Chapter 1

Background

1.1 Myopia

1.1.1 Definition

Helmholtz (1871) described the myopic eye as "one for which the far point is a short distance away, sometimes only a few inches from the eye". Donders (1864) defined it as "one in which the focus of the dioptric system lies in front of the retina". More recently, Curtin (1985) defined myopia as "the state of refraction in which parallel rays of light entering the eye at rest are brought to a focus in front of the retina".

emmetrope myope

Figure 1.1.1 Schematic representation of a myopic eye as compared with an emmetropic eye.

1.1.2 Incidence

The rate of myopia incidence varies widely across the world. In order to describe these differences the effect of geographical location and type of environment will be discussed. The lowest documented myopia rates are for Tibetan children of Katmandhu most of whom are emmetropic (Garner et al, 1995). North America, Australia and Europe have the next greatest rate of incidence. A sample adult population (both urban and rural) in Victoria, Australia showed a 17% rate of myopia (Wensor et al, 1999) and 2 studies put the rate in the US adult population at 25% (Mutti et al, 1996) and 43% (McCarty, 1997). The trend in Western countries appears to be an incidence of myopia of 30-35%

(Grosvenor & Goss, 1999) and the highest rates are found in Asia with one study stating that among Hong Kong schoolchildren (ages 8-19) 62% are myopic (Lam et al, 1999).

1.1.3 Lifestyle Factors

Regardless of geographical location myopia incidence can also vary with the type of environment; higher myopia incidence rates are found in those living in urban environments and those who undertake increased amounts of near work. Children raised in a rural community in Nepal showed a myopia incidence of 2.95% whereas those of the same ethnicity who moved into Tibet where there is more schooling showed an incidence of 21.7% (Garner et al, 1999). Also, in India the myopia incidence in rural areas is 3% compared with a national average of just under 20% (Mohan et al, 1988). As the level of education increases so does the incidence of myopia (Curtin, 1985) and there are certain professions that tend to involve near work in which a disproportionate number of myopes are employed, for example, clinical microscopy (Adams & McBrien, 1992).

Animal studies also suggest a link between a restricted visual environment and myopia. Monkeys raised in an environment restricted to the nearpoint have a tendency to become myopic (Young, 1961; Young, 1981). This will be discussed further in section 1.2.1.

1.1.4 Genetic Versus Environmental Factors

There has long been debate as to whether or not myopia has a hereditary or genetic component. A study involving indiginous families in Alaska suggested no major hereditary component (Young et al, 1969) and a study in Greenland did not find a strong familial association for refractive error (Alsbirk, 1979). Through twin studies and statistical genealogical studies, however, myopia has been shown to have a level of correlation with heredity. The concordance of refractive error is greater in uniovular than biovular twins (Chen et al, 1985) demonstarting a genetic involvement. The method of transmission is, however, not understood; it may be that there is a separate transmission of each component of refraction and a correlation factor between them (Curtin, 1985; Hui et al, 1995).

1.1.5 Anatomical Correlates of Myopia

There are four components of the eye which combine to produce the overall refractive power. These are corneal power, anterior chamber depth, lens power and axial length. The population distribution of axial length is the only one not to demonstrate a Gaussian curve being skewed with a tail towards a longer eye length. It has been suggested that it is this increase in axial length (mainly due to an elongation of the posterior vitreous chamber) which is the most common refractive element to cause myopia (Curtin, 1985). Vitreous chamber depth and axial length have been observed as being greater for myopes than for emmetropes as has the ratio of corneal radius/axial length (Grosvenor & Scott, 1991). Further evidence for refractive errors being predominantly axial in nature is the finding that there is a relationship between the degree of hyperopia and axial length (Strang et al, 1998).

1.1.6 Classification

The classification system to be used in this thesis splits myopia into 4 basic types: 1)*congenital myopia* which is present at birth and throughout life, *2)youth onset myopia* which appears between the ages of 5-6 and physical maturity in the mid- to late teens, 3) *early adult onset myopia* which has its onset after physical maturity but before the age of about 40, and 4)*late adult onset myopia* which has its onset after the age of 40 (Grosvenor & Goss, 1999). Youth and early adult onset myopia are the only types of myopia that will be investigated in this work.

1.2 Mechanisms of Myopia Development

1.2.1 Animal Studies

During growth the development of the visual system is sensitive to environmental factors and patterns of growth will adapt to the conditions imposed. The effects of refractive lenses, light and peripheral occlusion on the growth of the refractive state will be reviewed.

Neonates are not usually emmetropic but with favourable conditions neonatal refractive errors progress towards emmetropia. This process is called emmetropization (Wallman et al, 1981) and is studied by manipulating refractive states in animals (usually chicks and to a lesser extent tree shrews and monkeys) by fitting them with positive, negative or cylindrical lenses and observing the compensation that takes place in the eye of the animal. Myopia can be induced using negative lenses and the physical characteristics associated with this induced myopia that have been documented are axial elongation (Wallman & Adams, 1987), a thinning of the choroid (Phillips & McBrien, 1995; Wildsoet & Wallman, 1995) and thicker than normal rods and cones (Liang et al, 1995).

The underlying mechanisms of the emmetropization process are not well understood. What is known is that it is a vision dependent process (Rabin et al, 1981) and an active emmetropization response is dependent on the clarity of image falling on the retina (McBrien et al, 1999). Chromatic cues are not necessary (Schaeffel & Howland, 1991) and neural activity in the retina is thought to play a part (Raviola & Wiesel, 1990). There have also been studies which have reduced experimentally induced myopia with the use of a drug (tetrodotoxin) to block retinal ganglion cell action potentials. This reduction was obtained by a nonaccommodative mechanism (suggesting that accommodation is not involved in the process) and showed evidence for local ocular control of emmetropization (McBrien et al, 1993; Leech et al, 1995; McBrien et al, 1995; Cottriall & McBrien, 1996).

1.2.2 Effect of Light/Dark Regulation

Another factor which has been shown to affect emmetropization is the regulation of light and dark. Rearing chicks under conditions of constant light produces hyperopia. A shallowing of the anterior chamber, a flatter that normal corneal curvature and an elongation of the vitreous chamber is observed in these animals. These studies suggest the need for normal circadian rhythms, or at least a dark period, in the regulation of eye growth (Li et al, 1995; Stone et al, 1995). There has also been a strong correlation between myopia and ambient light exposure during sleep in children before they reach 2 years of age, suggesting that the absence of a daily period of darkness during early childhood is a potential precipitating factor in the development of myopia (Quinn et al, 1999).

1.2.3 Effect of Field Restriction

As well as experimental manipulations using refractive lenses, extreme myopia has also been induced in chicks by restricting vision to the frontal field (Wallman & Turkel, 1978). See figure 1.2.3 for an illustration of the experiment. See chapter 4 for a discussion of peripheral vision.

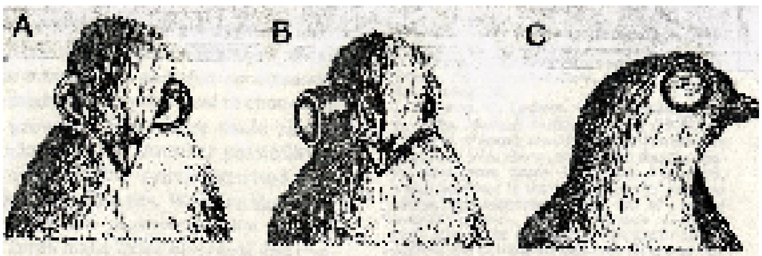


Figure 1.2.3 Devices used to restrict the frontal visual field (A) and the lateral field (B) and to prevent form vision (C). From Wallman and Turkel, 1978.

1.2.4 Modelling Emmetropization

Van Alphen (1961) proposed a model for emmetropization which was based on autonomic innervation characteristics of the ciliary muscle and the elasticity of the sclera. A more recent model (Flitcroft, 1998) incorporates a classical model of accommodation and convergence with blur driven feedback control of eye growth. This model has been extended with computer modelling to include the parameters of ocular refraction, oculomotor performance and the spatial sensitivity of the retinal elements (Flitcroft, 1999). Blackie and Howland (1999) have extended the Flitcroft (1998) model (a differential equation model comprised of 3 feedback loops: growth, accommodation and convergence) to include the effects of illumination on accommodation, vergence and pupil diameter. The parameters of accommodative controller gain, vergence controller gain, tonic accommodation, tonic vergence, accommodative convergence and convergence accommodation are used in the mathematical model which attempts to simulate the emmetropization process. The model predicts an increase in the progression of myopia under conditions of reduced illumination and extended periods of near work. It also predicts that the prescription of negative lenses (increasing the accommodative demand on a less efficient accommodative system compared to emmetropes) augments the advancement of myopia.

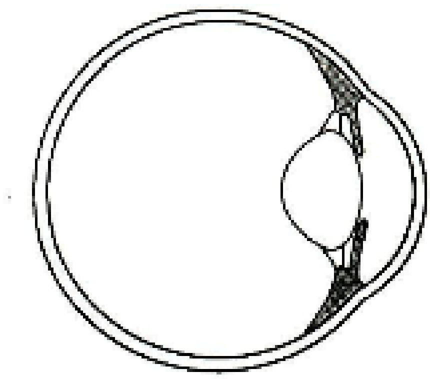
1.2.5 Applying the Animal Work to Humans

Experimental work with animals cannot be applied to the human situation without some consideration. Arguments against the application of animal models to the aetiology of human myopia include the points that the chick visual system is different to the human and the sensitive period for deprivation myopia in animals appears to be too early to account for human early onset myopia (Zadnik et al, 1995). Unilateral lid suture in adolescent monkeys, however, was found to induce myopia raising the possibility that visual experience may be involved in the genesis of youth onset myopia in primates (Smith et al, 1999).

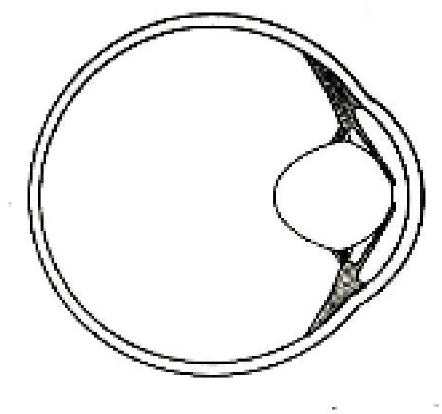
There is evidence that a similar process of emmetropization takes place in human eyes. Studies have shown a trend towards emmetropia in infants from 1 to 3 years of age when the initial refraction was myopic (Ingram & Barr, 1979; Ehrlich et al, 1995). Extrapolating the findings of animal studies to humans suggests that young eyes can control their refractive state according to visual input (Wildsoet, 1997) and leads to the hypothesis that the human eye growth can be altered by spectacle lenses (Flitcroft, 1999).

1.3 Accommodation

Accommodation is the function whereby the refractive power of the optical system of the eye can change so that images of both distant and near objects can be brought to a clear focus on the retina (Rabbetts, 1998). The action of the ciliary muscle in this process is shown in figure 1.3. Accommodation innervation is from the autonomic nervous system which is predominantly parasympathetic but which also has a sympathetic component. Parasympathetic stimulation produces an increase in accommodation to focus near objects. The sympathetic component is inhibitory (it helps to offset large increases in parasympathetic tone with sustained fixation), slow and subject to individual variation (Gawron, 1983; Gilmartin, 1986).



unaccommodated



accommodated

1. Figure 1.3 An illustration of the ciliary muscle's action on the lens during accommodation. After Kaufmann (1992).

1.3.1 Tonic Accommodation

Tonic accommodation is the resting state of the accommodation system when there is no stimulus to accommodate. Studies have found lower dioptric levels of tonic accommodation in corrected myopes than in emmetropes. Rosenfield and Gilmartin (1997) measured the tonic accommodation as 0.4D for corrected youth onset myopes and 0.75D for emmetropes. McBrien and Millodot (1987) measured 0.49D for corrected adult onset myopes, 0.92D for corrected youth onset myopes and 0.89D for emmetropes. The tonic accommodation values have been found to become lower as myopia develops but not before its onset (Gwiazda et al, 1995). The accommodation level as measured in darkness and as measured when viewing is through a pinhole were found to be different in emmetropic and myopic subjects (Strang et al, 2000) suggesting that when there is no blur stimulus but visual information is present then the system does not rest in the tonic or dark focus position.

1.3.2 Accommodative Lag

Subjects with myopia showed higher lags of accommodation than emmetropes for higher accommodative stimulus levels (McBrien & Millodot, 1986). An even greater lag for myopes was found when the accommodative stimulus was a target viewed at the same distance through a series of minus lenses (Abbot et al, 1998). Also myopes have been shown to be less sensitive to blur and this has been suggested as a possible explanation for the accommodative lag (Rosenfield & Gilmartin, 1999).

1.3.3 Nearwork Induced Transient Myopia

Nearwork-induced transient myopia has been defined as the short term myopic shift in far point of around, on average, 0.25D, which occurs immediately following a sustained near visual task and persists for up to 30 seconds (Rosenfield & Gilmartin, 1998). This accommodative adaptation (an incomplete relaxation of accommodation) has been measured as a mean shift of 0.34 D after an 8-minute fixation period at the near point (Ebenholtz, 1983), 0.6D after 1 hour of nearwork (Owens & Wolf-Kelly, 1987) and 0.29D after a 2 hour task at 20cm (Ehrlich, 1987). These shifts do eventually return to baseline.

1.3.4 Associated Observations

People who exhibit a sluggish blur-driven accommodative response are likely to exhibit an increased lag of accommodation to near, have a reduced sympathetic input to accommodation, esophoria at near and an increased AC/A ratio (that is, a tendency to over converge to the accommodative stimulus). The chronology and synergistic associations of these changes are, however, unclear (Rosenfield & Gilmartin, 1999). Schor (1999) modelled interactions between accommodation, convergence and refractive error, the results suggesting that adaptable tonic vergence could potentially reduce the progression of myopia by reducing the lag of accommodation.

1.4 Mechanical factors

The link between near-work and myopia has also been explored with reference to the mechanical implications of convergence and tension in the extraocular muscles. The sclera of myopes has been found to have thinning, narrowing and dissociation of the collagen fibre bundles (Ong & Ciuffreda, 1997). It is not clear if this stretching is the result of the causal forces of the myopia or just an associated characteristic. Greene (1980) calculated that the oblique muscles can exert significant amounts of localised tensile stress on the posterior sclera. With the increase in vitreous pressure associated with convergence this concentrated stress may be sufficient to stretch the sclera out of shape permanently (Greene, 1980). See figure 1.4 for an illustration of a stretched sclera. Ong and Ciuffreda (1997) argue that there is little evidence pertaining to Greene's calculations and that myopia is not primarily due to biomechanical aspects of accommodation, vergence and the intraocular pressure relationship.

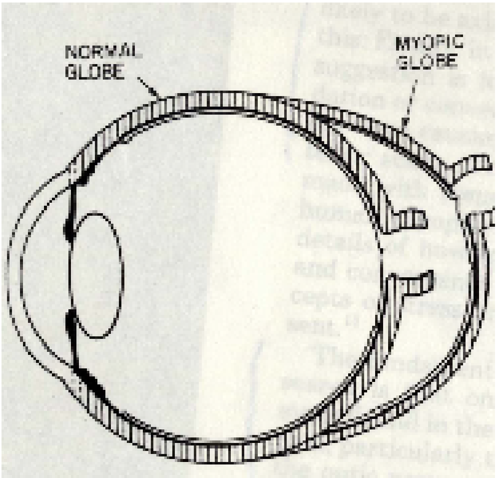


Figure 1.4 Geometry of the axial myopic globe superimposed on the normal emmetropic globe. This section represents a horizontal section through the left globe as viewed from above. From Greene (1980).

1.5 Mental Effort and Suggestion

1.5.1 Volitional Control of Accommodation

It has been shown that trained subjects can exhibit volitional control over their accommodation, that is, "thinking far" or "thinking near" can override presented stimuli (Malmstrom & Randle, 1976; Randle, 1988). For one of the volitional control exercises used by Randle, subjects were required to hold focus for a far distance while the target was stepped from far (0.50D) to near (3.50D) and vice versa. He demonstrated that 8 of his 12 myopic subjects could significantly extend their far points. Substantial changes were also evident in pre- and post-task measures of refractive error and Snellen acuities but there did not appear to be a relationship between these changes and the corresponding facility to control the farpoint (Gilmartin et al, 1991). The range of volitional negative accommodation observed is 0.5 to 2D (Richter & Franzen, 1994). Accommodation training will be considered further in chapter 2.

1.5.2 Effect of Mental Effort

Performing a mental task has been shown to change the level of accommodation. A mean increase in accommodation of 0.28D was measured when subjects with a mixture of corrected refractive errors added numbers at a distance of 40cm as compared with simply reading them (Kruger, 1980). A group of emmetropes showed an increase in accommodation of 0.09D when adding numbers as compared with reading them with an accommodation stimulus of -1D. The same task showed a decrease of 0.09D with a -3D stimulus and a decrease of -0.04D with a -5D stimulus (Bullimore & Gilmartin, 1988). Winn et al (1991) measured a 0.17D increase in accommodation (stimulus distance 30cm) for a group of emmetropes when the task involved responding to a particular letter instead of just reading the letters.

1.5.3 Hypnotic Suggestion

Hypnotic suggestion has also been reported to change visual perception and more specifically to increase the visual acuity of myopic subjects. Small changes in visual acuity have been observed contingent upon social-verbal approval e.g. praise for correct answers (Giddings & Lanyon, 1974) and monocular scores for a spatial discrimination task improved for myopes after listening to music and to taped suggestions (Sheehan et al, 1982). The greatest increases in measured acuity have been found for those subjects with the poorest acuity and this improvement was not observed to be because of any alteration of the refractive power of the eye (Graham & Leibowitz, 1978).

1.6 Perceptual Effect of Blurred Vision

Monocular diplopia (or an array of clear images) has been observed in situations of uncorrected myopic blur and blur induced by introducing positive lenses in front of an emmetropic eye. This phenomenon of uncorrected monocular vision showing diplopia or a distortion of multiple clear images in the presence of hyperopic defocus (uncorrected myopia or emmetropia with blur induced by positive lenses) has been documented (Obstfield, 1991) and explanations put forward using an extension of Mach effect theory (Remole, 1980; Remole, 1991). This phenomenon has been successfully modelled as an interaction between defocus and ocular spherical aberration (Woods et al, 1996). In a clinical situation this effect would allow correct identification of the letter although a single clear image is not available.

1.7 Short Term Adaption to Refractive Changes

It has been observed that uncorrected vision improves after a period of exposure to blur. Low myopes read 0.039 logMAR units more after a 90 minute distance task wearing no prescription than after having performed the same task wearing their full prescription (Pesudovs & Brennan, 1993). Similarly, after emmetropes performed a 30 minute distance task through a +1.00D lens a significant improvement in visual acuity of 0.09 logMAR units (nearly one line) was measured (Mon-Williams et al, 1998).

Chapter 2
The Treatment of Myopia

2.1 Optometric Compensatory Treatments

The most common method of treating myopia is to alter the refractive state at the front of the eye to compensate for the myopic refractive error and allow light entering the eye to focus on the retina. This can be done by one of several methods:

(1) *Spectacles* Concave refractive lenses made of glass or plastic are worn in front of the eye. The strength of the lenses is determined in an optometric examination.

(2) *Contact lenses* As for spectacles but they are usually made of plastic and are worn directly on the cornea.

(3) *Orthokeratology* is the procedure in which rigid contact lenses are fitted in such a way as to temporarily flatten the corneal apex and thus compensate for the myopia.

(4) *Surgery* Surgery to permanently alter the refractive state of the cornea is also available. Radial keratotomy (RK) is a procedure in which incisions are made into the corneal stroma to flatten the central cornea. Laser Photorefractive Keratectomy (PRK) is a process in which a laser is used to ablate the central cornea. Another surgery method, Laser in situ Keratomileusis (LASIK) begins with the removal of a corneal flap followed by the use of a laser to ablate the stroma. The flap is then replaced (Grosvenor, 1999).

2.2 Attempts to Reverse or Control Myopia

It has been suggested, based on the literature on myopiogenesis (see chapter 1) that, however useful, spectacle intervention (or any of the other methods described above) for the optical correction of myopia may lead to its exacerbation (Blackie and Howland, 1999). Comparing myopia progression for full time spectacle wearers, distance wearers only and non-wearers did not, however, show any significant differences (Ong et al, 1999). Similarly one study followed patients with exotropia who were overcorrected with minus lenses. The rationale behind such treatment is that negative lenses stimulate accommodation which in turn stimulates accommodative convergence (AC/A ratio). Exotropia is therefore combatted with minus lenses. No significant increase in the rate of myopia progression was found for those overcorrected (Kushner, 1999).

Attempts to halt or reverse myopic progression have been numerous and have employed a wide range of methods from the prescription of bifocals or contact lenses to visual training.

2.2.1 Bifocals

The prescription of bifocals for young people is based on the idea that excessive or sustained accommodation promotes myopic increases (Goss, 1982). Myopia is regarded as an adaptation to nearpoint stress in which distance visual acuity is sacrificed in order to achieve heightened visual efficiency at near. Early relief of the nearpoint stress with low plus is thought to prevent myopia (Jennings, 2000). Private practice records (Roberts & Banford, 1967; Oakley & Young, 1975; Neetans & Evans, 1985) have shown a slowing of the rate of myopia progression in bifocal wearers as compared with those in single vision lenses (between 0.1D and 0.42D less per year). A clinical trial of +1.00D and +2.00D add bifocals worn by subjects aged 6-15 for 3 years showed no significant difference in myopia progression as compared with subjects wearing single vision lenses (Grosvenor et al, 1987). Contrasting with this are studies which found a slowing of myopic progression using +1.50D and +2.00D adds (Leung & Brown, 1999) and a slowing of progression to a slight degree with a +1.50D add (Fulk et al, 2000). In summary there is no consensus regarding the efficacy of bifocals which may partly be due to variation in experimental design and heterogeneity in the subject samples.

2.2.2 Contact Lenses

As the result of a 3 year study it was concluded that, for wearers of rigid gas permeable (RGP) lenses myopia progressed at a significantly slower mean rate than for wearers of spectacles, however, due to the large standard deviations of both groups it would not be possible to predict the effect for a given patient. The slower rate for the RGP lens wearers was associated with corneal flattening although the flattening as measured by the keratometer was not enough to account for all the myopia control (Perrigin et al, 1990). Another study showed no difference in myopia progression between a group of adolescent spectacle wearers and soft contact lens wearers (Horner et al, 1999). In conclusion, soft contact lenses appear to have no effect on myopia progression whereas rigid lenses can slow myopia progression but not in any reliable or predictable way.

2.2.3 Auditory Biofeedback

Another technique which is used to attempt myopia control and reduction is biofeedback of accommodation. This technique involves using an infrared optometer to record the vergence of light reflected from the retina. This signal is then converted to an auditory tone. As accommodation decreases the pitch increases giving feedback of the accommodative state. This feedback allows for volitional control which ideally could be transferred to the everyday environment. The treatment consists of a series of training sessions on the apparatus accompanied by home based peripheral awareness and relaxation techniques and a correction to 6/9 acuity (Angi et al, 1996).

Trachtman (1987) reported a compilation of 240 case histories from 11 optometry practices using biofeedback for which the median change in refractive correction was +0.87D with a range of 0 to +4.75D. Koslowe et al (1991) found no change in unaided visual acuity, retinoscopy or subjective refraction between treatment and control groups when testing the biofeedback equipment. Angi et al (1996) showed a significant improvement in unaided visual acuity of 0.16 logMAR units for the right eye and 0.11 logMAR units for the left eye. The refractive errors did not decrease, but a psychological assessment showed that the treated myopes had an improved subjective perception of psychological well being and often reported a sensation of warmth and increased eye volume after training. There were also reports of monocular diplopia with the perception of a central blurred image accompanied by a clear image alongside.

Figure 2.2.3 The biofeedback visual training system. See text for a description of biofeedback visual training. From Angi et al, 1996.

The discussion of clinical trials of this technique have been criticised for a lack of a plausible physiological model linking accommodation and myopia development (the initial cases were based on the assumption that the myopia was caused by a ciliary muscle spasm) (Gilmartin et al, 1991).

2.2.4 Visual Training

Visual training for myopia control is a term used to cover a range of different methods, most of which attempt to reduce myopia by encouraging an extension of the farpoint. One large scale study of vision training (methods unspecified) evaluated the outcome using Snellen charts and cycloplegic retinoscopy. Most subjects had an improvement in unaided vision which averaged approximately 2 lines of letters, however, the results for the cycloplegic retinoscopy did not show an overall trend towards myopia reduction (Woods, 1946).

Berens et al (1957) studied the effects of a tachistoscopic training procedure on myopia. The training procedure involved reading digits projected onto a screen. When all the digits were correctly identified the distance to the screen was increased, the number of digits being shown increased and the exposure time decreased. This procedure was carried out three times a week for ten weeks. The mean unaided visual acuity increased in the experimental group while it decreased in the control group and cycloplegic retinoscopy showed a significant decrease in myopia in the treatment group of +0.22D and a significant increase in myopia of -0.29D in the control group.

Giddings and Lanyon (1974) showed that positive reinforcement on a visual acuity task could produce short term decreases in myopia. Whilst viewing slides of 4 rings, and having to determine which ring had a gap, a positive reinforcement group were told when they were correct, a noncontingent reinforcement group received verbal encouragement on a random basis unrelated to whether the response was correct and a control group received no response from the experimenter. The positive reinforcement group had less myopia at the end of the training period as measured by retinoscopy without a cycloplegic. This change was 0.22D more than the change in the control group and 0.20D more than the change in the noncontingent reinforcement group. (Values not stated.)

Rosen et al (1984) used a training program which consisted of instructions for avoiding eyestrain, for eye relaxation massage techniques and for fixating on targets at increasing distances. There were 3 groups in the experiment; behavioural training plus feedback, behavioural training only and a no treatment control group. The behavioural training plus feedback group were told when they made correct responses on a Landolt ring discrimination task such as that described above. Both training groups showed significantly greater increases in acuity than the control group (6/38 to 6/20 and 6/40 to 6/30 as compared with no change at 6/40). Refractive error changes showed a trend towards decreased myopia of approximately a quarter of a dioptre in the two treatment groups, but this was not found to be statistically significant.

Instead of digits or letters one study used a computer game that had to be played at increasing distances. The reported findings from this study was an increase in visual acuity (Gil & Collins, 1983). Another method used is similar to the biofeedback techniques described above but with the inclusion of a projected target for the trainees to clear. Successful extensions of the farpoint of the order 0.2D were achieved but were hypothesized to be instrument specific (Randle, 1988).

Vision training has also been shown to alleviate transient near work myopia. A 10 week training procedure involved rocking fixation and focus repeatedly from far to near targets and trying to maintain a target in focus whilst flipping between viewing through positive and negative lenses. Monocular accommodative facility showed an improvement as measured by an autorefractor in 5 subjects after the training period (Ciuffreda & Ordonez, 1998).

The range of training methods attempted is wide although most are based on increasing accommodative flexibility and extending the myopic farpoint. This has been done using various projections and computer screens with targets of varying sizes and at varying distances. There were also various levels of feedback given in the form of auditory signals as to the state of accommodation or verbal encouragement and information as to how much of the target was seen correctly. Different methods of vision training have shown small improvements in acuity and objective refraction although there is no widespread agreement on the mechanisms producing these changes.

2.2.5 Behavioural Optometry

The training procedure used in the paper by Woods (1946) was carried out by Dr. A.M. Skeffington whose work forms the basis of the branch of optometry called behavioural optometry. He postulated that visual disorders are frequently the end-points of either interference in visual development or are adaptations to stress - notably near-point visual stress. This has led to the tenets of behavioural optometry that vision is a developed motor skill, that ophthalmic lenses can be used for prevention, protection, compensation and enhancement, and that vision is trainable (Holland, 1996). There is, however, concern that behavioural optometry can not perform under evidence-based scrutiny which means that although it is widely practised and is a very active international movement it does not enjoy the credibility of mainstream optometry (Jennings, 2000).

Chapter 3
Holistic Vision

3.1 Natural Vision

3.1.1 Background

There are claims of methods that improve myopic sight without optical correction or surgery, the oldest documented ones being from within the Indian yoga systems and traditional Chinese medicine. Today there exists a field in which vision problems such as myopia are approached holistically. There are many different methods used within this field which I will refer to collectively as vision therapy. Although there are many different approaches to vision therapy most incorporate the work of W. H. Bates, an American ophthalmologist.

In 1920 "The Cure of Imperfect sight by Treatment Without Glasses" by W. H. Bates was published. This book presents the idea that sight can improve with the removal of spectacles and sets forward the techniques to aid this improvement. The main idea is that imperfect sight is caused by strain and the objective is to remove the strain; normal sight being restored once this has been achieved. This strain can take the form of physical tension not allowing full movement of the eye, which in turn can lead to a pattern of staring in which rapid changes of fixation are not possible. The proposed techniques to aid the improvement process are palming, sunning, swinging (see below) and the restoration of central fixation, since any tendency to eccentric fixation will mean that foveal sight will not be used. "Since central fixation is impossible without mental control, central fixation of the eye means central fixation of the mind. It means, therefore, health in all parts of the body" (Bates, 1920). It is at this point, regarding vision as part of overall health, in essence a holistic viewpoint, that Bates's theories depart from conventional optometry. Contemporary natural vision work uses the techniques and ideas that Bates proposed whilst incorporating them in a holistic health model that allows for the possibility of other approaches if necessary (e.g. cranio-sacral therapy, Alexander technique).

A holistic approach to health includes the view that a symptom indicates an underlying health problem which may need attention, the symptom being the best attempt the body can make to heal itself. Treatment generally involves attempts to boost overall health in order to allow the body's regulatory systems to overcome any problems e.g. working to restore strength and flexibility in the whole of the back to relieve localised back pain. Natural vision and vision therapy techniques are based on the idea that reduced vision is a symptom indicating more general problems that can be addressed.

There is also an assumption with vision therapy that seeing is learned and so a process of re-education is possible. There are techniques to aid this process but it is not simply a question of doing exercises to achieve a result. Working in this way places each person in a position of responsibility in which he or she is expected to apply the learned techniques (Birnbaum, 1981; Friedman, 1981) and a determination to view vision as part of the whole human process is also crucial to success (Mansfield, 1992). There are currently many books in print which outline different methods for vision improvement (Benjamin, 1929; Huxley, 1943; Corbett, 1949; Kavner, 1978; Rosanes-Berrett, 1983; Goodrich, 1985, Kaplan, 1987, 1995; Mansfield, 1992; Schneider et al, 1994; Berne, 1995; Liberman, 1995; Quackenbush, 1997). As well as these books there are courses and workshops available during which the techniques are taught. Sections 3.1.2 through to 3.2.4 summarise the work in these texts.

3.1.2 Physical Correlates

The associated characteristics of myopia implicit in the holistic perspective are set out in these texts. It is suggested that the body of a myope will follow a specific pattern of pronounced tension in the forehead, jaw, neck, shoulders, upper arms and lower back. He or she will also have reduced peripheral awareness and a prolonged central fixation time. A combination of vision exercises, bodywork and body relaxation exercises has been found to be far more effective at improving vision than simply doing vision exercises alone (Schneider et al, 1994).

3.1.3 Emotional Correlates

It is not only the physical characteristics of myopes that are reported to follow a pattern but perceptual style and personality type also. The typical myope is said to be academically proficient and in a state of compressed anxiety and unconscious apprehension (Goodrich, 1985). There have also been many correlational studies linking myopia with personality characteristics. These have linked myopia with introvertedness, shyness, over-control of emotions and a high tolerance for anxiety (Lanyon & Giddings, 1974). Many of the vision therapy approaches include a psychotherapy aspect dealing specifically with these issues.

3.2 Vision Exercises

Within the natural vision literature there are a common body of exercises that are generally recommended as beneficial for myopia. The first recommendation is that whenever safe (i.e. not for tasks that require a certain standard of acuity e.g. driving) no refractive correction should be worn and when this is not possible a reduced prescription should be used. There are also techniques for encouraging co-ordination, flexibility and movement, these factors being considered as essential to good vision.

3.2.1 Movement Stimulation

1) *Blinking* is encouraged wherever possible and can be co-ordinated with breathing, jaw flexion and neck rotations. This is suggested to help reverse a pattern of rigidity and staring.

2) *Stimulating peripheral vision* is attempted by patching across the nose to block out central vision (see figure 3.2.1a). Throwing and catching a ball with the hands to the side, or any form of peripheral movement detection are said to add further benefit to this activity.

Figure 3.2.1a Stimulation of peripheral vision using movement of the hands with a nosecard used to block central vision. Illustration from *The Handbook of Self-Healing* (Schneider et al, 1994).

3) *Swinging* the head and body through 180^{o} encourages co-ordination of the visual system with movement. The aim of the exercise is to smoothly observe the apparent motion of the surroundings in the opposite direction to the movement of the body and to fixate each point as it moves through the central line of vision (see figure 3.2.1b).

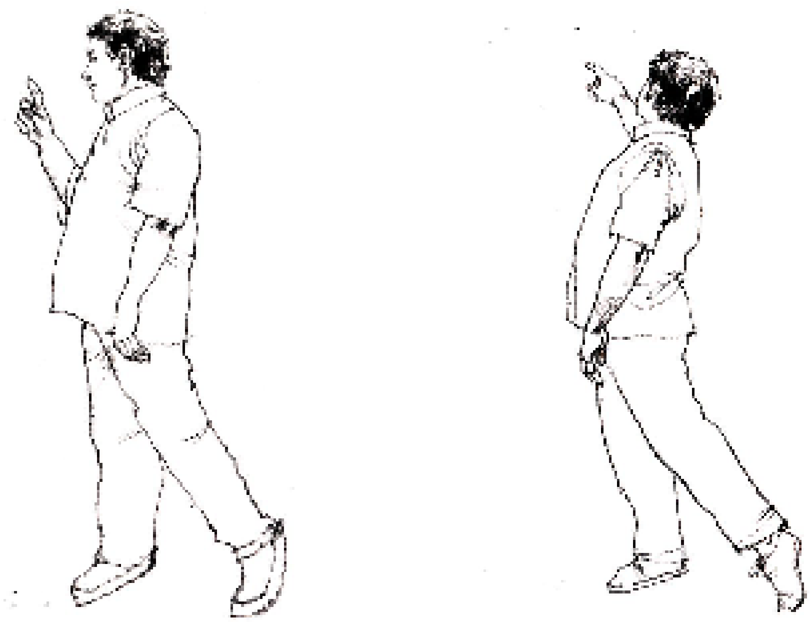


Figure 3.2.1b Swinging using the outstretched hand as a reference point for the oppositional movement. Illustration from *The Handbook of Self-Healing* (Schneider, 1994).

4) *Swaying* from side to side whilst looking, for example, through a window and observing the movement of the foreground and background in opposition to one another is also said to stimulate this co-ordination of vision and movement. This is best done with a rocking motion keeping the neck and back in one line i.e. swaying from foot to foot and not bending at the waist or the neck.

5) *Shifting* exercises are designed to restore the natural free movement of the eyes and counter the tendency for slower, larger and less frequent saccadic eye movements that are said to accompany deteriorating vision. These exercises involve shifting one's point of focus from place to place in imitation of normal eye movements. This can be done, for example, by taking a picture and tracing with the focus of attention around details of the picture. Though this movement must be consciously practised at first, with time it becomes an automatic and effortless process. A smaller and subtler oppositional movement as described for swinging can also be observed when accurate shifting is achieved. (The point of fixation will always be in the centre of the visual field so that if the gaze moves to the right the point that was being observed will now be moved to the left in the visual field.)

3.2.2 Relaxation

1) *Palming* is the name given to the technique of sitting with the palms covering the eyes (see figure 3.2.2). This allows the eyes a time of total rest and is best done in darkness. Palming for an hour a day is recommended.

Figure 3.2.2 Two different ways of palming. Illustration from *The Handbook of Self-Healing* (Schneider, 1994).

2) Facing the sun with closed eyes and slowly rotating the head is said to warm the muscles around the eyes and stimulate the retina. This is known as *sunning*. Alternating between palming and sunning is said to aid pupil flexibility making the transition from dark to light less painful.

3.2.3 Nutrition

Good eyesight and eye co-ordination are said to depend on good nutrition. There is no single recipe for a good diet for all people since people vary in their nutritional needs, however, a diet rich in fresh fruit and vegetables (eaten raw as much as possible) and avoiding foods high in fats (e.g. crisps), processed sugars and white flour is recommended.

3.2.4 Possibility of improvement

With regard to improvements in myopia the general consensus within the field of vision therapy is that, although by no means guaranteed, restoring good vision is possible (Schneider, 1994). This argument,that myopic vision can improve, places natural vision techniques outside of contemporary optometry practice.

3.3 Personal Experiences of Natural Vision

Case studies and personal experiences of natural vision techniques, although anecdotal in origin, are worthy of discussion because the techniques are novel and have not been rigorously investigated. Analysing the experiences of those who have tried the techniques and written about them is useful in determining which direction further research should take. One thread which runs through these articles is the connection between vision and posture. It is suggested that the sharp acuity achieved with negative lenses for myopic vision brings with it stress and muscular tension, that is, that the most relaxed and healthy eye is one which moves and sees well and that poor vision and muscular tension come together. In addition the necessity of always looking through the optical centre of corrective lenses for best vision can lead to reduced flexibility with a tendency to move the head, neck and upper body instead of using eye movement only (Gallop, 1994).

Another widespread theme is that of the spatial percepts of myopic vision. Visual information is used for balance, an awareness of spatial volume and orientation and interactions within this space. It is suggested that there is a tendency in myopic vision to over concentrate on a central target making peripheral awareness poorer (Birnbaum, 1978). There is also often an emphasis on near-centred tasks that are two dimensional and do not include adequate motor involvement i.e refined physical movement and co-ordination are not necessary (Gallop, 1994). The effect that minus lenses have on spatial perception is described as visual compression with the deep three-dimensional reality of good vision becoming in subtle ways a two-dimensional image (Orfield, 1994). The following quotation is from someone who followed a program of vision therapy with a behavioural optometrist over a time span of seven years.

"I saw space visibly expanding - people grew taller and the volume of space expanded enormously. Seeing space, very different from having 20/20 sight is the vision thing which is lost with strong lenses when central sight is all that is prescribed for. Regaining it is what makes reducing and controlling my myopia worthwhile." (Orfield, 1994)

This idea of spatial perception being altered by minus lenses also includes the perception of motion with the relative speeds and distances as altered by minus lenses having very specific perceptual consequences (see chapter 4). The following is an observation of what it was like to wear a reduced prescription.

"The 'apparent motion' of the trees and hedges where I walked caused me to perceive distances in new ways. I noted that the apparent speed of the stationary objects that seemed to move past me and around each other was all related to their distance from me as I walked past them. I felt as if the pillars were whizzing by, the pavement rolled under my feet. It was quite different from the telescopic sight in my strong lenses." (Orfield, 1994)

As well as noting the experiences of working with vision some of what is involved when change is attempted is also discussed in this literature. The difficulty of measuring comfort, awareness, thinking or behaviour compared with the ease with which refractive errors, axial length and corneal curvature can be measured is an inherent problem of researching the holistic approach to vision. Balance, movement and awareness, all of which are important when working with vision holistically, are developed and malleable, but deep rooted, emotionally charged and sensitive when it comes to change. In order to deal with these and other issues when trying to manipulate myopia there is a need for a sound plan to avoid the fear and panic that often accompanies the first awareness of blur (Gallop, 1994).

Chapter 4
Theoretical Possibilities for Holistic Hypotheses

4.1 Theoretical Possibilities

4.1.1 Introduction

The main aim of this thesis is to explore vision therapy techniques as they are practised today within complementary medicine using conventional optometry tests. Although there exists a wealth of popular literature on the subject there is at present a lack of academic study and this brings about a contrast of styles in the literature review: one, from the natural health literature (chapter 3), which introduces the ideas and concepts employed in vision therapy; and the other (chapters 1 and 2), a more structured approach taken from academic papers which explore the workings of the visual system and the implications of clinical interventions. It should be made clear that the aims of these two bodies of work are quite different. The natural health literature usually consists of a collection of techniques designed to be read and used by an individual with no specialist training; in essence they are "do it yourself" books. They are included here because they are the only source which set out the techniques to be applied. By contrast the clinical and scientific academic literature records the attempts to understand the workings of the visual system and the effect of interventions by specific experimental methods and is designed to be read by a specialised audience. Direct comparison between the two bodies of work is difficult not only because the approaches differ but also because the situations described will also differ. For example a case study in a natural vision text may involve a person removing their -3D prescription and describing changes that take place during therapy. There is no analogue for this within the clinical literature where such a person would remain with their prescription, although in some cases it may be modified slightly. In this sense it could be said that, within the field of natural vision, unique experimental situations exist. Looking at these techniques as experimental, the next step is to explore the theoretical possibilities that they open up. In order to do this the idea that analysing the process of vision, specifically myopic vision, using the theoretical tool of a holistic viewpoint is investigated. This is done by taking the statements from the natural vision literature (chapter 3) which stand without a scientific rationale and comparing them with some of the theoretical possibilities explored in chapter 1.

4.1.2 Can Vision Be Trained?

The theoretical hypotheses that are put forward to explain the practice of vision therapy stem from the idea that vision is a learned activity and is a process which involves physical, psychological and perceptual elements. Through the manipulation and training of these different elements it is argued that vision is also trainable (Sherman, 1993;

Holland, 1996). This training is similar to the conditioning of other involuntary visceral and glandular responses e.g. blood pressure (Miller, 1969) and can be done by bringing a greater awareness to the area to be trained, as is the case in yoga systems, or by being shown through some sort of feedback device (e.g. biofeedback accommodation trainer, see section 2.2.3) the state of a particular autonomic function.

4.2 Minus Lenses, Peripheral Awareness and Movement

In order to explore and attempt to explain the perceptual consequences of minus lenses their effect is examined.

4.2.1 Minification

Relative spectacle magnification (RSM) may be defined as

$$RSM = \frac{\text{the retinal image size of a distant object in the corrected eye}}{\text{the retinal image size of that object in the standard reduced emmetropic eye}}$$

It can be shown (Obstfeld, 1978) that the RSM can be given by the formula for spectacle magnification (SM)

$SM = \omega/\omega_0$ (Obstfeld, 1978)

where ω= angle of incidence of light at the cornea with no correction in place and ω_0= angle of incidence at the cornea after correction.

The approximate percentage change produced by the spectacle correction in the retinal image size is given by

$SM\% = dF_{sp}$

where d is the vertex distance between the spectacle correction and the front of the eye and F_{sp} is the power of the correcting lens.

Using these formulae and taking the example of a -6D lens at 1cm from the cornea the relative angular difference can be calculated.

$SM\% = 1 \times (-6)$
$\quad = -6$

Therefore the image in the corrected eye is 6% smaller than that in the uncorrected eye. Looking now at the angular field of view it is assumed that the angle viewed wo $=130^{o}$ in the uncorrected eye. Using the result from the calculation for spectacle magnification then

$94/100 = \omega/130$

$\omega=122.2^{o}$

This then means that information that would fall across the stretch of retina allocated to 130^{o} in the uncorrected eye would fall across the smaller area of retina allocated to approximately 122.2^{o} in the corrected situation. See figure 4.2.1 for a diagrammatic representation of this (not to scale).

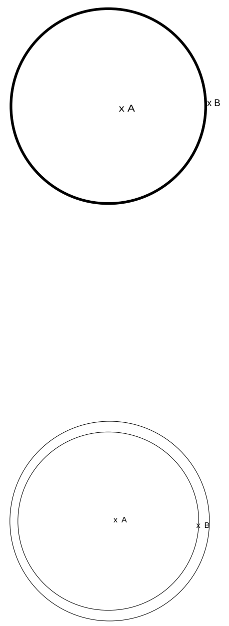


Figure 4.2.1 Diagrammatic representation of two retinae. The top circle shows the uncorrected situation of a whole retina. The outer circle of the bottom diagram represents the retina and the inner circle represents the corrected image as it falls on the retina.

This minification means that the visual field is imaged onto a smaller section of the corrected myopic retina than would be the case for an emmetropic eye. Taking the example of an object in the periphery this minification will mean that the object will be viewed by a more central part of the retina for a corrected myope than would be the case for the emmetropic eye. The advantages of cell specialisation with cells at the edge of the retina detecting motion more easily may be in this circumstance reduced, i.e. motion detection would not be so strong. This could account for the observations on myopic visual style (section 4.2.4).

It is assumed that the emmetropic eyeball and the myopic eyeball are the same size. This is not correct, however the assumption is made since the amount of cells available is the same and so although the myopic retina is stretched and the area over which the minified image is falling may be the same size as the emmetropic retina the amount of cells available is reduced and the cell type will be different.

4.2.2 .*Relative Slowing*

From section 4.2.1 the distance from an object point A to an object point B as imaged on a corrected myopic retina will be reduced as compared with the same points imaged on an emmetropic retina.

Let the time taken for an object to travel from A to B be t. This must be the same in both situations since it takes place outside the eyes. Let the distance between the image of A and B on the emmetropic retina be d_e. Let the distance between the image of A and B on the corrected myopic retina be d_{cm}. Using the formula velocity = distance/time (v=d/t) then

$v_e = d_e/t$

and

$v_{cm} = d_{cm}/t$

Combing these formulae gives $v_e/v_{cm} = d_e/d_{cm}$.

Since $d_e > d_{cm}$ this implies that $v_e > v_{cm}$.

The relative retinal image velocity is therefore different in these two situations, the movement of the image being relatively slower (and travelling across fewer cells) in the corrected myopic situation.

4.2.3 Eye Movements

The changes that negative lenses bring about to the size and speed of the visual world may well also have consequences for eye movements. If there is a reduced peripheral awareness, as is being hypothesised in natural vision texts, then there will be less motivation to perform quick eye movements to more clearly observe something that "catches the corner of the eye". This in turn could lead to a lack of flexibility in the extraocular muscles and a relative slowing of eye movements although targets will always be accurately observed.

4.2.4 Peripheral Awareness

If wearing negative lenses reduces movement awareness in the periphery then removing them and retraining the vision may bring back this awareness. This is put forward as an explanation for the description in chapter 3 in which the sensation of walking with changing vision is described: "I felt as if the pillars were whizzing by, the pavement rolled under my feet" (Orfield, 1994).

The minification effect of negative lenses will mean that there are areas of the peripheral retina that are not used for perception (see section 4.2.1). This reduced stimulation in the periphery can be compared to the peripheral occlusion which has (in chicks, see section 1.2.3) been shown to induce myopia (Wallman, 1978). If these effects hold true for humans and the lack of peripheral stimulation is enough to simulate occlusion then wearing negative lenses will induce and augment myopia (that is a stretching of the posterior segment of the eye).

4.3 Changing Myopic Visual Style

One of the important points about natural vision work is that corrected myopic vision is seen as being different from emmetropic vision. These differences can be highlighted by describing the visual characteristics of individuals with myopia. These include (1) a heightened central visual field sensitivity and/or reduced peripheral field awareness in open space, (2) a tendency to scrutinise visual details while suppressing the surrounding field in nearpoint activities and (3) a tendency to prolong central fixation (Friedman, 1981).

If these characteristics are correct, any attempt to alleviate myopia would aim to alter these tendencies, that is, work towards a situation of expanding peripheral field awareness and promoting rapid, fluid, accurate eye movements. These are the basic aims of the vision exercises outlined in section 3.2.1 which are described again here but with an emphasis on the theoretical arguments above. In this way the myopic eye can be viewed as one that sees well through minus lenses and the process of vision therapy is to try to actively change the visual style to enable a change to emmetropia to take place.

4.3.1 Peripheral Stimulation

If emmetropia relies on healthy functioning of all parts of the retina then doing exercises to stimulate peripheral vision may help to promote emmetropia.

4.3.2 Shifting

The exercise of shifting aims to recoordinate the eye movements and localisation of the visual system and regain accuracy of fixation. If the effect of minus lenses as outlined above in section 4.2.1 is considered then any attempt to remove the spectacles would imply a need to reconfigure the way that the visual system moves from looking at a point A to looking at a point B. Shifting exercises are a way to practise this co-ordination.

4.3.3 Swinging

Movement and motor skills are seen as essential to good vision with proprioception (awareness of body orientation) and spatial localisation being of particular importance (Birnbaum, 1984). As well as encouraging this awareness of body orientation, swinging will also provide movement in the periphery to stimulate this aspect of vision.

4.3.4 Swaying

Swaying is a means of relearning the apparent relative distance motion of objects in relation to each other which is distorted with the use of minus lenses as described in section 3.3. The quotation "the 'apparent motion' of the trees and hedges where I walked caused me to perceive distances in new ways" (Orfield, 1994) describes the sensation of swaying.

4.3.5 Sunning and Palming

The hypothesis that Bates puts forward is that poor vision is the result of strain. This is the basic tenet of all natural vision work, the aim of which is to reduce this strain and achieve relaxed visual function with the assumption that this also brings increased vision. Palming as a relaxation activity does just this. It could also be argued that the scotopic situation is the one in which the peripheral retina is most likely to be used and that if this area of the retina is under used then more time in this condition is necessary. Palming can provide this situation as well as an opportunity to relax the central vision. This could also account for the finding that children who sleep with nightlights (i.e. no real rest for the central retina because there is no true scotopic time and therefore no time when the dark adaption cells get a chance to work) are more likely to become myopic (see section 1.2.2). Again an analogy can be drawn between this and the situation of peripheral occlusion i. e. constant light means constantly working the central retina without any time for the peripheral retina to be stimulated.

Sunning can also be viewed in the same way as a gentle means to stimulate retinal cells not normally used when corrected with lenses and as an aid to regulating light/dark rhythms necessary to normal functioning.

4.4 Problems With Previous Trials

It should be noted that none of the clinical trials mentioned in chapter 2 approach vision therapy in the same manner as contemporary natural vision workers do, the main differences being that a long term, individual and supported approach will usually be taken as opposed to the short term specific tasks required in the majority of these trials.

(The importance of personal support can be seen if a parallel is drawn with fitness or diet programs where success is much more likely in the context of a group or with the help of a personal trainer). Also with a holistic approach other therapies may be involved in the work with vision e.g. massage, cranio-sacral therapy and the Alexander technique as well as the use of the vision exercises already described.

If change is taking place it will be, at least at first, unstable and when placed in any unfavourable situation the eye with myopic tendencies will show them to the greatest extent. Conventional chart testing could be said to be one of these conditions with a reduction in peripheral stimulation. This will mean that chart testing of an unstable eye will most likely record the worst possible vision.

4.5 Discussion of Possible Physiological Changes

Natural vision therapy techniques imply a change has taken place in order for visual performance to increase. If it assumed that real visual changes are taking place and do not just reflect an increased confidence and skill at interpreting blurred letter charts the possibilities for what the physiological changes might be are:

1. Changes in the refractive power
    - a)change in corneal curvature
    - b)change in axial length
    - c)change in crystalline lens power
2. Changes in the way the eye is used
    - a) improved co-ordinated use of foveal vision
    - b) neural clean up of blur

4.6 Purpose of the Experimental Work

The purpose of the experimental work was to:

1) investigate the effect that an introduction to vision therapy had on the chart performance, autorefractor reading, and autokeratometry reading of a myopic population.

2) explore differences between corrected and uncorrected myopic vision.

3) investigate the experience of vision therapy from the participants' viewpoints.

Chapter 5
Experimental Method

5.1 Physical Parameter Measurement

5.1.1 A-scan Ultrasound

The Mentor/Teknar Ophthalsonic A-scan was used to measure the axial length of the eyes of the participants. It transmits ultrasound at 7.0 MHz into the cornea and collects reflections from the lens and the retina with a piezoelectric element in the probe. This information is used to obtain measurements of the anterior chamber depth, lens thickness and the axial length of the eye. The auto-biometric repeat reading mode was used and the average of 10 readings calculated. The cornea was anaesthetised using 1-2 drops of 0.4 % Benoxinate Hydrochloride and the hand held transducer held to the cornea to take the readings as shown in figure 5.1.1. The participant was asked to fixate a point on the wall to steady fixation and applanation was made as close to the visual axis as possible. The instrument has an alignment system which makes an auditory signal to indicate when this is achieved.

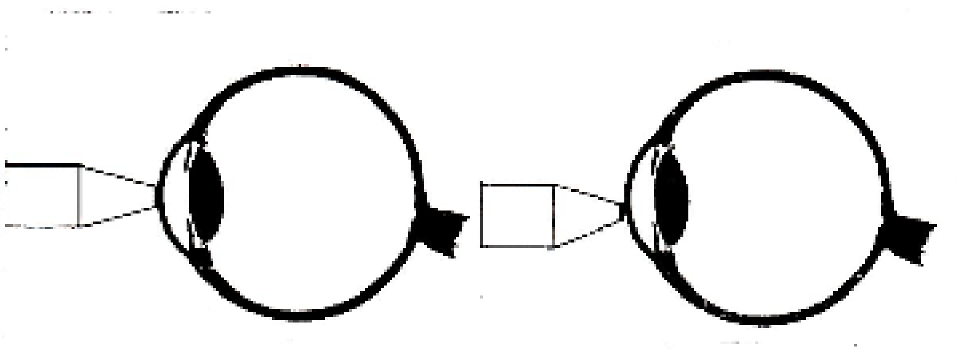


Figure 5.1.1 An illustration of the a-scan probe application. The first picture shows correct alignment flush to the cornea along the visual axis. The second picture shows an incorrect alignment. Diagram from Mentor/Teknar Ophthalsonic A-scan manual.

5.1.2 Autorefractor

The Humphrey Automatic Refractor Model 570 which works on the retinoscopy principle was used for all the refractions. Measurements were taken in the objective refraction mode and the spherical and cylindrical components of the refractive error measured were provided on a printout. Each measurement is the average of 20 readings. For each autorefractor measure 5 consecutive readings were taken, the mean sphere for each found and then the mean of these calculated.

5.1.3 Autokeratometer

The Humphrey Autokeratometer was used. The mire of the autokeratometer is composed of three infra-red emitting diodes arranged in a triangular shape. It uses a solid state detector that records the exact position of each diode image after reflection from the cornea. It uses this information to calculate the radius of curvature of the cornea. It gives a reading of corneal curvature in dioptres and millimetres along two axes, one closest to the horizontal and one closest to the vertical meridian. Each reading of corneal curvature from the machine is derived from 10 measurements (Henson, 1996). For each autokeratometry measure 5 consecutive readings were taken.

5.1.4 Technical Data Reliability

The table below shows the confidence limits for change of the ocular anatomical parameters (Zadnik et al, 1992). For these measures a Canon R-1 autorefractor, a Bausch and Lomb keratometer and an Allergan-Humphrey A-scan were used. These values give a guide to the difference needed to determine if a change has taken place, although different models of the instruments are being used. One study showed, however, that for autorefractors the model used does not vary the results significantly (Winn et al, 1998).

	stdev (n=40 normal pre-presbyopic adults))	*95% confidence limit (sd x1.96)*
non-cycloplegic autorefraction	± 0.37D	± 0.73D
corneal curvature	± 0.48D	± 0.94D
axial length	± 0.18mm	± 0.35mm

Table 5.1.4 Confidence limits for autorefractor, autokeratometer and A-scan readings (Zadnik et al, 1992).

5.2 Visual Acuity Charts

5.2.1 High and Low Contrast Bailey Lovie charts (HCBL, LCBL)

The Bailey-Lovie distance visual acuity test chart has 5 approximately equally legible letters on each row and the separation of letters within rows and between rows is uniform to control for contour interaction. The between-letter spacing is equal to 1 letter width and the between row spacing is equal to the height of the letters in the smaller row. This ensures that as far as possible the only variable reading down the chart is the angular size of the letters. The progression of letter sizes follows a geometric progression whose ratio is equal to $\sqrt[10]{10}$. This allows for easy conversion of vision scores when test distances other than the standard 6m are used as is the case when low acuity is being measured (Bailey & Lovie, 1976). Both high (90%) and low (8%) contrast versions of this chart are used. The mean difference in score between the 2 charts has been measured as 0.26 log units (2.5 lines). This result was found across a range of uncorrected refractive errors (+4.00 to -7.00D) (Brown & Lovie-Kitchin, 1989). Figure 5.2.1 shows a high contrast Bailey-Lovie chart.

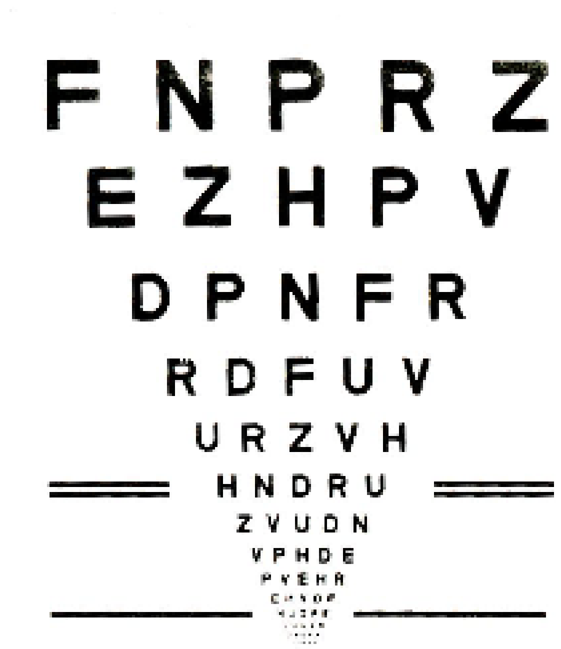


Figure 5.2.1 Bailey-Lovie chart.

5.2.2 Regan Repeat Letter (RRL) Chart

The repeat letter format of the RRL charts is designed to measure visual acuity independently of abnormal fixational eye movements due to the repeated nature of the central letter (Kothe & Regan, 1990). See figure 5.2.2 for an example of a card from the RRL chart. The central area of each 15cm x 15cm card is covered by an array of identical letters. These are surrounded by several rows of assorted letters one letter width apart, generating contour interaction without providing any clue to which letters form the central array. The chart task is to identify the letter in the central array. Four letters were presented at each acuity level. The letter sizes follow the same geometric progression as the Bailey-Lovie chart allowing for score conversion at different distances.

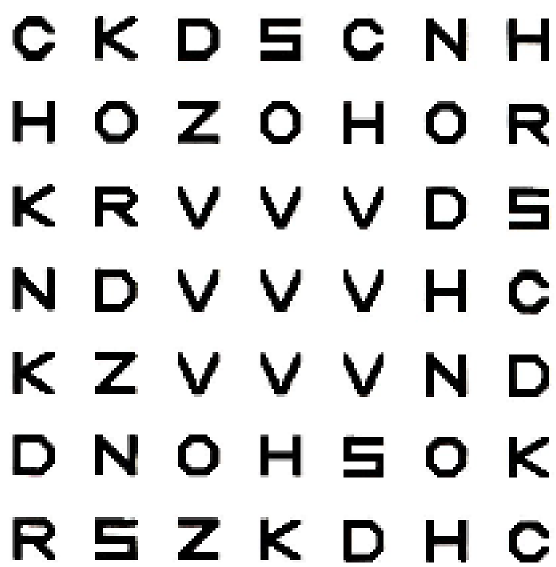


Figure 5.2.2 An example of a Regan Repeat Letter chart test card.

5.2.3 Crowded Logarithmic Acuity Test (CLAT)

This test was originally designed for children and as such all the letters used are symmetrical about the mid-line to avoid lateral confusion. There are 4 high contrast letters with surrounding contours on each card. The letters are selected from the set X V O H U and Y. The letter size progression of the CLAT follows the same pattern as that of the Bailey-Lovie chart i.e. letter size follows a geometric progression whose ratio is equal to $\sqrt[10]{10}$. Letter spacing is equal to 0.5 letter diameter for a contour interaction that is approximately 80% of maximum (McGraw & Winn, 1993). See figure 5.2.3 for an example of a test card.

Figure 5.2.3 An example of a Crowded Logarithmic Acuity Test card.

5.2.4 Single Letter Acuity Test with a Logarithmic Progression of Letter Size (SO)

This test employs the same six optotypes and size progression as the CLAT but 4 separate unflanked single letters are presented at each acuity level.

5.2.5 Pelli-Robson Chart (PR)

The Pelli-Robson chart consists of letters of the same size but of decreasing contrast. Letters of the same contrast are grouped in threes, with 2 groups in each line and a total of seven lines. The contrast decreases from 89% in the top left corner to 0.5% in the bottom right-hand corner of the chart in steps of 0.15 log units. Each letter correctedly identified is scored as 0.05 log units (Elliott et al, 1990).

5.3 Scoring Systems

The scoring method is based on the logarithm of the minimum angle of resolution (logMAR) originally designed for the Bailey-Lovie chart. For example, a 6/6 letter limb width subtends 1 min arc at a distance of 6m. As the log of 1 is 0, 6/6 is given the score of 0. Similarly since a 6/60 letter limb width subtends 10 min arc, the score is 1. The letters change by a constant amount (0.1 log unit) from one line to the next in the charts used so interpolation of acuity scores between lines on the chart is possible. The scoring system used throughout this thesis designates 6/6 a score of 1 and 6/60 a score of 0 (CLAT score) (McGraw & Winn, 1993). This allows for an increase in acuity to be reflected by an increase in score. Conversion from the conventional Bailey-Lovie LogMAR units to these units can be calculated using

CLAT score = 1 - logMAR(Bailey-Lovie). Eqn.1

logMAR score used in this thesis CLAT	Bailey-Lovie LogMAR	Snellen
0	1	6/60
0.2	0.8	6/38
0.4	0.6	6/24
0.6	0.4	6/15
0.8	0.2	6/9.5
1.0	0	6/6

Table 5.3 Comparison of CLAT and Bailey-Lovie logMAR scores with Snellen scores.

A change of 0.1 is one line of a chart. Five letters are presented at each acuity level on the Bailey-Lovie chart and four at each level on the other charts. Since a letter size change is measured by 0.1 log units each letter correctly identified is ascribed a score of 0.02 log units on the Bailey-Lovie charts and 0.025 log units on the other 3 high contrast charts.

5.4 Measuring Change Using Charts

When visual acuity or any other continuous variable is graded there exists a statistical probability that values will differ despite the fact that no real change has occurred. To decide, therefore, whether a real change has occurred confidence limits for the test need to be established. When a re-test value falls outside these limits then it can be said that a change has taken place. A summary of these designated changes is shown in table 5.5.

chart	95% confidence limit for change	No of letters this represents	source
High Contrast Bailey-Lovie	0.16	8	Lovie-Kitchin, 1988
Low contrast Bailey-Lovie	0.16	8	Lovie-Kitchin, 1988
Crowded logarithmic acuity chart	0.125	5	McGraw, 1995
single optotypes on a logarithmic scale	0.2	8	McGraw, 1995
Regan Repeat letter chart	0.16	6	Simmers, 1997
Pelli-Robson chart	0.2	4	Elliott, 1992

Table 5.4 Repeatibility measures for the charts used.

5.5 What Affects Chart Performance?

Three factors which affect chart performance in the absence of ocular disease or amblyopia are retinal blur, decision criteria and chart design.

5.5.1 *Retinal Blur*

Retinal blur caused by a refractive error will impair the ability to read letters on a chart. It has been shown that VA will decrease by one log unit with 2-2.5D of blur (Bradley et al, 1991). The severity of this impairment will be related to the degree of the refractive error although the relationship is not straight forward and knowing the refractive error does not neccessarily mean that chart performance can be accurately predicted. See figure 5.5.1 and results in chapter 6.

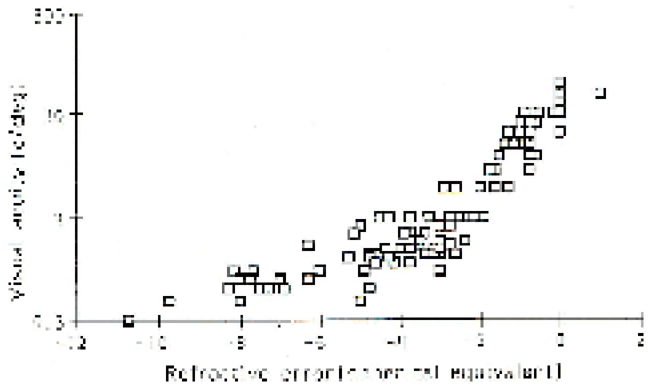


Figure 5.5.1 Visual acuity is plotted as a function of the spherical equivalent refractive error for 140 eyes without their appropriate refraction in place (Bradley et al, 1991). 30 c/deg, 3 c/deg and 0.3 c/deg are the equivalents of converted LogMAR scores 1.0 (6/6), 0 (6/60) and -1.0 (6/600).

5.5.2 Crowding Effect

The crowding effect is the name given to the phenomenon of single letter acuity generally being higher than that measured using letters surrounded by other letters on a chart. The crowding effect has been shown to include: 1) contour interaction (measured acuity depends on the proximity of the surrounding edges), 2) attentional factors and 3) fixational eye movements (Flom, 1991). The CLAT, RRL and the Bailey-Lovie chart are all designed to make crowding consistent for each letter size. The crowding ratio for high contrast letters is significantly higher than that for low contrast letters (Simmers, 1999).

5.5.3 Testing Distance and Illumination

There are variations in visual acuity with testing distance. These variations are, however, small and mostly associated with small testing distances (Heron et al, 1995). For the purposes of data analysis it is assumed that testing distance has no effect on chart acuity and so measurements taken at different testing distances can be compared. The distances that were used in this study were as follows:1m for PR, 3m for CLAT, SO and RRL, and 6m for B-L high and low contrast with the exception of the lower vision situations when it was necessary to reduce the test distance and the fully corrected situation in which 6m was used for CLAT, SO and RRL to reach threshold more easily.

The charts were evenly lit with a luminance of 80-90 cd/m2 which is within the photoopic range.

5.6 Procedures

5.6.1 Recruitment and Measurement

Twenty-one pre-presbyopic myopes (10 women and 11 men aged 19-45) were recruited into the study by means of posters displayed around the campus of Glasgow Caledonian University (see appendix 1 for a copy of the poster). The purpose of the study was explained and informed consent obtained. The refractive error range of the group was restricted to a spherical component of less than -7D and a cylindrical component of less than -1.5D.

For each participant the following measures were taken at the initial visit: A-scan ultrasonography, autokeratometry, autorefraction and cycloplegic autorefraction. Binocular and monocular corrected VA and unaided vision were also measured with all of the charts detailed above in a random order. Monocular measures were always taken before binocular and uncorrected vision before corrected VA.

All chart measurements were made in the GCU eye clinic in the same room. There was full knowledge of which group each participant was in during all testing (except the first visit in which testing took place before group allocation).

5.6.2 Group Allocation and Therapy Sessions

After the initial set of data collection the participants were assigned to one of three groups. The allocation was done (by someone who had never met the participants) with the aim of creating groups as evenly matched as possible for refractive error, age and sex. The participants in groups A and B were introduced to vision therapy techniques and provided with a reduced prescription while those in group C were not.

Group A had sessions with a trained Bates Method vision therapist, Aileen Whiteford. She trained with the Bates College of Vision Education and approaches all the vision work she does from a holistic perspective. The nature of her sessions with the participants were therefore very individual with activities and discussions based on each person's particular needs. These may have included some of the exercises as detailed in chapter 3. A typical session could include some time palming, some time with vision movement exercises and some time talking about the experiences and difficulties of working with blur and how to find time for vision work. Her sessions with the participants took place in the Eye Clinic at GCU and her fees and expenses were paid with a grant received from the Visual Research Trust. There follows the details of her contact with the participants. Sessions were usually held at between 2 week and 2 month intervals.

Participant No.	No. of sessions	Date of first	Date of last
1	6	28/4/98	18/3/99
2	7	8/5/98	29/4/99
7	10	15/5/98	29/4/99
11	12	8/5/98	17/6/99
17	6	8/6/98	10/9/99
22	10	1/10/98	7/6/99
24	10	1/10/98	6/5/99

Table 5.6 Details of the vision therapy sessions.

The participants in group B were given a handout (see appendix 2) detailing the ideas of vision therapy and the exercises of palming, sunning, shifting and swinging. They were also shown these techniques during one session with a post-graduate student, thereafter being left to practise on their own.

Those in group C remained in their full prescriptions and were given no instructions.

5.6.3 Details of the Reduced Prescriptions

Each participant in groups A and B was provided with a reduced prescription. This was done with the aim of reducing the prescription as much as possible and equalising the prescription between the two eyes.

Subject	Autorefractor Reading	Initial Prescription	Reduced Prescription
A1 R	-1.00/-0.50x27	-1.25DS	-1.00DS
A1 L	-1.00/-0.25x168	-1.50DS	-1.00DS
A2 R	none	-2.25/-0.25x82	-2.00DS
A2 L	none	-2.55/-0.20x110	-2.00DS
A7 R	-2.75/-1.00x7	-2.25DS	-1.50DS
A7 L	-1.00/-1.25x172	-1.50DS	-0.50DS (-1.50DS)
A11 R	-3.25/-0.25x150	-3.75/-0.25x80	-3.25DS
A11 L	-3.75/-0.25x78	-3.50/-0.25x100	-3.25DS
A22 R	-0.75/-1.50x7	-1.00/-1.00x165	-1.00/-0.25x165
A22 L	-2.50/-1.75x180	-3.25/-1.25x175	-2.00/-0.25x175
A24 R	-6.00/-2.00x12	-5.75/-1.25x5	-2.75/-1.25x5
A24 L	-5.25/-2.50x178	-5.25/-1.5x175	-3.00/-1.50x175
B8 R	-1.50/-0.25x30	-1.50/-0.25x65	-1.25DS
B8 L	-2.00/-0.50x15	-2.00/-0.25 x90	-1.25DS
B9 R	-3.25/-1.50x65	-2.75/-1.25x72	-1.00/-1.00x72
B9 L	-2.00/-0.75x150	-1.75/-0.75x140	-1.25/-0.50x140
B20 R	-5.25/-1.50x11	-4.75/-0.75x15	-3.75/-0.75x15
B20 L	-6.75/-1.25x177	-6.25/-0.50x150	-5.25/-0.50x150
B21 R	-0.50/-0.75x90	-0.75/-0.75x90	none
B21 L	-0.75/-0.75x8	-1.00/-0.25x25	none

Table 5.6.3 The autorefractor reading, the prescription of the spectacles the participant was wearing at the start of the study and the reduced prescription given. Participant A7 had her prescription adjusted to the value in brackets.

5.6.4 Repeat Data Collection

Ten to fifteen months after the initial data collection repeat measures were taken. 1 subject from group A, one from group B and 2 from C withdrew leaving a total of 17 (2 women and 4 men in group A, 2 women and 3 men in group B and 4 women and 2 men in group C). The uncorrected vision, autokeratometry and autorefraction measures were taken. Limited repeat a-scan measures were taken.

The VA measures were not repeated because the therapy groups were being encouraged to spend no time in their full prescription. The cycloplegic autorefraction measures were not repeated because there was no significant difference between the cycloplegic and non-cycloplegic autorefractions (see section 6.1.2).

5.6.5 Participant Interviews and Questionnaires

Each participant in group A was interviewed at the end of the project. These interviews were recorded and full transcripts are provided in appendix 3. The interviews were semi-structured with questions leading the participants to particular topics, however, they were left conversational is style to maintain as relaxed an approach as possible and to allow for the possibility of extra information not directly covered in the given topics. Questions outlining the themes covered in the interviews are shown below.

1. Did you experience a vision improvement through palming?
2. How much home practice of palming did you do?
3. How much do you wear your reduced prescription?
4. Did specific exercises improve your vision?
5. Did other people take an interest in what you were doing?
6. What was your overall impression of vision therapy?

At the start of the project and then again 6 to 12 months later questionnaires (see appendix 2) were given to the participants. The aim of these questionnaires was to monitor the levels of visual and physical comfort. The questions which were answered by marking on a sliding scale an answer between 2 possible extremes were:

1. In the last 7 days have you felt comfortable with your vision?
2. In the last 7 days have you felt frustrated with your vision?
3. Has this week been a typical week for you?
4. In the last 7 days have your eyes felt tingly?
5. In the last 7 days have your eyes been stinging?
6. How are you feeling today?
7. In the last 7 days have your eyes been watering?
8. Approximately how much time have you spent without your spectacles these past 7 days?
9. Approximately how much time have you spent palming these past 7 days?
10. Approximately how much time have you spent wearing your reduced prescription in the past 7 days?
11. Approximately how much time have you spent doing other vision activities in the last 7 days? e.g. going for a walk without spectacles, swinging, shifting.

5.7 Statistical Analysis

All the data was analysed using the StatView package. Linear regressions, t-tests and factorial ANOVAs were the tests applied where appropriate (see text in results chapters 6,7 and 8). The cut off for significance was chosen as 5%.