prismatic power, but gave the same magnification as the prescribed lens being tested. The magnification of the prescribed lenses was calculated using the equations below (Jalie, 1994 pp 469-470) for Spectacle Magnification (SM):

SM = Power factor x Shape factor

Power factor = $1/(1-dFs)$

Shape factor = $1/\{1-(t/n)F_1\}$.

Where:

d= vertex distance (meters)

Fs = the lens power (D)

F_1 = the power of the front surface of the lens (D)

t = lens thickness (in meters)

n is the refractive index of the lens material

Each corrective lens used in the study was then matched to the size lens that provided the closest magnification (Table 10.5). This size lens was used as the control for the prescribed lens being tested.

Table 10.5 Size lenses used as the control condition for hypermetropia and presbyopia.

Spherical lens power (DS)	Spectacle Magnification (decimal)	Spectacle Magnification (%)	Closest size lens (%)
+0.50	1.0078	0.8	1
+0.75	1.0118	1.2	1
+1.00	1.0159	1.6	1.5
+1.25	1.0198	2.0	2
+1.50	1.0239	2.4	2
+1.75	1.0280	2.8	3

For astigmatism, the spherical equivalent refraction (SER), calculated as the spherical power plus half the cylindrical power, was used as the control, in order to place the circle of least confusion on the retina. Many studies on astigmatism have used the SER in their analysis (e.g. Abrahamsson et al., 1988, Fulton et al., 1980).

10.4.4   Wilkins Rate of Reading Test

The WRRT consists of four differing passages of text (Figure 10.1). To check that each subject was able to read the text, and that the instructions were understood, they were initially asked to read the first line from the fourth passage whilst wearing their current spectacles at their usual reading distance, or without any spectacles if none had previously been prescribed. All the subjects were then asked to read the WRRT twice with the prescribed lens and twice with the control lens (see below), in an ABBA configuration, with the order of testing determined using computer generated randomised numbers, allocated to subjects at their research appointment. For example, the randomisation meant that for approximately half the subjects the prescribed lens was condition A. These subjects carried out the WRRT first with the prescribed lens, then with the control lenses, again with the control lenses, and finally again with the prescribed lens. The ABBA configuration was designed to control for any practice effect, and a different passage of text was used for each of the four measurements, with no interval between each run apart from the time taken to change the lenses in the trial

frame. For each run, the examiner recorded the number of correctly read words in a minute on a worksheet (see Appendix 2). In order to do this, every word was that was read incorrectly or omitted was crossed through on the worksheet, and if the subject finished the passage before the minute was up, the time taken to complete the passage was noted. Words that were read incorrectly or omitted were not counted in the number of words correctly read, and were therefore excluded from the calculation of 'words per minute'.

The author placed the appropriate lenses in a trial frame, and a colleague, who was unaware of which lenses were being used, conducted the WRRT. Subjects were also unaware of which lenses were being used, and the study was therefore double masked. The subjects were instructed on how to perform the WRRT and were told that the purpose of the study was to determine at what point it would be beneficial to correct borderline visual anomalies. They were told that they would be tested with two sets of lenses, but were not told that one of these sets was a control. The term *prescribed lens* is used to indicate that this lens was individually prescribed for the present research based on refractive and binocular vision findings, in contrast with the *control lens* which was chosen as described above. It is not implied that all the subjects would have been prescribed lenses for use outside of the research (indeed, some were not).

To test whether the size lenses were an adequate control, and whether the increase in magnification alone would influence the WRRT results, the control group previously described on page 144 undertook all the WRRT twice with the size lenses over the top of their own prescription (taken as the subjective refraction from their most recent eye examination), and twice without. For half of the control group a size lens producing 1% magnification was used, and for the other half 2%. As in the main study, the WRRT

testing was carried out in an ABBA configuration with A and B randomly allocated to the size lens or no size lens condition.

10.4.5   Symptom questionnaire

After each participant had completed the tests, they were asked to respond *yes* or *no* to a series of questions in a questionnaire about symptoms (see appendix 3): When reading, do words ever become doubled, blurred, jump around, change size, fade, or disappear? They were also asked whether they closed or covered an eye when reading, whether they thought that they blinked more than normal, skipped words, read slowly, had poor co-ordination, or were light sensitive. Each participant was given a score of one point for each of these symptoms that was present. For the two questions asking if they ever had double vision or sore eyes when reading, the scores were weighted on an interval scale from 0-1 depending on how often this occurred: hardly ever (weighting 0.25), only if reading for a long time (weighting 0.50), when reading for a moderate time (weighting 0.75) or when reading for a short time (weighting 1.00). They were also asked how many headaches they had over the last three months, and whether these were related to reading. If they had more than two headaches related to reading then a point was added to the final symptom score. This scoring system was chosen as it has previously been used in studies involving the Mallett fixation disparity test (Karania and Evans, 2006) and the WRRT (Evans et al., 1999). To check the validity of the subjects' responses, the question asking if they had sore eyes and if so how often this occurred was asked twice, once at the beginning of the questionnaire, and again at the end.

As the control group described in the previous section was very heterogenous, the symptom scores of the experimental groups were compared with symptom scores of a subset of the control group who were 'optometrically normal'. For the heterophoria

group this subset was selected as the control participants who did not have any horizontal or vertical aligning prism (n=28), and for the refractive error groups the subset was selected consisting of those subjects who had not had a refractive change of more than 1.00 DS at their last eye examination (n=24).

CHAPTER 11   STUDY TWO: RESULTS AND ANALYSES

11.1   INTRODUCTION

11.1.1   Subjects and raw data

A total of 80 participants with a near heterophoria took part in the research: 58 subjects with exophoria with a mean age of 39 (range 6-83 years), 15 subjects with esophoria (mean age 16; range 6-43) and seven subjects with vertical heterophoria (mean age 61; range 9-80). There were 208 subjects with low refractive errors, comprising 32 subjects with hypermetropia (mean age 14 years; range 6-35), 58 subjects with presbyopia (mean age 46 years; range 39-58 years), and 118 subjects with astigmatism (mean age 46 years; range 7-79 years).

11.1.2   Introduction to statistical analyses

The results of the two runs with the refractive or prismatic correction in place were averaged to give the subject's rate of reading with the prescribed lens. The rate of reading with the control lens was calculated the same way.

The WRRT data can be quantified in two ways: as the difference $(x - y)$ between the rate of reading with the intervention (x) and the control (y), or as the percentage difference $(100*(x - y)/y)$. Scatter plots revealed that there was no detectable correlation between the difference $(x - y)$ and the reading speed (y) and this low

correlation was confirmed with the calculation of the correlation coefficient of 0.27 and the r^2 value of 0.08. Therefore, the difference was used in these analyses.

Before the results were analysed, histograms were plotted showing the difference in words per minute for each category and a visual inspection showed that the data approximated normal distributions for all the groups (Figure 11.1).
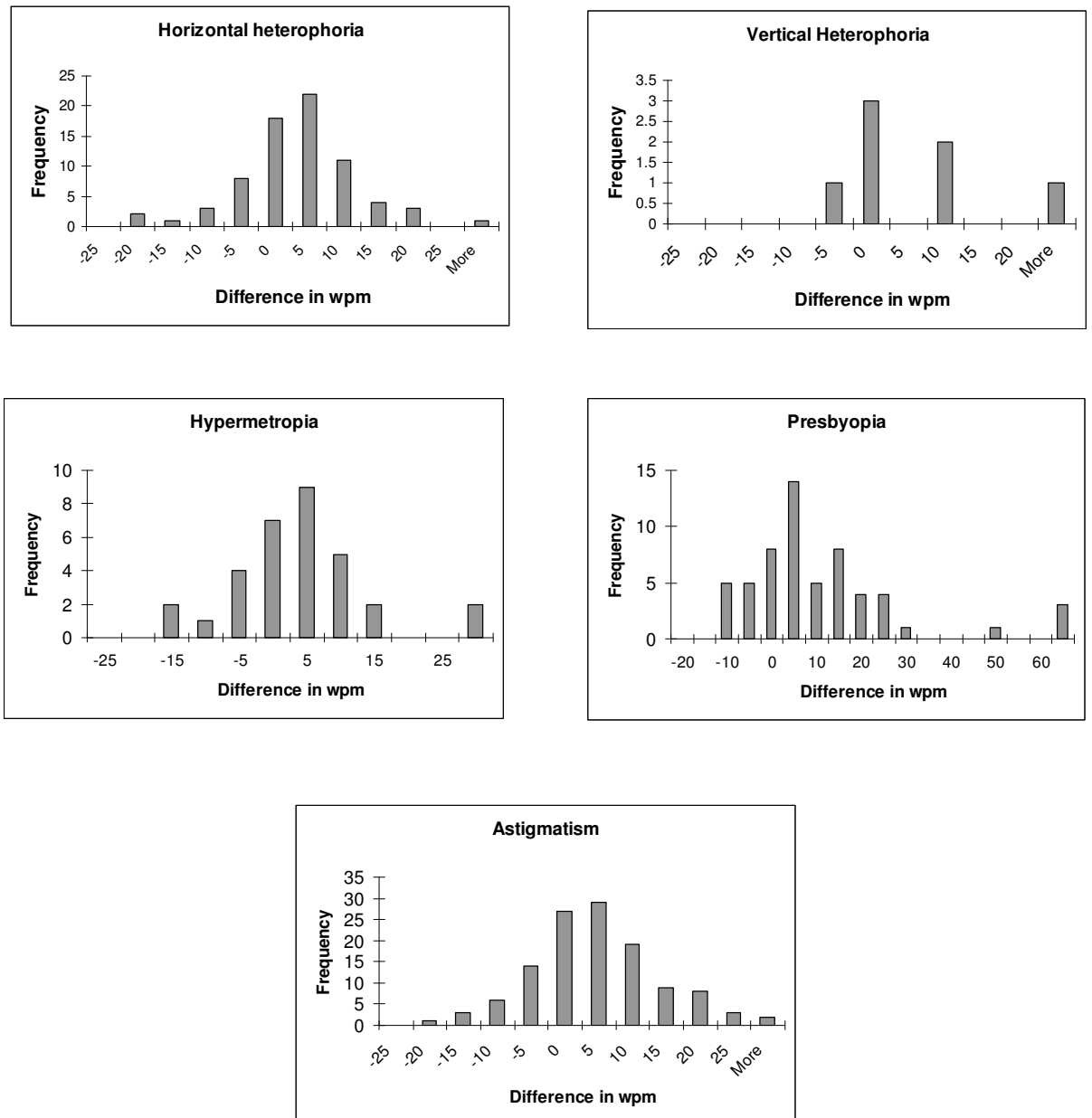
Figure 11.1 Histograms to assess the normality of the data

As the data approximated normal distributions parametric tests were used in the statistical analyses.

The level of significance required to support a hypothesis was taken as p≤0.05. Although the hypothesis is looking for an improvement in the WRRT with the intervention, it is also possible that the intervention may cause a decrease in the reading speed. Therefore two-tailed probability values were calculated throughout.

11.2 CONTROL GROUP

A paired t-test was performed on the control group data (N=40) to check that the size lenses were an inert control. The mean WRRT result with the size lenses (132.6 words per minute ± 95% Confidence Interval 10.5) was compared to the result without the size lenses (133.1± C.I 11.1). The difference between the results of the two groups was not statistically significant (two tailed, p=0.66), confirming that the size lenses were an adequate control. As each subject performed the rate of reading test twice with and twice without the placebo lens on top, this data was also used to estimate the test-retest reliability of the WRRT. There was a strong correlation between the two measurements for each subject (r^2 correlation coefficient = 0.95) and the mean difference in words per minute for the group was 0.41, indicating that the WRRT is a reliable method of assessing reading performance.

11.3 EXOPHORIA

11.3.1 Overview of data

The exophoric group contained 58 participants. To obtain an overview of the data, the difference in the rate of reading (words per minute) between the prescribed lens and the control for each subject was plotted on a scattergram (Figure 11.2). Twelve of the 58 subjects had an improvement in the WRRT of >5% (represented by the black circles)

and five of these 12 subjects required an aligning prism of 2Δ. There were also nine subjects who read more than 5% slower with the prescribed lens compared to the control (represented by the black lines), and five of these subjects required aligning prisms of 1Δ.
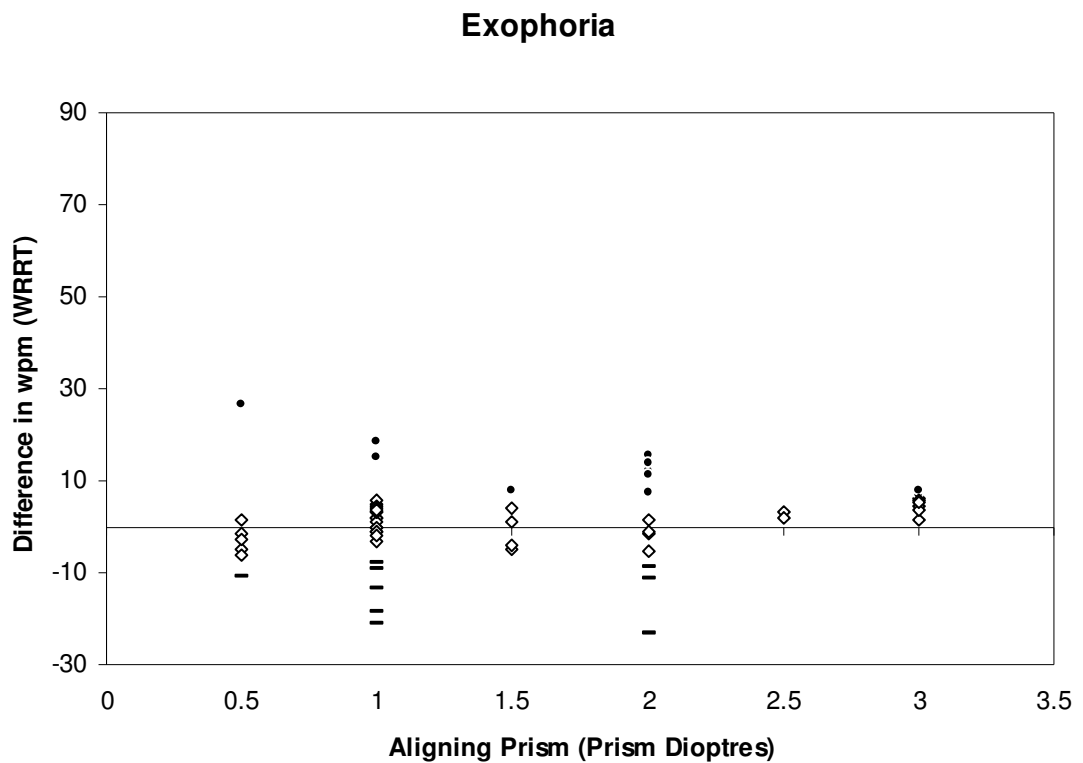
Exophoria

Figure 11.2 Scattergram showing the difference between the rate of reading (words per minute) with the prescribed lens and rate of reading with the control lens (y axis) for each subject with exophoria (x axis) for each power of aligning prism. Positive values represent better performance with the prescribed lens than with the control. The y axis scale has been selected so that this graph can be directly compared with those from the other groups below. The black circles represent subjects with >5% improvement on the WRRT, and the black lines represent those subjects who read more than 5% slower

11.3.2   Statistical analysis

To determine if correcting the exophoric aligning prism found on the Mallett unit improved the rate of reading, and if so, at what prismatic power the benefit became apparent, the participants were divided into three groups according to the magnitude of aligning prism (in prism dioptres, Δ) that they required: 0.5 to 1Δ (N=30, mean age 34 years; range 6-74), 1.5 to 2Δ (N=18, mean age 41; range 11-73), and 2.5 to 3Δ (N=10,

mean age 53; range 10-83). These sub-groups were chosen in order to divide the range of prismatic powers into equal categories with two step sizes in each sub-group (e.g. 0.5Δ and 1Δ).

A paired t-test was performed in each sub-group on the WRRT data to determine if the subjects performed better with the prescribed lens or with the control lens. The results showed that the prescribed prism became more beneficial as the prismatic power increased but that there was not a significant improvement at the WRRT until the power reached 2.5Δ (paired t-test, N=10, p=0.00008) (Figure 11.3). For this prismatic power, the mean rate of reading was 3.2% faster with the prescribed lens (150.4 words per minute $\pm$ 95% CI 14.1) than with the control size lenses (145.7 $\pm$ 14.5). Although all the participants in the 2.5 to 3Δ group read faster with the intervention than the control, only two participants had an increase in reading speed of 5% or greater. The mean rate of reading with the prescribed lens was 0.02% slower than with the control lens (p=0.87) in the 0.5 to 1.0Δ sub-group and 1.3% faster (p=0.61) in the 1.5 to 2.0Δ sub-group.
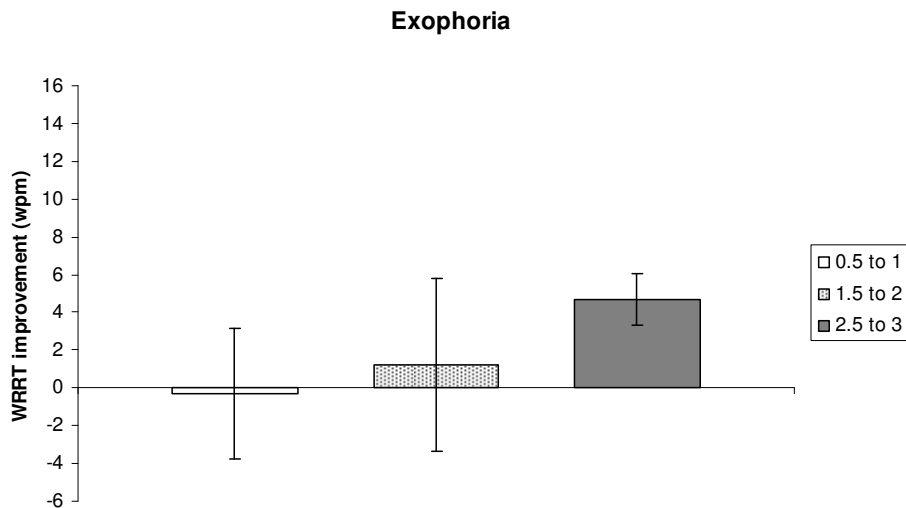
Exophoria

Figure 11.3 A comparison of the mean improvement in rate of reading (y axis) in words per minute (wpm) with the prescribed prism compared to the control lens for exophoria in prism dioptres (x axis). The error bars represent the 95% confidence limits of the mean.

11.4   ESOPHORIA

11.4.1   Overview of the data

The scattergram showing the difference in the rate of reading for each individual was plotted using the same scale as for the other groups to enable easier comparison (Figure 11.4). In figure 11.4 it is shown that three out of the 15 subjects had an improvement on the WRRT of greater than 5%, and only one subject read more than 5% slower with the aligning prism compared to the control. All four of these subjects required an aligning prism of ≤ 1Δ when tested with the Mallett Unit.

Esophoria
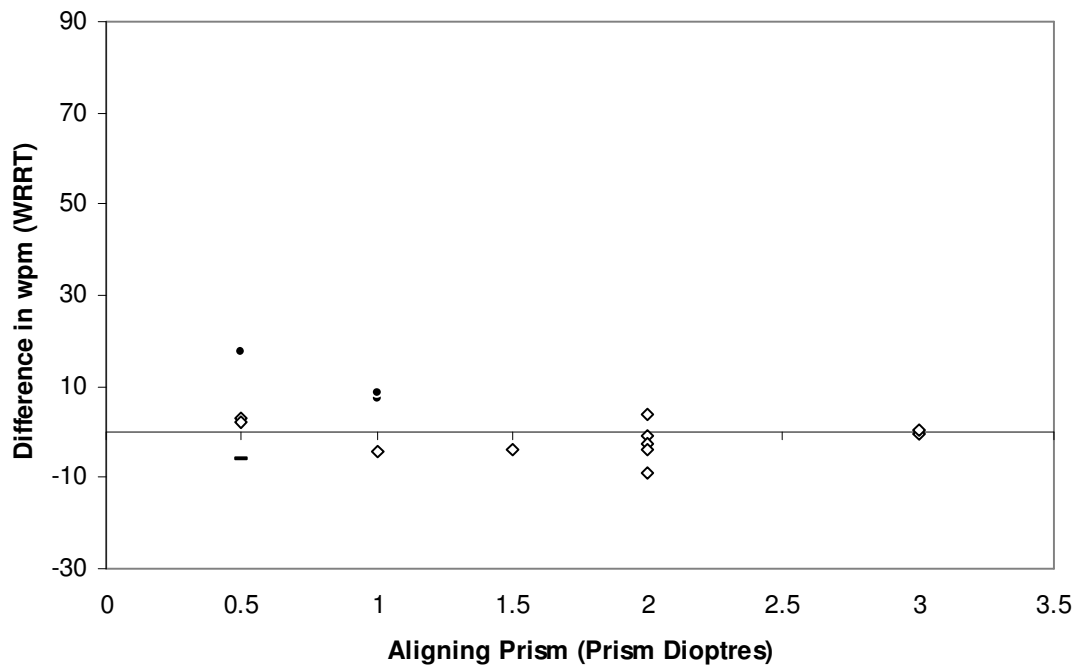
Figure 11.4 Scattergram showing the difference between the rate of reading (words per minute) with the prescribed lens and rate of reading with the control lens (y axis) for each subject with esophoria (x axis) for each power of aligning prism. The y axis scale has been selected so that this graph can be directly compared with the others. Positive values represent better performance with the prescribed lens than with the control. The black circles represent subjects with >5% improvement on the WRRT, and the black lines represent those subjects who read more than 5% slower

11.4.2   Statistical analysis

There were far fewer participants with an esophoria (N=15) at near compared to the number with exophoria, as one would expect from the literature (Pickwell et al., 1991). Therefore in order to maximise the number of subjects in each subgroup and improve the statistical power, the category was divided into two subgroups instead of three: 0.5 to 1.5Δ inclusive (N=8) and 2 to 3Δ inclusive (N=7). There was very little difference in the rate of reading with prescribed prism compared to control lens for both of these groups (Figure 11.5) and neither was statistically significant. The mean rate of reading with the prescribed lens was 3.7% faster than with the control lens (p=0.31) in the 0.5 to 1.5Δ sub-group and 0.9% slower (p=0.28) in the 2.0 to 3.0Δ sub-group.

Esophoria

Figure 11.5 A comparison of the mean improvement in rate of reading (y axis) in words per minute (wpm) with the prescribed prism compared to the control lens for esophoria in prism dioptres (x-axis). The error bars represent the 95% confidence limits of the mean.

11.5   VERTICAL HETEROPHORIA

11.5.1   Overview of the data

There were only a few subjects with a vertical heterophoria at near (N=7), and the scattergram showed that for six out of these seven subjects, there was very little difference between the rate of reading with the prism in place and the rate of reading with the control lens (Figure 11.6). Only one subject had a difference of >5%, and this subject read 16% faster with the prescribed lens compared to the control. None of the subjects had a decrease in reading speed of greater than 5%.

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Vertical heterophoria
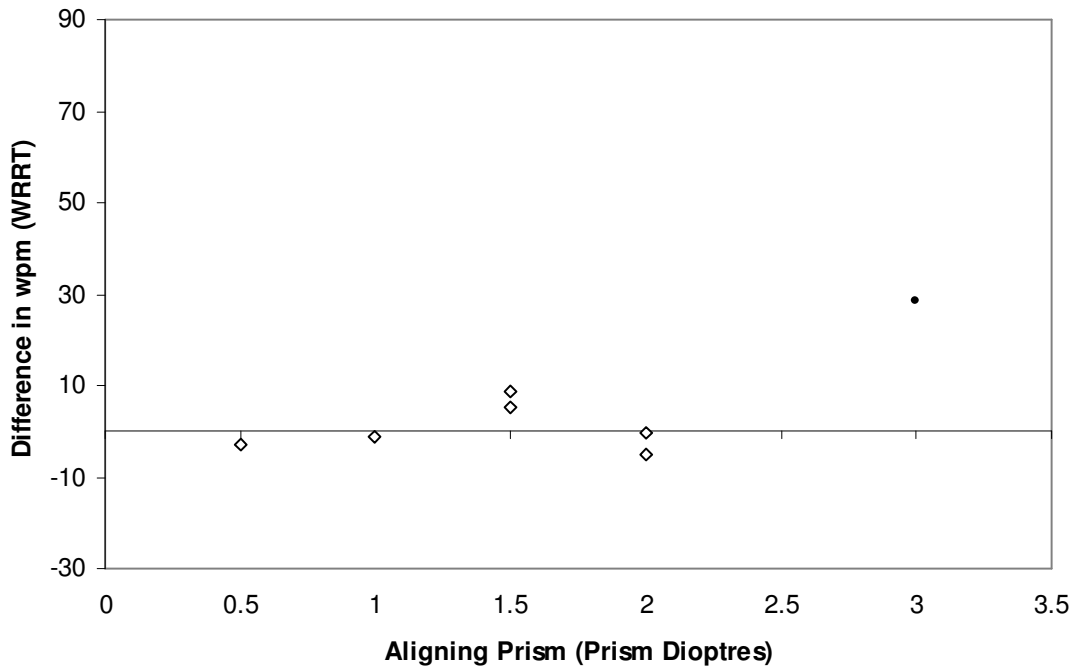
Figure 11.6 Scattergram showing the difference between the rate of reading (words per minute) with the prescribed lens and rate of reading with the control lens (y axis) for each subject with vertical heterophoria (x axis) for each prismatic power. The y axis scale has been selected so that this graph can be directly compared with the others. Positive values represent better performance with the prescribed lens than with the control. The black triangles represent subjects with >5% improvement on the WRRT, and the black squares represent those subjects who read more than 5% slower

11.5.2   Statistical analysis

In view of the small number of participants, they were not subdivided into subgroups (Figure 11.7). The mean rate of reading was only 2.2% faster with the prescribed lens compared to the control, and this was not significant when tested with a paired t-test (p=0.33).

Vertical Heterophoria
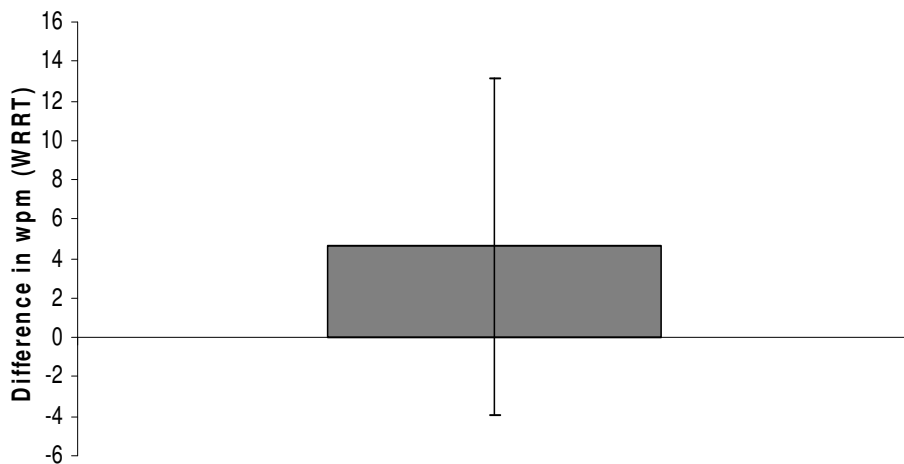
Figure 11.7 A comparison of the mean improvement in rate of reading (y axis) in words per minute (wpm) with the prescribed prism compared to the control lens for vertical heterophoria in prism dioptres (x-axis). The error bar represents the 95% confidence limits of the mean.

11.6   SUMMARY OF PAIRED T-TEST RESULTS FOR HETEROPHORIA

A summary of the paired t-test results for heterophoria is shown in Table 11.1.

Table 11.1 A summary of the mean difference in words per minute (wpm) for each heterophoric sub-group on the WRRT. Positive values represent better performance with the prescribed lens than with the control.

Heterophoria	Aligning prism (Δ)	Number of subjects (N)	Mean difference in wpm	Confidence Interval of the mean (±)	t-test p value
Exophoria	0.5 to 1.0	30	-0.29	3.47	0.87
	1.5 to 2.0	18	1.22	4.60	0.61
	2.5 to 3.0	10	4.68	0.69	0.00008
Esophoria	0.5 to 1.5	8	3.05	5.51	0.31
	2 to 3	7	-1.81	1.54	0.29
Vertical heterophoria	0.5 to 3	7	4.65	8.54	0.33

11.7   HYPERMETROPIA

11.7.1   Overview of the data

The scattergram showing the difference in rate of reading (words per minute) between the prescribed lens and control for each subject revealed that seven of the 32 subjects

had an improvement in the WRRT of >5% and that 5 of these 7 subjects had a hypermetropia of +0.75DS (Figure 11.8). There were also 7 subjects who had a decrease in the rate of reading of more than 5%. Although one subject with 1 dioptre sphere of hypermetropia had a very small decrease in the rate of reading with the prescribed lens (–2), this subject had a very slow general reading speed (31.5 with the intervention and 33.5 with the control), and therefore this equated to a 5.97% difference in wpm. Those subjects with at least a 5% decrease in the rate of reading were distributed fairly evenly across the range of hypermetropic powers.

Hypermetropia
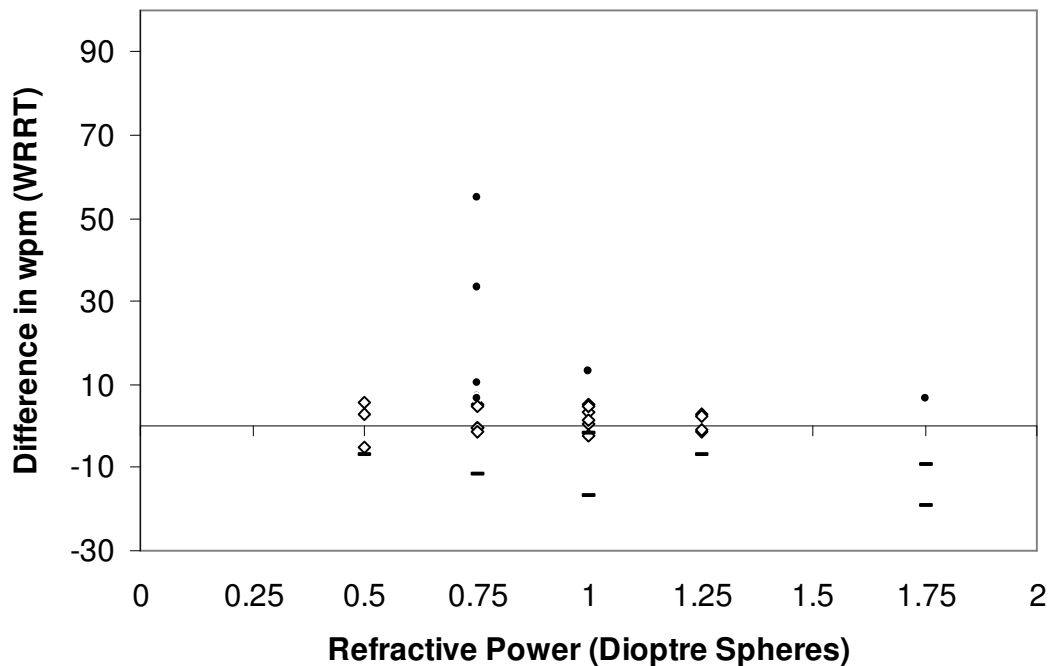
Figure 11.8 Scattergram showing the difference between the rate of reading (words per minute) with the prescribed lens and rate of reading with the control lens (y axis) for each subject with hypermetropia (x axis) for each power. The y axis scale has been selected so that this graph can be directly compared with the others. Positive values represent better performance with the prescribed lens than with the control. The black circles represent subjects with >5% improvement on the WRRT, and the black lines represent those subjects who read more than 5% slower

11.7.2   Statistical analysis

The hypermetropia group was then divided into two sub-groups according to spherical

refractive error: +0.50 to +1.00DS (N=24) and +1.25 to +1.75DS (N=8). These sub-

groups were again chosen in order to divide the range of refractive errors tested into two

equal categories, whilst maintaining a useful number of subjects in each group i.e. three

refractive power step sizes in the first sub-group (+0.50, +0.75, +1.00), and three in the

other (+1.25, +1.50, +1.75). A paired t-test was performed in each sub-group on the

WRRT data to determine if the subjects performed better with the prescribed lens or

with the control lens. The results showed that the mean rate of reading was not

statistically significantly different between the conditions in either of the sub-groups

(Figure 11.9). The mean rate of reading with the prescribed lens was 4.9% faster than with the control lens in the +0.50 to +1.00 sub-group (p=0.12) and 3.8% slower in the +1.25 to +1.75 sub-group (p=0.30).
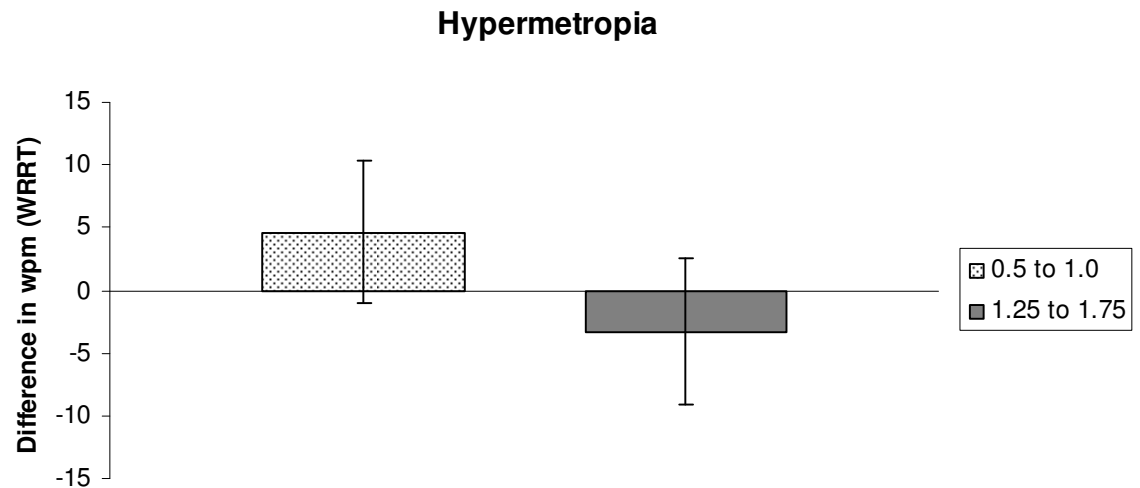
Hypermetropia


Figure 11.9 A comparison of the mean improvement in rate of reading (y axis) in words per minute (wpm) with the prescribed lens compared to the control lens for hypermetropia in dioptre spheres (DS) (x-axis).

11.8   PRESBYOPIA

11.8.1   Overview of data

The scattergram of individual data showed that 23 subjects out of the 58 tested had an improvement on the WRRT of >5%, and that the difference in the rate of reading increased as the reading addition increased (Figure 11.10). There were only seven subjects who had a decrease in their rate of reading of >5%, and these subjects were evenly distributed between 0.5 and 1.25D reading additions.
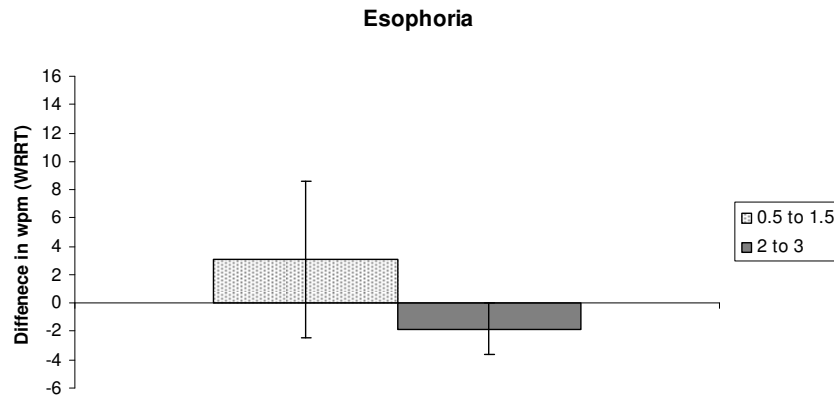
Presbyopia
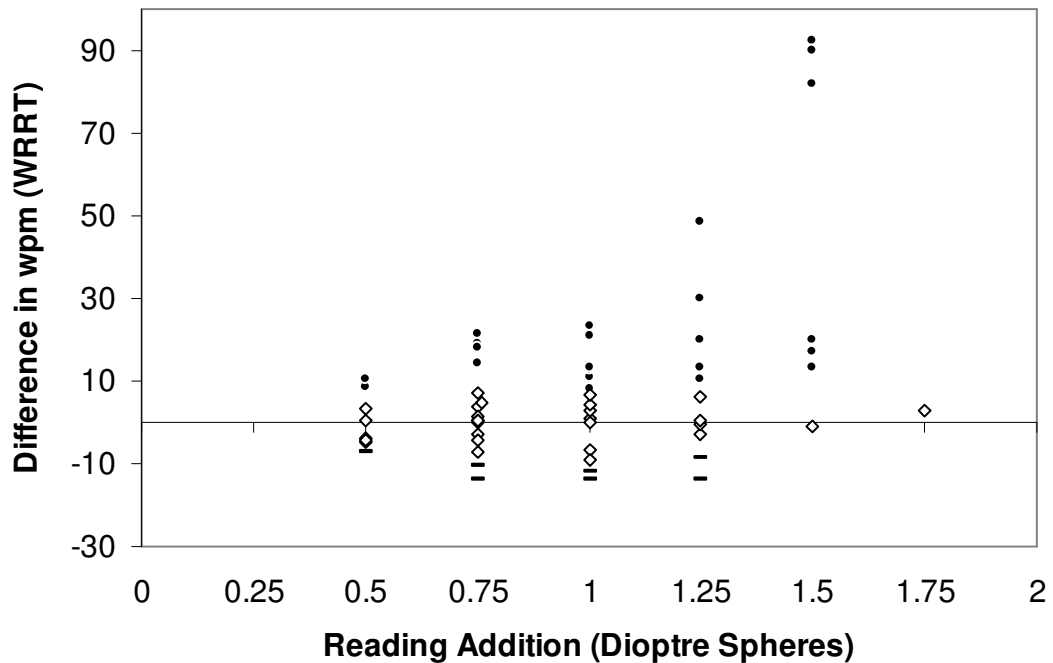
Figure 11.10 Scattergram showing the difference between the rate of reading (words per minute) with the prescribed lens and rate of reading with the control lens (y axis) for each subject (x axis) for each reading addition. The y axis scale has been selected so that this graph can be directly compared with the others. Positive values represent better performance with the prescribed lens than with the control. The black circles represent subjects with >5% improvement on the WRRT, and the black lines represent those subjects who read more than 5% slower.

11.8.2   Statistical analysis

The data were then divided into sub-groups relating to the power of the reading addition: +0.50 to +0.75DS (N=24), +1.00 to +1.25DS (N=26) and +1.50 to +1.75DS (N=8). As there were more subjects in the presbyopia group compared to the hypermetropia group, the presbyopia group was divided into three sub-groups, each containing two prescribing step sizes (e.g., +0.50 and +0.75). There was a greater difference between the prescribed lens and the control as the power of the reading addition increased, and as the differences were much larger than in the hypermetropia category, different axes were used on the graph for presbyopia to make it easier to interpret the data for each category (Figure 11.11). There was a statistically significant difference between the conditions for the mean of the WRRT data for the +1.00 to

+1.25 sub-group and for the +1.50 to +1.75D sub-group (Paired t-test, p=0.03 for both) (Table 11.2). For the sub-group with reading additions of +1.00 to +1.25D, the mean rate of reading was 4.6% faster with the prescribed lens (160 words per minute ± C.I.11.4) than with the control size lenses (153.6 ±11.0). There was a greater improvement when the reading addition required was higher (+1.50 to +1.75D). In this sub-group, the mean rate of reading with the prescribed lens was 60% faster (150.7±12.0) than with the control (111.1±27.7).

Presbyopia
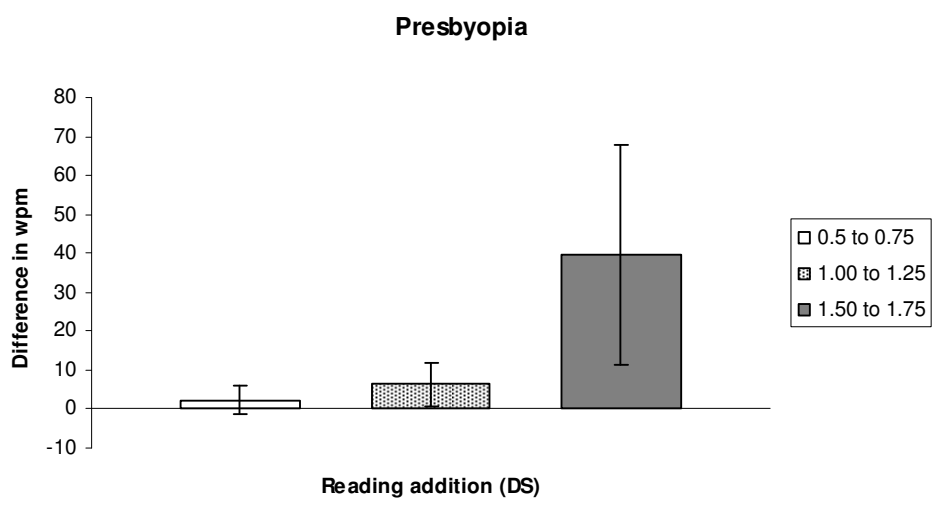
**Figure 11.11 A comparison of the mean improvement in rate of reading (y axis) in words per minute (wpm) with the prescribed lens compared to the control lens for hypermetropia in dioptre spheres (DS) (x-axis).**

11.9   ASTIGMATISM

11.9.1   Overview of data

Out of the 118 subjects in the astigmatic group, the scattergram (Figure 11.2) showed that 26 subjects had an improvement in the WRRT of >5% when reading with the prescribed lens, and 14 subjects had a reading rate that was at least 5% slower. Twenty of the 26 subjects with an improvement of >5%, and 11 of the 14 subjects with a decrease >5% had a cylindrical correction of less than –1.25DC.

Astigmatism
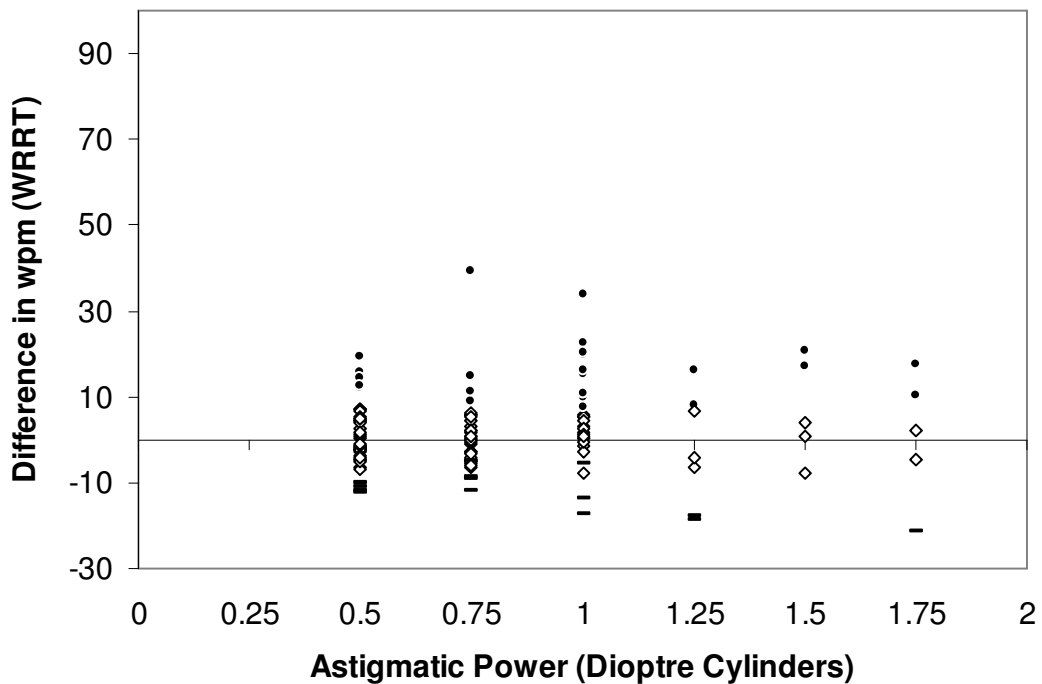
Figure 11.12 Scattergram showing the difference between the rate of reading (words per minute) with the prescribed lens and rate of reading with the control lens (y axis) for each subject (x axis) for each astigmatic power. The y axis scale has been selected so that this graph can be directly compared with the others. Positive values represent better performance with the prescribed lens than with the control. The black circles represent subjects with >5% improvement on the WRRT, and the black lines represent those subjects who read more than 5% slower

11.9.2 Statistical analysis

As there were a large number of astigmatic subjects, the astigmatic data were divided into three sub-groups of increasing cylindrical power: -0.50 to –0.75 DC (N=73), -1.00 to –1.25 DC (N=35) and –1.50 to –1.75 DC (N=10). These sub-groups were chosen so that there were two prescribing steps (e.g., -0.50DC and –0.75DC) in each sub-group. A paired t-test was performed on the WRRT data and there was no statistically significant difference in mean reading speed between the intervention and the control group in the –0.50 to –0.75 sub-group (p = 0.32) (Figure 11.13). Subjects in the -1.00DC to -1.25DC sub-group read, on average, 3.4% faster with the prescribed lenses (145.1 ± C.I. 11.6) than with the control lenses (141.3 ± 10.4) but the difference in the mean reading speed did not reach statistical significance (p=0.06). There was less of an

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improvement in the WRRT with the prescribed lens in the –1.50 to –1.75DC sub-group and again there was no statistically significant difference between the conditions (p=0.37).
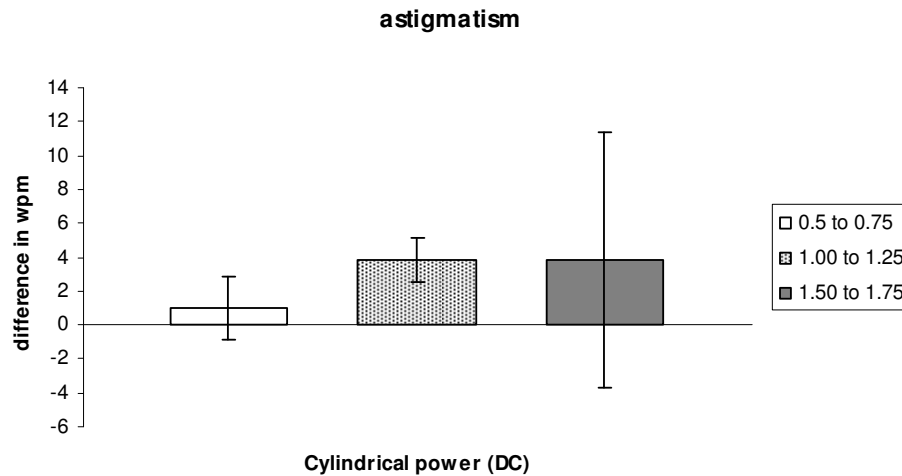
astigmatism

Figure 11.13 A comparison of the mean improvement in rate of reading (y axis) in words per minute (wpm) with the prescribed lens compared to the control lens for astigmatism in dioptre cylinders (DC) (x-axis).

11.9.3   Axis direction

Some authors state that it is important to consider the axis of astigmatism before deciding whether to prescribe (see 2.4.3). The data were therefore reclassified into three categories: with-the-rule (negative axis 180° ±15°), against-the-rule (negative axis 90° ±15°) and oblique astigmatism (all other cases). As before, subjects were allocated according the axis of astigmatism in their least astigmatic eye. The axis of astigmatism is normally symmetrical between the two eyes, and this was true for most of the subjects in the with and against-the-rule groups. For with the rule astigmatism, 82% of the subjects had with the rule astigmatism in both eyes, 7% had against the rule astigmatism in the other eye, and in 11% the other eye had oblique astigmatism. In the against-the-rule group 85% also had against-the-rule astigmatism in the other eye, 2% had with-the-rule and 13% had oblique astigmatism. However there was more variety in the oblique astigmatism group. In this group, 55% of the subjects also had oblique astigmatism in the other eye, 24% had with-the rule astigmatism and 21% had against-

the rule. The modal cylinder powers in these sub-groups were –1.00DC (range –0.50 to -1.75), -0.75DC (range -0.50 to –1.50), and –0.50DC (range –0.50 to –1.75) respectively.
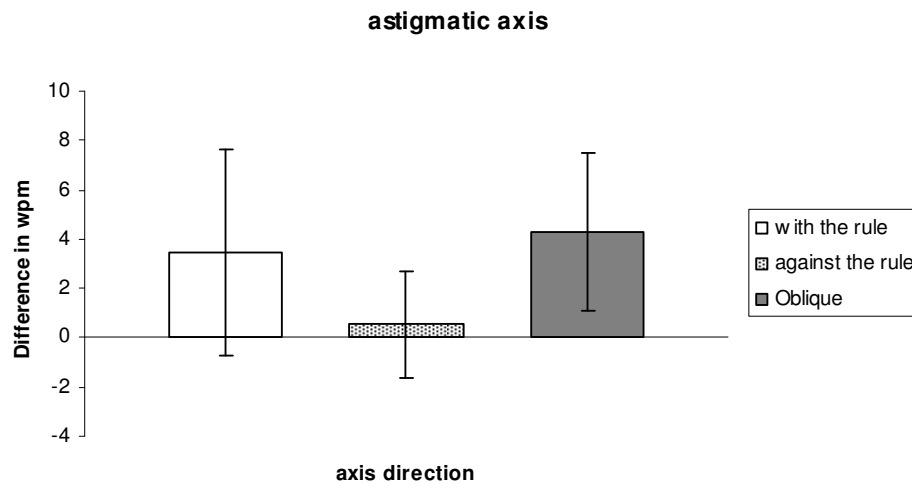
astigmatic axis

Figure 11.14 A comparison of the mean improvement in rate of reading (y axis) in words per minute (wpm) with the prescribed lens compared to the control lens for each astigmatic axis (x-axis).

In Figure 11.14 it is shown that subjects with oblique astigmatism performed significantly better on the WRRT with the intervention compared to the control (N=38, p=0.01). In this sub-group the mean rate of reading was 3.9% faster with the intervention (148.6 ± C.I. 10.6) than with the control (144.3 ±11.2). Those subjects who had with-the-rule astigmatism performed better on the WRRT with the intervention (154.4 ± 10.9) than with the control (151.0 ± 11.1), but there was no statistically significant difference between the mean WRRT in the two conditions (N=28, p=0.11). There was little difference between the intervention (136.9 ± 8.4) and the control (136.3 ± 8.2) when the astigmatic axis was against-the-rule (N=52, p=0.6)

In Table 11.2 a summary of the paired t-test results for hypermetropia, presbyopia and

astigmatism is shown.

Table 11.2 A summary of the mean differences in words per minute (wpm) for each refractive sub-group on the WRRT. Positive values represent better performance with the prescribed lens than with the control.

Refractive error	Refractive power (DS/DC)	Number of subjects (N)	Mean difference in wpm	Confidence Interval of the mean (±)	t-test p value
Hypermetropia	0.50 to 1.00	24	4.65	5.70	0.12
	1.25 to 1.75	9	-3.27	5.76	0.30
Presbyopia	0.5 to 0.75	24	2.34	3.75	0.23
	1.00 to 1.25	26	6.40	5.56	0.03
	1.50 to 1.75	8	39.57	28.40	0.03
Astigmatism	-0.5 to-0.75	73	0.96	1.87	0.32
	-1.0 to -1.25	35	3.83	1.28	0.06
	-1.50 to -1.75	10	3.88	8.10	0.37
	Axis				
	With the rule	28	3.44	4.17	0.12
	Against the rule	52	0.55	2.18	0.62
	Oblique	38	4.31	3.20	0.01

11.10.1   Receiver Operating Characteristic (ROC) Curves

Receiver operating characteristic curves show the sensitivity of an intervention (ability

to correctly identify subjects with the anomaly) and 1-specificity (specificity is the

ability to correctly identify subjects who do not have the anomaly). The closer each

point on the curve is to the top left hand corner of the graph, the more effective the

criterion is for identifying those subjects with an improvement in the WRRT. For this

research ROC curves were calculated to determine which refractive or prismatic lens

power would best predict a clinically significant improvement in the WRRT. As noted

previously in section 10.3.1, a >5% improvement has been used in previous work

(Wilkins, 2002) and this precedent was followed below (see 13.3.7).

11.10.1.1   Heterophoria

Previous studies (Jenkins et al., 1989) have used receiver operating curves to determine which prismatic power would best predict the presence of symptoms. The authors calculated separate curves for those subjects under 40 years and those 40 and over and found that 1Δ was the best criterion for symptomatic subjects under 40, and 2Δ for subjects over 39 years. The exophoric subjects in the current study were therefore divided into the same two age groups. However, there were not enough subjects in the esophoria or vertical heterophoria categories to split them into separate age groups.

11.10.1.1.1   Exophoria

It is shown in the ROC curves for subjects with exophoria under the age of 40 (Figure 11.15, top), that the best criterion for predicting a 5% or more increase in the WRRT was 2Δ. This criterion had a sensitivity of 67% (ability to successfully predict those subjects who had an improvement in the WRRT of 5% or greater), and a specificity (ability to correctly identify subjects who did not have an improvement of 5% or greater) of 79%. For subjects with exophoria aged 40 and over (Figure 11.15, bottom), the best criterion was again found to be 2Δ with a sensitivity of 67% but a lower specificity of 52%.

Exophores aged 39 and under

Exophores aged 40 and over
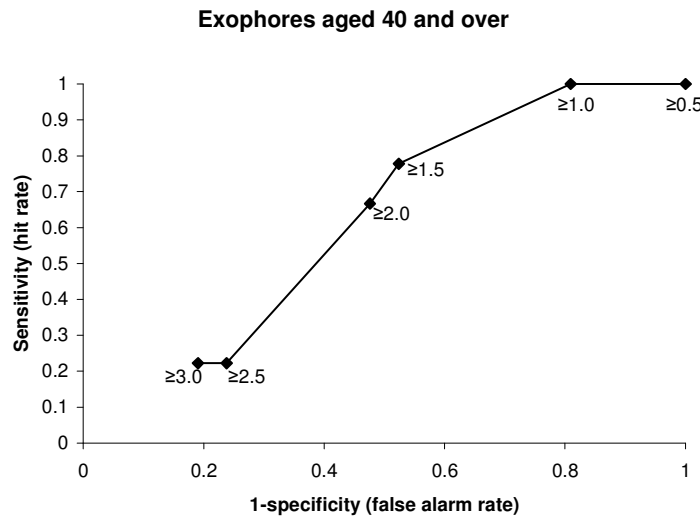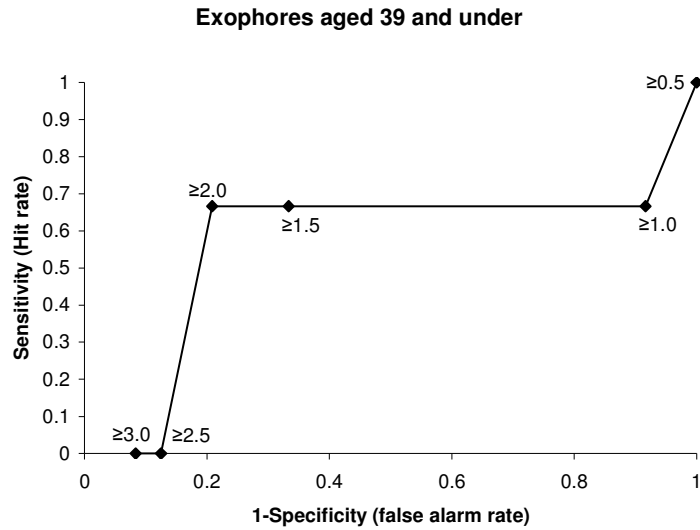
Figure 11.15 Receiver Operating Characteristic Curves showing 1-specificity (x axis) and sensitivity (y axis) for each aligning prism, in prism dioptres: top graph – subjects with exophoria aged 39 and under, bottom graph – subjects with exophoria aged 40 and over.

11.10.1.1.2   Esophoria

The ROC curve for esophoria is in Figure 11.16. Although a criterion of 1Δ would correctly identify 67% of those subjects with a 5% improvement, it would also incorrectly identify 75% of those subjects who did not this improvement. There was no point on the graph that would be very helpful in distinguishing those subjects with

symptoms. There were not enough subject numbers to calculate a meaningful ROC for

vertical heterophoria.
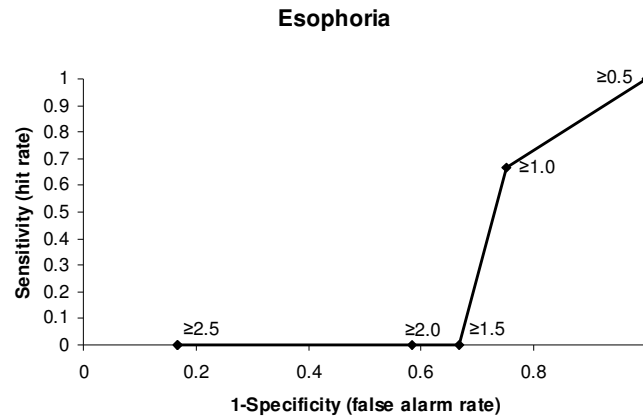
Figure 11.16 Receiver Operating Characteristic Curve for esophoria showing 1-specificity (x axis) and sensitivity (y axis) for each aligning prism, in prism dioptres. The point labelled ≥2.5 represents overlying points signifying ≥2.5 and ≥3.0.

11.10.1.2   Refractive errors

Although ROC curves have been used to demonstrate the effectiveness of prescribing

prism (Jenkins et al., 1989), a search of the literature suggests that this is the first time

ROC curves have been utilised for borderline refractive errors.

11.10.1.2.1   Hypermetropia

In the ROC curve for hypermetropia (Figure 11.17) it is shown that a criterion of

prescribing a power of +0.75DS or above would correctly identify 100% of those

subjects with an improvement on the WRRT of 5% (sensitivity), but would also

incorrectly identify 84% of the subjects who did not have an improvement of >5% (1-

specificity). For the criterion of +1.00D or above, 60% of subjects would still be

incorrectly identified as having an improvement of >5%, and only 29% would be

correctly identified as having symptoms. There is no point on the graph that would be

very helpful in distinguishing those subjects with a >5% improvement in the WRRT for hypermetropia from those without such an improvement.
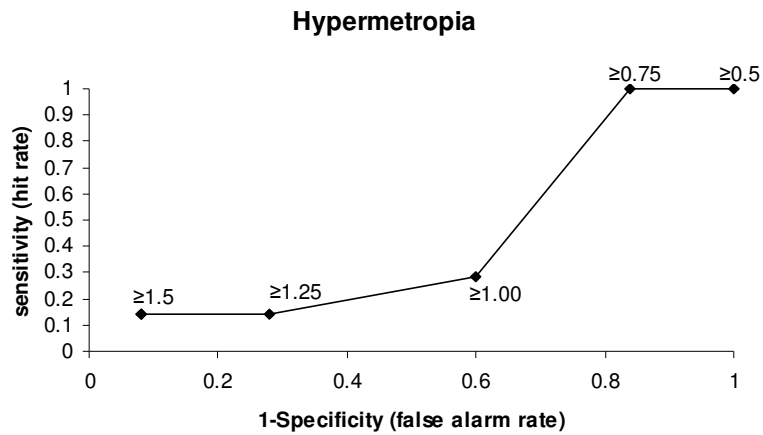
Hypermetropia

Figure 11.17 Receiver Operating Characteristic Curve for hypermetropia showing 1-specificity (x axis) and sensitivity (y axis) for each refractive power, in dioptre spheres. The point labelled ≥1.5 represents overlying points signifying ≥1.5 and ≥1.75.

11.10.1.2.2 Presbyopia

For presbyopia, the WRRT results showed a significant improvement in the WRRT for powers above +1.00DS. In Figure 11.18 it is shown that a prescribing criterion of +1.00DS or above would correctly identify 74% of those subjects with a >5% improvement in WRRT, but would also incorrectly identify 49% of those subjects who did not have a >5% improvement. If this criterion is increased to +1.25DS or above, the sensitivity decreases to 48%, but the specificity would improve so that only 23% would be incorrectly identified.

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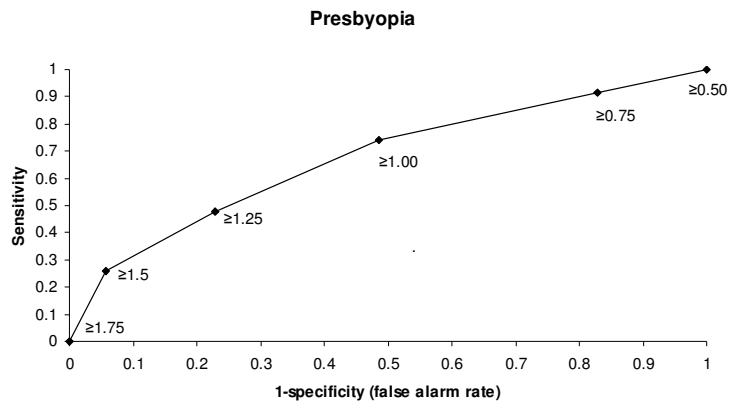
Figure 11.18 Receiver Operating Characteristic Curve for presbyopia showing 1-specificity (x axis) and sensitivity (y axis) for each reading addition, in dioptre spheres.

11.10.1.2.3   Astigmatism

Figure 11.19 shows the ROC curve for astigmatism in general, and there is no point on the graph that would be very helpful in distinguishing those subjects with an improvement of >5% in the WRRT. A criterion of prescribing cylindrical powers of 1DC or above has a sensitivity of 57%, but would also incorrectly identify 32% of those without a >5% change in WRRT score.
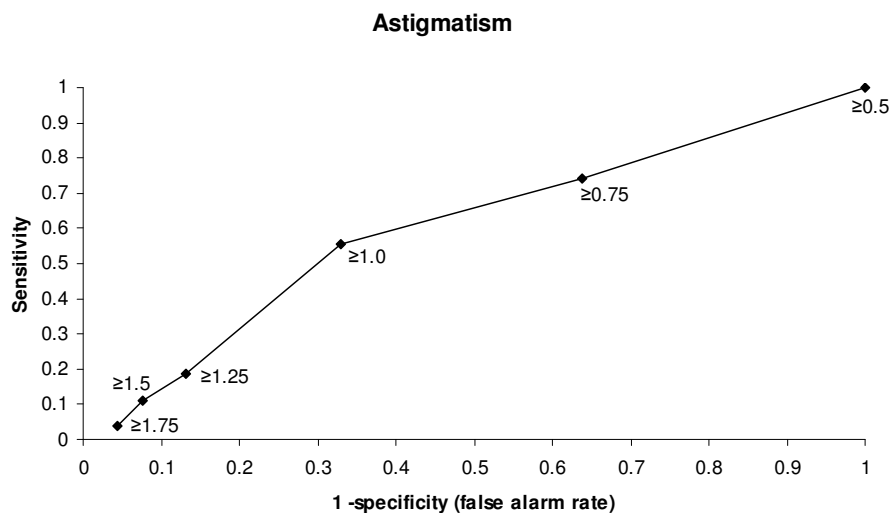
Figure 11.19 Receiver Operating Characteristic Curve for astigmatism showing 1-specificity (x axis) and sensitivity (y axis) for each power, in dioptre cylinders.

The ROC curve for subjects with oblique astigmatism (Figure 11.20) is more useful, and shows that correcting oblique astigmatism of 1.00DC or over would correctly

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identify 67% of those subjects who had an improvement of >5% in the WRRT and

incorrectly identify only 31% of those who did not have this improvement.

Oblique astigmatism
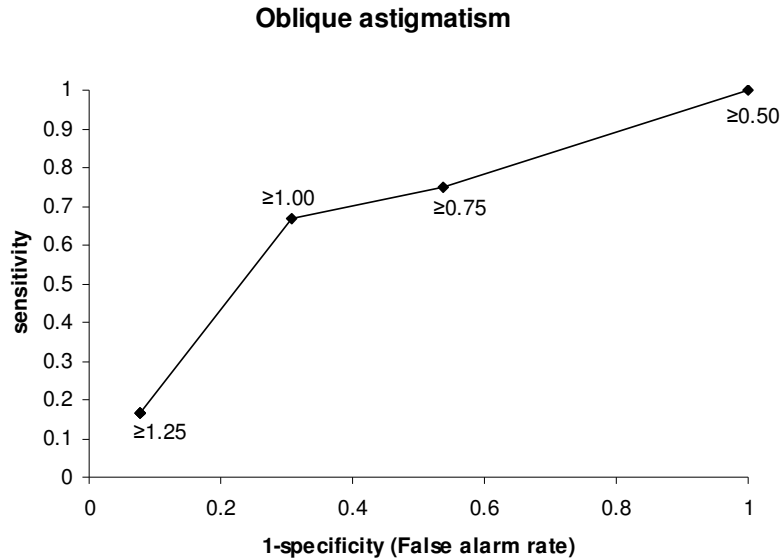
Figure 11.20 Receiver Operating Characteristic Curve for oblique astigmatism showing 1-specificity (x axis) and sensitivity (y axis) for each power, in dioptre cylinders. The point labelled ≥1.25 represents overlying points signifying ≥1.25, ≥1.50 and ≥1.75.

11.10.2   Symptoms

11.10.2.1   Heterophoria

For the purpose of analysing the symptom scores, a subset of the control group was

chosen, which consisted of those subjects who did not have any horizontal or vertical

aligning prism (N=27, mean age 47 years).
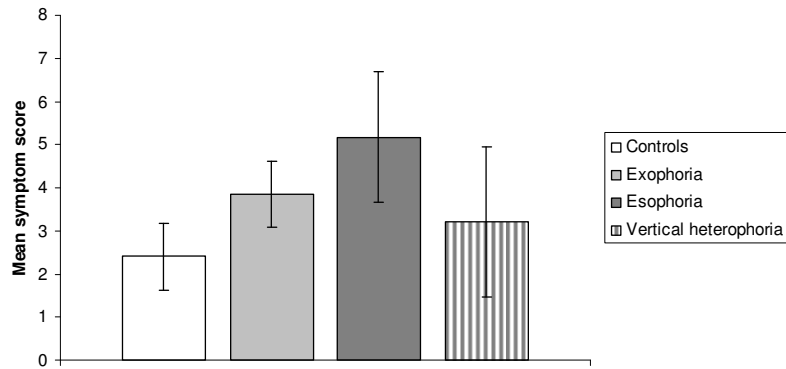
Figure 11.21 Bar chart comparing the mean symptom scores of the controls, exophoria, esophoria, and vertical heterophoria groups. The error bars are the 95% confidence intervals of the means.

In Figure 11.21 it is shown that the mean symptom score of the controls was significantly lower than that of the subjects with exophoria (t-test, p=0.011) and with esophoria (t-test, p=0.004), but was not significantly lower than the symptom score of the vertical heterophoria group (t-test, p=0.42). There was no evidence of a linear relationship between the symptom score and the improvement in WRRT results with the prescribed prism, revealed by the low Pearson's correlation coefficient which yielded the following values of r^2: 0.02 for exophoria, 0.09 for esophoria and 0.08 for vertical heterophoria. In order to determine whether a non-linear relationship exists between the symptom score and any change in WRRT scattergrams were plotted for each subgroup. No relationship was found. In addition, scattergrams were plotted to identify any association between the symptom scores and the rate of reading with the control lens (absolute reading speed). No relationship was found for exophoria or vertical heterophoria, but there was a weak relationship in those subjects with esophoria where those subjects with a slower absolute reading speed had more symptoms (r^2=0.37) (Figure 11.22).
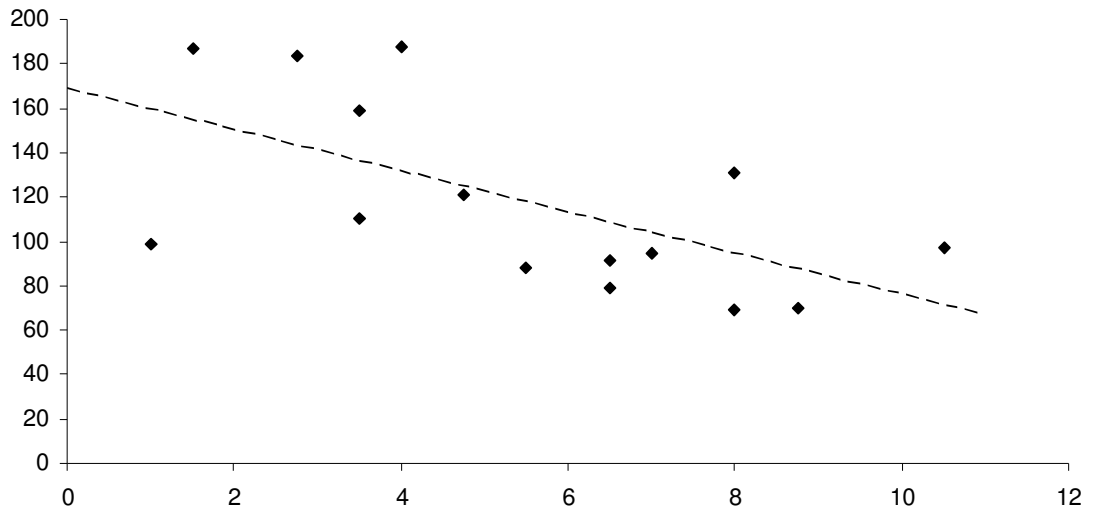
Figure 11.22 A comparision of symptom score (x-axis) and the rate of reading with the control lens (y-axis) for esophoria.

Finally, scattergrams were plotted to determine if subjects with larger amounts of heterophoria had more symptoms (Figure 11.23). There was a large variation in the number of symptoms for each category and no evidence of any relationship as revealed by the low Pearson correlation coefficients.
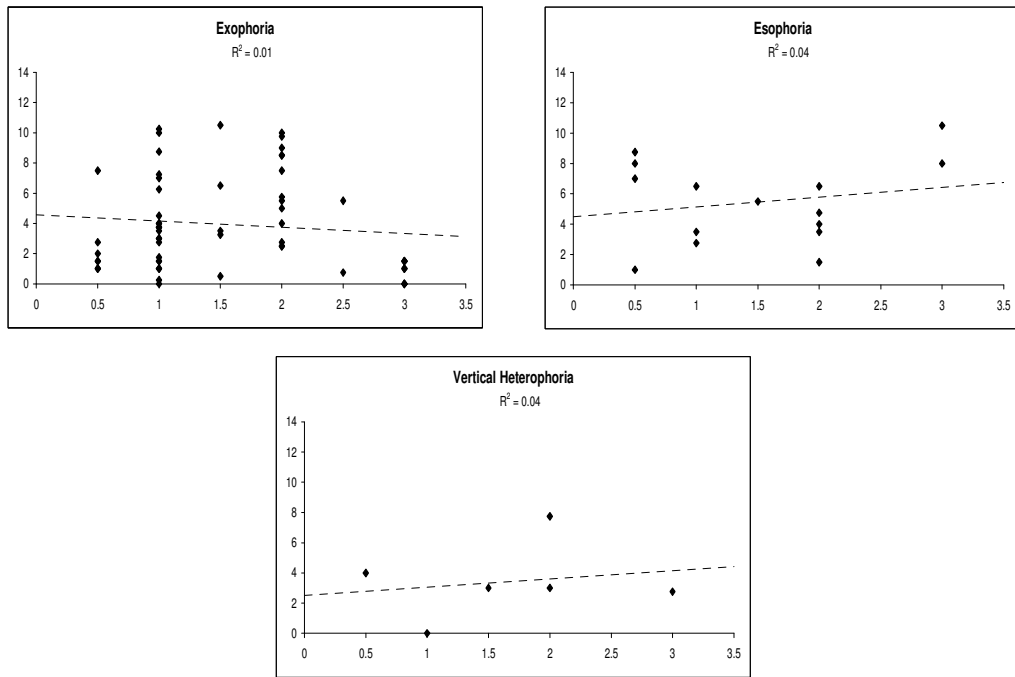
Figure 11.23 A comparison of heterophoric power (x-axis) and symptom score (y-axis)

11.10.2.2   Refractive errors

The symptom scores of the experimental group were compared with symptom scores of a subset of the control group which consisted of those subjects who had not had a refractive change of more than 1.00 DS at their last eye examination (N=24).

Refractive error

Astigmatic axis
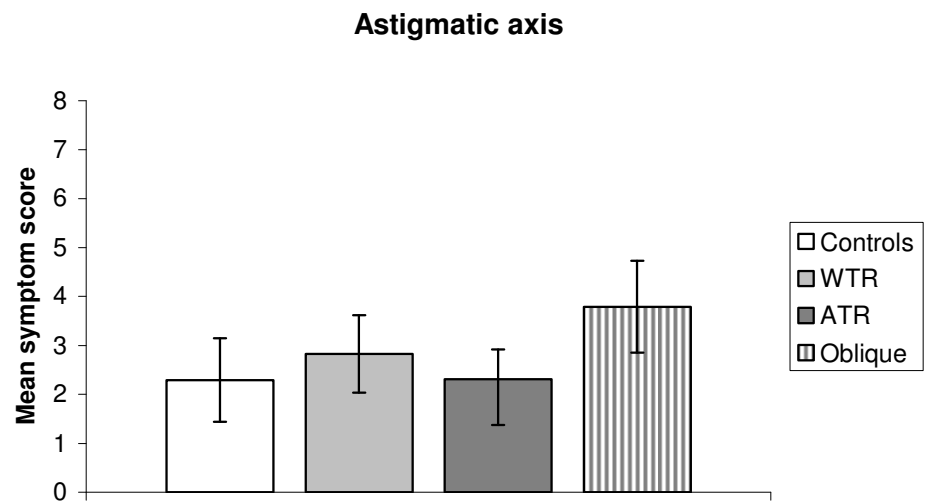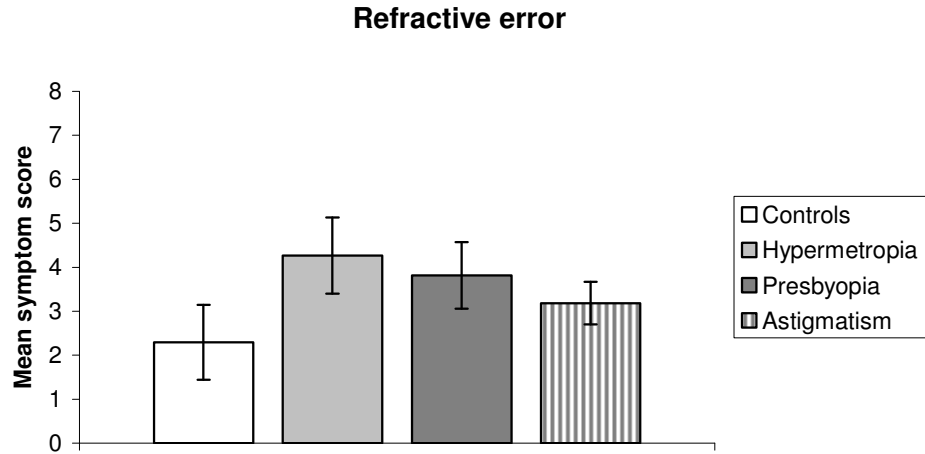
Figure 11.24 Bar chart comparing the mean symptom scores of each refractive error. The error bars are the 95% confidence intervals of the means.

The top graph in Figure 11.24 shows that the mean symptom score of this control subset was significantly lower than that of the hypermetropia group (unpaired t-test, p=0.002), and the presbyopia group (p=0.02), but not the astigmatic group (p=0.08). However, a calculation of Pearson's correlation coefficient between the difference in the WRRT results and the symptom score again shows that there was no evidence of any linear relationship, revealed by low values of r^2: 0.05 for hypermetropia, 0.01 for presbyopia,

and 0.01 for astigmatism. Scattergrams comparing the symptom score to the difference in WRRT were plotted for each subgroup, and again no relationship was found.

When the symptom scores were analysed in terms of the astigmatic axis (Figure 11.24, bottom), only those subjects with oblique astigmatism had a statistically significantly higher mean symptom score compared to the control subset (p=0.04). There was no significant difference between the mean symptom scores of subjects with against the rule (p=0.90) or with the rule (p=0.50) astigmatism compared to the control subset, and again no linear correlation between the symptom score and the change in the WRRT, revealed by the results for r^2 : 0.1 for with-the-rule, 0.003 for against-the-rule, and 0.02 for oblique astigmatism. Scattergrams comparing the symptom score to the difference in WRRT were plotted for each astigmatic axis, and again no relationship was found. Scattergrams also showed that there was no relationship between the symptom score and the rate of reading with the control lens for any of the refractive categories.

Finally, scattergrams were plotted to determine if there was an association between the symptoms score and the magnitude of refractive error (Figure 11.25). The scattergrams indicated that the subjects with larger amounts of hypermetropia had on average a greater symptom score than those with less hypermetropia. However, a low Pearson correlation coefficient of 0.13 indicates that this relationship was very weak. No relationship between magnitude of refractive error and the symptom score was found for subjects with presbyopia or astigmatism.
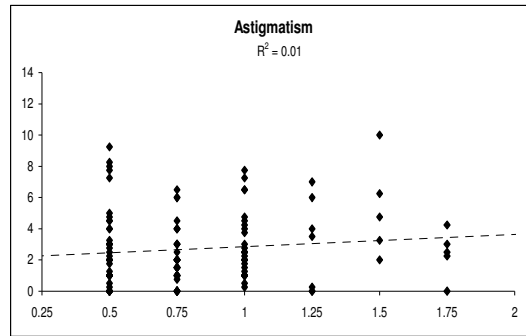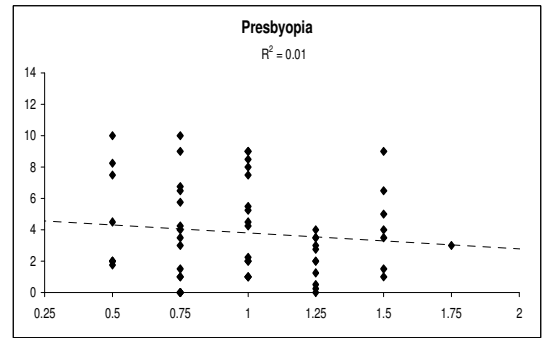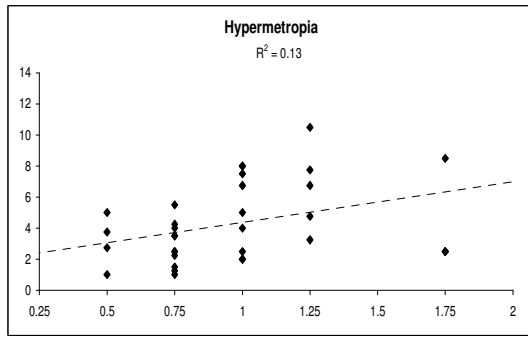
Figure 11.25. A comparison of refractive power (x-axis) and symptom score (y-axis)

CHAPTER 12   STUDY TWO: DISCUSSION

12.1.1   Adequacy of control lenses

The largest heterophoria group was exophoria, and for these subjects the control size lenses were selected based on the assumption that base-in prism would cause a perceived magnification of a degree that was similar to that for the five volunteer optometrists who were used to calibrate the size lenses. It is often reported that base-in prisms cause objects to appear to become larger and further away: the so-called SILO response (Hokoda and Ciuffreda, 1983, pp75-97). However, the size of this effect varies from one observer to another and some people show the reversed (SOLI) response, where base-in prism causes objects to appear to diminish in size (Hokoda and Ciuffreda, 1983, pp75-97). All five trained observers who were used to select the size lenses showed the usual SILO response.

None of the participants reported a difference in perceived image size between the control lenses and prescribed prism although they were not specifically asked about this. In any event, if there was a magnification difference between the two conditions for any of the participants then this would have been unlikely to interfere with the results since the magnification factors in the study were very small and participants would still not have known which was the active and which the control condition. Indeed, one might hypothesise that any participants who were SOLI responders and who were disposed to guess about which condition was the active correction might have assumed that this would be the more magnified condition, which for them would have been the control lenses. This means that there would have been a lesser placebo effect associated with the prismatic correction than with the control lens, hence reducing the chance of a type one error.

The experimental design included a control group of 40 participants to investigate whether the size lenses had a significant effect on performance at the WRRT. These subjects had a wide range of refractive errors (from –3.75 DS to +8.75DS and up to –2.50DC). Several of these subjects also had a near fixation disparity on the Mallet unit, with horizontal aligning prism of up to 2Δ found in 13 subjects (33%) and vertical aligning prism of up to 1Δ found in 3 subjects (8%).The data from the control group show that the control size lenses did not have a significant effect on the WRRT results, confirming that the size lenses were an inert placebo.

For the esophoria group, since most of the participants were likely to have been SILO responders then their prismatic correction would have reduced the perceived image size compared with the control plano lenses that were used for this group. This would reduce the chance of a type one error.

12.1.2   Exophoria

The different approaches of t-test comparisons (Figure 11.3) and ROC curves (Figure 11.15) indicate slightly differing criteria for the correction or treatment of decompensated exophoria at near: 2.5Δ and 2Δ, respectively. Figure 11.3 shows that the correction of exophoric aligning prisms only had a significant effect on the WRRT for aligning prisms of 2.5–3Δ or more. This result was similar in the combined and in the under 40 and 40+ age groups. The ROC curves (Figure 11.15) showed that although no prismatic power perfectly identified all the subjects with a 5% or more improvement in the WRRT, 2Δ was the best criterion for both age groups. This absence of an effect of age is in contrast to Jenkins et al. (1989) and Pickwell et al.(1991) and possible explanations for this may be as follows. These researchers investigated the correlation

between the aligning prism power and symptoms, whereas the present study investigated the correlation between aligning prism power and an improvement in the rate of reading; an objective measurement. In addition, Jenkins et al. (1989) classified their subjects as symptomatic if they had any symptoms with close work, and these authors noted that they did not use any other criteria to establish whether these symptoms were related to a binocular vision anomaly.

The increase in the rate of reading with prisms of 2.5Δ and over contrasts with the findings of Sheedy et al. (1988) who found introducing vergence inducing prisms of up to 8Δ did not significantly affect reading performance. However the results of their study were based on 10 subjects with normal binocular vision, and there is substantial evidence to suggest that the presence of an aligning prism on the near Mallet unit (as used in the selection criteria for the exophoria group in the current study) is an indication of abnormal binocular vision (see 7.3). Sheedy et al. (1988) also used the Sheedy disparometer to measure the dissociated heterophoria and it has been shown that this often results in a higher amount of heterophoria being recorded due to the lack of central fusional lock (see 6.6.4).

12.1.3   Esophoria

There is very little information available in the literature regarding the use of prisms to correct esophoria at near. This may be due to the fact that esophoria at near is rare, and the low number of subjects with esophoria in our study reflects this. Our results showed that no power on the ROC curve was useful for differentiating those subjects with symptoms and that, unlike exophoria, the correction of esophoria of up to 3Δ had little effect on the WRRT. Interestingly, esophoria has less of a detrimental effect on binocular visual acuity than exophoria (Jenkins et al., 1994). These authors suggests that

this is due to the nasal part of the central retinal region (stimulated in an esophoric fixation disparity) having a slightly higher visual acuity than the temporal part (stimulated in exophoric fixation disparity).

12.1.4 Vertical heterophoria

Due to difficulties in obtaining participants with vertical heterophoria, it is difficult to draw firm conclusions from the vertical heterophoria data. Vertical aligning prisms did not improve the WRRT score, and this may be due to a variety of reasons, including low subject numbers. It has been shown that some patients will easily adapt to vertically orientated prisms placed before the eyes (Rutstein and Eskridge, 1986, and Rutstein, 1992), in that the amount of heterophoria with the prism reverts to the amount present without any prismatic correction within only 2-3 minutes (Henson and North, 1980). Indeed this phenomenon of vergence adaptation has made some practitioners wary of prescribing prismatic corrections. However, many studies have shown that this only occurs in those patients who have normal vertical fixation disparity curves (Rutstein and Eskridge, 1986, and Rutstein, 1992) and that prism adaptation fails in patients with abnormal binocular vision (North and Henson, 1981 and North and Henson, 1992). The previous literature review demonstrates that the presence of a fixation disparity on the Mallett Unit usually indicates abnormal binocular vision (see sections 6.6.4 and 7.3). Another explanation is that the size lenses that were used as a control might have been associated with a small treatment effect.

12.1.4.1 Binocularity and visual performance

Normal binocular vision (normal retinal correspondence without suppression) is essential for good depth perception and stereopsis, and several studies have shown that visual performance is decreased when stereopsis is absent.

Sheedy et al. (1986) examined the effect of stereopsis on 13 subjects whilst undertaking two tasks requiring depth perception (placing pointers in straws arranged at different angles and threading beads onto a needle), and two tasks that did not require depth perception (reading a Bailey Lovie chart at 45cms and counting the number of specific letters in a paragraph on a VDU). They found that under binocular conditions there was a 29.5% and 20.4% improvement in performance in the first two tasks. The authors conclude that normal binocular vision enhances the performance of visually demanding tasks, especially when the tasks involve perception of depth.

12.1.5   Hypermetropia

The current research showed that correcting hypermetropia up to +2.00 DS did not significantly improve performance on the WRRT, and this supports the opinion that borderline hypermetropic refractive errors should not be corrected unless clinically necessary. The results of study one showed that most optometrists would not correct less than two dioptres of hypermetropia unless there were symptoms, and the WRRT results and ROC curve confirm that this is best practice.

One of the clinical tests that may help determine whether a borderline hypermetropic correction would be beneficial is the measurement of the amplitude of accommodation and hence the accommodative reserves. Patients with low amounts of hypermetropia rarely notice a drop in visual acuity (Brookman, 1996b, p125), and this is particularly true of younger patients, where the large amount of accommodation available enables the image to be clearly focussed onto the retina. The subjects with hypermetropia in the current study had a mean age of 14 years and a mean amplitude of accommodation of 11 dioptres. Millodot and Millodot (1989) found that the maximum accommodation used when reading is between 50% and 75% of the total amplitude, and therefore it is

likely that the subjects in the current study had an adequate accommodative reserve to comfortably overcome +2.00DS of hypermetropia. It is likely that patients with less than the expected amount of accommodation for their age would have a greater improvement on the WRRT than those with adequate accommodation. One possibility would have been to further subdivide the hypermetropia group according to age or accommodation reserve (accommodation – uncorrected hypermetropia), but because of the sample size (n=32) and young mean age (14 years) of the present sample it was concluded that this type of analysis would not be likely to be productive. Accommodation is returned to in section 13.3.6.

12.1.6   Presbyopia

Previous studies have shown that non-tolerance to optical prescriptions is most commonly the result of an incorrectly prescribed reading addition, often one that is too strong (Hanlon et al., 1987).   These authors evaluated which presbyopic reading additions were most likely to be successful for each age group, and suggested a first reading addition for patients aged 40 to 45 of +1.00DS. Hofstetter's review of prescribing for presbyopia in 1949 suggested that practitioners will delay prescribing a reading addition until a prescription of +1.00DS is reached. Study one (Chapter 9) found that practitioners would prescribe a reading addition of +0.75DS if symptoms were present, and of +1.50DS in the absence of symptoms. The results of Study two agree with Hanlon's advice, as a significant improvement in the WRRT was found with a reading addition of +1.00 DS to +1.25 DS, but not with smaller powers. However the mean age of the subjects in this group was a little higher than Hanlon's at 46 years of age (range 39 to 58).

The ROC curve (Figure 11.18) shows that there is no criterion that will competently differentiate between those subjects who are likely to have an improvement in their rate of reading from those who are not, and the results may be more useful if considered in combination with a patient's symptoms. For example, if the patient attends an eye examination with symptoms that may, equivocally, be related to reading it may be more important to consider the sensitivity of a criterion in identifying an improvement. In this case, if a reading addition of +1.00DS or greater is required, the ROC curve indicates that there is a 74% chance that prescribing the addition will improve that patient's rate of reading (and hopefully reduce their symptoms). However if a reading add of +1.00 or greater was found in a patient without symptoms there would be a 49% chance that there would not be an improvement in the rate of reading, and therefore it may be wise to defer prescribing reading glasses until a reading addition of +1.25 or greater was reached when this figure drops to 23%.

12.1.7   Astigmatism

The literature provides a wide range of recommendations as to when to correct astigmatism. Previous studies have suggested that the 'normal' amount of astigmatism in children up to the age of 3 years is between 0.75 DC and 1.00 DC (Atkinson et al., 1980 and Fulton et al., 1980), and that only 9% of adults have astigmatism of over 0.75 DC (Fulton et al., 1980). In addition Harvey et al. (2007) found that children with an astigmatic error of -0.75DC or more had significantly worse mean best visual acuity compared to the non astigmatic children. However, Shea and Gaccon (2006) attempted to identify the magnitude of astigmatism likely to lead to amblyopia, and concluded that astigmatism of less than -1.75DC did not impair visual acuity in three and four year olds. The results of Study one (Chapter 9) indicated that that most U.K. optometrists would correct 0.75DC of astigmatism if symptoms were present and 1.50 DC in their

absence. Much of the literature on astigmatism considers the relationship between symptoms and astigmatic axis, with the general conclusion that against-the-rule astigmatism is likely to produce more symptoms than with-the-rule, and that oblique astigmatism is more likely to produce symptoms than any other axis direction. However, much of this research has been theoretical rather than clinical and may be based on the orientation of letters in the English language, and the assumption that people with with-the rule astigmatism can squeeze their eyelids together to reduce blur. The results from study two for against-the-rule astigmatism contradicts the literature, as this group of subjects had the lowest symptom score of all the astigmatism groups, and also had the least improvement on the WRRT. However, these results confirm that oblique astigmatism does cause most symptoms and, despite the fact that most of the subjects with oblique astigmatism had a relatively small cylindrical error (39 out of the 43 subjects with oblique axis had astigmatism of 1DC or less), correcting this astigmatism resulted in a statistically significant improvement in the mean WRRT. The likely cause of this finding is that oblique astigmatic blur has a greater effect on Snellen acuity than horizontal or vertical blur (see Figure 2.4). Correcting oblique astigmatism resulted in a greater improvement in the WRRT than correcting either of the other types of astigmatism, and therefore the axis of astigmatism should be considered before deciding when to prescribe an astigmatic correction. The ROC curve for these subjects (Figure 11.20) showed that correcting oblique astigmatism of 1.00DC or over would correctly identify 67% of those subjects who had an improvement of >5% in the WRRT and would correctly identify 69% of those who did not have this improvement.

12.1.8   Symptoms

The results of Study one showed that the presence or absence of symptoms is of paramount importance to optometrists when deciding whether to prescribe a borderline

optometric intervention and numerous authors only advise correcting heterophoria, hypermetropia, astigmatism or presbyopia if symptoms are present. Participants with a horizontal fixation disparity had a significantly higher mean symptom score than the controls, although the low correlation between the number of symptoms reported and the improvement in the WRRT with the prismatic intervention indicates that the participants who had the greatest performance benefit from the prescribed prism did not necessarily have the most symptoms. The symptom score was higher in esophoria than in exophoria, which supports clinical experience. It is surprising that participants with vertical heterophoria reported fewer symptoms than those with a horizontal heterophoria, which contradicts the general belief that vertical heterophoria is more likely to cause symptoms due to the limited vertical fusional vergences (Carter, 1963; Mallett, 1974). This lack of reported symptoms may be due to the fact that most decompensated heterophoria develops slowly over a long period of time. It may also be an artefact due to the small subject numbers with a vertical heterophoria, or other explanations including the presence of foveal suppression (Tang and Evans, 2007), or a lack of critical visual tasks in day-to-day life (Mallett, 1974).

Subjects with hypermetropia, presbyopia, and oblique astigmatism also had a significantly higher number of reported symptoms than the control group, but the low r^2 values indicate that the subjects with the highest symptom scores were not necessarily the subjects with the greatest improvement in the WRRT. This is likely to reflect the heterogeneous nature of symptoms.

The results of study two indicate that symptoms are a poor predictor of whether a prescribed prism is likely to result in an improvement in the WRRT. The results also showed that there were large variations in the type of symptoms reported within each

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category, supporting the observation that symptoms are often non-specific (Ball 1982, p111).

CHAPTER 13 GENERAL DISCUSSION & CONCLUSIONS

13.1 GENERAL DISCUSSION

Perhaps the most frequent decision that optometrists make is whether to correct a refractive or binocular vision anomaly, whether it be with spectacles, contact lenses or orthoptic exercises. This decision is generally an easy one if a large uncorrected anomaly is present, but becomes much more difficult in marginal or borderline cases. Considering the fact that most optometrists make these decisions several times every day, it is surprising that little clinical research has been undertaken to help determine at what point an intervention is beneficial.

13.2 STATISTICAL SIGNIFICANCE VERSES CLINICAL SIGNIFICANCE

The current study has concentrated on identifying a statistically significant difference in the rate of reading with a refractive or prismatic correction in place, compared to a control lens. This method of analysis is commonly used in well designed research studies, and gives a good indication as to whether a real improvement in performance exists. However, a statistically significant difference is not always the same as a clinically significant difference. We can show that correcting a certain error is likely to improve reading speed by at least 5%, but cannot tell whether that is a clinically significant amount. Other research studies are needed to establish whether a patient would notice a 5% improvement in their day-to-day life. In addition, the WRRT only measures reading speed and does not indicate whether correcting a small refractive error or heterophoria would improve other factors such as comfort. Therefore longitudinal studies where prescribed glasses and placebos are given to patients to try over a period

of time and where details of any improvements in visual performance during daily activities are recorded may be useful.

13.3 LIMITATIONS

13.3.1 Confounding factors

To determine the effect of each heterophoric or refractive anomaly on the rate of reading, ideally each subject would only have the anomaly being measured. For example a subject in the hypermetropia category would not have any astigmatism, presbyopia or heterophoria. However, in reality this situation rarely occurs and therefore even with well designed inclusion and exclusion criteria, some confounding is inevitable. As a result, it cannot be concluded that a difference in reading speed is solely attributable to a particular refractive error or heterophoric condition.

One possible way around this would be to perform a multivariate analysis where the effects of all the key variables and their interactions are analysed. However this would have required a much larger number of subjects. Another possibility would have been to simulate the individual target conditions, to ascertain their effect on the rate of reading. However, this approach can be criticised because, for example, a person who briefly reads through a toric lens to simulate astigmatism will not necessarily behave in the same way as a person who habitually has astigmatism.

13.3.2 Inclusion criteria

The inclusion criteria for all the groups apart from the astigmatism group specified that subjects had astigmatism of no greater than 0.50DC in the better eye. This was based on the assumption that the visual system will automatically use the eye with better vision, as has been shown to occur when patients are fitted with monovision contact lenses (Evans, 2009). This assumption is supported by the findings of Pardhan (1993) and

Banton and Levi (1991) who found that although there may be a reduction in visual performance in low contrast targets, the worse eye does not greatly interfere with the better eye when high contrast targets (e.g. the WRRT text used in study two) are used. However, some people are better able to suppress the image from the worse eye than others, as shown by Evans (2007a) whose review of the literature found that between 59 and 67% of contact lens patients successfully adapt to monovision. Therefore it cannot be definitely concluded that higher amounts of astigmatism in one eye did not affect the WRRT results.

13.3.3   Subject numbers

The low subject numbers in both the esophoria and vertical heterophoria groups reduce the power of the statistical tests and make it difficult to draw any definite conclusions about these conditions. The small number of subjects in these groups reflects the low prevalence of these conditions, for near, in the population as a whole (see section 6.3).

Indeed several other studies also report difficulties obtaining subjects with near esophoria and vertical heterophoria. Jenkins et al. (1989) commented that there were very few subjects with esophoria at near in their study on the criteria for decompensation in near vision. Their subjects were selected from routine optometry clinics in the U.K and Iran, and the esophoria data had to be combined with the exophoria data in the data analysis.

13.3.4   The use of the Mallett unit for the inclusion criteria and measurement of the aligning prism

There are several instruments available to enable the optometrist to measure aligning prism, and all have advantages and disadvantages (see section 6.6.4). The aim of Study

two was to provide guidelines based on dynamic visual performance as to when it becomes beneficial to correct small amounts of heterophoria when found in routine clinical practice and, as previous studies have found that the Mallett unit is used by the majority of optometrists in the U.K (Karania and Evans, 2006), the Mallett unit was used for both the inclusion criteria and also for the measurement of the aligning prism during the study. However the Mallett unit has some disadvantages, particularly when used to assess distance heterophoria. Pickwell et al. (1991) found that the distance aligning prism readings taken on the Mallett unit did not differentiate between those patients with symptoms related to binocular vision problems and those without.

The review in section 6.6 supports the view that, for near heterophoria, the Mallett unit is the best method of detecting decompensation and of prescribing prisms to correct decompensation. However, the review also highlights that there are only a few studies that have compared the ability of different methods for diagnosing decompensation, and therefore it is impossible to determine if the results of the study would had differed had an instrument other than the Mallett unit been used (although a difference would be likely). As such, the results of Study two, and subsequent prescribing guidelines can only be applied when a Mallett unit has been used to identify the aligning prism required.

13.3.5   The use of cycloplegia

In order to attract a large number of subjects who were routinely consulting a primary eyecare practice, it was decided not to carry out a cycloplegic refraction as part of the research. Cycloplegic refraction has been described as 'an invasive technique that is uncomfortable or even distressing for the child' (Woodhouse, 2007). This decision to omit cycloplegic refraction is unlikely to be of any consequence for the presbyopia and

astigmatism groups, whose mean age was 46 years. However, for the hypermetropia group, whose mean age was 14 years (range 6-35), it is possible that there were some subjects who had a significantly higher degree of hypermetropia than was detected by non-cycloplegic retinoscopy or non-cycloplegic subjective refraction. In view of the age range of the subjects in Study two, a cycloplegic refraction was not generally necessary for clinical reasons. Obstfeld (1998, p466) suggests that cyloplegia is only indicated in young children with muscle imbalance, and that it is not necessary to routinely examine schoolchildren under cycloplegia. Viner (2004, p23) points out that although cycloplegia is useful in revealing latent hypermetropia, it also has several disadvantages such as photophobia, distress to the child, the risk of an allergic reaction and decreased ability in near work for a few hours. Therefore she advises that cycloplegia is not likely to be necessary in healthy co-operative children with good visual acuities, stereopsis and accommodation, and with no binocular problems or family history.

The effect of the selection criteria (Section 10.2) on the need for cycloplegic refraction also needs to be considered. Table 10.1 shows that subjects with hypermetropia and significant esophoria would have been recruited to the esophoria group and not the hypermetropia group. The detection of an eso-deviation in a child is a common sign of latent hypermetropia and one of the main reasons for carrying out a cycloplegic refraction (Evans, 2007b, p35). So, the sequential nature of the selection criteria (Table 10.1) would have reduced the likelihood of patients in the hypermetropia group having significant degrees of latent hypermetropia.

Nonetheless, four of the 32 subjects in the hypermetropia group had previously had a cycloplegic refraction, all of which were undertaken at least a year prior to their research appointment (mean age of these subjects at research appointment 8.5 years,

mean age at cycloplegic refraction 6.25 years). The cycloplegic refractions were approximately +1.00 dioptre higher than the non-cycloplegic findings. As most optometrists would not prescribe the full cycloplegic refraction for patients with this symptom profile, but would reduce the correction by between 1.00DS and 1.50DS (Viner, 2004, p25), the final prescription given in most cases would be similar to the non-cycloplegic findings.

There are advantages and disadvantages associated with using non-cycloplegic data. As already mentioned, a disadvantage is that latent hypermetropia will not always be detected. However, an advantage is that, in patients without significant esophoria in the age range under investigation, it is likely that most community optometrists would not have carried out a cycloplegic refraction, so these results relate directly to the effect of the refractive error that is most likely to have been detected in U.K clinical practice. Another advantage of the use of the presenting refractive error is that this is indicative of the degree of hypermetropia for which each subject's accommodative system was not adequately compensating (see below). Baldwin (1990) compared norms for refractive errors obtained from studies using cycloplegic refraction with those from studies with non-cycloplegic data and found only 0.50D difference.

13.3.6   Accommodation

Accommodation is a confounding variable in any analysis of the effect of hypermetropia in non-presbyopic patients. One possible approach would be to calculate the available amplitude of accommodation, for example by subtracting the degree of hypermetropia from the amplitude of accommodation. However, this approach would imply an homogeneity in patients' adaptation to hypermetropia which is not clinically valid. For example, clinicians encounter some children with high amplitudes of

accommodation and no eso-deviation who benefit from correction of low degrees of hypermetropia, and other cases who do not seem to benefit from correction of high degrees of hypermetropia, yet who are otherwise clinically similar. It could be argued, that by using presenting (non-cycloplegic) hypermetropia the measure of hypermetropia obtained is more likely to reflect the degree of hypermetropia that the patient is having difficulty compensating for than a calculated measure of the theoretically available amplitude of accommodation. Other measures of accommodative function (e.g., accommodative lag, accommodative facility; Evans, 2007b, pp31-32) might have produced valuable co-variates for the hypermetropia group, but these variables were not assessed in the present study.

Accommodation is also likely to be a confounding variable in the astigmatism group. Astigmatism can be coupled with a myopic, hypermetropic or emmetropic refractive error, or a mixture when one principle meridian is myopic and the other hypermetropic (mixed astigmatism). In hypermetropic compound astigmatism, accommodation can be used to bring the text into focus, at least in pre-presbyopes, whereas this is not possible in myopic astigmatism. The impact of the type of astigmatism on the rate of reading is therefore likely to vary depending on the available accommodation, and the astigmatic axis relative to the orientation of the letters in the text. However, it has also been suggested that the use of accommodation to overcome an astigmatic error may be the cause of asthenopia (Rabbetts, 2007, p103), especially in the case of small astigmatic errors. Therefore a multivariate analysis of these factors may be useful for future work.

It was noted in the Methods section that the term *prescribed lens* is used in this research to describe the lens that was prescribed for use in the WRRT, based on the refractive

findings during the eye examination. In cases where patients were prescribed spectacles, their optometrist followed their usual clinical practice and may have modified the refractive findings (e.g., giving a partial correction to reduce the risk of non-tolerance associated with large changes in prescription from a patient's existing spectacles; Elliott, 2007, pp144-147). When designing the study, the refractive findings were chosen rather than a final spectacle prescription to avoid the confounding variable of individual prescribing philosophies. Also, the practice of modifying refractive findings seems to be aimed at making spectacles more comfortable or easier to adjust to (Elliott, 2007, pp144-147), and the effect of this, if any, on visual performance is unknown.

13.3.7   The validity of the ROC curve data

Analyses with ROC curves are dependent on the definition of the target condition, which was set in the present research as an improvement in WRRT of >5%. Although this is a commonly used criterion in the literature (Wilkins et al., 1996; Evans and Joseph, 2002; Northway, 2003; Kriss and Evans, 2005; Singleton and Trotter, 2005; O'Leary and Evans, 2006; Ludlow et al., 2006), a paper by Kriss and Evans (2005) has suggested that a >10% criterion might be more appropriate and called for more research to investigate which criterion best predicts a sustained benefit from an optometric intervention. In the absence of such research, it was decided to keep with precedent and use the >5% criterion. As a precaution, the ROC curve analyses were repeated using a >10% criterion. In most cases, this had little effect on the ROC curves. One exception was the ROC curve for against-the-rule astigmatism. A criterion of 1DC or more of against-the-rule astigmatism detected 100% of those with a >10% improvement at the WRRT and correctly identified 76% of those who did not show this improvement. When a 5% criterion was applied the specificity was similar at 74%, but the sensitivity was worse at only 44%.

13.3.8   Does the WRRT provide additional information to the improvement in

              visual acuity?

One question which may arise is whether an improvement in WRRT performance with

refractive correction provides information which is not provided by an improvement in

visual acuity with refractive correction. This was analysed by investigating the

correlation between the change in WRRT and the change in visual acuity upon

refractive correction. For the subjects with hypermetropia, all subjects with astigmatism,

and those with oblique astigmatism only, correlation analysis reveals no association

between any change in the WRRT and the change in the near visual acuity ($r^2 = 0.00$,

0.03 and 0.08 respectively). For the presbyopia group, the correlation between the

change in WRRT and the change in near visual acuity is statistically significant

($p<0.001$), with $r^2=0.30$, i.e. 30% of the variation in WRRT results is explained by the

variation in visual acuity. These results are consistent with accepted clinical experience

for, unlike WRRT score, near VA rarely improves with the correction of a low

hyperopic prescription or a low astigmatic correction, but near VA may improve when

presbyopia is first corrected. No association exists between any change in near VA

(logMAR) and symptoms for hypermetropia ($r^2=0.06$), presbyopia ($r^2=0.00$), or

astigmatism ($r^2 =0.02$). There was a statistically significant correlation between the

change in near VA and symptom score for those subjects with oblique astigmatism

($p<0.02$), although surprisingly this was a negative relationship, where those subjects

with the greatest symptom scores tended to have the smallest improvement in near VA

when the refractive error was corrected. These correlations indicate that, in general, the

WRRT data provide a measure of change in visual performance with refractive

correction that is unrelated to any improvement that may occur in visual acuity, which

in turn is unrelated to any reduction in symptoms.

13.3.9   Inferences about prolonged reading tasks

The WRRT is designed to be a visually demanding dynamic test that more closely resembles typical day-to-day reading tasks than other more traditional static reading charts. In the WRRT the participant is only required to read the text for a maximum of one minute at a time. Research to investigate the effect of individually prescribed coloured filters initially indicated that the beneficial effect was only apparent with prolonged reading (Tyrrell et al., 1995). It later emerged that the WRRT was sensitive enough to determine the benefit from filters over a period as short as one minute (Wilkins, 2002). Wilkins implied that it is the visually intensive nature of the WRRT that allows it to detect a beneficial effect that would otherwise require longer test periods. Research with coloured overlays has shown that a significant initial improvement in rate of reading with an intervention predicts subjects who voluntarily use the intervention for prolonged periods (Wilkins et al., 1996; Jeanes et al., 1997).

It is possible that the research with coloured filters is not in this respect analogous to the effect of refractive errors and prisms on performance on the WRRT. It is possible that one minute test sessions may not be a long enough interval to demonstrate an improvement in reading efficiency or comfort. One possible way to establish whether the WRRT is effective at identifying whether small refractive or prismatic corrections improve reading performance would have been to perform a pilot study with simulated refractive errors and heterophoria. It would be beneficial to establish the effectivity of the WRRTfor this purpose, before any further research in this area is undertaken.

It should be stressed, therefore, that these results only look at one facet of the potential benefit from prescribing for refractive errors. Other factors such as the patient's

responses to the clinical tests and the presence of symptoms should also be taken into account (Brookman, 1996b, p127).

13.4 IMPLICATIONS: GUIDELINES FOR PRESCRIBING

13.4.1 Heterophoria

Clinicians need to know how to detect the cases of heterophoria that are likely to benefit from treatment, either in terms of a reduction in symptoms or an improvement in visual performance. As noted in the literature review (Chapter 7) there have been very few systematic studies of the relationship between heterophoria and symptoms and even fewer on the relationship between heterophoria and visual performance. The only studies found relating to visual performance show an effect of aligning prism on improving binocular visual acuity by about one half of a Snellen line at distance (Jenkins et al., 1994) and an acuity improvement of about 5% at near (Jenkins et al., 1995). Patients rarely carry out any tasks in everyday life that are equivalent to reading a letter chart and the author believes that the current study is the first to assess the effect of correcting poorly compensated heterophoria on a dynamic everyday task such as reading rapidly.

13.4.1.1 Horizontal heterophoria

The results of the t-test and ROC curves indicate slightly differing criteria for the correction or treatment of decompensated near exophoria: 2.5Δ and 2Δ respectively, and this difference may be due to several factors. Although the t-test may be considered a more robust statistical test, the result is affected by inter-subject variability, unlike the ROC curves. There was a large amount of variability in individual reading speeds, and this would have affected the t-test results. In addition, some of the results were grouped together (e.g. 0.5 to 1Δ) to increase the power of the t-test, and to ensure sufficient

subject numbers for the calculation. This grouping together of powers for the t-test calculation may have masked some of the results, whereas the ROC curves showed the sensitivity and specificity of each individual prismatic power. Overall, the conclusion is that the ROC curves would be more helpful to optometrists with decision making in day-to-day clinical practice. For example, for a patient with 2Δ of exophoria at near, the ROC curves show that there would be a 67% chance of an improvement in reading performance if the optometrist chose to correct or treat the decompensated heterophoria. However, this percentage figure is not absolute, and the results of any other binocular vision tests (e.g. near point of convergence), also need to be taken in consideration.

The results of study one (see 9.3.1) indicate that practitioners typically would prescribe an aligning prism of 1.5Δ or more if found at near in a symptomatic patient with exophoria, but would not correct any amount of aligning prism in the absence of symptoms. However, the results of study two indicate that correcting 2Δ or more is likely to result in an improvement in reading performance. Therefore, if a suspicious heterophoria (e.g., poor cover test recovery and high aligning prism) is detected even in the absence of symptoms, then these data suggest that correction or treatment is likely to improve visual performance if the aligning prism is 2Δ or more in a patient with exophoria of any age.

Esophoria at near is rare, and this may be why most published studies have either investigated near exophoria only, or have combined both the esophoria and exophoria subjects into one group. This makes it difficult to identify any prescribing guidelines for subjects with near esophoria. The result of study two shows that the correction of less than 3.5Δ of aligning prism is unlikely to improve reading performance in subjects with esophoria. However, subjects with esophoria had the highest symptom score of any of

the groups studied, and also had a significantly higher symptom score than the control group (see section 11.10.2.1). As studies have shown that esophoria has little effect on binocular visual acuity (Jenkins et al., 1994), and as reading performance appears not to be affected, the cause of these symptoms remains unclear. There is therefore a need for further research to investigate whether the prismatic correction of near esophoria would result in a reduction in symptoms.

13.4.1.2   Vertical heterophoria

Most authors agree that the prismatic correction of vertical heterophoria is beneficial (see section 7.6), but there is still debate as to how much prism to prescribe. Some authors suggest that any amount of vertical heterophoria should be corrected if symptoms are present (Carter, 1963), and others only correcting vertical heterophoria of 1Δ and over (Giles, 1965, p191). The result of study two suggests that reading performance is unlikely to be affected by vertical heterophoria of less than 4Δ (see section 11.5). In addition, subjects with vertical heterophoria of up to 3.5Δ did not have more symptoms than the control group (11.10.2.1). As the prescription of vertical prisms can result in spatial distortion (Carter, 1963), it is suggested that prisms under 3.5Δ are only prescribed when symptoms with clear links to visual activities are present.

Two caveats should be stressed. First, although the Mallett fixation disparity test provides very useful information for detecting symptomatic heterophoria, the sensitivity and specificity of the test are inevitably not 100%. Clinically, it is important to combine this test with other information, including symptoms, cover test recovery, and other test results, such as fusional reserves (Evans, 2007b, p87). In particular, if the cover test result suggests that a heterophoria may break down into a strabismus if not treated then, even in the absence of other signs, treatment is a priority to prevent the onset of a

strabismus. This is especially true with children. Also, it should be noted that although this thesis has concentrated on the correction of heterophoria with prisms, other interventions (exercises or refractive correction) are more appropriate in many cases (Evans, 2007b, pp100-105).

13.4.2   Refractive errors

13.4.2.1   Hypermetropia

Hypermetropia is the most commonly encountered refractive error in general practice, and in the absence of a drop in visual acuity, it is difficult to assess whether it would be beneficial to prescribe glasses. The literature review suggests that when good acuity is present, the two most important factors to consider are age and symptoms. As hypermetropia is common in childhood, and in most children reduces rapidly in the first few years, hypermetropic corrections of less than +2.50 rarely need to be prescribed, although it is advisable to correct larger amounts to prevent refractive amblyopia. Older children and adults are unlikely to wear a refractive correction if their visual acuity is good, and they have no symptoms. Therefore a hypermetropic correction is only required if near vision symptoms are present, particularly if they are also accompanied by clinical signs such as reduced accommodation or low fusional reserves.

Another reason commonly given for prescribing glasses is the improvement in visual performance, especially in tasks such as reading. Uncorrected hypermetropia places a strain on the accommodative system, and therefore it might be predicted that there would be a decrement in near task performance, however surprisingly very few studies have investigated this. The results of study two indicate that correcting hypermetropia up to +1.75DS does not improve performance on a visually demanding near reading task for participants with the characteristics of those in the present research (see 11.7).

This finding supports the current practice of not prescribing hypermetric corrections of less than +2.00DS in the presence of adequate accommodation and absence of symptoms (see 9.3.3). Practitioners place great importance on the presence of symptoms when deciding to prescribe a hypermetropic correction (as advised in the literature), and would correct hypermetropia of +0.75 to +1.00 and above when symptoms are present. The ROC curve for hypermetropia (Figure 11.17) shows that a criterion of +1.00DS would correctly identify 29% of those subjects with 5% improvement on the WRRT, but would mean that 60% of the subjects without an improvement would also have been prescribed glasses. In addition, Figure 11.24 shows that there is little correlation between hypermetropia and symptoms. Therefore it seems prudent in these cases to only prescribe only if there are also clinical signs (as suggested in the College of Optometrists guidelines).

13.4.2.2   Presbyopia

Many people first attend their optometrist after noticing a deterioration in their near vision at the onset of presbyopia (Pointer, 2002). This deterioration can be distressing if the patient has previously has good eyesight, and has not worn glasses before. Often these patients are reluctant to wear spectacles, and therefore information regarding reading performance would be helpful.

The literature is divided as to when to prescribe a first reading addition, and the first reading addition advised varies between +0.50 and +1.00DS. It has been shown that several factors affect the timing of the first prescription, with females and patients with hypermetropia requiring a reading addition earlier than males or patients with myopia.

The practitioner questionnaire in study one (see 9.3.4) showed that symptoms are again important to practitioners when prescribing for presbyopia. Most practitioners reported correcting +0.75D if the patient reported symptoms and only +1.50DS in the absence of symptoms. The results of study two however, show that prescribing reading additions of +1.25 when indicated is likely to significantly improve reading performance, as subjects in study two read 60% faster on the WRRT test with this correction in place. Optometrists may therefore want to discuss this likely improvement with their patients if their lifestyle involves a moderate amount of detailed near vision even if they are asymptomatic.

13.4.2.3   Astigmatism

There is a variety of advice given in the literature regarding the correction of astigmatic errors. In young children (under four) the advice is generally to correct astigmatism as low as -1.00DC to prevent meridional amblyopia (section 4.6). For children older than four, this value rises to between -1.50 and -2.00DC. For adults the axis of astigmatism is an important factor when deciding to prescribe. It is generally believed that oblique cylinders result in the most blur and cause the most symptoms, followed by against-the-rule astigmatism, and then with-the-rule astigmatism, although this seems to be mainly based on optical calculation rather than experimental studies.

The practitioner survey in study one (see 9.3.5) unfortunately does not identify reported prescribing criteria based on different astigmatic axes. However it shows that practitioners follow the advice in the literature for non symptomatic subjects by prescribing cylindrical corrections of -1.50 or over. As study two shows that correcting with-the-rule or against-the-rule astigmatism did not result in a statistically significant improvement on the WRRT for astigmatism of -1.75 or less (Figure 11.14), this

confirms that eye-care practitioners are working to best practice. However, as there was a significant improvement in the WRRT with the correction of oblique astigmatism this suggests that the axis of astigmatism should be considered before deciding when to prescribe an astigmatic correction. Combining the results, therefore, indicates that having established that a patient has oblique astigmatism, correcting it is likely to be beneficial when the power reaches 1.00DC. Correcting with-the-rule astigmatism or against-the-rule astigmatism correction up to -1.75DS is unlikely to result in an improvement in visual performance when reading, and therefore no prescription is needed in the absence of symptoms.

13.5   SUGGESTIONS FOR FURTHER WORK

The first aim of this research was to investigate whether optometrists use a variety of prescribing criteria when correcting small refractive and heterophoric anomalies, and whether these criteria follow the advice given in the literature. Whilst the results of study one do establish that a wide variety of criteria are used, the extent to which the UK Optometry Email List members represent typical optometric opinion is not known and the small subjects numbers and selection criteria makes it impossible to know whether the results are representative of U.K optometrists as a whole. It would therefore be useful to repeat this study with a much larger number of optometrists from across the U.K, randomly selected from practitioners working in multiple practices, independent practices and hospitals.

The aim of this research was to establish what magnitude of heterophoria, hypermetropia, astigmatism and presbyopia results in a decrement in near visual performance, and to see how the results relate to current prescribing criteria. It is not implied that it would be useful clinically to carry out the WRRT to determine whether

patients would be likely to benefit from a correction, although this is a possibility. To investigate this would require longitudinal studies that would relate the WRRT results to current tests of visual function and to changes in symptoms and quality of life (including workplace related indices) following prismatic or refractive correction.

As previously mentioned in section 13.3.4, there is a lack of evidence-based research comparing the ability of different instruments to distinguish between compensated and decompensated heterophoria. Therefore it would be worthwhile comparing the measurements obtained by the Mallett Unit (used in the UK), Sheedy disparometer (used in the U.S.A) and the Polatest (used in Germany) on the same set of subjects. Any improvement in visual performance with the suggested prism in place could be compared.

Another area for future research that has been highlighted in the present work is the relationship between hypermetropia, accommodation, eso-deviations, symptoms, and visual performance. The complex interaction between these variables is the source of considerable controversy and a common cause of clinical dilemmas for eyecare practitioners. It would be interesting to explore these factors in more detail in a cohort of children with hypermetropia. Tests of available accommodation (e.g., amplitude of accommodation, accommodative facility, dynamic retinoscopy, autorefraction) could be carried out and related to non-cycloplegic and cycloplegic retinoscopy to determine which measure best predicts an improvement in rate of reading and symptoms with refractive correction.

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APPENDIX 1- PRACTITIONER SURVEY USED IN STUDY ONE

We are optometrists and are currently undertaking research as part of the EyeNET research group based at City University. We are investigating the effect of optometric interventions for borderline prescriptions.

Surprisingly, there seems to be very little in the literature regarding current guidelines for prescribing borderline prescriptions and so, to obtain the most widely held view, we would be grateful if you could spend a few minutes answering the following questions. The information that you provide will be treated confidentially.

We appreciate that several factors are taken into account for each individual case when deciding whether to prescribe. However, for the purpose of this study, if you could imagine that you are reviewing your prescribing habits over the last four months to give an overall estimate of how often you have prescribed any intervention (spectacles, contact lenses, or eye exercises) for each of the following refractive errors.

Please write in the table boxes below, your estimate of the percentage of people who you have seen with each refractive error for whom you have decided to correct or treat the patient. To take an extreme example, you might have prescribed an intervention for 100% of people with and without symptoms who have a refraction of +10.00.

1. Patients under 40 who have a cylindrical component under 0.75DC and who have a refraction of:

Refraction:	+0.50	+0.75	+1.00	+1.25	+1.50	+1.75
With symptoms	%	%	%	%	%	%
Without symptoms	%	%	%	%	%	%

2. Patients aged 40-50 who have a cylindrical component under 0.75DC and with a reading add of:

Refraction:	+0.25	+0.50	+0.75	+1.00	+1.25	+1.50	+1.75	+2.00
With symptoms	%	%	%	%	%	%	%	%
Without symptoms	%	%	%	%	%	%	%	%

3. Patients of any age who have no significant spherical refractive error but who have a cylindrical component of:

Refraction:	-0.25	-0.50	-0.75	-1.00	-1.25	-1.50	-1.75
With symptoms	%	%	%	%	%	%	%
Without symptoms	%	%	%	%	%	%	%

4. How often have you prescribed a horizontal prism to patients of any age who, when tested with Mallett OXO test, need a prism to eliminate a horizontal fixation disparity of:

Refraction:	0.5Δ	1Δ	1.5Δ	2Δ	2.5Δ	3Δ	3.5Δ
With symptoms	%	%	%	%	%	%	%
Without symptoms	%	%	%	%	%	%	%

5. How often have you prescribed a vertical prism to patients of any age with a vertical heterophoria of:

Refraction:	0.5Δ	1Δ	1.5Δ	2Δ	2.5Δ	3Δ	3.5Δ
With symptoms	%	%	%	%	%	%	%
Without symptoms	%	%	%	%	%	%	%

Thank you for your time.

Wilkins Rate of Reading Test Record Sheet

Name: _____   Date: _____

Version A   With Overlay, colour:_____

come see the play look up is cat not my and dog for you to
1   2   3   4   5   6   7   8   9   10   11   12 13   14 15

the cat up dog and is play come you see for not to look my
16   17 18 19   20 21 22   23   24   25 26 27 28 29 30

you for the and not see my play come is look dog cat to up
31   32 33 34 35 36 37   38   39 40 41   42 43 44 45

dog to you and play cat up is my not come for the look see
46 47 48 49   50   51 52 53 54 55   56   57 58   59 60   Words-per-min

play come see cat not look dog is my up the for to and you
61   62   63 64 65   66   67 68 69 70 71 72 73 74 75   ....

to not cat for look is my and up come play you see the dog
76 77 78 79   80 81 82 83 84   85   86   87 88 89   90

my play see to for you is the look up cat not dog come and
91   92   93 94 95   96 97 98 99 100 101 102 103 104   105

look to for my come play the dog see you not cat up and is
106 107 108 109   110   111   112 113 114 115 116 117 118 119 120

up come look for the not dog cat you to see is and my play
121 122   123 124 125 126 127   128 129 130 131 132 133 134 135

is you dog for not cat my look come and up to play see the
136 137 138 139 140 141 142 143   144   145 146 147 148 149 150

Version B   Without Overlay

see the look dog and not is you come up to my for cat play
1   2   3   4   5   6   7   8   9   10 11 12 13 14 15

not up play my is dog you come look for see and to the cat
16   17 18 19 20 21   22   23   24 25 26 27 28 29 30

look up come and is my cat not dog you see for to play the
31   32 33   34 35 36 37 38 39   40 41 42 43 44   45

my you is look the dog play see not come and to cat for up
46   47 48 49 50   51   52   53 54   55   56 57 58 59 60   Words-per-min

for the to and you cat is look up my not dog play see come
61   62 63 64   65   66 67 68   69 70 71 72   73   74   75   ....

you look see and play to the is cat not come for my up dog
76   77   78 79   80   81 82 83 84 85   86   87 88 89 90

come not to play look the and dog see is cat up you for my
91   92 93 94   95   96 97   98   99 100 101 102 103 104 105

and is for dog come see the cat up look you play my not to
106 107 108 109   110   111 112 113 114 115 116   117 118 119 120

dog you cat to and play for not come up the see look my is
121 122 123 124 125   126 127 128   129 130 131 132   133   134 135

the come to up cat my see dog you not look is play and for
136   137 138 139 140 141 142 143 144 145 146 147 148   149 150

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Version C   **Without Overlay**

you is not come cat up look to play dog my the for and see
1 2 3   4   5 6   7   8   9   10 11 12 13 14 15

look for up and the play is dog cat not see to come my you
16   17 18   19   20   21 22 23   24 25   26 27   28   29 30

to not play come see look cat you for up the my is dog and
31 32   33   34   35   36   37   38   39 40 41 42 43 44   45

the look you dog is cat play see come to for and up not my
46   47   48   49 50 51   52   53   54   55 56   57 58 59 60

cat up to my the see and come dog for is you not look play
61   62 63 64   65   66   67   68   69   70 71 72   73   74   75

see and dog come cat is play the not look to up my you for
76   77   78   79   80 81   82   83   84   85 86 87 88   89 90

dog to cat the is you my see for up play come and not look
91   92 93   94 95 96   97   98   99 100 101   102 103 104 105

up my for and to come dog see look cat you is the play not
106 107 108 109 110   111   112   113 114   115 116 117 118   119   120

come you is see my for look to not the dog play cat and up
121   122 123 124 125 126   127   128 129 130 131   132   133 134 135

is the look to cat not and come play for you up my see dog
136 137   138   139 140 141   142   143   144   145 146 147 148   149 150

Words-per-minute

....

Version D   **With Overlay**

cat for the you not up my dog see to is come play look and
1   2   3   4   5 6   7   8   9 10 11   12   13   14   15

see you dog for is cat look play my the up and come not to
16   17   18   19 20 21   22   23   24 25 26 27   28   29   30

look cat see my and dog the is play come not for to you up
31   32 33 34   35   36   37 38   39   40   41 42 43   44   45

my see is the come play look for and up to cat you dog not
46   47 48 49   50   51   52   53   54 55 56 57   58   59 60

and you cat look to see not my dog the for come is up play
61   62   63   64   65 66   67 68   69   70 71   72   73 74   75

dog to and play up come you the not is cat look for my see
76   77 78   79   80   81   82   83 84 85 86   87   88   89   90

the play look cat see up come for my you and not is to dog
91   92   93   94   95 96   97   98 99   100 101 102 103 104 105

for to not you come play the look cat see is dog up and my
106 107 108   109   110   111   112   113 114 115 116 117 118 119 120

you dog and for up not see my cat is the play come to look
121 122   123 124 125 126 127 128 129 130 131   132   133 134 135

come not and to see you is play look up the cat dog my for
136   137   138 139 140 141 142 143   144 145 146 147 148 149 150

Words-per-minute

....

APPENDIX 3a
PRACTITIONER WORKSHEET USED IN STUDY TWO
CONTROLS (Page 1)

CONTROLS

Px name: _____ CMT #: _____

Date of birth: _____ Date of appointment: _____ male/female

> Do you ever experience sore or tired eyes when reading?   yes ☐   no ☐
>
> If you do suffer from sore or tired eyes, how often:
>
> hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Distance Rx: Ret: R _____ L _____

Sub: R _____ =6/ L _____ =6/

Add: R _____ L _____

- *For pxs seen on even dates, do NV tests without size lenses first (wearing any usual N Rx), for those seen on odd dates do NV tests with size lenses (wearing usual N Rx) first*

- *If patient last name starts with A-L then use size lens 1, if starts with M-Z use 2.*

NEAR VISION TESTS WITHOUT SIZE LENSES

Amp. Accomm.: R _____ D   L _____ D

NV VA with D Rx: R 20/ _____   L 20/ _____   B 20/ _____

COVER TEST phoria/tropia Vt _____ Δ Hz _____ Δ Rec. grade: 1/2/3/4/5

NPC Break: _____ cm recovery: _____ cm

FIXATION DISPARITY
patient cannot be tested because:

Horizontal
cannot resolve the letters "OXO" with each eye
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason: _____

if no fixation disparity tick here and go to vertical result ☐
if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: _____ Δ *in / out RE*
_____ Δ *in / out LE*

Vertical
patient cannot be tested because:
cannot resolve OXO with each eye
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason: _____

if no fixation disparity tick here ☐
if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: _____ Δ *up / down RE*
_____ Δ *up / down LE*

FOVEAL SUPPRESSION BINOCULAR **R.** _____ **L.** _____ **letters** *stationary/moving*

(reverse if necessary) MONOCULAR **R.** _____ **L.** _____

DISSOC. TEST WING **HZ.:** _____ Δ XOP/SOP ± ____ with +2.00: _____ Δ XOP/SOP

VERT.: _____ Δ

FUSIONAL RESERVES **Base in:** _____ / _____ / _____ Δ **&** **Base out:** / _____ / _____ Δ

Base up R.: _____ / _____ / _____ Δ **Base up L.:** _____ / _____ / _____ Δ

RANDOT CIRCLES _____ seconds of arc

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NEAR VISION TESTS WITH SIZE LENSES

Amp. Accomm.: R............D L............D

NV VA with D Rx: R 20/........ L 20/........ B 20/........

COVER TEST phoria/tropia Vt......Δ Hz......Δ Rec. grade: 1/2/3/4/5

NPC Break:......cm recovery:........cm

FIXATION DISPARITY
patient cannot be tested because:

Horizontal
cannot resolve the letters "OXO" with each eye
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason:...

if no fixation disparity tick here and go to vertical result ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: ....Δ *in / out RE*
................Δ *in / out LE*

Vertical
patient cannot be tested because:
cannot resolve OXO with each eye
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason:...

if no fixation disparity tick here ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: ....Δ *up / down RE*
................Δ *up / down LE*

FOVEAL SUPPRESSION BINOCULAR **R.**................ **L.**................ **letters** *stationary/moving*

(reverse if necessary) MONOCULAR **R.**................ **L.**................

DISSOC. TEST WING **HZ.:**..........Δ XOP/SOP ±..... **with +2.00:**........Δ XOP/SOP

VERT.:..........Δ

FUSIONAL RESERVES **Base in:**........../........../..........Δ & **Base out:** /........../..........Δ

RANDOT CIRCLES ....seconds of arc

RATE OF READING TEST

toss coin: *heads:* condition A: no size lenses   *tails:* condition A: size lenses *(delete)*

A   number of words correctly read: ....   time taken: ....seconds
B   number of words correctly read: ....   time taken: ....seconds
B   number of words correctly read: ....   time taken: ....seconds
A   number of words correctly read: ....   time taken: ....seconds

SYMPTOMS & HISTORY

Learning Difficulties
Please tick if you have had any specific difficulties at school with the following:

reading ☐   spelling ☐   writing ☐   maths ☐   other ....

....

Visual History

Has anyone ever noticed your eye(s) turning inwards or outwards?   yes ☐   no ☐

If yes, at what age, how often , when, and how long did it normally last?...........................

....

Has you ever had an eye operation for a turning or "lazy" eye? yes ☐   no ☐

Have you ever received eye exercises or patching? yes ☐   no ☐

Do you have glasses that you have been prescribed to correct your long-sightedness? yes ☐   no ☐

If yes, what proportion of the time when you read do you wear them?...................%

How much do they help? a lot / a moderate amount / very little

Visual Symptoms (with any Rx usually used for reading)

When you are reading or writing in a book, is it normally clear?   yes ☐   no ☐

Do words in a book ever :-   go blurred?   yes ☐   no ☐

jump around?   yes ☐   no ☐

go smaller/bigger?   yes ☐   no ☐

fade or disappear?   yes ☐   no ☐

Do you ever experience double vision when reading (see two things when there is only one)?
yes ☐   no ☐

If you do experience double vision when reading, how often is it:
hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Do you ever experience sore or tired eyes when reading?   yes ☐   no ☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Have you or anyone else ever noticed that you do any of the following?

	Yes	No	If so, please give details
Holds reading unusually far away:	☐	☐	....
Closes or covers one eye:	☐	☐	....
Frequently rubs eye(s):	☐	☐	....
Blinks excessively:	☐	☐	....
Skips, re-reads or omits words or lines:	☐	☐	....
Reads slowly:	☐	☐	....
Poor general coordination:	☐	☐	....
Light sensitive:	☐	☐	....

General Health

Are you in good physical condition and healthy?   yes☐   no☐

   If no, please give details: ....

Please list any pills or medicines that you are currently using: ....

....

Headaches

Approximately how many times have you had a headache (migraine or otherwise) in the last three

months? ....

For some people headaches can be triggered by, or tend to follow, near visual tasks such as reading, sewing, computer work, etc. To what extent do you think that your headaches are triggered by reading: not at all / rarely / occasionally / quite often / very often

VERTICAL HETEROPHORIA

Px name: .... CMT #: ....

Date of birth: .... Date of appointment: .... male/female

---

Do you ever experience sore or tired eyes when reading? yes☐ no☐

If you do suffer from sore or tired eyes, how often:

   hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

---

If patient usually (=50% of time) wears a refractive correction for reading then do all testing with

this (excluding any vertical prism) and record this here

Reading Rx: R .... =20/ vt. prism in specs: .... Δ

L .... =20/ vt. prism in specs: .... Δ

Amp. Accomm.: R .... D L .... D

N.B. for pxs seen on even dates, do NV tests using aligning prism first, for those seen on odd

dates do NV tests with control lenses first (always wearing any N Rx they usually wear)

   NEAR VISION TESTS WITH ALIGNING PRISM

COVER TEST phoria/tropia Vt .... Δ Hz .... Δ Rec. grade: 1/2/3/4/5

NPC Break: .... cm recovery: .... cm

FIXATION DISPARITY	*Horizontal*
patient cannot be tested because:	**cannot resolve the letters "OXO" with each eye**
	cannot describe the test normally without visor
	transient / alternate / constant / R/L/B suppression
	other reason: ....

if no fixation disparity tick here and go to vertical result ☐

if fixation disparity, in which eye:	*RE / LE / BE*
what type of slip:	*eso / exo / binocular instability*
magnitude of aligning prism:	.... *Δ in / out RE*
	.... *Δ in / out LE*

   Vertical
   patient cannot be tested because: **cannot resolve OXO with each eye**
                                         cannot describe the test normally without visor
                                         transient / alternate / constant / R/L/B suppression
                                         other reason: ....

if no fixation disparity tick here ☐

if fixation disparity, which eye:	*RE / LE / BE*
what type of slip:	*[R/L] / [L/R] / binocular instability*
magnitude of aligning prism:	.... *Δ up / down RE*
	.... *Δ up / down LE*

FOVEAL SUPPRESSION BINOCULAR   **R.** ....   **L.** .... **letters** *stationary/moving*

(reverse if necessary)   MONOCULAR   **R.** ....   **L.** ....

DISSOC. TEST   WING   **HZ.:** .... Δ XOP/SOP ± ......   **with +2.00:** .... Δ XOP/SOP

                  VERT.: .... Δ

FUSIONAL RESERVES   **Base in:** .... / .... / .... Δ   **&**   **Base out:** / .... / .... Δ

                  Base up R.: .... / .... / .... Δ   **Base up L.:** .... / .... / .... Δ

RANDOT CIRCLES   .... seconds of arc

NEAR VISION TESTS WITH CONTROL LENSES

COVER TEST   phoria/tropia Vt ...... Δ   Hz ...... Δ   Rec. grade: 1/2/3/4/5

NPC   Break: ...... cm   recovery: .... cm

FIXATION DISPARITY   *Horizontal*
    patient cannot be tested because: **cannot resolve the letters "OXO" with each eye**
                             cannot describe the test normally without visor
                             transient / alternate / constant / R/L/B suppression
                             other reason: ....

if no fixation disparity tick here and go to vertical result   ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: .... *Δ in / out RE*
                               .... *Δ in / out LE*

     Vertical
    patient cannot be tested because: **cannot resolve OXO with each eye**
                             cannot describe the test normally without visor
                             transient / alternate / constant / R/L/B suppression
                             other reason: ....

if no fixation disparity tick here   ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: .... *Δ up / down RE*
                               .... *Δ up / down LE*

FOVEAL SUPPRESSION BINOCULAR   **R.** ....   **L.** .... **letters** *stationary/moving*

(reverse if necessary)   MONOCULAR   **R.** ....   **L.** ....

DISSOC. TEST   WING   **HZ.:** .... Δ XOP/SOP ± ......   **with +2.00:** .... Δ XOP/SOP

                  VERT.: .... Δ

FUSIONAL RESERVES   **Base in:** .... / .... / .... Δ   **&**   **Base out:** / .... / .... Δ

                  Base up R.: .... / .... / .... Δ   **Base up L.:** .... / .... / .... Δ

RANDOT CIRCLES   .... seconds of arc

RATE OF READING TEST

toss coin: *heads:* condition A: Vt prism   *tails:* condition A: control   *(delete)*

A	number of words correctly read:	time taken: ....seconds
B	number of words correctly read:	time taken: ....seconds
B	number of words correctly read:	time taken: ....seconds
A	number of words correctly read:	time taken: ....seconds

SYMPTOMS & HISTORY

Learning Difficulties

Please tick if you have had any specific difficulties at school with the following:

reading ☐   spelling ☐   writing ☐   maths ☐   other ....

....

Visual History

Has anyone ever noticed your eye(s) turning inwards or outwards?   yes ☐ no ☐

If yes, at what age, how often , when, and how long did it normally last? ....

....

Has you ever had an eye operation for a turning or "lazy" eye? yes ☐ no ☐

Have you ever received eye exercises or patching? yes ☐ no ☐

Do you have glasses that you have been prescribed with a vertical Δ? yes ☐ no ☐

    If yes, what proportion of the time when you read do you wear them? ....%

    How much do they help? a lot / a moderate amount / very little

Visual Symptoms (with any Rx usually used for reading)

When you are reading or writing in a book, is it normally clear?   yes ☐ no ☐

Do words in a book ever :-   go blurred? yes ☐ no ☐

                                                         jump around? yes ☐ no ☐

                                                   go smaller/bigger? yes ☐ no ☐

                                                    fade or disappear? yes ☐ no ☐

Do you ever experience double vision when reading (see two things when there is only one)?

                                                                   yes ☐ no ☐

If you do experience double vision when reading, how often is it:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Do you ever experience sore or tired eyes when reading?   yes ☐ no ☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Have you or anyone else ever noticed that you do any of the following?

	Yes	No	If so, please give details
Holds reading unusually far away:	☐	☐	------------------------------------
Closes or covers one eye:	☐	☐	------------------------------------
Frequently rubs eye(s):	☐	☐	------------------------------------
Blinks excessively:	☐	☐	------------------------------------
Skips, re-reads or omits words or lines:	☐	☐	------------------------------------
Reads slowly:	☐	☐	------------------------------------
Poor general coordination:	☐	☐	------------------------------------
Light sensitive:	☐	☐	------------------------------------

General Health

Are you in good physical condition and healthy?   yes ☐ no ☐

   If no, please give details: --

Please list any pills or medicines that you are currently using: ----------------------------------

----

Headaches

Approximately how many times have you had a headache (migraine or otherwise) in the last three

months? -----

For some people headaches can be triggered by, or tend to follow, near visual tasks such as reading, sewing, computer work, etc. To what extent do you think that your headaches are triggered by reading: not at all / rarely / occasionally / quite often / very often

HORIZONTAL HETEROPHORIA

Px name:_____ CMT #:_____

Date of birth:_____ Date of appointment:_____ male/female

Do you ever experience sore or tired eyes when reading?   yes ☐   no ☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

---

If patient usually (≥50% of time) wears a refractive correction for reading then do all testing with

this (excluding any Hz prism) and record this here

Reading Rx: R_____ =20/____ (Hz. prism in specs:_____Δ)

L_____ =20/____ (Hz. prism in specs:_____Δ)

Amp. Accomm.:   R_____D   L_____D

NEAR VISION TESTS

COVER TEST   phoria/tropia Hz _____Δ   Vt _____Δ   Rec. grade: 1/2/3/4/5

NPC subj   Break:_____cm recovery:_____cm

NPC obj   Break:_____cm recovery:_____cm

FIXATION DISPARITY   *Horizontal*
      patient cannot be tested because: **cannot resolve the letters "OXO" with each eye**
                                              cannot describe the test normally without visor
                                              transient / alternate / constant / R/L/B suppression
                                              other reason:_____

if no fixation disparity tick here and go to vertical result   ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: _____Δ *in / out RE*
                                                _____Δ *in / out LE*

            Vertical
      patient cannot be tested because: **cannot resolve OXO with each eye**
                                              cannot describe the test normally without visor
                                              transient / alternate / constant / R/L/B suppression
                                              other reason:_____

if no fixation disparity tick here   ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: _____Δ *up / down RE*
                                                _____Δ *up / down LE*

FOVEAL SUPPRESSION BINOCULAR   **R.**_____   **L.**_____ **letters** *stationary/moving*

(reverse if necessary)   MONOCULAR   **R.**_____   **L.**_____

DISSOC. TEST   WING   **HZ.:**   _____ Δ XOP/SOP ± ____   **with +2.00:**_____ Δ XOP/SOP

                                VERT.:_____ Δ

FUSIONAL RESERVES   **Base out:** /_____ /_____ Δ   **&**   **Base in:**_____ /_____ /_____ Δ

                        Base up R.:_____ /_____ /_____ Δ   **Base up L.:**_____ /_____ /_____ Δ

RANDOT CIRCLES   _____ seconds of arc

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RATE OF READING TEST

toss coin: *heads:* condition A: Hz prism   *tails:* condition A: control   *(delete)*

A   number of words correctly read: ....   time taken: ....seconds
B   number of words correctly read: ....   time taken: ....seconds
B   number of words correctly read: ....   time taken: ....seconds
A   number of words correctly read: ....   time taken: ....seconds

SYMPTOMS & HISTORY

Learning Difficulties

Please tick if you have had any specific difficulties at school with the following:

reading ☐   spelling ☐   writing ☐   maths ☐   other ....

....

Visual History

Has anyone ever noticed your eye(s) turning inwards or outwards?   yes☐ no☐

If yes, at what age, how often , when, and how long did it normally last?.............................

....

Has you ever had an eye operation for a turning or "lazy" eye? yes☐ no☐

Have you ever received eye exercises or patching? yes☐ no☐

Do you have glasses that you have been prescribed with a Hz Δ? yes☐ no☐

   If yes, what proportion of the time when you read do you wear them?...................%

   How much do they help? a lot / a moderate amount / very little

Visual Symptoms (with any Rx usually used for reading)

When you are reading or writing in a book, is it normally clear?   yes☐ no☐

Do words in a book ever :-   go blurred? yes☐ no☐

                                                            jump around? yes☐ no☐

                                                    go smaller/bigger? yes☐ no☐

                                                      fade or disappear? yes☐ no☐

Do you ever experience double vision when reading (see two things when there is only one)?

                                                                        yes☐ no☐

If you do experience double vision when reading, how often is it:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Do you ever experience sore or tired eyes when reading?   yes ☐   no ☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Have you or anyone else ever noticed that you do any of the following?

	Yes	No	If so, please give details
Holds reading unusually far away:	☐	☐	....
Closes or covers one eye:	☐	☐	....
Frequently rubs eye(s):	☐	☐	....
Blinks excessively:	☐	☐	....
Skips, re-reads or omits words or lines:	☐	☐	....
Reads slowly:	☐	☐	....
Poor general coordination:	☐	☐	....
Light sensitive:	☐	☐	....

General Health

Are you in good physical condition and healthy?   yes ☐   no ☐

If no, please give details: ....

Please list any pills or medicines that you are currently using: ....

....

Headaches

Approximately how many times have you had a headache (migraine or otherwise) in the last three

months? ....

For some people headaches can be triggered by, or tend to follow, near visual tasks such as reading, sewing, computer work, etc. To what extent do you think that your headaches are triggered by reading: not at all / rarely / occasionally / quite often / very often

<u>HYPERMETROPIA</u>

Px name:_____ CMT #:_____

Date of birth:_____ Date of appointment:_____male/female

Do you ever experience sore or tired eyes when reading?   yes☐   no☐
If you do suffer from sore or tired eyes, how often:
hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Distance Rx: Ret: R_____ L_____

　　　　　　Sub: R_____=6/ L_____=6/

N.B. for pxs seen on even dates, do NV tests with Rx first, for those seen on odd dates do NV tests with size lenses first

　　NEAR VISION TESTS WITH Rx

Amp. Accomm.:　　R_____D　　　　　　　L_____D

NV VA with D Rx:　R 20/_____　　　　　L 20/_____　　B 20/_____

COVER TEST　　phoria/tropia Vt_____ Δ　　Hz_____ Δ　　Rec. grade: 1/2/3/4/5

NPC　　　　　Break:_____cm recovery:_____cm

FIXATION DISPARITY　　　　　　　*Horizontal*
　patient cannot be tested because:　**cannot resolve the letters "OXO" with each eye**
　　　　　　　　　　　　　　cannot describe the test normally without visor
　　　　　　　　　　　　　　transient / alternate / constant / R/L/B suppression
　　　　　　　　　　　　　　other reason:_____

if no fixation disparity tick here and go to vertical result　　☐

if fixation disparity, in which eye:　　*RE / LE / BE*
what type of slip:　　　　　　　　*eso / exo / binocular instability*
magnitude of aligning prism:　　　_____Δ *in / out RE*
　　　　　　　　　　　　　　_____Δ *in / out LE*

　Vertical
　patient cannot be tested because:　**cannot resolve OXO with each eye**
　　　　　　　　　　　　　　cannot describe the test normally without visor
　　　　　　　　　　　　　　transient / alternate / constant / R/L/B suppression
　　　　　　　　　　　　　　other reason:_____

if no fixation disparity tick here　　☐

if fixation disparity, which eye:　　*RE / LE / BE*
what type of slip:　　　　　　　　*[R/L] / [L/R] / binocular instability*
magnitude of aligning prism:　　　_____Δ *up / down RE*
　　　　　　　　　　　　　　_____Δ *up / down LE*

FOVEAL SUPPRESSION BINOCULAR　**R.**_____　　**L.**_____**letters** *stationary/moving*

(reverse if necessary)　　MONOCULAR　**R.**_____　　**L.**_____

DISSOC. TEST   WING   **HZ.:** .... Δ XOP/SOP ± ....   **with +2.00:** .... Δ XOP/SOP

                                            VERT.: .... Δ

FUSIONAL RESERVES   **Base in:** .... / .... / .... Δ   &   **Base out:** / .... / .... Δ

RANDOT CIRCLES   ...... seconds of arc

NEAR VISION TESTS WITH SIZE LENSES

Amp. Accomm.:   R............D   L............D

NV VA with D Rx: R 20/..........   L 20/..........   B 20/..........

COVER TEST   phoria/tropia Vt......Δ   Hz......Δ   Rec. grade: 1/2/3/4/5

NPC   Break:......cm recovery:............cm

FIXATION DISPARITY   *Horizontal*
    patient cannot be tested because: **cannot resolve the letters "OXO" with each eye**
                                            cannot describe the test normally without visor
                                            transient / alternate / constant / R/L/B suppression
                                            other reason:...

if no fixation disparity tick here and go to vertical result   ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: ....Δ *in / out RE*
                                            ....Δ *in / out LE*

        Vertical
        patient cannot be tested because: **cannot resolve OXO with each eye**
                                            cannot describe the test normally without visor
                                            transient / alternate / constant / R/L/B suppression
                                            other reason:...

if no fixation disparity tick here   ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: ....Δ *up / down RE*
                                            ....Δ *up / down LE*

FOVEAL SUPPRESSION BINOCULAR   **R.**.................   **L.**.................**letters** *stationary/moving*

(reverse if necessary)   MONOCULAR   **R.**.................   **L.**.................

DISSOC. TEST   WING   **HZ.:** .... Δ XOP/SOP ± ....   **with +2.00:** .... Δ XOP/SOP

                                            VERT.: .... Δ

FUSIONAL RESERVES   **Base in:** .... / .... / .... Δ   &   **Base out:** / .... / .... Δ

RANDOT CIRCLES   ...... seconds of arc

RATE OF READING TEST

toss coin: *heads:* condition A: D Rx *tails:* condition A: size lenses *(delete)*

A number of words correctly read: .... time taken: ....seconds

B number of words correctly read: .... time taken: ....seconds

B number of words correctly read: .... time taken: ....seconds

A number of words correctly read: .... time taken: ....seconds

SYMPTOMS & HISTORY

Learning Difficulties

Please tick if you have had any specific difficulties at school with the following:

reading ☐ spelling ☐ writing ☐ maths ☐ other ....

....

Visual History

Has anyone ever noticed your eye(s) turning inwards or outwards? yes☐ no☐

If yes, at what age, how often , when, and how long did it normally last?....................................

....

Has you ever had an eye operation for a turning or "lazy" eye? yes☐ no☐

Have you ever received eye exercises or patching? yes☐ no☐

Do you have glasses that you have been prescribed to correct your long-sightedness? yes☐ no☐

　　　If yes, what proportion of the time when you read do you wear them?....................%

　　　How much do they help? a lot / a moderate amount / very little

Visual Symptoms (with any Rx usually used for reading)

When you are reading or writing in a book, is it normally clear? yes☐ no☐

Do words in a book ever :- 　　　　　　　　　　　　　　go blurred? yes☐ no☐

　　　　　　　　　　　　　　　　　　　　　　　jump around? yes☐ no☐

　　　　　　　　　　　　　　　　　　　　go smaller/bigger? yes☐ no☐

　　　　　　　　　　　　　　　　　　　　fade or disappear? yes☐ no☐

Do you ever experience double vision when reading (see two things when there is only one)?

　　　　　　　　　　　　　　　　　　　　　　　　　　yes☐ no☐

If you do experience double vision when reading, how often is it:

　　hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Do you ever experience sore or tired eyes when reading?   yes ☐ no ☐

If you do suffer from sore or tired eyes, how often:

   hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Have you or anyone else ever noticed that you do any of the following?

	Yes	No	If so, please give details
Holds reading unusually far away:	☐	☐	------------------------
Closes or covers one eye:	☐	☐	------------------------
Frequently rubs eye(s):	☐	☐	------------------------
Blinks excessively:	☐	☐	------------------------
Skips, re-reads or omits words or lines:	☐	☐	------------------------
Reads slowly:	☐	☐	------------------------
Poor general coordination:	☐	☐	------------------------
Light sensitive:	☐	☐	------------------------

General Health

Are you in good physical condition and healthy?   yes ☐ no ☐

   If no, please give details: --

Please list any pills or medicines that you are currently using: -----------------------------------

----

Headaches

Approximately how many times have you had a headache (migraine or otherwise) in the last three

months? -----

For some people headaches can be triggered by, or tend to follow, near visual tasks such as reading, sewing, computer work, etc. To what extent do you think that your headaches are triggered by reading: not at all / rarely / occasionally / quite often / very often

PRESBYOPIA

Px name: .... CMT #: ....

Date of birth: .... Date of appointment: .... male/female

Do you ever experience sore or tired eyes when reading? yes ☐ no ☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Distance Rx: R .... =6/   add ....

L .... =6/   add ....

N.B. for pxs seen on even dates, do NV tests with full NV Rx first, for those seen on odd dates do NV tests with size lenses first (wearing these over any D Rx they usually wear)

NEAR VISION TESTS WITH FULL NV Rx

Amp. Accomm.:   R .... D   L .... D

NV VA with Full NV Rx: R 20/ ....   L 20/ ....   B 20/ ....

COVER TEST   phoria/tropia Vt .... Δ   Hz .... Δ   Rec. grade: 1/2/3/4/5

NPC   Break: .... cm recovery: .... cm

FIXATION DISPARITY   *Horizontal*
patient cannot be tested because: **cannot resolve the letters "OXO" with each eye**
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason: ....

if no fixation disparity tick here and go to vertical result   ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: .... *Δ in / out RE*
.... *Δ in / out LE*

Vertical
patient cannot be tested because: **cannot resolve OXO with each eye**
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason: ....

if no fixation disparity tick here   ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: .... *Δ up / down RE*
.... *Δ up / down LE*

FOVEAL SUPPRESSION BINOCULAR   **R.** ....   **L.** .... **letters** *stationary/moving*

(reverse if necessary)   MONOCULAR   **R.** ....   **L.** ....

DISSOC. TEST   WING   **HZ.:** _____ Δ XOP/SOP ± _____   **with +2.00:** _____ Δ XOP/SOP

                                           VERT.: _____ Δ

FUSIONAL RESERVES   **Base in:** _____ / _____ / _____ Δ   **&**   **Base out:** / _____ / _____ Δ

RANDOT CIRCLES   _____ seconds of arc

NEAR VISION TESTS WITH SIZE LENSES (with any D Rx usually used for NV)

Amp. Accomm.:   R _____ D   L _____ D

NV VA with size lenses: R 20/ _____   L 20/ _____   B 20/ _____

COVER TEST   phoria/tropia Vt _____ Δ   Hz _____ Δ   Rec. grade: 1/2/3/4/5

NPC   Break: _____ cm recovery: _____ cm

FIXATION DISPARITY   *Horizontal*
patient cannot be tested because: **cannot resolve the letters "OXO" with each eye**
                                           cannot describe the test normally without visor
                                           transient / alternate / constant / R/L/B suppression
                                           other reason: _____

if no fixation disparity tick here and go to vertical result   ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: _____ Δ *in / out RE*
                                           _____ Δ *in / out LE*

          Vertical
          patient cannot be tested because: **cannot resolve OXO with each eye**
                                           cannot describe the test normally without visor
                                           transient / alternate / constant / R/L/B suppression
                                           other reason: _____

if no fixation disparity tick here   ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: _____ Δ *up / down RE*
                                           _____ Δ *up / down LE*

FOVEAL SUPPRESSION BINOCULAR   **R.** _____   **L.** _____ **letters** *stationary/moving*

(reverse if necessary)   MONOCULAR   **R.** _____   **L.** _____

DISSOC. TEST   WING   **HZ.:** _____ Δ XOP/SOP ± _____   **with +2.00:** _____ Δ XOP/SOP

                                           VERT.: _____ Δ

FUSIONAL RESERVES   **Base in:** _____ / _____ / _____ Δ   **&**   **Base out:** / _____ / _____ Δ

RANDOT CIRCLES   _____ seconds of arc

RATE OF READING TEST

toss coin: *heads:* condition A: NV Rx   *tails:* condition A: size lenses *(delete)*

A   number of words correctly read: ....   time taken: ....seconds

B   number of words correctly read: ....   time taken: ....seconds

B   number of words correctly read: ....   time taken: ....seconds

A   number of words correctly read: ....   time taken: ....seconds

SYMPTOMS & HISTORY

Learning Difficulties

Please tick if you have had any specific difficulties at school with the following:

reading ☐   spelling ☐   writing ☐   maths ☐   other ....

Visual History

Has anyone ever noticed your eye(s) turning inwards or outwards?   yes ☐   no ☐

If yes, at what age, how often , when, and how long did it normally last? ....

Has you ever had an eye operation for a turning or "lazy" eye? yes ☐   no ☐

Have you ever received eye exercises or patching? yes ☐   no ☐

Do you have glasses that you have been prescribed to correct your long-sightedness? yes ☐   no ☐

If yes, what proportion of the time when you read do you wear them? ....%

How much do they help?   a lot / a moderate amount / very little

Visual Symptoms (with any D Rx usually used for reading; not with NV Rx)

When you are reading or writing in a book, is it normally clear?   yes ☐   no ☐

Do words in a book ever :-   go blurred?   yes ☐   no ☐

jump around?   yes ☐   no ☐

go smaller/bigger?   yes ☐   no ☐

fade or disappear?   yes ☐   no ☐

Do you ever experience double vision when reading (see two things when there is only one)?

yes ☐   no ☐

If you do experience double vision when reading, how often is it:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Do you ever experience sore or tired eyes when reading?   yes ☐   no ☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Have you or anyone else ever noticed that you do any of the following?

	Yes	No	If so, please give details
Holds reading unusually far away:	☐	☐	....
Closes or covers one eye:	☐	☐	....
Frequently rubs eye(s):	☐	☐	....
Blinks excessively:	☐	☐	....
Skips, re-reads or omits words or lines:	☐	☐	....
Reads slowly:	☐	☐	....
Poor general coordination:	☐	☐	....
Light sensitive:	☐	☐	....

General Health

Are you in good physical condition and healthy?   yes ☐   no ☐

If no, please give details: ....

Please list any pills or medicines that you are currently using: ....

....

Headaches

Approximately how many times have you had a headache (migraine or otherwise) in the last three

months? ....

For some people headaches can be triggered by, or tend to follow, near visual tasks such as reading, sewing, computer work, etc. To what extent do you think that your headaches are triggered by reading: not at all / rarely / occasionally / quite often / very often

ASTIGMATISM

Px name:.. CMT #:...

Date of birth:........................... Date of appointment:........................male/female

Do you ever experience sore or tired eyes when reading?   yes☐   no☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

CLINICAL TESTS

Glasses (rdg.):   R.................................. L..................................

Retinoscopy: R.................................. L..................................

Subjective :   R.................................. =6/   Add.......... =20/

L.................................. =6/   Add.......... =20/

BVS   :   R.................................. =6/   Add.......... =20/

L.................................. =6/   Add.......... =20/

N.B. for pxs seen on even dates, do orthoptic tests with cyl first, for those seen on odd dates do orthoptic tests with BVS first

NEAR ORTHOPTIC TESTS WITH FULL NEAR Rx (INCLUDING CYL)

COVER TEST   phoria/tropia Vt....... Δ   Hz....... Δ   Rec. grade: 1/2/3/4/5

NPC   Break:...... cm recovery:............ cm

FIXATION DISPARITY   *Horizontal*
patient cannot be tested because: **cannot resolve the letters "OXO" with each eye**
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason:...

if no fixation disparity tick here and go to vertical result   ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: ....Δ *in / out RE*
.................Δ *in / out LE*

Vertical
patient cannot be tested because: **cannot resolve OXO with each eye**
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason:...

if no fixation disparity tick here   ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: ....Δ *up / down RE*
.................Δ *up / down LE*

RANDOT CIRCLES   ...... seconds of arc

NEAR ORTHOPTIC TESTS WITH BVS NEAR Rx

COVER TEST phoria/tropia Vt _____ Δ   Hz _____ Δ   Rec. grade: 1/2/3/4/5

NPC Break: _____ cm recovery: _____ cm

FIXATION DISPARITY
  patient cannot be tested because:

Horizontal
cannot resolve the letters "OXO" with each eye
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason: _____

if no fixation disparity tick here and go to vertical result ☐

if fixation disparity, in which eye: *RE / LE / BE*
what type of slip: *eso / exo / binocular instability*
magnitude of aligning prism: _____ *Δ in / out RE*
    _____ *Δ in / out LE*

  Vertical
  patient cannot be tested because:
cannot resolve OXO with each eye
cannot describe the test normally without visor
transient / alternate / constant / R/L/B suppression
other reason: _____

if no fixation disparity tick here ☐

if fixation disparity, which eye: *RE / LE / BE*
what type of slip: *[R/L] / [L/R] / binocular instability*
magnitude of aligning prism: _____ *Δ up / down RE*
    _____ *Δ up / down LE*

RANDOT CIRCLES   _____ seconds of arc

RATE OF READING TEST

toss coin: *heads:* condition A: Rx with cyl   *tails:* condition A: BVS   *(delete)*

A	number of words correctly read:	_____	time taken:	_____ seconds
B	number of words correctly read:	_____	time taken:	_____ seconds
B	number of words correctly read:	_____	time taken:	_____ seconds
A	number of words correctly read:	_____	time taken:	_____ seconds

SYMPTOMS & HISTORY

Learning Difficulties
Please tick if you have had any specific difficulties at school with the following:

reading ☐   spelling ☐   writing ☐   maths ☐   other _____

_____

Visual History

Has anyone ever noticed your eye(s) turning inwards or outwards?   yes ☐ no ☐

Has you ever had an eye operation for a turning or "lazy" eye? yes ☐ no ☐

Have you ever received eye exercises or patching? yes ☐ no ☐

Do you have glasses? yes ☐ no ☐

    If yes, what proportion of the time when you read do you wear them?_____%

    How much do they help? a lot / a moderate amount / very little

Visual Symptoms (with any Rx usually used for reading)

When you are reading or writing in a book, is it normally clear? yes ☐ no ☐

Do words in a book ever :-

                                            go blurred? yes ☐ no ☐

                                       jump around? yes ☐ no ☐

                         go smaller/bigger? yes ☐ no ☐

                           fade or disappear? yes ☐ no ☐

Do you ever experience double vision when reading (see two things when there is only one)?

                                                  yes ☐ no ☐

If you do experience double vision when reading, how often is it:
hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Do you ever experience sore or tired eyes when reading? yes ☐ no ☐

If you do suffer from sore or tired eyes, how often:

hardly ever / rarely, only if read for a very long time / when read for a moderate time / often, if read for a fairly short time

Have you or anyone else ever noticed that you do any of the following?

	Yes	No	If so, please give details
Holds reading unusually far away:	☐	☐	....
Closes or covers one eye:	☐	☐	....
Frequently rubs eye(s):	☐	☐	....
Blinks excessively:	☐	☐	....
Skips, re-reads or omits words or lines:	☐	☐	....
Reads slowly:	☐	☐	....
Poor general coordination:	☐	☐	....
Light sensitive:	☐	☐	....

General Health

Are you in good physical condition and healthy?   yes ☐   no ☐

    If no, please give details: ....

Please list any pills or medicines that you are currently using: ....

....

Headaches

Approximately how many times have you had a headache (migraine or otherwise) in the last three

months? ....

For some people headaches can be triggered by, or tend to follow, near visual tasks such as reading, sewing, computer work, etc. To what extent do you think that your headaches are triggered by reading: not at all / rarely / occasionally / quite often / very often

APPENDIX 4

SUPPORTING PUBLICATIONS

O'Leary, C. I. & Evans, B. J. (2003)

Criteria for prescribing optometric interventions: literature review and practitioner survey.

Ophthalmic and Physiological Optics, **23**, 429-439.

O'Leary, C. I. & Evans, B. J. (2006)

Double-masked randomised placebo-controlled trial of the effect of prismatic corrections on rate of reading and the relationship with symptoms.

Ophthalmic and Physiological Optics, **26**, 555-565.

Criteria for prescribing optometric interventions: literature review and practitioner survey

Claire I. O'Leary[1,2] and Bruce J. W. Evans[1,2,3]

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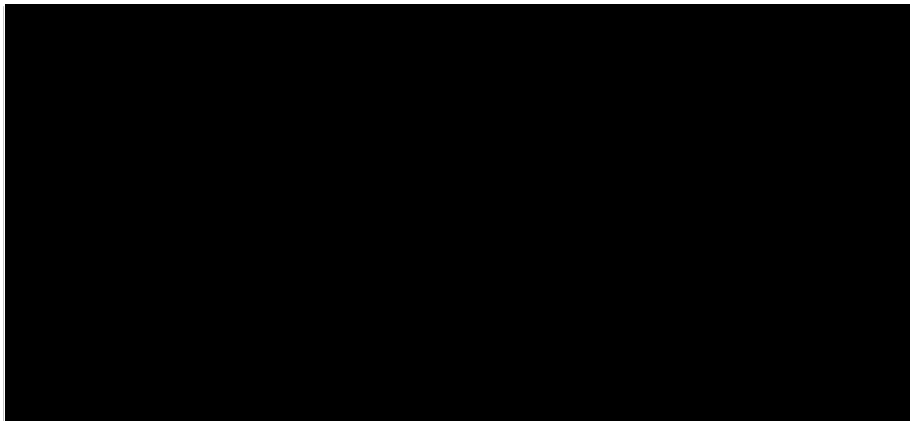
Abstract

Introduction

Background
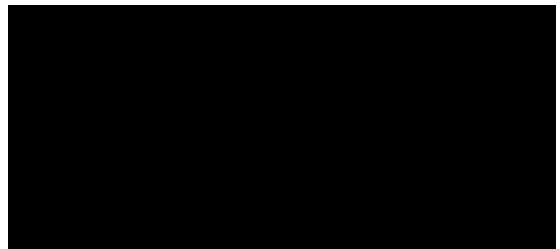
429

Double-masked randomised placebo-controlled trial of the effect of prismatic corrections on rate of reading and the relationship with symptoms

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Abstract

Keywords: asthenopia, heterophoria, prism, rate of reading, symptoms, visual performance
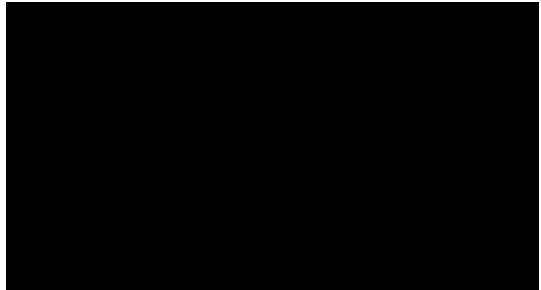
Introduction

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