OCULOMOTOR RESPONSES IN EMMETROPIA AND MYOPIA

NICOLA RUTH EDWARDS

Doctor of Philosophy

THE UNIVERSITY OF ASTON IN BIRMINGHAM

September 1994

The University of Aston in Birmingham

OCULOMOTOR RESPONSES IN EMMETROPIA AND MYOPIA

NICOLA RUTH EDWARDS
Doctor of Philosophy
September 1994

SUMMARY

It has been proposed that early-onset myopia (EOM) i.e. myopia onset before the age of 15 is primarily inherited whereas late-onset myopia (LOM) i.e. myopia onset after the age of 16 is induced by environmental factors, principally sustained near vision. No consensus exists as to which aspect of the near vision response; accommodation, vergence or their synergistic cross links promotes LOM development. Furthermore, the mechanism by which near vision could induce elongation of posterior chamber is obscure although there is evidence to show that ciliary muscle tone plays an important role. By comparing accommodation and vergence responses of emmetropes (EMMs), EOMs and LOMs under both open- and closed-loop conditions, this thesis aims to define further the oculomotor correlates of myopic development.

A Canon Autoref R-1 optometer was used to measure accommodation responses while a an Apple IIe controlled the flashed Maddox Rod sequence used when measuring vergence. Both techniques permitted open- and closed-loop measures to be obtained.

No significant differences were found between the refractive groups for accommodative convergence / accommodation and convergence accommodation / convergence ratios, accommodative response gradients, tonic vergence disparity and heterophoria. Further, the ability to adapt to and recover from induced base-out and base-in prism at 5 m and 45 cm was investigated. Although EOMs consistently displayed the fastest time-constants for both adaptation and recovery, the differences between the responses of EMMs, EOMs and LOMs were not significant.

Steady-state open-loop accommodation (SOLA), a putative indicator of the inherent tone in the ciliary muscle was measured under darkroom and pinhole conditions. Both with and without the imposition of concurrent mental effort the mean SOLA levels of EMMs ($N = 43$) were highest followed by EOMs ($N = 31$) and LOMs ($N = 30$) respectively although differences were only significant between the EMMs and the LOMs.

The influence of proximity on accommodative regression patterns following sustained visual tasks was determined for each refractive group. Proximity did not influence the patterns although LOMs and EOMs took longer to regress to pre-task SOLA levels than EMMs. To determine whether the time taken to regress is linked to variations in the innervational characteristics of the ciliary muscle, topical β-adrenoceptor antagonists were employed. Individuals representing each of the refractive groups showed accommodative shifts following timolol instillation thus the proposal that a deficit in sympathetic inhibition acts as a precursor to the development of LOM was not supported.

The results presented demonstrate that it is unlikely that those individuals susceptible to LOM can be distinguished with regard to oculomotor responses or innervational characteristics of the ciliary muscle. The aetiology of LOM may be associated with ciliary muscle function but account needs to be taken of interactions between the ciliary muscle, choriod, sclera and intraocular pressure and further research is necessary before those EMMs susceptible to LOM can be identified.

Key words: accommodation, vergence, oculomotor cross-links, near vision, myopia.

To Mum, Dad and my husband Julian,
thank you for making this possible.

In the last resort nothing is ridiculous except the fear of being so. (Henri Fauconnier)

ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor Dr. Bernard Gilmartin for all the guidance and advice he has given to me. He has always made himself available for discussion despite his many other commitments and I consider myself very privileged for having had the opportunity of working with him. In addition I would also like to thank Professor Barry Winn for his help and guidance during the first year of my Ph.D. course and for securing the initial funding allowing me to undertake this work; grateful thanks goes to the British College of Optometrists for providing the funding.

Thanks are also due to my parents who have sacrificed a great deal in order to give me a good education which has enabled me to get this far. I would also like to thank Richard Warrillow without whose encouragement I would not have undertaken my first degree course. In addition, I owe a great deal to my husband Julian for his unending support, encouragement and patience especially during the latter stages.

I am indebted to the staff and students of Aston University, fellow post-graduates and my sister Julia for sacrificing many hours of their time to act as subjects without whom none of this would have been possible. I would also like to thank Dave Sculfor for his contribution during the initial procedures for measuring vergence; Barry Brooks for the photographic work, Johnson and Johnson for the supply of *Acuvue* disposable contact lenses, Merk, Sharp and Dohme for supplying timolol maleate and Alcon Laboratories for supplying Betaxolol HCl.

CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

GENERAL INTRODUCTION

Many workers have proposed a link between sustained periods of near vision and the development of myopia although there is also considerable evidence supporting a genetic basis to myopia. Consequently, it has been suggested that early-onset myopia (EOM) i.e. myopia onset before the age of 15 is primarily inherited whereas late-onset myopia (LOM) i.e. myopia onset after the age of 16 is induced by environmental factors, principally sustained near vision. At present no consensus exists as to which aspect of the major factors of the near vision response; accommodation, vergence or their synergistic cross-links promotes the development of LOM. The aim of this thesis is to define further the oculomotor correlates of myopic development.

The accommodative mechanism, together with the vergence mechanism produce the major oculomotor responses of the visual system. Under normal conditions accommodation and vergence are linked synergistically via the oculomotor cross-links, i.e. accommodative convergence and convergent accommodation. The function of the oculomotor system is to maintain clear, single vision at all times. Under normal closed-loop viewing conditions accommodation and vergence interact, together with pupil miosis producing a triad of near vision responses. Thus when an object is viewed, the eyes accommodate to bring the image into focus, converge to eliminate retinal disparity and the pupil constricts for reasons which are not entirely clear at this stage.

The role of accommodation is to maximise the contrast and quality of the foveal image which it achieves under normal conditions via a negative feedback loop. The ciliary muscle, a major component of the accommodative mechanism is primarily innervated by parasympathetic innervation although it also receives supplementary sympathetic innervation. The role of sympathetic innervation is not yet fully understood but it has been proposed that its presence is more relevant to sustained near vision tasks than those requiring rapid changes in accommodative level.

The accommodative response comprises four main components (Heath, 1956b); tonic accommodation, reflex or blur-induced accommodation, proximally-induced accommodation and convergent accommodation. Tonic accommodation represents the intermediate resting position of accommodation which it adopts under 'stimulus free' conditions. However, it is impossible to obtain such conditions in the laboratory, thus workers try to assess tonic accommodation by measuring accommodation under various open-loop conditions (steady-state open-loop accommodation, SOLA). Reflex accommodation is stimulated by negative feedback in the form of target blur, it maintains the maximum contrast of the retinal image by maintaining the aggregate accommodative

response. Proximally-induced accommodation is stimulated by the knowledge of the apparent distance of an object from the observer and convergent accommodation represents the cross-link between the accommodation and vergence mechanisms and it is stimulated by retinal disparity. Furthermore, convergent accommodation can only be measured when the accommodative system is open-loop. The accommodative system consists of both a fast, reflex component (reflex or blur-induced accommodation) and a slow, adaptive component which manifests itself as the delayed return of accommodation following a sustained visual task to the pre-task SOLA level (accommodative regression). A detailed account of the accommodative mechanism appears in Chapter 1.

The role of the vergence system is to eliminate retinal disparity and in the same way as accommodation, it achieves this under normal conditions via a negative feedback loop. Vergence eye movements are those in which the eyes move in opposite directions (disjunctive eye movements) and they can be classified into tonic vergence, fusional vergence, proximal vergence and accommodative convergence. In the same way as tonic accommodation represents the intermediate resting position of accommodation, tonic vergence represents the intermediate resting position of the vergence mechanism. In addition, fusional vergence can be compared to reflex accommodation as it is stimulated by negative feedback in the form of retinal disparity and it maintains the aggregate vergence response. The vergence mechanism, like the accommodative mechanism is stimulated by the apparent nearness of an object, this type of vergence is known as proximal vergence. In addition, as the cross-links between accommodation and vergence are synergistic, accommodation can induce vergence via the cross-link accommodative convergence. The vergence mechanism, like the accommodative mechanism has fast, reflex phases (fusional vergence) and slow, adaptive phase. The slow, adaptive component of vergence manifests itself as the ability of the oculomotor system to tolerate poorly centred spectacles and the apparent adaptation to induced retinal disparity (vergence or prism adaptation). A detailed account of the vergence mechanism appears in Chapter 2 and Chapter 3 describes the relationship between accommodation and convergence.

Oculomotor function with respect to the development of refractive error and in particular, LOM is explored in this thesis. Chapter 4 provides a brief review of the role of the near vision response in the development of myopia. In addition, other proposed theories of refractive development are reviewed. A discussion of the classification of myopia with emphases on the age of myopic onset and the differential effects of genetic and environmental aspects on various forms of myopia also appears in Chapter 4. Evidence from studies distinguishing the oculomotor profiles of emmetropes and myopes is included to support the proposals that near work plays a role in the aetiology of myopia

and that myopia can be divided into groups distinguished by the differential effect of environmental and genetic factors.

It is well documented and confirmed in this thesis that the principal physical correlate of both EOM and LOM is elongation of the posterior chamber. The mechanism by which near vision could induce axial elongation of the posterior chamber is obscure although there is evidence to suggest that ciliary muscle tone plays an important role. By comparing the accommodation and vergence responses of emmetropes (EMMs), EOMs and LOMs under both open- and closed-loop conditions, this thesis aims to define further the oculomotor correlates of myopic development. The aim prompted various research issues which are addressed by a series of research questions;

i) Are anomalous oculomotor responses responsible for the development of LOM?
ii) Is the ability of the vergence mechanism to adapt to induced retinal disparity correlated with refractive group?
iii) Is the ability of the vergence mechanism to recover from induced retinal disparity correlated with refractive group?
iv) How does the accommodative system respond to vergence adaptation?
v) Does a relationship exist between steady-state open-loop accommodation (SOLA) and refractive group?
vi) What is the relationship between SOLA measured under various open-loop conditions?
vii) What is the effect of mental effort on the SOLA levels of EMMs, EOMs and LOMs?
viii) What is the effect of proximity on the closed-loop accommodation responses of EMMs, EOMs and LOMs?
ix) What is the effect of proximity on the accommodative regression patterns of EMMs, EOMs and LOMs?
x) How are SOLA levels of EMMs, EOMs and LOMs affected by β-adrenergic receptor antagonists?
xi) Is the retardation of accommodative regression in myopes induced by a deficit in sympathetic inhibition of the ciliary muscle?

All of these issues are addressed in the experimental programme of this thesis (Chapters 6 to 10) which explores extensively the oculomotor responses of emmetropes and myopes. Chapter 5 describes the methodology and methods of statistical analysis used in answering these questions. The conclusions that can be drawn from the results of the research programme together with proposals for future work appear in the final Chapter, Chapter 11.

The results presented in this thesis demonstrate that it is unlikely that those individuals susceptible to LOM can be distinguished with regard to oculomotor responses or innervational characteristics of the ciliary muscle. The aetiology of LOM may be associated with ciliary muscle function but account needs to be taken of interactions between the ciliary muscle, choroid, sclera and intraocular pressure and further research is necessary before those emmetropes susceptible to LOM can be identified.

CHAPTER 1

THE ACCOMMODATIVE MECHANISM

1.1 - INTRODUCTION

The accommodative mechanism, together with the vergence mechanism produce the major oculomotor responses of the visual system. Under normal conditions accommodation and vergence are linked synergistically via the oculomotor cross-links that is accommodative convergence and convergent accommodation. The role of the accommodative mechanism is to maximise the contrast and quality of the foveal image. It achieves this by providing a variable refractive power which acts as a supplement to the majority of the eye's refractive power which is provided by the cornea. This Chapter reviews the anatomy, physiology and other aspects of the accommodative mechanism relevant to this thesis.

1.2 - ANATOMY OF THE ACCOMMODATIVE MECHANISM

1.2A - The ciliary muscle

In transverse section the ciliary muscle is triangular in shape and has its origin at the corneal-scleral spur. From here fibres proceed to their insertion onto the span fibrils of the zonule of Zinn at Brüch's membrane. Although once thought to consist of three fibre types, the ciliary muscle is a unified muscle with the fibres crossing each other at various angles creating an intertwining meshwork as opposed to discrete fibre bundles (Alpern, 1969a; Hogan et al. 1971).

Human smooth muscle is usually involuntary in nature but the ciliary smooth muscle is unique, the major difference being the ability to exert voluntary control over it (Warwick, 1956). Other physiological features which are not consistent with smooth muscle elsewhere in the body have also been identified; the post ganglionic parasympathetic fibres are both mylinated and enlarged (Ruskell and Griffiths, 1979) which aid the speed of nerve impulse conduction (Bowman and Rand, 1980) and are consistent with the ability to exert voluntary control over it.

1.2B - The zonule of Zinn

The role of the zonule of Zinn is to suspend the crystalline lens in position between the iris and vitreous body and transmit the force produced by contraction of the ciliary muscle to the lens capsule. The zonule consists of a series of fibres having a gel-like structure

(Hogan et al., 1971). These fibres, similar in composition to the vitreous except with a more defined organisation, were once thought to be inelastic (Wolff, 1976). Recent work suggests they possess elastic-like properties, though not to the same degree as true elastic fibres (Streeten and Licari, 1983). Rohen and Rehntsch (1969) proposed the existence of two different groups of zonular fibres;

Main fibres which run from pars plana in the ora serrata region of the ciliary body and become continuous with the lens capsule. The axial portion of the zonule inserts onto the capsule both anteriorly and posteriorly after splitting at the zonular fork whereas the peripheral portion spans the distance between the axial portion and the anchor fibrils. The anchor fibrils pass through the epithelial layer and interact with the matrix of Brüch's membrane and connect the main fibres of the zonule to the ciliary body (see Figure 1.2).

Span fibrils which branch off from the main fibres at the junction of the peripheral and axial regions and pass through the epithelium to insert into the matrix of Brüch's membrane where they form the insertion of the ciliary muscle fibres (Stark, 1987).

1.2C - The crystalline lens

The crystalline lens is a transparent bi-convex elastic body situated behind the iris and held in place by the zonules and supported by the vitreous body (Coleman, 1970). It provides a variable refractive power known as accommodation which acts as a supplement to the majority of the eye's refractive power which is provided by the cornea (~43 D, Bennett and Rabbetts, 1984). The amplitude of accommodation decreases linearly with age from about 13 D at the age of 16 to 2 D at the age of 50 (Ramsdale and Charman, 1989). The structural and elastic characteristics of the lens can be divided into three components:

The capsule is a transparent collagen-containing basement membrane which acts as an envelope to the lens substance. It has a Young's Modulus of Elasticity about 2,000 times greater than the underlying lens substance (Fisher 1969a). Fincham (1937) found that the capsule varies in thickness; the thickest areas being the equatorial regions of the anterior and posterior surfaces, the thinnest being the posterior pole but Fisher and Pettet (1973) showed that the lens capsule does not have the thickness observed by Fincham until advancing age.

The epithelium is a single layer of cuboidal cells which extend under the anterior portion of the capsule. As the epithelial cells continuously progress towards the equator, they become more columnar in shape and eventually become lens fibres. The constant process of mitosis and migration of these cells throughout life increases the number of lens fibres present.

The lens substance consists of many layers of lens fibres connected by interlocking knobs and depressions. The oldest fibres are situated in the nucleus of the lens, with new fibres being added continuously to the cortex giving the lens its layered texture (Wolff, 1976; Weale, 1979; Cotlier, 1987) which helps to reduce aberrations such as spherical aberration (Charman, 1983).

Figure 1.1: Section through the crystalline lens and capsule. The variation in thickness of the capsule at different points can be seen (from Pipe and Rapley, 1984).

The equatorial diameter of the adult lens is between 9-10 mm. The anterior surface is elliptical in form (Fisher, 1969b) and less convex than the posterior surface (Wolff, 1976). The crystalline lens has an unhomogeneous refractive index of 1.41 at the nucleus dropping to 1.38 in the outer cortical layers (Nakoa et al. 1969). Recent work has suggested that the mean refractive index of the lens undergoes changes during childhood, dropping from 1.442 in 7 year olds to 1.436 in 12 year olds (Mutti et al., 1991). In addition, the refractive index of the nucleus tends to increase in middle to later life due to dehydration and sclerosis (Fincham, 1937). The continued growth of the lens throughout life causes the axial thickness of the lens and its volume to increase (Cotlier, 1987). However recent work suggests that the lens actually thins during childhood by 0.11 mm between the ages of 7 and 12 years, suggesting a slow growth rate in the early years (Zadnik et al., 1991).

1.3 - PHYSIOLOGY OF ACCOMMODATION

The mechanism resulting in the change in refractive power of the eye namely accommodation, has been the source of much controversy over the years with several aspects still remaining in dispute today. Our current understanding of the accommodative mechanism is based mainly on the theory proposed by Helmholtz in 1855. Although Helmholtz's theory does not constitute fully our present day understanding of the mechanism, it is in essence correct..

The role of the ciliary muscle and zonular fibres in accommodation

When the ciliary muscle contracts it pulls on the span fibrils (SF) of the zonule which in turn exerts tension on the peripheral portion of the zonule. When the peripheral portion of the zonule is under tension, the axial portion is relaxed and the lens and capsule adopt a more bulbous profile. When the ciliary muscle relaxes, the peripheral zonule (PZ) shortens under its own elasticity and pulls on the ciliary muscle fibres causing them to lengthen, hence the peripheral zonule acts as the elastic antagonist to the ciliary muscle. Meanwhile the axial portion of the zonule (AZ) is under tension which causes flattening of the lens and capsule but the span fibrils are relaxed (Stark, 1987). Figure 1.2 shows the action of the zonules and ciliary muscle during accommodation.

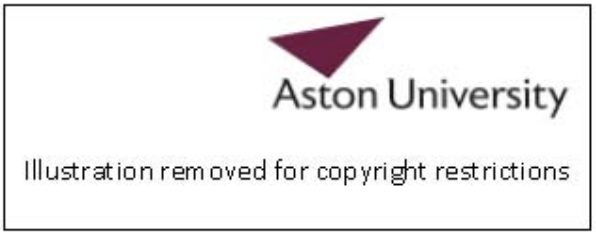

Figure 1.2: The role of the zonules during a) the accommodated state and b) the relaxed state of the crystalline lens (redrawn from Rohen and Rentsch, 1969).

Role of the lens capsule in accommodation

Fincham (1937) was the first to demonstrate that the lens capsule plays an active role in bringing about the change in the power of the crystalline lens. Using an individual who's lens substance had dissolved as a result of an accident leaving the lens capsule intact, he demonstrated that when the subject viewed a distant object the surfaces of the capsule lay parallel and within close proximity to one another; conversely when the subject viewed a near object the central portion of the anterior surface bulged forward while the posterior surface became slack. Fisher (1969a) supports the view that the energy required to change the shape of the lens is stored in the lens capsule although he did acknowledge

that the lens substance has some elasticity of its own. Koretz and Handleman (1982; 1983) by deriving mathematical expressions for the stress and strains exerted on the anterior lens surface during accommodation, conclude that forces transmitted through the zonular fibres act on the capsule at the site of zonular attachment. The capsule then evenly distributes these forces across the whole lens surface which results in a reorganization of the underlying lens fibres. Koretz and Handleman argue that the lens material is not *moulded* by the capsule but it is the nature of the fibre organization within the lens that converts the applies stress to the observed shape changes.

Shape of the lens during accommodation

The shape of the lens during accommodation has been the source of much debate; Helmholtz (1909) utilized Purkinje images to observe an increase in lens thickness of about 0.5 mm during accommodation. He found this was attributable to the forward movement of the anterior surface and to a much lesser degree, the backward movement of the posterior surface. Moreover, Helmholtz postulated that owing to the unchanged volume of the lens, the equatorial diameter must reduce during accommodation. Fincham (1937) confirmed Helmholtz's findings and by observing *in vivo* the lens of an aniridic human, supported the proposal that the equatorial diameter decreases during accommodation, finding this decrease to be about 1 mm. Fincham went on to demonstrate, using slitlamp photographic techniques, that the anterior surface of the lens takes on a conoidal shape during accommodation an observation also reported by Brown (1973). However, subsequent calculations by Fisher (1969b) have shown that the lens capsule is not capable of providing the force necessary to produce the conoidally shaped anterior surface.

Helmholtz (1909) postulated that the difference in induced convexity of the two lens surfaces is due to variations in the position of zonular fibre attachments which results in less tension on the anterior surface thus permitting greater forward bulging. Conversely, Fincham (1937) suggested that the differences arose from variations in the thickness of the capsule resulting in maximum force being exerted at the capsule's thickest part, the equator. This would cause a decrease in the equatorial diameter of the lens and hence forward bulging of the anterior surface where the capsule is thinner. Coleman (1970) points out that the capsule is actually thinnest at the posterior pole thus inferring that it cannot be the lens capsule alone which determines the shape of the lens. Brown (1973) argued that the conoidal profile he observed was due to the difference in the moulding abilities of the nucleus and the cortex. Fisher (1982) offers substantial evidence that the elasticity of the lens substance accounts for the form of the lens during accommodation. Furthermore, Koretz et al., (1984), suggest that, although the capsule acts as a force distributor, it is the lens fibres themselves which, by altering the position of their cytoplasm, account for the change in lens shape during accommodation.

Much controversy surrounds the mechanism by which the lens changes its shape but it is now generally accepted that the capsule has elastic properties whereas the lens substance is plastic in nature. It is a combination of these two factors, not the elasticity of the capsule alone which determines the shape of the lens in accommodation.

Figure 1.3: Sagital section of the eye showing the important accommodature structures in the anterior third of the eye (from Stark, 1987).

The role of the vitreous in accommodation

At present no consensus of the role of the vitreous in accommodation exists. Coleman (1970) reasons that if the vitreous had no role to play in accommodation then the variation in capsular thickness would allow the posterior surface of the lens to become more convex than the anterior surface. Using ultrasonography to measure the movement of the lens during accommodation, he observed that the posterior lens surface moved backwards by 0.2 mm when a subject accommodated in the primary position; in the position of upward gaze no such movement was detected. He proposed that the anterior movement of the ora serrata during accommodation (Moses, 1987) causes the vitreous to move forward and press on the posterior lens surface thus altering its shape and providing it with support.

Fisher (1982) using *in vitro* methods of experimentation reported that the relatively large movement of the anterior lens surface compared with the posterior surface of the lens are due to its elastic properties and not to changes in vitreous pressure. Fisher (1983) was later able to confirm his *in vitro* findings by observing a young man who had undergone total vitrectomy in one eye. With no vitreous at all, the *in vivo* lens accommodated as well as that in the normal eye but was less stable in position, suggesting to Fisher that the role of the vitreous was merely to provide a stabilizing force for the lens. Koretz and Handleman (1982) place more emphasis on the vitreous during accommodation than

Fisher suggesting that the vitreous body provides an *essential* support function during the accommodative process.

1.4 - NEUROLOGY OF ACCOMMODATION

The ciliary muscle, the contraction of which brings about the process of accommodation, is controlled by the autonomic division of the nervous system. It is well established that the ciliary muscle receives parasympathetic innervation, whereas the existence of sympathetic innervation to the ciliary muscle is less well documented. However it is now generally accepted that the ciliary muscle does receive dual innervation although the exact role of sympathetic innervation in accommodative function is still unresolved but will be discussed later in this Chapter. A comprehensive review of the role of sympathetic innervation of the ciliary muscle in ocular accommodation is given by Gilmartin (1986).

1.4A - Parasympathetic innervation of the ciliary muscle

It is well established that each ciliary muscle fibre receives an excitatory neural input from parasympathetic oculomotor nerve endings which synapse with acytylcholine receptors. Whether the parasympathetic fibres which supply the ciliary muscle synapse in the ciliary ganglion or not is open to debate. Early studies support the view that the fibres do synapse in the ganglion (Behr, 1924; Kuntz, 1929). However a study on monkeys by Westheimer and Blair (1973) provided electrophysiological evidence that the oculomotor fibres serving the ciliary muscle pass through the ciliary ganglion without synapsing (Figure 1.4b). A recent study (Ruskell and Griffiths, 1979) suggests that in humans, synapsing of the fibres supplying the ciliary muscle does indeed occur in the ciliary ganglion, agreeing with the conventional parasympathetic pathway (Figure 1.4a).

Figure 1.4: Diagram showing a) the conventional and b) the revised pathway of the parasympathetic division of the oculomotor (III) nerve. The conventional pathway shows a synapse in the ciliary ganglion for the nerve paths to the ciliary muscle (CM) and the iris sphincter pupillae muscle (IS). The revised version shows only a synapse in the iris pathway and not in the ciliary pathway. Key: SCN - Short ciliary nerves, IO - inferior oblique muscle, MR - medial rectus muscle, IR - inferior rectus muscle, SR - superior rectus muscle, LP - levator palpebrae muscle, EW - Edinger-Westphal nucleus (from Ruskell and Griffiths, 1979).

1.4B - Sympathetic innervation of the ciliary muscle

The possibility of dual innervation of the ciliary muscle had been realized as early as 1854 by Von Graefe (cited by Linksz, 1958) who, although offering no evidence for its existence, suggested that it was likely to be present simply because all other smooth muscle in the human body is under control of both the parasympathetic and sympathetic branches of the autonomic nervous system. Although separate innervations had not been identified at this time, Henke (1860) took the idea of dual innervation one step further and proposed that the circular fibres of the ciliary muscle were used in near accommodation whereas the longitudinal fibres helped relax the eye for distance accommodation. Donders (1864) rejected the idea of dual innervation on the grounds that there was no need for it and Helmholtz (1855) objected to the idea stating that the muscle fibres were too intertwined to allow such duality.

Evidence supporting sympathetic innervation of the ciliary muscle

In 1886 Jessop provided the first pharmacological evidence of sympathetic innervation of the ciliary muscle in humans using cocaine to demonstrate ciliary muscle relaxation. A few years later, Morat and Doyon (1891) observed a flattening of the crystalline lens upon stimulation of the cervical sympathetic nerve in dogs. However, due to the crude techniques available to assess changes in Purkinje images, such results could not be confirmed at that time and it was denied by others that the sympathetic nervous system had any control over accommodation. The findings of Morat and Doyon were confirmed many years later by other researchers such as Cogan (1937) and Olmstead (1944). Cogan (1937) conducted experiments on 5 humans in whom a portion of the sympathetic chain had been surgically removed, producing partial Horner's syndrome. He noted an increase in the amplitude of accommodation on the ipsilateral side to the lesion, whereas stimulation of the sympathetic system by local instillation of sympathomimetic drugs produced a decrease in the amplitude of accommodation. Following Cogan's work, Morgan et al. (1940) made extensive observations concerning the effect of stimulating the cervical sympathetic ganglion in rabbits, cats and dogs and found an increase in hyperopia irrespective of whether the eye was atropinized, oculomotor nerve completely severed or extraocular muscles removed from the globe. It was thus generally accepted by the 1940s that the ciliary muscle is dually innervated.

Temporal nature of the sympathetic response

Törnqvist (1967) found the accommodative response to parasympathetic stimulation reached maximum effect after 1-2 seconds which is in good agreement with the work of Campbell and Westheimer (1960) who found that in humans, after an initial latency of 370 ms, the accommodative response stabilizes in about 1 s. In contrast, Törnqvist (1967) found that sympathetic inhibition takes between 20 and 40 s to stabilize and also vanishes more slowly than parasympathetic excitation. He observed that the magnitude

of the sympathetic effect, although only about 1.50 D at its maximum, is augmented by the level of background parasympathetic activity. Support for the findings of Törnqvist was given by Hurwitz et al. (1972a; 1972b) who electrically stimulated the oculomotor nerve of monkeys whilst simultaneously administering adrenergic antagonist and agonist drugs to investigate the change in ciliary muscle activity. They found that inhibitory effects were only significant when the background parasympathetic activity produced at least 4 D accommodation. Törnqvist (1967) questioned the significance of sympathetic inhibition in the accommodative response due to its small magnitude and long time-course. Gilmartin and Hogan (1985) speculate that the role of sympathetic innervation is more relevant to those tasks requiring sustained near vision rather than those requiring rapid changes of accommodation. Evidence for this being the case is mounting and will be discussed later.

The action of sympathetic innervation on the ciliary muscle

Two theories as to how the action of sympathetic innervation on the ciliary muscle brings about flattening of the crystalline lens have been proposed. Fleming (1957) and Morgan (1944a) subscribed to the idea that stimulation of α-receptors within the ciliary muscle causes vasoconstriction which leads to shrinkage of the ciliary muscle thus increasing the tension in the zonular fibres which in turn flattens the lens. Other workers dispute this indirect action, preferring instead to consider direct muscular action. Melton et al. (1955) using an enucleated eye, showed that lens flattening is bought about by the ciliary muscle itself. Direct muscular action is supported by Törnqvist (1966) who demonstrate that sympathetic innervation is mediated via the β as opposed to α-receptors.

1.4C - The adrenergic receptors of the ciliary muscle

Evaluation of the distribution of the adrenergic receptors in ciliary smooth muscle was initially conducted on animals. Van Alphen et al. (1965) discovered that the ciliary muscle of rabbits has predominantly α-receptors whereas cats have roughly equal numbers of both α- and β-receptors and monkey ciliary muscle exhibits only β-receptors. Ruskell (1973) observed that in monkeys, nerve terminals containing vesicles of the type known to be sympathetic only contributed 1% on average to the total number of terminal variscosities present and are therefore too few to provide a significant role in the control of accommodation. The adrenoceptors of human ocular muscle were first analysed by Kern in 1970. The receptors in the dilator pupillae were found to be mainly of the α-type whereas a combination of α and β were present in the sphincter pupillae. The ciliary muscle comprised of β-receptors which were found to be inhibitory in nature (Kern, 1970). These findings were later confirmed by Van Alphen (1976).

Following the development of a technique capable of determining the proportions of receptors belonging to the α and β subgroups in ocular muscle, Wax and Molinoff

(1987) discovered by using the β_1-selective antagonist ICI 89,406 that only 10% of the beta receptors present in the iris and ciliary body were of the β_1 subtype. Zetterström and Hahnenberger (1988), in addition to supporting this finding, reported the presence of α_1 receptors in human ciliary muscle. Other workers (Logrando and Reibaldi, 1986; Nathanson, 1980; 1981) failed to observe ciliary muscle contraction when treated with phenylepherine, a known α agonist, following the use of the β-blocking drug propranolol. As a result they denied the existence of any α_1 receptors and maintain that the ciliary muscle only comprises of β-adrenoceptors. It should be noted that presence of a particular type of receptor does not guarantee the presence of nerves to stimulate that receptor; for example, despite the presence of β-receptors in vascular smooth muscle, stimulation of the adrenergic nerves only produces vasoconstriction and never vasodilation.

The use of different pharmacological agents has enabled workers to determine the actions of the various adrenoceptors on the eye. The predominantly α-agonist drug phenylepherine produces pupil dilation and decreased amplitude of accommodation due to vasoconstriction of the ciliary body (Rosenfield et al., 1990). In addition, the α_1-receptors of Müller's muscle in the upper lid and those of the superficial conjunctival vessels produce widening of the palpebral aperture and conjunctival blanching respectively. A non-selective β-agonist drug such as isoprenaline will cause a slight decrease in accommodation due to direct action on the ciliary muscle but effect on pupil size is minimal (Gilmartin et al., 1984). Thymoxamine, an α-receptor antagonist produces pupil miosis and an increase in the amplitude of accommodation (Zetterström, 1988; Rosenfield et al., 1990).

The effect of β-blocking agents such as timolol maleate on the accommodation response is more difficult to quantify as the background parasympathetic activity has to be of a sufficient magnitude to augment sympathetic innervation. Studies using laser optometers to assess steady-state open-loop accommodation have shown that timolol increases the accommodative level (Gilmartin et al., 1984), whereas those using objective infrared (IR) optometers (Gilmartin and Bullimore, 1987) have failed to demonstrate these myopic shifts due to the lower baseline levels of steady-state open-loop accommodation usually obtained with IR optometers; the reasons for this will be discussed in section 1.7C. Furthermore an attempt is made in Chapter 10 to increase steady-state open-loop accommodation levels so that the effect of β-blocking agents on accommodative function can be monitored.

Timolol maleate is a non selective β-blocking drug which, in addition to acting on the ciliary muscle of the eye, produces a drop in intraocular pressure (IOP) principally due to the inhibition of aqueous formation at the ciliary processes (Zimmerman et al., 1977;

Coakes and Brubaker, 1978). The selective β_1 blocking agent betaxolol HCl. also produces a reduction in IOP but the vast majority of the β-receptors in the ciliary muscle which are of the β_2 type (Wax and Mollinoff, 1987) remain unaffected by this drug at normal concentrations. Consequently, some researchers use it as a control for timolol (see Chapter 10) although it may be that betaxolol induces β_2 effects at high concentrations.

In conclusion, the nature of sympathetic innervation to the ciliary muscle can be summarized as follows (Gilmartin,1986):
i) Sympathetic input is inhibitory and mediated predominantly via the β_2 subgroup of the adrenoceptors.
ii) It appears to be augmented by the level of background parasympathetic activity to a maximum magnitude of ~1.50 D.
iii) It displays a relatively slow time-course, taking between 10 and 40 s to reach its maximum magnitude compared with 1 to 2 s for parasympathetic activity.

1.5 - THE STIMULUS TO ACCOMMODATION

The aggregate accommodative response comprises four main components (Heath, 1956b) i.e. tonic accommodation, reflex or blur-induced accommodation, proximally-induced accommodation and convergent accommodation. These components may be considered analogous to the components of vergence proposed by Maddox (1893 - see section 2.4A). The accommodative response to stimuli in normal visual environments is derived from a complex and subtle integration from both optical and non-optical sources (Fincham, 1951; Campbell and Westheimer, 1959; Toates, 1972). Optical factors instigate a change in accommodation as a consequence of alteration in retinal image composition primarily by stimulating blur-induced accommodation. Non-optical factors such as proximity and mental effort can influence the accommodation response in a way which is independent of the quality of the retinal image.

1.5A - Optical Factors

i) Defocus blur

Defocus blur is generally considered to be the primary stimulus to accommodation (Kruger and Pola, 1986) and has been used in many experiments to stimulate accommodation. Defocus blur alone is not an ideal accommodative stimulus due to its even-error nature which renders identically blurred retinal images irrespective of the direction, towards or away from the eye, in which the object has moved. As a result, to initiate the correct accommodative response without further cues is a case of trial-and-error (Fincham, 1951) and many investigators (Stark and Takahasi, 1965; Troelstra et

al., 1964) have demonstrated erroneous accommodative responses for 50% of trials under such special conditions. Furthermore researchers have found that the accommodative mechanism usually fails to respond to blur produced by lenses over about -1.25 D (Ogle, 1966; Fincham and Walton, 1957).

ii) Spherical aberration

Spherical aberration of a refracting surface is exhibited when light rays become excessively deviated as the point of incidence gets further from the optical axis (Figure 1.5). The eye can be considered as a wide aperture optical system and although none of its refracting surfaces are truely spherical the effect of a wide pencil of light incident on the eye when no astigmatism is present is similar to that caused by true spherical aberration (Jenkins 1963a). Unlike chromatic aberration, ocular spherical aberration varies considerably from person to person (Jenkins 1963b). While increasing accommodation reduces the amount of uncorrected spherical aberration, pupil dilation increases it.

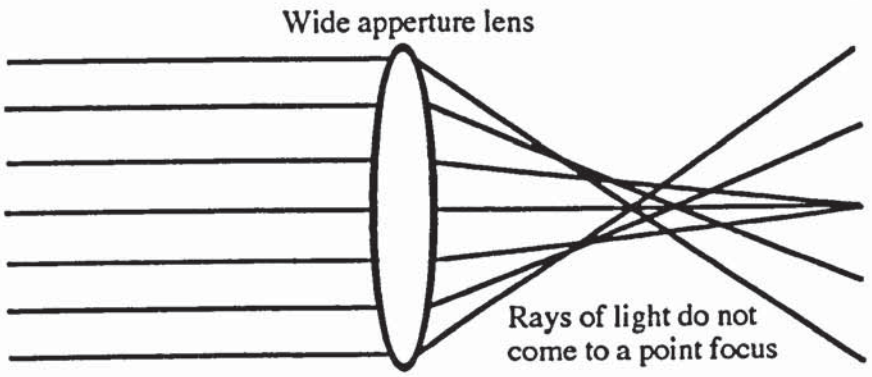

Figure 1.5: Diagrammatic representation of spherical aberration

Campbell and Westheimer (1959) concluded that spherical aberration plays an active role in guiding the accommodative response. They eliminated spherical aberration by viewing a monochromatic light source through a fixed pinhole centred over the eye and found a reduction in the accuracy of the accommodative response. However, Charman and Jennings (1979) disagreed with the conclusions made by Campbell and Westheimer. They suggested that the reduction in accuracy of the accommodative response was because the pinhole effectively increased depth-of-focus of the eye thereby partially opening the accommodative loop. Later Ward and Charman (1987) reported that when viewing targets in white light 0.5 mm diameter pupils do in fact open the accommodative loop

iii) Chromatic aberration

Ocular chromatic aberration arises from the fact that the refractive index of the optical media increases as the wavelength of light decreases. The longer wavelengths at the red

end of the visible spectrum are less strongly refracted than the shorter ones at the blue end. The magnitude of ocular chromatic aberration is dependent on the eye's accommodative state due to the effect of spherical aberration (Jenkins, 1963b). For example Jenkins (1963b) found that the mean chromatic difference in focus for 28 eyes between wavelengths 445 υm and 670 υm was 1.58 D when viewing a distant target. When 15 of the original 28 eyes were assessed for chromatic differences in focus over the same wavelength range but while accommodating on average 2.51 D, the measured chromatic aberration dropped to 1.05 D.

With respect to the role of chromatic aberration as a stimulus to accommodation, Fincham (1951) demonstrated that 60% of individuals had difficulty in producing the appropriate accommodative response when deprived of chromatic aberration. Campbell and Westheimer (1959) suggested that some individuals do use chromatic aberration as a directional cue to accommodation but once it is removed they learn to use other available cues. Kruger and Pola (1986) investigated the relative importance of defocus blur, chromatic aberration and target size as stimuli to accommodation and found that they all play a part in accommodative control. Furthermore, recent evidence provided by Kruger et al. (1991) suggests that when subjects track a sinusoidally moving target, the deprivation or reversal of chromatic aberration appears to decrease accommodative gain or severely disrupt the accommodative response. Such results support the role of chromatic aberration as an accommodative cue.

In contrast, Stark and Takahashi (1965) and Troelstra et al. (1964) believe that chromatic aberration is of minimal importance in guiding the accommodative response. The inability of the accommodative mechanism to respond accurately to isoluminent red green targets (Wolfe and Owens, 1981; Switkers et al, 1990) provides additional evidence which casts doubt on the role of chromatic aberration in accommodation. Hence the importance of chromatic aberration as a stimulus to accommodation is still unknown.

iv) Spatial frequency

Heath (1956a) was the first to investigate the effect of spatial frequency on accommodation. Utilizing lacquered lenses to degrade the image of a high contrast letter and alter its spatial frequency characteristics, he observed a decrease in the accuracy of the accommodative response. It is now generally accepted that spatial frequency characteristics of the target affect the accommodative response but the exact nature of the accommodative response over a range of spatial frequencies is disputed.

Charman and Tucker (1977, 1978) reported that the accuracy of the accommodative response decreases for low spatial frequency stimuli and tends towards an intermediate resting state, whereas at higher frequencies the accuracy increases monotonically with

increased spatial frequency. They suggested that low spatial frequencies guide the accommodative response of a defocused eye until higher spatial frequency information becomes available and is used to refine the response (Charman and Tucker, 1977; 1978; Charman and Heron, 1979). The findings of Charman and his co-workers are in agreement with the fine-focus control hypothesis of accommodation which suggests that the effect of defocus is most marked at high spatial frequencies and thus the most accurate accommodative response is obtained in the presence of high as opposed to mid-range spatial frequencies.

The contrast-control hypothesis of accommodation theorises that the accommodative system attempts to maximise the spatial contrast at the fovea and predicts that the accommodative response will be at its most accurate over mid-range spatial frequencies where the visual sensitivity to the detection of threshold contrast is at its maximum. Owens (1980) found that the accuracy of the accommodative response peaked at the mid-range spatial frequency of 4 cpd for 3 out of 4 of his subjects. In addition, he demonstrated a significant correlation between the spatial frequency accommodative response profile and the contrast sensitivity function of the eye which supports the contrast-control hypothesis.

Ciuffreda and Hokoda (1985) found that the response profiles of some visually normal subjects support both hypotheses. The variation in the response profiles reported by other workers (Charman and Tucker, 1977; 1978; Charman and Heron, 1979; Owens, 1980) have been attributed to the differences in the instructions issued to the subjects (Ciuffreda and Hokoda, 1985). Charman and his co-workers told their subjects to obtain the best possible focus of the target, thus the instruction may initiate both reflex and voluntary accommodation whereas the the instruction 'to focus the target naturally without straining' used by Owens (1980) may only initiate reflex accommodation.

Kotulak and Schor (1987) investigated the combined effect of spatial frequency, luminance and contrast on the accommodative response profile using Difference of Gaussian (DOG) targets in which the bandwidth of spatial frequency is held constant by bandpass filtering. They reported that the accommodative response to low spatial frequency DOG targets tended to be independent of vergence and was similar to the resting focus of accommodation. In addition, Kotulak and Schor observed that the effect of contrast on the accommodative response is dependent on the spatial frequency of the target; at medium spatial frequencies, the contrast could be markedly decreased before the accommodative response accuracy was affected, whereas at higher and lower spatial frequencies, a slight decrease in contrast led to large accommodative inaccuracies.

1.5B - Non-optical factors

i) Proximity

It is generally accepted that the knowledge of nearness of an object of regard (i.e. its proximity) or the awareness of the proximity of adjacent surroundings (propinquity) provides a stimulus to vergence (see section 2.4E) whereas the role of proximity as a stimulus to accommodation is less clear. Proximity is judged as the apparent distance of an object from the eye. Target size is often used as a cue in determining apparent distance as the smaller the object appears, the further away it is often perceived although this is not necessarily true (see Chapter 8).

Ittleson and Ames (1950) investigated the effect of changing the apparent size of a stationary object and found that both accommodation and vergence responses were modified slightly. From their observations they surmised that proximity acts as a stimulus to both accommodation and vergence. Hoffstetter (1950) disagreed, suggesting that the change in vergence was probably due to accommodative convergence and deduced that proximity only acts as a cue for accommodation, not vergence. Fincham (1951), in complete contrast to Hoffstetter, proposed that proximity acts only as a stimulus to vergence and changes in accommodation were due to convergent accommodation. Alpern (1958a) repeated the experiment of Ittleson and Ames (1950) with only slight modification to its design and observed that changes in target size produced changes in vergence but not in accommodation. Other researchers (Hoffstetter, 1942; Morgan, 1944b) have also failed to demonstrate any significant change in the accommodative response following alterations in apparent target size.

Campbell and Westheimer (1959) support the view that size acts as a stimulus to accommodation. In an experiment designed to place blur and size cues in conflict, they found that size is a more powerful cue than blur. Kruger and Pola (1985) demonstrated when size is the only cue available, it acts as an effective stimulus for the accommodative system; furthermore, when combined with blur, size acts to reduce the phase lag of the accommodative response leaving the accommodative gain unchanged. Kruger and Pola (1989) went on to discover that blur is particularly powerful as a stimulus to accommodation at low temporal frequencies whereas at moderate and high temporal frequencies size becomes more effective. The implication is that at low frequencies the accommodative system has time to respond correctly to blur despite the size conflict, whereas at higher spatial frequencies the system is unable to respond to the information from the feedback system thus size becomes the primary cue.

In the series of studies (Kruger and Pola, 1985; 1986; 1987) designed to change the size of the target by sinusoidally varying the size of an iris diaphragm, Kruger and Pola (1987) noted that the effect could be perceived as variations in target distance.

Furthermore they report that the responses of the subjects who did not perceived target motion were substantially reduced or even absent whereas those who perceived motion responded significantly to the sinusoidally varying target size (Kruger and Pola, 1987). Morgan (1968), and Hennessy (1975) have also investigated the effect on the accommodative response of varying the apparent target distance. Neither Morgan nor Hennessy found any change in the accommodative response on alteration of apparent distance although this was probably due to the fact that the target was not perceived to be continuously moving in either experiment.

The importance of proximity as an accommodative stimulus has recently received much attention from Rosenfield and his co-workers. In 1990, Rosenfield and Gilmartin investigated the effect of target proximity on accommodation. They observed an increase in the accommodative response of both emmetropes and late-onset myopes when viewing a 3 D target compared to a 0.2 D target under open-loop accommodative and vergence conditions. Rosenfield and Gilmartin termed the increase proximally-induced accommodation (PIA) as they were unsure whether it was the change in target distance that produced the change in accommodative responses or if it resulted from proximal vergence stimulating convergent accommodation. Rosenfield and Gilmartin (1990) also showed that a change in target size was not necessary in order to alter the output of PIA which, for emmetropes amounts to 0.6 D per dioptre of stimulus. From their open-loop accommodative results, Rosenfield and Gilmartin speculated that under normal closed-loop viewing conditions, proximal effects may be of prime importance in initiating a substantial proportion of the oculomotor responses. However such speculation on closed-loop accommodation from open-loop data may not be appropriate and further clarification is necessary.

Rosenfield and Ciuffreda (1990) provided additional evidence for the dependence of open-loop accommodation responses on PIA at two levels of cognitive demand. These authors found PIA/stimulus demand ratios of 0.43 and 0.39 D/D for passive (listening to music) and active (performing mental arithmetic) mental states, respectively. Subsequently, Rosenfield and Ciuffreda (1991) investigated the effect of surround propinquity on accommodative responses measured in complete darkness in two different sized rooms. They found that when subjects had prior knowledge of the dimensions of the room, the accommodative responses measured in the smaller room were significantly higher, whereas when the subjects had no prior knowledge of the size of the room, the accommodative levels were not significantly different.

A later study by Rosenfield et al. (1991) investigated the range over which systematic changes in PIA could be produced and found that proximity was ineffective as a cue to accommodation when targets were located at distances greater than 3 m; although at lesser

distances, the magnitude of PIA was linearly related to the target distance measured in dioptres. The effect of proximity on the accommodative response has therefore been established under open-loop viewing conditions. Under closed-loop conditions the effects of proximity are difficult to ascertain as blurring produced by an increase in accommodative response provides negative feedback to the system. The system thus reacts by altering the magnitude of accommodation making it impossible to distinguish the effect of proximity alone on accommodation in the normal visual environment.

ii) Mental effort

The effect of mental effort on accommodative responses has been investigated using a variety of experimental designs. Various combinations of open- and closed-loop accommodative conditions and mental tasks which relate directly to the stimulus, i.e. stimulus dependent tasks (SDTs) such as adding rows of numbers presented in the target, and stimulus independent tasks (SITs) for example a backward counting task while looking at an unrelated target, have been employed.

Malmström et al. (1980) investigated the effect of a backward counting task on both open- and closed-loop measures of accommodation. For the closed-loop condition, two stimulus positions were employed, 3 D and infinity. When the target was placed at distance, the task had no effect on the accommodation response, whereas a negative task-induced shift was found when the subjects focused on the near target. Accommodation responses under the open-loop condition were very variable which prompted Malmström et al. to suggest that open-loop measures of accommodation are not ideally suited for measuring changes in accommodation due to secondary tasks. Kruger (1980) also investigated the effect of mental effort on closed-loop accommodation responses and found that when the subjects changed from the passive condition of reading numbers at 40 cm to adding them, the mean level of accommodation for the group increased by 0.28 D. The difference in the results of these two studies may be attributable to the fact that Malmström et al. imposed a SIT, whereas Kruger asked his subjects to perform a SDT.

Bullimore and Gilmartin (1987a; 1987b) found significant positive shifts under open-loop (dark room) conditions when subjects performed a SIT. In a later experiment, Bullimore and Gilmartin (1988) modified Kruger's experiment by placing the target (an array of numbers) at vergences of -1 D, -3 D and -5 D. They found that concurrent mental effort induced a significant increase in the mean accommodative response of 12 emmetropic subjects for the -1 D stimulus. When the target was located at -3 D no difference in the response was observed, whereas for the -5 D stimulus, the response decreased with the introduction of the SDT. A significant interaction between cognitive demand and PIA has recently been demonstrated under open-loop conditions for a

proportion of subjects (4 out of 12) in an experiment designed to examine the influence of mental activity on PIA (Rosenfield and Ciuffreda, 1990).

The exact role of mental effort and other non optical factors such as mental imagery (Malmström and Randle, 1976; Malmström et al., 1980) and motivation (Provine and Enoch, 1975) in determining the accommodative response is still unclear due to the diversity of experimental designs and problems of stimulus interactions occurring under both open- and closed-loop accommodative conditions. Such problems make it impossible to quantify the individual effects of both optical and non-optical stimuli on the accommodative response however the effect of mental activity on open-loop accommodation levels is investigated in Chapter 8 in an attempt to clarify the issue.

1.6 - THE ACCOMMODATIVE RESPONSE

The aim of the accommodative response is to maximise the quality of the retinal image at the fovea (Ciuffreda, 1991). To achieve this the accommodative system, like the vergence system, operates what is termed a negative feedback loop. By subtracting the response from the stimulus, the negative feedback loop generates an error signal whenever the response does not exactly match the stimulus; for the accommodative system the error signal is blur whereas for the vergence system the error signal is retinal disparity. Toates (1972) noted that when the accommodative system has stabilized an error still exists between the response and the stimulus. This steady-state error represents the dead-space within the system which in ocular terms traditionally represents the depth-of-focus of the eye (Hung and Semmlow, 1980) although there is evidence to suggest that accommodation responses can be elicited by stimuli which are below the perceptual blur threshold (Ludlam et al., 1968; Kotulak and Schor, 1986b).

1.6A The stimulus/response function

The accommodative mechanism has the ability to operate over a wide range, this is represented by the stimulus/response function (Figure 1.6). Under accommodation, also known as accommodative lag occurs for near targets, whereas when the distance of the target exceeds approximately 2 m, over accommodation or accommodative lead occurs (Morgan, 1944b). Accommodative lag and lead represent the steady-state error described above.

The central portion of the stimulus/response curve between stimulus levels of about 1 D and 6 D is approximately linear and its gradient represents the gain of the accommodative system or alternatively the magnitude of response per unit stimulus (Hung and Semmlow, 1980 - see Chapter 6). The effects of various factors such as luminance,

spatial frequency and contrast on the slope of linear part of the the stimulus/response curve has been studied by Charman (1986) who devised an equation linking the gradient (m) of the linear part of the curve to the minimum angle of resolution (MAR):

$$|m| = 1 - C\ (MAR)$$

Using data from a number of studies, Charman (1986) predicted a value for the constant C of between ~0.1 and 0.5 min^{-1}.

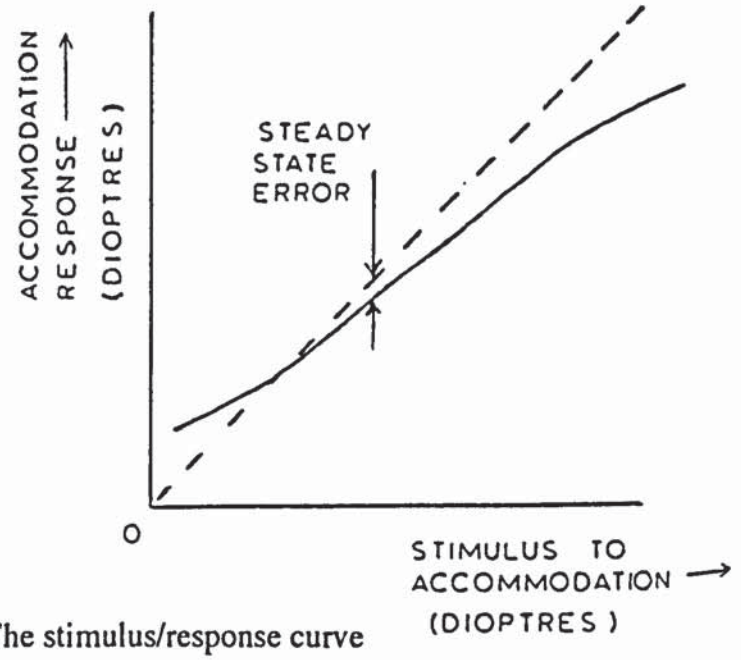

Figure 1.6: The stimulus/response curve

1.7 - STEADY-STATE OPEN-LOOP ACCOMMODATION (SOLA)

1.7A - Historical aspects of the accommodative resting point

The classical theory of accommodation provided by Helmholtz (1855) maintains that, when the accommodative mechanism of an emmetropic eye is at rest, the eye is focused at infinity. Evidence now shows this not to be the case; instead, in the absence of adequate visual stimuli, the accommodative mechanism adopts an intermediate resting position which can be considered analogous to the vergence system whereby the physiological position of rest is more convergent than the anatomical position of rest (see section 2.4B). Observations of various visual phenomena provided the first clues to the concept of an intermediate rather than dioptrically distant resting position of the accommodative system.

Night myopia

The concept of an intermediate resting position of accommodation first came to light after observations made by Rayleigh in 1883 of a decrease in visual acuity with decreasing luminance. He found that negative lenses facilitated his vision at night thus identifying the phenomenon night myopia. Interest in night myopia increased during and after the second world war due to its possible effects on visual performance. Otero and Duran

(1942) demonstrated night myopia up to 2 D when measured subjectively. Various factors such as chromatic and spherical aberration were thought to contribute to this phenomenon (Rayleigh, 1883; Otero and Duran, 1942, Wald and Griffin, 1947; Ivanhoff, 1947) although it is now well established that the major contributor is involuntary accommodation (Epstein, 1983; Gilmartin and Hogan, 1985).

Myopic shifts measured in complete darkness can be thought of as a limiting form of night myopia as in the absence of any stimulus at all, factors such as spherical and chromatic aberration fail to play a part in determining the extent of these shifts. The intermediate resting position adopted in complete darkness has been given various names such as dark focus, tonic accommodation and the resting focus of accommodation; the terminology to describe the phenomenon in this thesis will be discussed in section 1.7B.

Empty field or space myopia

Accommodation has been shown to adopt an intermediate resting position in conditions other than darkness. When the visual field is devoid of details adequate to stimulate accommodation such as experienced in daylight fog or high level flying, myopic shifts occur. The terms used to describe the myopia experienced in these conditions are empty field or empty space myopia. Using their sensitomatic technique Luckiesh and Moss (1937) demonstrated that for a group of 100 subjects the mean level of myopia recorded under bright empty field conditions was -0.75 D, with a range -0.37 to -1.37 D. In a later investigation, Whiteside (1952) reported levels of empty space myopia which ranged from -0.5 to -2.0 D. Due to the constant photopic levels of illumination experienced in bright empty fields, spherical and chromatic aberration do not contribute to this type of myopia. Hence it is analogous to myopia measured in complete darkness and its existence supports the theory that when the accommodative state is independent of retinal image contrast (or vice versa) the accommodative mechanism adopts an intermediate resting position.

Instrument or small pupil myopia

It is a well known tendency to over accommodate, thus inducing a form of myopia, when using optical instruments such as microscopes (Baker, 1966; Schober et al., 1970; Hennessy, 1975). Hennessy (1975) measured instrument myopia levels of 15 emmetropic subjects and found it to range between -0.96 and -2.78 D whereas Leibowitz and Owens (1975) found that it ranging from -0.7 to -4.0 D for a group of 30 subjects. The possibility that the field stop in an optical instrument such as a microscope may bias the accommodative response by virtue of the Mandlebaum effect (described below) was investigated by Hennessy (1975) but this phenomenon was found to be ineffective unless the normally black field stop was covered with a checkerboard pattern. Instrument myopia appears to be due to a combination of both proximally-induced accommodation,

brought on by the knowledge that the object of regard is close to the eyes plus the small exit pupils of the instrument which increase the depth-of field of the eye (Schober et al., 1970; Hennessy 1975). It has been shown that as the depth-of-field increases, the accommodative response approaches its intermediate resting position (Ripps et al., 1962; Hennessy et al., 1976; Ward and Charman, 1985; 1987) therefore instrument or small pupil myopia can be thought of as another form of resting state myopia.

The Mandlebaum effect

Difficulty in maintaining a clear focus on a particular object when other objects appear within the field of view to rival our attention is commonly experienced; for example looking at a distant target through a wire fence or a dirty window. Mandlebaum (1960) was the first to investigate this phenomenon and discovered that, depending on the position of the intervening surface, rivalry in accommodation actually results in unconscious focusing on the nearer object (such as a plane of glass) despite more conscious efforts to focus on the more distant one. This phenomenon became known as the Mandlebaum effect. Mandlebaum suggested that its occurrence was due to involuntary accommodation since it failed to occur after cycloplegia of the ciliary muscle. Owens (1979) found that the Mandlebaum effect was most pronounced when the intervening surface was placed at or close to the distance corresponding to the accommodative level measured in complete darkness. When this was the case the eyes tended to focus on the intervening surface instead of the object of regard irrespective of whether it was positioned nearer or further away than the intervening surface; whereas when the object of regard was positioned at this distance, the eye found no difficulty in focussing on it and seemed uninfluenced by the presence of the intervening surface. Owens (1979) offered these observations as further evidence of the intermediate resting position of accommodation.

1.7B - Terminology

Several terms have been used to describe the intermediate level of accommodation measured under so called 'stimulus free' conditions (see Rosenfield et al., 1993) e.g. *tonic accommodation* (Luckiesh and Moss, 1937; Heath, 1956a; Gilmartin et al, 1984; Schor et al, 1986; McBrien and Millodot, 1987b), *the ABIAS* (Phillips, 1974), *dark-focus* (Leibowitz and Owens, 1978; Miller, 1978; Ebenholtz, 1983; Rosenfield and Gilmartin, 1989), *dark accommodation* (Rosenfield et al., 1992) and the *resting point or focus* (Charman, 1982; Morgan, 1957; Johnson et al., 1984) .

The terminology used by others often fails to accurately describe the intermediate position of accommodation measured under 'stimulus free' conditions; the expressions 'dark-focus' and 'dark accommodation' imply that the myopic shifts only occur in darkness which is clearly not the case as other conditions such as bright empty fields and pinhole

pupils also produce myopic shifts (see section 1.7A). The term 'tonic accommodation' is misleading as various studies have shown that the level of accommodation measured under 'stimulus-free' conditions not only represents the tonic component of the accommodative response but is in fact an aggregate of various components of the accommodative response. Furthermore, the word 'focus' used in the terms 'dark-focus' and 'resting focus' indicates that the eye is able to control the accommodative level experienced under stimulus-free conditions by means of a feedback loop which is incorrect as the accommodative loop is open. The term ABIAS is a bioengineering term and is not deemed appropriate for use in this thesis as it is not consistent with other terms used in clinical literature.

It was decided that a new expression, devised by the author, should be used in this thesis to describe the accommodative level measured under conditions of inadequate visual stimuli. 'Steady-state open-loop accommodation' (SOLA) was chosen as it most accurately describes the measurement.

1.7C - Methods of opening the accommodative loop

i) Dark empty field

The easiest way of removing all optical stimuli in order to open the accommodative loop is by placing the subject in complete darkness. Although all optical stimuli are eliminated under such conditions it is important to note that non-optical factors can still influence the measured SOLA. Rosenfield and Ciuffreda (1991) demonstrated that prior knowledge of the size of the room used can significantly alter the level of SOLA; the smaller the room, the greater the effect of surround propinquity (awareness of nearness) causing higher mean levels of SOLA due to PIA.

ii) Bright empty field

An alternative way of opening the accommodative loop and removing all optical stimuli is for the subject to view an illuminated empty-field or Ganzfeld although instrument propinquity may effect SOLA levels. Further, Wolfe and O'Connell (1987) suggested that the presence of light increases SOLA compared to dark field conditions due to the accommodative mechanism maintaining a 'more vigilant state'.

iii) Pinhole pupil

Ward and Charman (1985) verified that a 0.5 mm pinhole will inhibit the blur-stimulus to accommodation by way of increasing the depth-of-focus of the eye. Several studies have used this technique to open-loop the accommodative mechanism (Schor et al., 1986; Ward and Charman, 1987; Rosenfield and Gilmartin, 1988c and others). PIA can influence SOLA if the target being viewed through the pinhole is less than 3 m from the

observer and the observer has prior knowledge of its position (Rosenfield and Ciuffreda, 1990; Rosenfield and Gilmartin, 1990)

iii) Difference of Gaussian targets

As mentioned in section 1.5A, Kotulak and Schor (1987) found that low spatial frequency ~0.1 c/deg difference of Gaussian (DOG) targets effectively open-loop the accommodative system. Consequently, Tsuetaki and Schor (1987) recommended their use in clinical environments together with dynamic retinoscopy to measure SOLA. Rosner and Rosner (1989a; 1989b) have found this experimental technique useful for assessing SOLA in children. However Rosenfield (1989) was unable identify any correlation between SOLA measured in darkness and SOLA measured when viewing DOG targets. He reasoned that this was because the presence of the illuminated DOG target stimulated PIA.

1.7D - Methods of measuring steady-state open-loop accommodation

i) Purkinje image photography

Photographing the Purkinge images formed on the front and back surfaces of the crystalline lens before and during the experimental condition was the earliest method of objectively measuring accommodative change, though the absolute value of accommodation cannot be measured. Investigators can use this method to measure accommodation change under both open- and closed-loop conditions. Campbell and Primrose (1953) measured SOLA using this technique and found a mean accommodative change of -0.82 D with values ranging from +0.60 to -1.10 D compared to distance focusing.

ii) Near retinoscopy

Controversy exists as to whether the retinoscope light constitutes a stimulus to accommodation or not. Owens et al. (1980) found that the retinoscope light did not act as a stimulus to accommodation, moreover they compared measurements of SOLA taken with a laser optometer and the near retinoscopy technique in a dark room and demonstrated a significant correlation ($r = 0.86$; $p < 0.001$) for 22 eyes between the two methods. Although the correlation between the two techniques was high, the values of accommodation measured by near retinoscopy were considerably lower (mean = -0.70 D) than those measured by laser optometry (mean = -1.50 D). Bullimore et al. (1986) also found lower mean SOLA levels when using near retinoscopy compared with laser and IR optometers, once correlation factors were added. Rosenfield (1989) used an infrared objective optometer to measure accommodation levels in the dark with and without a retinoscope beam acting as a target and found that although the responses to the two conditions were similar (complete darkness mean = -1.77 D, viewing retinoscope beam = -1.58 D) they were not correlated. It may be that the retinoscope beam influenced the

level of accommodation in some subjects by stimulating both blur and PIA or alternatively the colour temperature of the retinoscope beam may have influenced the results.

iii) Subjective optometers

Subjective optometers rely upon the subject's judgement of a characteristic of the target such as its sharpness, motion or alignment and the accuracy of the optometer is largely dependent on the observation skills of the subject. One of the most favoured subjective optometers used in assessing SOLA is the laser optometer for which the subject has to assess the direction of motion of speckles of light.

Leibowitz and Owens (1978) used the laser optometer to assess SOLA on 220 college students. They found the mean SOLA measured in darkness was -1.52 D, ranging from 0.0 D to -4.0 D. A similar mean value (-1.58 D) for 60 students was reported by Hogan (1985) when he used a laser optometer to measure SOLA in darkness. However, the use of the laser optometer as a tool for measuring SOLA has been brought into question following several studies comparing measurement techniques. Post et al. (1984) reported that 2 out of 5 subjects examined showed increased SOLA levels in excess of 2 D when measured using a laser opposed to IR optometer. They suggested the shifts were due to the mental effort required to judge the laser speckle movement.

In contrast, Bullimore et al. (1986) using an exposure time of 300 ms (70 ms less than the accommodative response latency), noted a high correlation between the results from the laser and IR optometers. They postulated that the longer time interval used by Post et al. (500 ms) permitted a transient accommodative response to the speckle pattern. This proposal was supported by Rosenfield (1989) who also suggested that the laser pattern may stimulate PIA. Another source for the discrepancy between measurements is the chromatic aberration correction factor which has to be added to the results of the laser optometer. This correction factor is dependent upon the chromatic aberration of the eye which varies between individuals and with accommodation (Jenkins, 1963b) although the variation is generally very small.

Other types of subjective optometers include the Hartinger coincidence refractometer which, although can be used objectively to measure ocular refraction, has to be used subjectively to determine SOLA; consequently the results are contaminated by both proximal and cognitive influences. In contrast, the influence of these factors when using stigmatoscopy to measure SOLA are thought to be minimal (Rosenfield et al. 1993). Details of this and other subjective optometers are given by Rosenfield et al. (1993).

iv) Objective optometers

Objective optometers, all of which use invisible IR light to assess refractive error, have many advantages over subjective optometers for example, the measurements are not dependent on the observation skills of the subject. Furthermore, SOLA measurements are not contaminated by cognitive effects produced when a subject has to make a judgement. In addition to assessing steady-state accommodation, with slight modifications some IR optometers can also assess dynamic responses such as accommodative regression patterns (see section 1.8D). The measurement times of IR optometers are very short, for example the Canon Autoref R-1 optometer takes only 0.2 s to evaluate the refractive state of the eye. The features of the infrared optometer the Canon Autoref R-1 have made it a very popular instrument of choice around the world for measuring accommodation and especially SOLA. Indeed, it was the instrument chosen to measure accommodation for the experimental programme detailed in this thesis. More details about this optometer appear in Chapter 5.

1.7E - The stability of steady-state open-loop accommodation

Studies assessing the long-term stability of SOLA have shown that it remains stable for periods of up to 1 year (Miller, 1978; Mershon and Amerson, 1980, Heron et al., 1981, Owens and Higgins, 1983; Post et al., 1984). However most of the studies have used a laser optometer in the assessment of SOLA the validity of which has previously been questioned due to the possible proximal and cognitive influences of this technique. Post et al. (1984) used an Ophthalmetron IR optometer to measure the stability of SOLA on 47 subjects over trials separated by a period of a few minutes, one day, 1 week and 2 weeks and the resulting correlation coefficients of 0.98, 0.72, 0.75 and 0.76 were obtained for the test-retest intervals respectively. These correlation coefficients although reduced for test-retest periods greater than a few minutes, indicate that the level of SOLA recorded is relatively stable over time. Diurnal variations in SOLA have also been studied and no systematic variation has been discovered (Miller 1978; Heron et al, 1981; Krumholtz et al, 1986).

The proven diurnal and long-term stability of SOLA suggests that it is a valid measurement although recent reports (Baker et al., 1983; Morse, 1992) indicate that SOLA is more accurately described as a 'zone' rather than a specific value. Care should be taken when obtaining measurements of SOLA to allow the subject to experience the open-loop condition for a few minutes before data collection begins as Heath (1962) Baker et al., (1983) and McBrien and Millodot (1987b) have observed fluctuations in the level of SOLA within the first few minutes of placing the subject in dark room conditions. Baker et al. have measured the time-course of the drift in accommodation from the closed- to open-loop level and estimate it to be between 1 and 3 s. In addition, the magnitude of SOLA may change transiently after a period of sustained fixation giving

rise to accommodative regression patterns (see section 1.8) and therefore a 'washout' period of a few minutes is recommended to counteract any effects of prior visual tasks to the level of SOLA.

1.7F - Pharmacology and physiology of steady-state open-loop accommodation

The tone of the ciliary muscle as opposed to any ocular aberrations is known to be the primary source of SOLA. In the past workers such as Charman (1982) and Schor et al. (1986) have subscribed to the idea that the SOLA position represented the point of equilibrium between parasympathetic and sympathetic innervation of the ciliary muscle. The work of Gilmartin and Hogan (1985) indicates that this is not correct. By using the muscarinic receptor antagonist tropicamide, they demonstrated that the level and distribution of SOLA collapses around zero when parasympathetic innervation is blocked. They therefore argue that it is predominantly variations in the parasympathetic rather than sympathetic system which are responsible for the intersubject variation in SOLA.

It is important to remember that sympathetic inhibition of the ciliary muscle has a slow time-course and is augmented by.the level of background parasympathetic activity (see section 1.4B). Gilmartin and Hogan (1985) investigated the contribution of the sympathetic inhibition to SOLA by instilling timolol maleate, a non-selective β-receptor antagonist and on a separate occasion isoprenaline sulphate, a β-receptor agonist into the eyes of 10 subjects. With timolol they observed an increase in the mean level of SOLA and noted that for the individual, the size of the increase bore a relationship to the baseline level of SOLA, with the greatest increases for the subjects with the largest baseline measurements therefore providing further evidence of parasympathetic augmentation of sympathetic inhibition. A mean hyperopic shift (i.e. a decrease) in SOLA of 0.47 D was observed 22.2 min after the instillation of isoprenaline. No significant differences between these hyperopic shifts were noted between subjects and they concluded that although parasympathetic innervation is responsible for the intersubject variation in SOLA, sympathetic inhibition does have a role to play.

When an IR optometer was used instead of a laser optometer to assess the effects of timolol on SOLA, Gilmartin and Bullimore (1987) failed to demonstrate any increase in the SOLA level. They suggest that this is because the laser measurement techniques instigate accommodative responses thus raising the background parasympathetic innervation to a level whereby sympathetic inhibition is augmented. When Gilmartin and Bullimore asked their subjects to undertake a concurrent mental task (counting backwards in sevens) the SOLA measurements of some individuals increased to a level that produced sufficient parasympathetic activity to demonstrate the timolol shifts found earlier with the

laser optometer. The level of background parasympathetic activity under true stimulus-free conditions is invariably insufficient to demonstrate sympathetic inhibition; thus the role of sympathetic innervation in determining the SOLA position appears to be minimal.

1.8 - ACCOMMODATIVE REGRESSION PATTERNS

Accommodative regression patterns represent the delayed return of open-loop accommodation to the SOLA level immediately following sustained closed-loop fixation. A comprehensive review of this phenomenon is given by Rosenfield et al. (1994).

1.8A - Terminology

Other terms used to describe accommodative regression patterns are accommodative adaptation (Schor and Tsuetaki, 1987; Wolfe and O'Connell, 1987; Rosenfield and Gilmartin, 1988a; 1988e) and accommodative hysteresis (Ebenholtz, 1983; 1985; 1992). The term accommodative adaptation implies an analogy with vergence adaptation which is disputable. Vergence adaptation represents the instigation of the slow fusional vergence response *in the presence of* an adapting vergence stimulus (see section 2.6). In contrast, accommodative regression is observed once the stimulus to accommodation has been removed and therefore is more analogous to the recovery of the vergence system on removal of the adapting stimulus rather than to adaptation itself. Furthermore vergence adaptation measures are carried out under closed-loop conditions whereas regression patterns are only observed under open-loop conditions. However, it is generally accepted that the regression of accommodation following sustained near vision tasks represents the decay of the slow or adaptive component of accommodation.

1.8B - Magnitude of the closed-loop stimulus and accommodative regression

Several workers have described a temporary increase in open-loop accommodation following sustained near vision (Ebenholtz, 1983; Schor et al 1984; Hogan and Gilmartin, 1985; Gilmartin and Bullimore, 1987 and others), however controversy exists as to the influence of distance fixation on hysteresis effects. Ebenholtz (1983) recorded a decrease in open-loop accommodation of 0.21 D immediately following an 8 min period of sustained fixation at the subject's far point, whereas Gilmartin and Bullimore, (1987) and Fisher et al. (1987a) failed to show any such effect following sustained distance fixation.

1.8C - Duration of the closed-loop task and accommodative regression

Hysteresis effects are evident after extremely brief periods of closed-loop accommodation (Fisher et al., 1988b; Rosenfield and Gilmartin, 1989) and therefore the time-course of

onset is exceedingly fast. Moreover no significant difference in terms of either magnitude or regression rate has been observed following a 15 s near vision task and that recorded after a task duration of 8 min (Fisher et al., 1988b) or 10 min (Rosenfield and Gilmartin, 1989).

1.8D - Methodology and accommodative regression

Not only is the magnitude of SOLA influenced by methodology (see sections 1.7C and 1.7D) but the time-course of accommodative regression has been shown to vary with both the method of measuring accommodation and the method of opening the loop. Laser optometers appear to prolong the effects of closed-loop viewing. Ebenholtz (1983) conjectured from his results that it would take 10.26 hrs for the hysteresis effect to dissipate completely following 8 mins of near point accommodation. In contrast, Wolfe et al. (1987) using a Hartinger subjective optometer found that regression was complete within 3 mins following a near vision task. Objective infrared optometers have yielded decay rates in the order of seconds rather than minutes; for example studies using static IR optometers have demonstrated that the SOLA level is attained within 30-90 s (Gilmartin and Bullimore, 1987; Rosenfield and Gilmartin, 1988a; 1988e), even quicker rates of decay have been observed when dynamic IR optometers have been used (Schor et al., 1986; Gilmartin et al., 1992).

The discrepancies in the measured time-course of hysteresis effects between each optometer may well relate to the time it takes to obtain a single measurement. For example, it can take in excess of 60 s to obtain a measurement from a laser optometer, whereas the Canon Auto-ref IR objective optometer has a measurement period of just 0.2 s when used in its static mode of operation although its recording period is longer (see Chapter 5). Several studies have shown that SOLA increases under prolonged open-loop conditions (Krumholtz et al., 1986; Rosenfield et al., 1990) and this passive shift may mask the regression of accommodation. In addition the cognitive and proximal effects associated with subjective optometers probably effect the results obtained.

The method by which the accommodative loop is opened immediately following sustained fixation has been shown by some to affect both the time-course and magnitude of accommodative regression. When dark room, bright empty field and pinhole pupil conditions are compared, darkness yields the most rapid decay and smallest magnitude of aftereffect, while both bright empty field and pinhole pupil reveal a larger and longer lasting after-effect (Phillips, 1974; Schor et al., 1986). Schor and his co-workers postulated that darkness actually masks the regression effect. Wolfe and O'Connell (1987) investigated accommodative regression under darkroom and bright empty field conditions in 21 subjects and reported that 5 of the subjects showed large differences in the regression patterns measured under bright field conditions compared with darkroom

conditions. Three out of 10 subjects examined by Bullimore and Gilmartin (1989) took significantly longer for the baseline SOLA level to be reached following closed-loop viewing under bright field compared to darkroom conditions; 2 subjects showed the opposite effect.

The influence of method of opening the accommodative loop on accommodative regression may be due to differences in proximal accommodation induced by the conditions. Due to the presence of light in bright empty field and pinhole pupil conditions the subject is more likely to be aware of the proximity of their surroundings, i.e. the surround propinquity; further the presence of a target under pinhole conditions will stimulate PIA. However a recent study by Chiu and Rosenfield (1994) has demonstrated that not only was the mean SOLA level under pinhole conditions when viewing a distance target (0.28 D) significantly lower than that measured in total darkness (0.60 D) but the two measures were correlated (r = 0.86). Chiu and Rosenfield concluded that people with high darkroom SOLA levels experience the largest propinquity effect.

1.9 - SUMMARY

The function of accommodation in the oculomotor response is to maximise the contrast and quality of an image on the fovea. This is achieved by continually responding to the output of the system via a negative feedback loop. Although primarily innervated by the parasympathetic nervous system, the ciliary muscle also receives supplementary sympathetic innervation. The role of sympathetic innervation is not yet fully understood although it has been speculated that due to its small magnitude, inhibitory nature, long time-course and augmentation by background parasympathetic innervation, its presence is more relevant to sustained near vision tasks than to tasks involving rapid changes in accommodation. The possibility of a connection between sympathetic innervation of the ciliary muscle and the development of myopia is investigated in Chapter 10

The stimulus to accommodation can take many forms, both optical and non-optical. Optical stimuli such as defocus blur, ocular aberrations and spatial frequency tend to be perceived as a decrease in the image contrast and therefore stimulate blur-induced accommodation whereas non-optical stimuli are independent of the quality of the retinal image. Proximally-induced accommodation is an example of accommodation stimulated by non-optical factors and its effect on accommodation in emmetropia and myopia is investigated in Chapter 9.

In the past workers believed that SOLA represented the tonus of the ciliary muscle but it is generally accepted that SOLA represents an aggregate response comprising of the ciliary tonus and the effect of non-optical factors on the accommodation response. Accommodative regression patterns represent the delayed return of the accommodative mechanism to the baseline SOLA level following a sustained closed-loop visual task. Together with SOLA they represent an important part of the accommodative profile and are used by many workers to explore various aspects of the accommodative system. Both SOLA and accommodative regression patterns, in addition to many other aspects of the accommodative and vergence mechanisms, are investigated extensively in this thesis to further our knowledge of the oculomotor profiles of emmetropes, early-onset myopes and late-onset myopes.

CHAPTER 2

THE VERGENCE MECHANISM

2.1 - INTRODUCTION

Vergence forms part of the oculomotor response and therefore has particular relevance to this thesis; its role is to maintain single vision at all times and eliminate retinal disparity. Vergence eye movements are those in which the eyes move in opposite directions (disjunctive eye movements). There are many types of vergence eye movements most of which are discussed in this Chapter. All eye movements, including vergence, are brought about by the extraocular muscles which are attached to the exterior of the globe. These muscles are also known as the extrinsic muscles and are described below.

2.2 - GROSS ANATOMY OF THE EXTRAOCULAR MUSCLES

Seven extraocular muscles exist in man but only six of them, the medial, lateral, inferior and superior recti and the inferior and superior oblique muscles are involved in oculo-rotatory control (see Figure 2.1). The seventh, the levator palpabrae acts to raise and lower the upper eye lid. Although absent in man, many lower animals have an additional ocular muscle, the retractor bulbi.

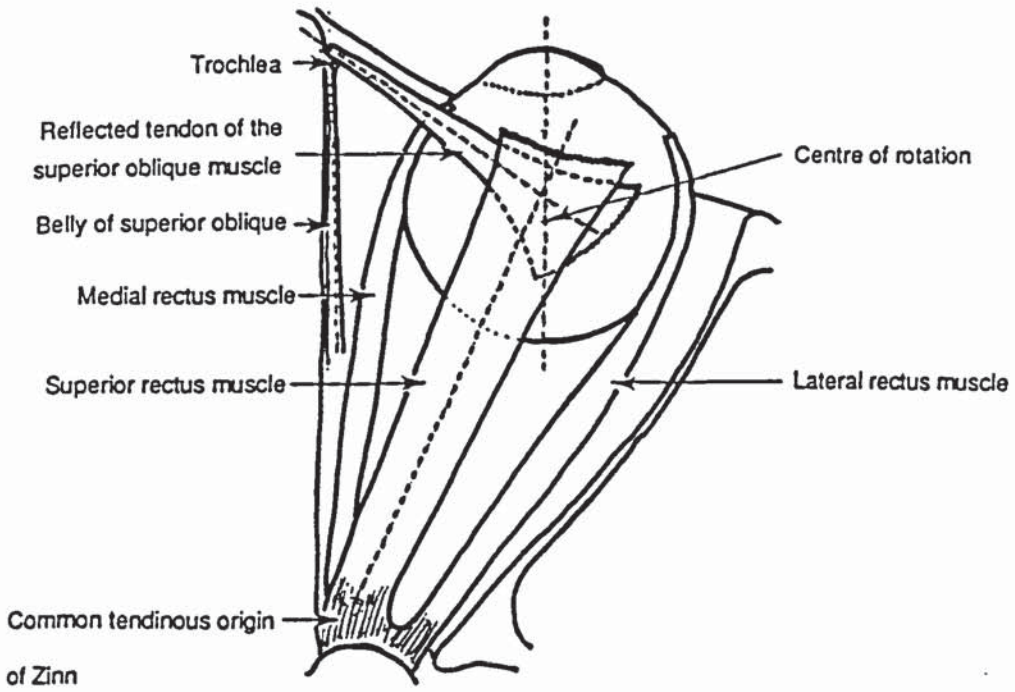

Figure 2.1: Superior aspect of the globe and extraocular muscles

2.2A - Structure of the extraocular muscles

The extraocular muscles, unlike the smooth intrinsic ciliary muscle, are of the striated skeletal type. Fusiform in shape with tendinous origins and insertions, the extraocular muscles differ from other striated muscles of the body in several respects. Kato (1938) identified two regions within the extraocular muscles; the outer (orbital) layer and the inner (global) layer. The connective tissue sheaths surrounding extraocular muscle fibres contains a larger quantity of elastic tissue and nerve fibres than normally found in striated muscle, thus enabling very precise and smooth ocular movements (Schiffendecker, 1905). The muscle fibres are generally finer and more numerous than those of other skeletal muscle, with several different types contained within each muscle.

Although six muscle fibre types have now been identified in extraocular muscle (Spencer and Porter, 1988) only the two basic types, identified by Siebeck and Kruger (1955) will be described here. *Fibrillenstructur* type fibres have a large diameter (11-15μm), contain regular fibrils in abundant sarcoplasm and are similar to the typical twitch fibres found in skeletal muscle. In contrast, the *felderstruktur* type are unique to the extraocular muscles, they are thin (9-11μm diameter), contain little sarcoplasm and consist of poorly defined fibrils.

In mammals, felderstruktur fibres resemble the multiply innervated slow or tonic fibres that are commonly found in skeletal muscles of amphibians and avians (Morgan and Proske, 1984). Generally, they have a slow, graded contraction response to stimulation although some of these fibres are slow twitch fibres and have the ability to propagate action potentials (Pilar, 1963; Hess and Pilar, 1963; Back-y-Rita and Ito, 1966) but the graded contraction is thought to occur without the propagation of action potentials (Pilar, 1963). Fibrillenstructur fibres respond to stimulation with all or nothing action potentials and thus produce a non-graded muscle twitch. About 80% of the fibres within each muscle are the fibrillenstructur type which have an innervation ratio of about 1:10. Only about 20% are of the felderstrukur type which have an innervation ratio of 1:3; these innervation ratios are very low compared to other striated muscle, thus allowing very precise movement of the eye.

2.3 - INNERVATION OF THE EXTRAOCULAR MUSCLES

The inferior division of the oculomotor (III) nerve provides innervation to the medial rectus, inferior rectus and inferior oblique muscles, the superior division serves the superior rectus. The trochlear (IV) nerve supplies the superior oblique and the abducent (VI) nerve innervates the lateral rectus muscle. The distal segments of the nerves have

both mylinated and unmylinated axons. The nerve terminals are associated with both motor and sensory innervation of the extraocular muscles.

2.3A - Motor innervation

Motor innervation of the extraocular muscles is derived from both the somatic and, in contrast to skeletal muscle elsewhere in the human body, autonomic nervous systems. Evidence of sympathetic involvement in the innervation of the extraocular muscles is provided by the condition Horner's syndrome in which the sympathetic system is paralysed, resulting in enophthalmus, amongst other indicators. Additional pharmacological evidence of sympathetic innervation has been offered by Sanghvi (1967) Eakins and Katz (1967) and Kern (1968).

Two types of motor nerve endings in extraocular muscles have been identified (Ruskell and Wilson, 1983); *en plaque* endings, associated with the fast fibrillenstructur singly-innervated muscle fibres, consist of a cluster of several endings from the same axon arranged either longitudinally or circumferentially around the muscle fibre and produce focal innervation; in contrast *en grappe* endings provide multiple innervation to the felderstrucktur muscle fibres with small superficial terminals present along virtually the whole length of the muscle fibre.

2.3B - Sensory innervation

Although potential sensory receptors such as neuromuscular spindles (Cooper et al. 1955), unencapsulated spiral nerve endings (Cooper et al. 1955) Golgi tendon organs (Ruskell, 1979) and myotendinous cylinders or palister endings (Ruskell, 1978) have all been identified in extraocular muscle, the classical sensory receptors of skeletal muscle, namely neuromuscular spindles and Golgi tendon organs, are probably not the most predominant sensory apparatus of extraocular muscles (Maier et al., 1974).

2.4 - VERGENCE EYE MOVEMENTS

Vergence eye movements are those in which the eyes rotate in opposite directions to ensure binocular fixation of an object. In contrast, conjugate, or version movements are those on which the two eyes move in the same direction to the same extent, for example saccadic and pursuit eye movements. Vergence eye movements can occur around the three principle axes of the eye, namely the horizontal (horizontal vergence), vertical (vertical vergence) and sagital axes (cyclovergence) although only horizontal vergence eye movements will be considered here as both vertical vergence and cyclovergence are outside the scope of this thesis.

Vergence eye movements are relatively slow compared to other ocular movements such as saccades, they take up to a second to complete and have a latency of 160 ms (Rashbass and Westheimer, 1961; Robinson, 1966). It has been postulated that the slow, tonic muscle fibres are responsible for vergence and slow pursuit eye movements, whereas the fast twitch muscle fibres produce the fast eye movements such as saccades (Alpern and Wolter, 1956; Hess and Pilar, 1963; Jampel, 1967) although Keller (1973) provides evidence which contradict this hypothesis. He demonstrated that the firing rates of motor units within the extraocular muscles of monkeys during vergence, smooth pursuit and saccadic eye movements were not significantly different for the vast majority of motor units sampled. It is probable that even though the different motor units may participate in all types of eye movement, the muscle fibres do not contribute equally to all movements.

2.4A - Maddox's classification of vergence eye movements

Maddox (1893) was the first to suggest that there are a number of different kinds of horizontal vergence movements. He believed that vergence eye movements could be analysed in terms of components, relating each one to the 'physiology of convergence' or to some property of the stimulus or to both. Maddox's classification was the result of clinical observations, not controlled experimental research, but it still remains the basis for analysis and therapy of the vergence system today.

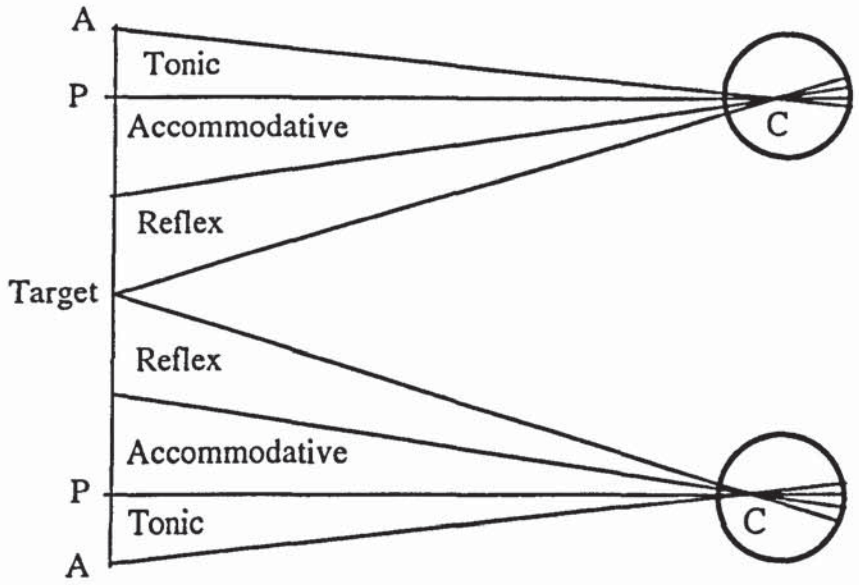

Figure 2.2: Schematic representation of the vergence movements according to Maddox (1893). A is the anatomical position of rest, P is the physiological position of rest.

The first component of the vergence system according to Maddox was *tonic convergence*, the role of which is to move the eyes from some unknown anatomical position of rest (which Maddox presumed to be divergent) to a relatively convergent position. For distance viewing tonic convergence is supplemented by *reflex convergence* (also named the fusional supplement or fusional vergence and more recently, disparity vergence)

which provides for any deficit or excess of tonic convergence and aligns the eyes in the primary position. When fixating an object closer than infinity, Maddox recognised that the accommodation required to focus the object also produces convergent eye movements. He also realized that accommodative *effort*, rather than the accommodative response is directly correlated to the magnitude of vergence produced; he named this component *accommodative convergence*. Furthermore, Maddox postulated that the 'knowledge of nearness' or as he defined it, 'voluntary convergence' produced additional convergence when viewing a near object. Today the term *proximal vergence* is used to describe this type of vergence eye movement (Morgan, 1980) although recently the term propinquity has been used to describe the knowledge of nearness (Rosenfield and Ciuffreda, 1991). In order to accurately bifixate a near object and maintain single binocular fixation, Maddox proposed that reflex (fusional) vergence supplements the sum of tonic, accommodative and proximal vergence. Parallels can be drawn between the vergence and accommodative mechanisms as the accommodative response represents the sum of components such as SOLA, convergent accommodation, blur-induced accommodation and proximally-induced accommodation (see Chapter 1, section 1.5).

In summary, Maddox proposed four components of the vergence system, namely:

1) Tonic convergence (also known as tonic vergence)
2) Accommodative convergence
3) Voluntary convergence (also known as proximal vergence)
4) Fusion or reflex vergence (also known as disparity vergence)

It is now well established that divergence, in addition to convergence, is an active mechanism (Toates, 1974) thus making it necessary to replace the word 'convergence' used by Maddox with the word 'vergence' to identify the fact that the components of the vergence system can produce both convergence and divergence. The components of the vergence mechanism will be considered with in more detail in the following sections.

2.4B - Tonic vergence

Maddox defined tonic vergence as representing the movement required to take the eyes from the anatomical position of rest to the physiological position of rest and this is still the generally accepted definition today. However, other workers have interpreted tonic vergence differently; Duke-Elder (1946) defined tonic accommodation as representing the movement of the eyes from the physiological position of rest to the primary position which is equivalent to tonic vergence plus fusional vergence according to Maddox's classification. Cogan (1956) defines ocular tonus as all fusional convergence, exerted at both distance and near and includes other factors as contributors to ocular tonus. Such a definition implies that the entire movement of the eyes from the anatomical position of rest to the bifixation position could be considered as the amplitude of tonic convergence.

Maddox (1893) believed that the magnitude of tonic vergence was influenced by sleep, drowsiness, alcohol, drugs and death via changes to the physiological position of rest. Furthermore he was of the opinion that the magnitude of tonic vergence is influenced by both the 'awareness of nearness' of objects (i.e. their proximity or surround propinquity) and the constant use of some degree of vergence in order to maintain bifoveal fixation. He was therefore aware that the magnitude of tonic vergence represents the sum of different vergence responses, in much the same way as SOLA represents not only the underlying tonus of the ciliary muscle but also the accommodative response to various non-optical stimuli (Chapter 1 section 1.7).

The anatomical position of rest

Maddox (1893) held the view that the anatomical position of rest, i.e. when the extraocular muscles were devoid of innervation such as in death, would be of 'considerable divergence', this opinion was supported by Alpern (1969b). Grut (1889) cited the work of Volkman who demonstrated that the inter-pupillary distance was larger on corpses than on living individuals. In addition Majoras (1935) stated that the post-mortem posture of the eyes was relatively divergent. Using general anaesthesia to mimic the anatomical position of rest, Meyers (1951) demonstrated a significant level of divergence in 65% of the patients examined, the mean level of divergence being 22°.

Drucker et al. (1951) used the muscle relaxant d-tubocurare to assess the anatomical position of rest of the eyes and found that in addition to ptosis of the upper lid, the eyes adopted an elevated, divergent position. Cogan (1956) failed to demonstrate divergence to the same degree as reported by others, finding instead that the eyes of the dead adopted a position ranging from slightly divergent to axis parallel. Duncalf and Jampel (1961) estimated that divergent eye positions ranged from 15° to 20° on 26 patients experiencing complete ophthalmoplegia induced by d-tubocurare prior to corrective surgery for strabismus. Moreover, Abraham (1951) speculated that the anatomical position of rest would vary throughout life because it is determined by the mechanical properties of the eyes and suspensory system which are changed by growth of the eyes and the surrounding tissues. Most notable is the change that takes place in muscle, known as hypertrophy or atrophy depending on its use or disuse, respectively.

The physiological position of rest

Controversy exists over what actually represents the physiological position of rest. In his paper on the measurement of tonic vergence, Hebbard (1952) highlights the different interpretations of the physiological position of rest:

i) the position of the eyes in sleep

ii) when the eyes are totally dissociated and viewing a distant (greater than 6 m) object

iii) when the eyes are in the primary position, bifixating a distant object

Maddox (1893) interpreted the normal physiological position of rest to be the primary position although he recognised that tonic vergence varied among individuals such that the dissociated distance heterophoria represents the degree of insufficiency (exophoria) or excess (esophoria) of tonic vergence; resulting in compensation by fusional vergence to produce bifoveal fixation.

Alpern (1969b) proposed that the physiological resting position can only be demonstrated by distance heterophoria when both proximal and accommodative vergence are negligible, i.e. under stimulus free conditions. Such an interpretation implies that heterophoria measurements recorded in normal consulting room conditions (like those observed by Maddox) are not a true indication of the difference between the primary position and tonic vergence. There is much evidence to suggest that the physiological resting state measured under stimulus-free conditions is more convergent then the primary position suggested by Maddox (1893). Indeed this was found to be the case on most of the subjects employed for the investigation detailed in Chapter 6.

Terminology

Although Alpern (1969b) stated that the absolute magnitude of tonic vergence cannot be measured as the anatomical position of rest cannot be determined, many workers use the term 'tonic vergence' to describe the magnitude of convergence adopted by the eyes in relation to the primary position under dual open-loop accommodation and vergence conditions (Gilmartin et al., 1984; Hogan, 1985; Fisher et al., 1988a; 1988b; O'Shea et al., 1988). Others use the term dark vergence (Owens and Wolf-Kelly, 1987; Miller and Takahama, 1988) although complete darkness is not the only method of opening both the vergence and the accommodative loops. A more accurate term and the one adopted in this thesis to describe the position of the eyes under open-loop accommodation and vergence conditions in relation to the primary position is 'tonic vergence disparity' (see section 2.5).

2.4C - Fusional (disparity) vergence

Maddox (1893) proposed the role of fusional vergence was to compensate for any excess or deficiency in; a) tonic vergence for distance viewing, or b) the aggregate response of tonic, accommodative and proximal vergence when viewing a near object. He identified retinal disparity as the primary stimulus to fusional vergence but also implied that it came about as a conditioned response due to constant use:

> "the joint sensations of the brain must all the while be bearing down between them the message of continually impending (yet as quickly averted) double vision, by threats of double images, so slight and frequent, that they produce the required effect without our being conscious of their existence"
>
> (Maddox, 1893)

Westheimer and Mitchell (1956) stated that when the images of the object of regard fall on non-corresponding points on the two retinae, fusional vergence is stimulated. When the image of the object of regard falls on non-corresponding points, it will be simultaneously localized in two separate visual directions which, if persistent, may result in diplopia and visual confusion (Leigh and Zee, 1983). Stark et al. (1980) provided experimental evidence demonstrating that it is the disparity between the position of the retinal images, not diplopia, that provides the stimulus for fusional vergence movements. Prior to this, Alpern (1969b) noted that the introduction of a weak prism before one eye will produce a vergence response even when diplopia is not consciously perceived by the subject. As a result of their work, Stark et al. (1980) renamed this response 'disparity vergence' nevertheless, in order to avoid confusion with tonic vergence disparity, the term fusional vergence (FV) will be used in this thesis.

The role of FV is to maintain images of the object of regard on corresponding retinal points which it does with precision but not perfection (Leigh and Zee, 1983). The closest correspondence occurs at the fovea where horizontal retinal disparity of greater than 10 mins of arc usually results in diplopia. The term 'Panum's area of single binocular vision' is given to the area around a corresponding point. If the retinal image falls within this area, FV is stimulated although diplopia is not perceived. The phenomenon whereby the image is perceived as being single even though it's image does not fall on exactly corresponding points is known as fixation disparity. Fixation disparity is considered to represent the steady-state error of the vergence mechanism (Schor, 1980). Like accommodation, vergence is controlled by a negative feedback loop with fixation disparity representing the error signal between the response and the stimulus. However, unlike accommodation, the vergence system only tolerates very small error signals. It should be noted that vergence movements are accompanied by synkinetic changes in accommodation and pupil size (Semmlow, 1981) such interactions will be discussed in Chapter 3.

2.4D - Accommodative convergence

In his classification of vergence eye movements, Maddox included under the single heading 'accommodative convergence' both the vergence due to accommodative effort and vergence due to the 'knowledge of nearness' which is now termed proximal vergence (see section 2.4E). It is generally accepted that the term 'accommodative vergence' represents the vergence response due only to accommodative effort stimulated by blur, and not to the additional effect of proximity. Although it may be either positive or negative (producing convergence or divergence, respectively), accommodative vergence is conventionally referred to in the literature as accommodative convergence (AC).

Maddox considered that the components of the vergence response were added together to produce the final vergence response and that FV occurred secondary to AC, making up the deficit in the vergence response produced by adding the tonic and accommodative components together. Fincham and Walton (1957) did not believe that the vergence components were simply added together to produce the final vergence response. Instead they hypothesized that the components were interlinked in such a way that FV provided the dominant, coarse-tuning for the vergence system and AC the fine-tuning. However, Phillips and Stark (1977) have since shown that the blur stimulus to accommodation must fall on or very near to the fovea to be effective, therefore any sizeable disparity makes blur ineffective as a stimulus to accommodation rendering accommodation open-loop (Semmlow, 1981).

Evidence now suggests that AC is secondary to FV and is driven by blur when disparity is reduced to an extent that blur can become an effective stimulus (Phillips and Stark, 1977). Unlike FV, AC does not operate on a negative visual feedback mechanism and the vergence movements associated with accommodation have no effect on the retinal blur that evokes them. It should be noted that Maddox's model assumes that accommodation stimulates vergence and not vice versa, in reality though vergence can stimulate accommodation (Morgan, 1954; Fincham and Walton, 1957; Kent, 1958; Balsam and Fry, 1959) and this is known as convergent accommodation (CA). Both AC and CA are discussed in more detail in Chapter 3 as they represent the cross-links of accommodation and vergence and therefore have an important part to play in the research programme of this thesis.

2.4E - Proximal vergence

Maddox (1893) recognized that the 'knowledge of nearness' produced a vergence response which he included under the heading of accommodative convergence although he felt that it was actually closely related to tonic vergence. He considered that this type of vergence was elicited voluntarily as he explains in the following abstract:

> "we cannot without special practice converge our eyes voluntarily under ordinary conditions, without doing so by thinking of a near object"
>
> (Maddox, 1893)

Since Maddox, many workers agree that proximal vergence is stimulated by an awareness of the nearness of a stimulus (Hofstetter, 1942; Ittleson and Ames, 1950; Knoll, 1959; Wick, 1985). Experiments have demonstrated that the vergence system responds to changes in target size (Ittelson and Ames, 1950; Alpern, 1958b) and changes in perceived distance (Morgan, 1962). Increased size or apparent nearness is associated with increased convergence although both Alpern (1958b) and Morgan (1962) found these responses to be independent of changes in accommodation.

Proximal vergence is demonstrated by the occurrence of convergent eye movements to near objects when both accommodative and fusional stimuli have been minimised. However, due to the intimate association between accommodation and vergence (see Chapter 3), it may be difficult to determine whether a change in the vergence response is directly due to proximal vergence or from proximal accommodation driving AC. Conversely, proximal accommodation may arise from proximal vergence stimulating convergent accommodation (see Chapter 1 section 1.5B). It is therefore wise to consider vergence movements induced by proximity as proximally-induced vergence (PIV), the equivalent for the accommodative system being proximally-induced accommodation (PIA).

2.5 - TONIC VERGENCE DISPARITY

As mentioned in section 2.4B, the term tonic vergence disparity (TVD) has been adopted to describe the intermediate vergence position which the eyes adopt when no stimulus to vergence exists. Complete darkness is often chosen as the condition to open-loop the vergence response and access TVD. Workers have also shown that the vergence system tends towards an intermediate position when the oculomotor system is stressed or when the stimuli are presented peripherally (see Owens and Leibowitz, 1983 for a review).

2.5A - Measuring tonic vergence disparity

The most convenient way of minimising vergence cues in order to measure TVD is by placing the subject in complete darkness. Ball (1951) was one of the earliest investigators to note that in addition to the normal eye becoming myopic under conditions of low illumination (see Chapter 1 section 1.7A), the eyes tend to converge. Several methods of measuring the position of the eyes in darkness, both subjective and objective, have been employed by various workers and are discussed.

i) Nonius alignment technique

Several investigators have used a type of Nonius alignment technique to determine TVD. In order to measure vergence, the Nonius alignment system must consist of two dichoptic targets i.e. targets which are viewed separately and independently by the eyes . One of the Nonius targets must be moveable so that the images can be placed on corresponding points of the eyes. When the images of the target do stimulate corresponding points, the subject will perceive one target as a result of overlapping or, depending on the stimulus, the subject will perceive them as being aligned. In order to calculate the vergence angle using trigonometric techniques, the actual separation of the two targets and the observer's inter-pupillary distance has to be measured. In addition, the distance of the Nonius plane

from the frontal plane which passes through the centre of rotation of the observer's eyes is needed to complete the calculation (see Figure 2.3)

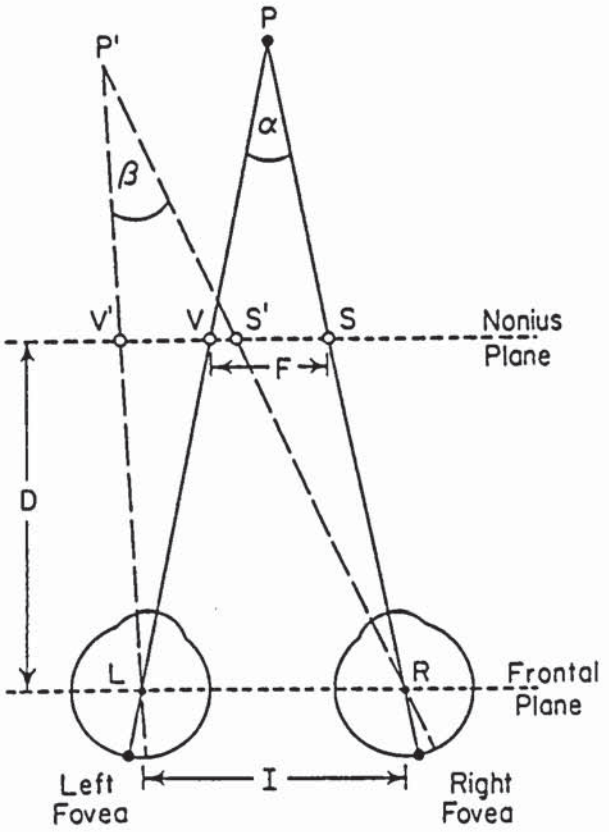

Figure 2.3: Logic of the Nonius system (from Miller, 1987). L and R represent the centres of rotation of the eyes. The image of the fixation point, P is projected onto each fovea. The vergence angle is α and D represents the distance between the frontal plane and the Nonius plane. V and S, the Nonius targets are identical and can be moved to any position in the Nonius plane. V is only visible to the LE while S is only visible to the RE. If the Nonius targets are placed in positions V and S, they intersect the visual axes and because they stimulate corresponding points, the subject perceives only one target. Points V' and S' represent alternative positions for the Nonius targets.

Owens and Leibowitz (1980) used a laser light Nonius alignment device to measure TVD in darkness. From a sample of 60 subjects they recorded a mean convergent TVD of 0.86 MA (3.22°). In addition Hogan (1985) recorded a mean convergent TVD in darkness of 0.93 MA for a group of 60 subjects. This result agrees fairly well with that obtained by Owens and Leibowitz (1980). In a more recent study, Owens and Wolf-Kelly (1987) measured TVD in 28 college students using a type of Nonius alignment technique. It differed from previously used devices in as much as the targets, although dichoptic, were not identical. The stimulus consisted of a spot light which was viewed through a Maddox rod by the left eye, producing the image of a red streak while simultaneously being viewed directly by the right eye. The subject reported the position of the streak relative to the spot of light which was then moved until alignment was achieved. The mean value of TVD recorded was 1.20 MA, larger than that recorded by both Hogan (1985) and Owens and Leibowitz (1980). One possibility for the discrepancy is that the technique employed by Owens and Wolf-Kelly (1987) could not

use vernier acuity to assess the alignment of the dichoptic stimuli used in their study as the targets were not identical.

ii) Stigmatometry

TVD and SOLA may be measured simultaneously using the haploscope-optometer, employing the principle of stigmatometry. This technique involves the subject rotating one arm of the haploscope and adjusting the Badal optometer on both arms of the haploscope until the two dim vertically dissociated pinpoints of light from the haploscope-optometer form the smallest diameter stigma and are in precise vertical alignment. When the stigma are at the position of sharpest focus, the distance from the eye at which they are imaged represents the level of SOLA. The position of the rotated haploscope arm represents TVD (O'Shea et al., 1988). Using this technique, O'Shea et al. demonstrated a mean TVD of 4.86 Δ eso (SEM ±0.84) for 30 subjects whereas Rosenfield and Ciuffreda (1990) reported a mean TVD of 2.31 Δ eso (SEM ±0.98) for 20 subjects using the same method. Such a discrepancy in the results reported may be due to large individual differences, which according to Owens and Leibowitz (1980), may alter significantly the average values obtained for small sample sizes.

iii) Infrared photography

IR photography, an objective method of assessing TVD and was employed by Fincham in 1962. He measured the position of the eyes in 31 subjects in total darkness and observed that when the subjects were instructed to look into the distance, the mean level of convergence was 0.41 MA (SD ±0.72) and ranged from 2.1 MA of convergence to 1.0 MA divergence. Although this method is objective, the accuracy of such a technique is disputable because subjective measurements have to be taken from the photographs and of the subject's inter-pupillary distance.

iv) Phi phenomenon

Levy (1969) employed a technique involving alternatively flashed monocular stimuli on a perimeter arc and the subjective perception of the phi phenomenon to determine the position of the eyes in darkness. Subjects observed a spot of light for one second followed by 3 s of total darkness then the light was displayed for a further second. The subject reported the position of the second stimulus with respect to the first. As the stimulus position remained the same between flashes, Levy suggested that the eyes would drift towards their 'resting' position during the period of darkness and as a result the second stimulus would appear displaced with respect to the first. Levy (1969) obtained a mean TVD of 2.6 MA for 31 subjects. Owens and Leibowitz (1983) suggested that the response strategies of the task requirement in Levy's study may have been contaminated by proximal vergence and may account for the larger value of TVD obtained compared to those reported in other studies (Ivanoff and Bourdy, 1954;

Fincham, 1962; Owens and Leibowitz, 1980; Hogan, 1985; Owens and Wolf-Kelly, 1987).

2.5B - The stability of tonic vergence disparity

Typical values of TVD range from about 0.5 to 0.9 MA of convergence (Fincham, 1962; Owens and Leibowitz, 1976; 1980) although large individual differences are not uncommon (Owens and Leibowitz, 1980) and may alter average values obtained from small sample sizes.

TVD , like SOLA appears to change transiently immediately after the introduction of darkness but settles to a more stable level within about 5 mins (Gilmartin et al. 1984) in the same way as SOLA varies immediately after the introduction of the open-loop condition (see section 1.7E). Fisher et al. (1988b) assessed both the short and long term stability of TVD. They measured TVD during a continuous 112 minute period in total darkness, at 30 minute intervals interspersed with periods of natural viewing over a 10 hr period and at intervals of approximately two weeks over a trial of 19 weeks. As with SOLA (see 1.7E), no significant systematic variation or large random fluctuations in TVD were noted during the course of days or weeks when interspersed with natural viewing conditions. During the condition of prolonged darkness, TVD tended towards the primary position, the position of the eyes becoming less convergent with time.

2.5C - The relationship between tonic vergence disparity and distance heterophoria

The relationship between TVD and heterophoria is of particular relevance to this thesis as it is explored in Chapter 6 of this thesis along with other aspects of the oculomotor profile as a possible way of distinguishing emmetropes, early-onset myopes and late-onset myopes.

O'Shea et al. (1988) measured, in addition to TVD, distance heterophoria under standard reduced illumination conditions (0.08 lux) and in total darkness using both the von Graefe and Maddox rod techniques (see Chapter 3 section 3.3A). TVD was measured with a haploscope-optometer and the relationship between distance heterophoria and TVD was investigated. They identified linear relationships between TVD and distance heterophoria measured under the conditions of reduced illumination and darkness by both techniques. However none of the four combinations of condition and measurement technique revealed a one to one relationship predicted by Maddox (1893) and Hebbard (1952). Both types of heterophoria measurement were more divergent than TVD, with the von Graefe (prism dissociation) technique producing the most divergent result of all. O'Shea et al. (1988) interpreted these results by considering the effects of proximity on TVD and of SOLA on the heterophoria measurements. They proposed that the

haploscope-optometer may induce a proximal effect, thereby contaminating the measured TVD. In addition, O'Shea and his co-workers suggested that in order to view a distant target, a decrease in accommodation relative to SOLA is necessary for accurate focus. Such a decrease in accommodation would produce a relatively more divergent 'phoria position compared to TVD due to the synkinesis between accommodation and vergence. The difference in 'phoria positions measured by the Maddox rod and von Graefe techniques may be explained by the effectiveness of the accommodative stimuli produced by each test. The Snellen letters of the von Graefe technique provide a very effective stimuli to accommodation ensuring accommodative relaxation whereas the Maddox rod technique is not as effective at relaxing the accommodative mechanism although an accommodative stimulus (the spot light) is still present (O'Shea et al., 1988).

Rosenfield and Ciuffreda (1990) attempted to clarify which of the two factors, proximity or accommodation, proposed by O'Shea et al. (1988), account for the discrepancy between distance heterophoria and TVD. In order to assess the role of accommodation in the distance heterophoria position, the heterophoria was measured under open-loop accommodation conditions so that AC would be eliminated. This was achieved by subjects viewing the target through 0.5 mm pinholes. TVD was measured on 20 young subjects using the haploscope-optometer, heterophoria was measured using the von Graefe method. The two measurements were not found to be significantly different and for 12 of the subjects examined, the difference between TVD and distance 'phoria was less than ±2 Δ. As with the results of O'Shea and his co-workers, a significant correlation was observed between TVD and distance 'phoria. As no significant difference between the measurements of TVD and distance 'phoria measured under open-loop conditions was demonstrated, Rosenfield and Ciuffreda (1990) conjectured that the previously observed variations (with heterophoria measured under closed-loop conditions) were produced by negative AC. However for about a third of the subjects examined, haploscopic measures of TVD were more convergent (in excess of 2 Δ) than the heterophoria. Such a finding suggests that in a proportion of subjects the proximity of the haploscope-optometer targets influences the measured TVD.

The conclusion that accommodative activity accounts for the discrepancy between TVD and distance heterophoria is supported by the findings of Owens and Tyrrell (1992). They demonstrated that a significant proportion of the discrepancy results from the relaxation of accommodation from the SOLA position to view a distant target thereby reducing AC. They also report that a model including both the subject's AC/A ratio (see Chapter 3 section 3.3) and magnitude of 'negative accommodation' (i.e. the difference between SOLA and the point of focus) produces more accurate predictions that are more strongly correlated with the measured 'phoria than those that do not include these factors.

2.5D - Relationship between tonic vergence disparity and steady-state open-loop accommodation.

It is well known that a synergistic relationship exists between the accommodation and vergence systems under normal viewing conditions and this relationship is discussed in the next Chapter but controversy exists as to whether this relationship is maintained under conditions of darkness. As both SOLA and TVD can be measured under conditions of darkness they are often compared to establish what, if any, relationship exists between these two measurements. Indeed, the relationship between TVD and SOLA is explored in Chapter 6 of this thesis.

Hogan (1985) measured TVD and SOLA simultaneously on 60 subjects using a Nonius alignment technique and a laser optometer, respectively. The results revealed a significant correlation ($r = 0.8$, $p < 0.001$) between these two measurements. The measurement techniques used are both subjective; furthermore, it has been demonstrated that SOLA measured by a laser optometer may be contaminated by proximal and cognitive effects thus altering the relationship between TVD and SOLA. Using similar equipment, Miller and Takahama (1988) failed to find any significant correlation between TVD and SOLA measured under various arousal states (e.g. mental activity, sudden noise, white noise, relaxation and others).

Different measurement techniques have been employed by various workers but apart from the studies of Ivanoff (1955), Hogan (1985) and Gray et al. (1993), most have failed to identify a direct correlation between TVD and SOLA. In contrast to Hogan (1985) and Miller and Takahama (1988), Epstein et al. (1986) monitored eye movements objectively as opposed to subjectively using a video camera in IR light while assessing SOLA using a laser optometer. Like Miller and Takahama (1988), Epstein and his co-workers did not demonstrate a significant correlation between the two measurements. However it must be remembered that for both studies, using a laser optometer to assess SOLA may have influenced the results. Subsequently Gray et al. (1993) used an objective IR optometer in conjunction with an objective eye tracking system to measure simultaneously TVD and SOLA. Their results indicate a significant correlation exists between these two measurements under passive open-loop photopic conditions and when concurrent mental effort is imposed.

Unlike Gray et el. (1993) who measured steady-state TVD and SOLA, Kotulak and Schor (1986a) measured SOLA and TVD continuously. Their data failed to demonstrate any correlation in the time domain, whereas the frequency domain did yield a correlation between the two measurements. Kotulak and Schor suggested that due to a correlation in the frequency domain being maintained under conditions of darkness, the cross-links between the two mechanisms, i.e. AC and CA, are not completely devoid of activity

under such conditions and may carry low amplitude noise between the two systems, at more or less fixed temporal frequency.

Bohman and Saladin (1980) found that in almost all of their 8 subjects, TVD was much more variable than SOLA which made it impossible to predict SOLA from just AC/A and TVD values. Other workers have included additional parameters in equations designed to predict SOLA from TVD measurements and vice versa. Wolf et al. (1990) found only a weak correlation between subjectively measured values of TVD and SOLA whereas the correlation between TVD and SOLA increased when the value of TVD was predicted by the equation:

$$\mathbf{TVD = DP + AC/A(TA - s)}$$

where DP is an abbreviation of distance heterophoria, TA is equivalent to SOLA and s represents the depth of focus of the eye. The relationship between TVD and SOLA described by the equation above indicates that accommodation and vergence are not uncoupled in darkness but remain related by neural cross-linkage. They suggested that the weak correlation between experimentally measured SOLA and TVD may be due to independent noise in the two systems under open-loop conditions. Rosenfield and Ciuffreda (1990) rearranged the equation suggested by Wolf et al. (1990) such that:

$$\mathbf{DP = TVD - AC/A(TA - s)}$$

Which indicates that the magnitude of the distance phoria is related to the output of both the accommodative and vergence responses. This idea is developed further in Chapter 6.

The existence of a direct correlation between TVD and SOLA is very much a matter of conjecture. Differences in the methodology used to measure TVD and SOLA are likely to account for the lack of agreement between results obtained by various workers. However the suggestion by Wolf et al. (1990) that independent noise in the two systems may reduce apparent coupling under open-loop conditions is worthy of note as methodology almost certainly has some influence on the apparent noise in the systems.

2.6 - VERGENCE ADAPTATION

Vergence adaptation is recognised clinically as the ability of patients to tolerate poorly centred spectacles, the failure of prescribed prism to produce a long term reduction in heterophoria or fixation disparity and the ability of anisometropes to demonstrate similar degrees of heterophoria regardless of the position of gaze. The initial stimulus to adaptation is retinal disparity. Forced vergences such as vergences induced by prisms which alter binocular parallax and lenses which alter the magnitude of AC and hence fusional vergence, produce the same degree of disparity across the whole motor field (i.e. concomitant disparities). Non-concomitant disparities are produced when the degree of

induced disparity varies with eye position, e.g. in extraocular muscle paresis and corrected anisometropes where the prismatic effects induced by their lenses vary with position of gaze. Vergence adaptation to concomitant disparity (also known as prism adaptation when the disparity stimulus is produced by a prism) is investigated in Chapter 7 of this thesis but a brief review of various aspects of vergence adaptation are given here.

2.6A - Historical aspects of vergence adaptation

Maddox (1893) stumbled upon the phenomenon of prism adaptation while measuring his own tonic vergence. He noticed that his 'phoria measured 5.5° instead of the usual 0.5° after wearing 11° base out prism for 10 minutes and took several minutes to return to the baseline value of 0.5°. Maddox proposed that the magnitude of tonic vergence had temporarily increased by 5°. He also noted that viewing a near object through positive lenses for a few hours decreased the near exophoria which he interpreted as increasing the tonic component of the vergence response. Maddox suggested that this adaptation occurs due to the altered balance of the other components of vergence i.e. the decrease of AC due to the lenses altering accommodative demand causes increased demand on fusional vergence. He noted that vergence adaptation may facilitate the adjustment of the eyes to new spectacles and be of importance in visual training.

Schubert (1943) was the next researcher after Maddox (1893) to make reference to vergence adaptation. He noted that a hyperphoria induced by vertical prism reduced back to its baseline value (pre-adaptation 'phoria position) after a short time of wearing the prism. Morgan (1947) reported that successive testing of fusional reserves for both base out and base in prism directions resulted in a shift in the lateral phoria in the same direction as the induced disparity caused by the prisms. Later, Ellerbrock (1950) confirmed Schubert's findings of vertical 'phoria adaptation to prism. Carter (1963) reported that a subject who originally displayed 1 Δ left hyperphoria kept displaying about 1 Δ of hyperphoria after progressively increasing the amount of prism in the spectacles up to a level of 3 Δ. Moreover on removal of the prism from the spectacles, the left hyperphoria once again measured about 1 Δ.

Carter (1963; 1965) demonstrated that prolonged viewing through base in or base out prism not only induces changes in the measured 'phoria, but also in fixation disparity and fusional reserves. He noted that when the opposite base prism to the baseline heterophoria was first introduced, subjects typically showed an increase in the lag of the vergence response to the demand i.e. an increase in fixation disparity. However this increase in fixation disparity was shown to disappear within 5 to 15 minutes of continued viewing through the prism; in addition, lateral phoria concurrently returned to the original baseline value. Carter found that with progressive increments of prism, the fixation

disparity and phoria measurements of some subjects adapted to levels of prism up to 10 Δ base in and 32 Δ base out. Moreover, fixation disparity curves and phoria measurements obtained with the prism in place were very similar to those measured prior to viewing through the prism. Using one subject, Carter demonstrated that the divergence reserve after prism adaptation to 9 Δ base in was within 2 Δ of the original value recorded before adaptation took place. Ogle et al. (1967) also demonstrated that the magnitude of both horizontal and vertical fusional reserves after adaptation to prisms remain the same as those measured before adaptation occurred.

2.6B - Measuring vergence adaptation

As already mentioned, the stimulus to vergence adaptation is retinal disparity which can be induced either by ophthalmic lenses or by prisms. The effect of prolonged wearing of prisms or lenses on the vergence system may be assessed by either measuring the magnitude of heterophoria or fixation disparity over the adaptation period. It is important to note that heterophoria may be measured under associated conditions (fixation disparity) where a limited amount of sensory fusion due to foveal binocular vision is permitted or under dissociated conditions in which no foveal sensory fusion is permitted. Although strictly speaking fixation disparity is a form of heterophoria measurement, the term heterophoria is usually used to describe dissociated heterophoria measurements.

Heterophoria method

Many workers have used heterophoria as an indication the level of vergence adaptation that has occurred (Maddox, 1893; Carter, 1963; Henson and North, 1980 and others). The use of fixation disparity techniques to monitor adaptation has been questioned by Henson and North (1980) because Carter (1963; 1965) considered that prism adaptation consists of a change in the innervational tonus of the extraocular muscles (as did Maddox, 1893) and Alpern (1969b) considered 'phoria, not fixation disparity, to be a direct measurement of that tonus. Consequently Henson and North developed a sophisticated technique for measuring heterophoria and it has been used in several studies investigating vergence or prism adaptation (Dowley, 1990a; 1990b; Henson and Dharamshi, 1982; North and Henson, 1981; 1985; North et al., 1986; 1989; 1990; Sethi and Henson, 1984; Sethi, 1986a and others).

Henson and North (1980) used a 'flashed' Maddox rod and tangent screen to measure the heterophoria during prism adaptation. A photographic shutter was used to limit the exposure time of the Maddox rod to 250 ms and was electronically connected to the test chart in such a way that the spot of light used to measure the heterophoria was only on while the shutter was open and the illumination of the test chart was only turned off during the time that the shutter was open. To assess adaptation to prisms the subjects would experience 15 s binocular viewing through the prism after which they were

occluded for a further 15 s and the Maddox rod was positioned infront of the occluded eye. Immediately after the 15 s occlusion a 'phoria measurement was recorded and binocular vision through the prism was once again permitted for a further 15 s after the removal of the Maddox rod. This technique could be repeated as many times as was desired and removal of the prism allowed the measurement of recovery rates. The period of occlusion before the measurement of 'phoria is necessary in order to allow the fusional element of convergence to decay (Ludvigh et al., 1964; Schor, 1979b, see section 2.6F) so that true adaptation is being measured. Henson and North chose the value of 15 s as they believed that after this time, the 'phoria had stabilized, this was checked using occlusion times of 30 and 60 s which showed a very slight migration of the 'phoria back to the baseline value (see section 2.6C for a discussion on the length of the dissociation period).

Fixation disparity method

Workers such as Carter (1963) and Schor (1979a; 1979b) have used fixation disparity as the measure of vergence adaptation. A lag in the vergence response compared with the vergence stimulus is not uncommon (Ogle et al., 1967). The lag of convergence and divergence responses are termed *exo* and *eso* fixation disparity, respectively. Fixation disparity is often plotted as a function of prism vergence stimulus (forced duction) to represent vergence adaptation unlike heterophoria measurements which are usually plotted against time. Ogle classified fixation disparity plotted as a function of prism vergence stimulus: type I indicates that the magnitude of fixation disparity increases approximately equally to both divergent and convergent stimuli; type II represents fixation disparity curves which show that errors of convergence are smaller than errors of divergence; type III describes fixation disparity curves showing greater errors to convergent than divergent stimuli and type IV, which is only found in some people with abnormal binocular vision shows a nearly constant fixation disparity and an abnormally small amplitude of vergence responses to prism.

Fixation disparity is measured using a Nonius alignment technique in a similar manner to TVD. In contrast to TVD measurement, binocular targets are present during fixation disparity assessment and surround the Nonius lines so that sensory fusion can take place. The prismatic stimulus can be progressively increased after periods of monocular occlusion (necessary to dissipate the fast fusional reflex) and a fixation disparity forced duction curve can be plotted. The flatter the fixation disparity curve appears, the greater the subject's adaptation ability.

The amount of fixation disparity recorded to a particular stimulus is dependent partly on the position of the binocular targets which induce fusion. If the binocular targets are placed at some distance from the fovea so there is a predominance of peripheral over

central fusion cues, the measured fixation disparity increases markedly with increasing prism vergence stimuli, i.e. the ability to adapt to prisms appears to decrease. In contrast, if the binocular targets stimulate the exact centre of the fovea, fixation disparity is almost reduced to zero. A blanked out central area of 1.5° has been shown to be optimum when measuring fixation disparity during vergence or prism adaptation.

2.6C - Time-course of vergence adaptation

Ogle and Prangen (1953) measured the time-course of adaptation on 7 subjects with the fixation disparity technique. They found the time-courses to be exponential with most of the adaptation occurring within the first few minutes. Further, the time taken for full adaptation to take place after fusion of the fixation targets was between 3-10 mins. In a much more recent study, Henson and North (1980) using a heterophoria technique confirm that prism adaptation occurs exponentially with time. Using 2 Δ base-up and base-down, Henson and North (1980) measured the time-course of adaptation, t, (i.e. the length of time it takes for 63% of adaptation to be completed) and found t = 80 s for both conditions. They also reported that 85% of adaptation was complete after 3.5 min. The time-course of adaptation may be influenced by the length of the period of dissociation between measurements which is designed to allow the fast fusional vergence response to decay (see section 2.6F). Dharamshi (1983) demonstrated that time constants increased from 3.2 to 16 mins for adaptation to 3 Δ base up when the dissociation period increased from 15 s to 90 s. She conjectured that in the absence of binocular vision, the response from the slow, adaptive fusional system starts to decay (see section 2.6F).

2.6D - Vergence adaptation and test distance

An asymmetrical adaptation to base-out and base-in prisms at distance has been found in all studies (Carter, 1965; Ogle et al., 1967; Schor, 1979a; Henson and North, 1980; North et al., 1990; and others). Ogle et al. (1967) as well as investigating the adaptation ability of subjects with binocular problems, also measured horizontal adaptation in one normal subject. The normal subject demonstrated better adaptation to base-out prism than to base-in. Schor (1979a) measured adaptation to 1.5, 3, 4.5 and 6 Δ base-out and base-in using a fixation disparity technique at 5 feet. He found that 8 out of 14 subjects adapted more readily to base-out than base-in prism whereas for the remaining 6 subjects the opposite was true. No subjects showed symmetrical adaptation to both prism directions. Henson and North (1980) measured the adaptation ability of 8 subjects to prisms using the 'phoria technique with the target at 4 m and 50 cm. They reported the average time course of adaptation to 6 Δ base-out (t = 38 s) was significantly quicker than to 6 Δ base-in (t = 158 s) at distance. In contrast the near condition revealed no asymmetry between the adaptation responses to base-in and base-out prisms. Henson and North found that compared with distance, base-in adaptation gets faster (t = 132 s) and base-out adaptation gets slower (t = 132 s). They explained their findings by

suggesting that the extraocular motor system deals with divergent disparity frequently at near (due to physiological exophoria) but rarely at distance whereas convergent disparity is rarely dealt with at near but frequently at distance.

In conclusion it could be said that on average adaptation to base-out is faster than to base-in at distance. At near, the adaptation responses are more symmetrical although for both testing distances large inter-subject variations exist. Furthermore due to the discrepancies in the time-course of the adaptation for distance and near, it follows that adaptation occurs independently for these two conditions (Henson and North, 1980).

2.6E - Vergence adaptation and stimulus exposure duration

When adaptation is monitored by the length of time it takes for the 'phoria or fixation disparity to reach baseline values after the introduction of a prism, the adaptation process has been shown to occur very quickly, within a few minutes (Ogle and Prangen, 1953; Henson and North, 1980). If adaptation is assessed by monitoring the rate of adaptive decay (also known as recovery) upon dissociation, the time taken for adaptation to be complete is much longer.

Mitchell and Ellerbrock (1955) found that the shape of the forced duction fixation disparity curve changed depending on how long the stimulus prism was in place. They found a significant reduction in eso-fixation disparity after prolonged forced convergence (base-in prism). No such changes were reported following prolonged forced divergence; in contrast Carter (1965) and Ogle et al. (1967) demonstrated that both eso and exo fixation disparities can be reduced with long term wearing of prism. Ludvigh et al. (1964) found that if forced convergence (8.8°) was induced for 5 s, the adaptation effect completely decayed within 15 s, whereas when the forced convergence was induced for 30 s adaptation was more complete and the rate of recovery decreased. Ellerbrock (1950) measured the rate of recovery following adaptation to vertical prisms and found it to be inversely proportional to the duration of the stimulus when the stimulus duration did not exceed 2.5 hr. Sethi and Henson (1984) measured adaptation to 2 Δ base-up over a prolonged period (22 hr); their data indicates that adaptation became more complete as time progressed, indicating that recovery would become slower with increased stimulus duration. They suggested that Ellerbrock's (1950) findings may be contaminated by the presence of peripheral vision during measurements and peripheral disparities are powerful cues to the vergence response in the absence of foveal fusional targets.

Sethi and Henson (1984) hypothesized that, in addition to recovery being negligible when adaptive change becomes complete after prolonged stimulus duration, adaptation to further vergence stimuli would have the same time-course as that measured before adaptation had taken place. Sethi and Henson criticized the use of 'phorias or fixation

disparities as measurement criteria for prism adaptation, they argue that these techniques underestimate the time taken to fully adapt to induced prismatic deviations.

2.6F -The mechanism of vergence adaptation

In a clinically-orientated paper, Carter (1963) disagreed with the conclusions of Hofstetter (1951) and Morgan (1960) that adaptive changes at near are the result of differences in the proximal component of vergence. He suggested that adaptation at distance and near is a conditioned reflex of the vergence system induced by FV.

The ideas of Carter are partly in agreement with the adaptation model proposed by Schor (1980). This model proposed that adaptation occurs in two stages: initially induced disparity drives the fast fusional response which is followed later by a slow tonic response (Figure 2.4). The fast fusional response is temporary whereas the tonic response represents the more sustained process of adaptation. Schor (1979b) made two observations which support this theory: the stimulus for a slow tonic response cannot be disparity induced, since the disparity is reduced within one second by the fast fusional response (Rashbass and Westheimer, 1961); also, a minimum of 30 s of disparity-induced vergence is required to obtain a sustained alteration in the 'phoria position and hence slow tonic adaptation occurs well after retinal image disparity has been eliminated by the fast fusional response. Schor cites Henson and North (1980) and Schor (1979a) in support of this second observation, although it is difficult to substantiate this minimum time requirement from the references given. However, Fisher et al. (1990) found a small but sustained TVD change 2 mins after only 15 s of forced vergence.

As further support of his model, Schor cites Ellerbrock (1950) who demonstrated the slow onset of adaptation and Carter (1963, 1965) who mentions that adaptation is very slow until fusion has been achieved. Sethi and North (1987) reported a similar slow rate of adaptation to prism magnitudes outside the range of fusional amplitude, but found that if the prism value was increased in 2 Δ steps, allowing fusion each time, higher values of prism could be adapted. Robertson and Williams (1986) also concluded that sensory fusion is required for prism adaptation to occur after observing an individual who suffered from post surgical diplopia due to a constant alternating concomitant exotropia. Once the diplopia had been relieved by the use of prisms, they found that over a period of 7 months, the exotropia reduced through vergence adaptation to an exophoria, indicating the importance of sensory fusion in prism adaptation. Carter (1965) suggested that poor sensory fusion is a partial cause of high heterophoria, rather than being the result of high heterophoria.

Figure 2.4: Schematic representation based on Schor's model of the relation of fast-fusional vergence, slow fusional vergence and fixation disparity (from Owens and Leibowitz, 1983)

2.7 - SUMMARY

The function of the vergence mechanism is to align the visual axes of the two eyes so that an image of the object of regard falls on corresponding points of the two retinae. By eliminating retinal disparity, diplopia and confusion are avoided. Under normal binocular viewing conditions, vergence and accommodation interact closely to produce a clear single image. Chapter 3 examines this relationship between accommodation and vergence. In Chapters 6 and 7 various aspects of the vergence mechanism are investigated in an attempt to determine whether oculomotor function has a part to play in the development of certain types of myopia.

CHAPTER 3

THE RELATIONSHIP BETWEEN ACCOMMODATION AND VERGENCE

3.1 - INTRODUCTION

In Chapters 1 and 2, accommodation and vergence were considered as components of the oculomotor response operating in isolation. However, under normal closed-loop binocular viewing conditions these two functions interact, together with pupil miosis producing a triad of near vision responses. Thus, when an object is viewed, the eyes accommodate to bring the image into focus, converge to eliminate retinal disparity and the pupil constricts for reasons which are not entirely clear. These responses are normally associated such that accommodation initiates both pupil constriction and a vergence response (accommodative convergence) and vergence drives accommodation (convergent accommodation) and, to a lesser degree than accommodation, pupil miosis. However, pupil constriction does not drive either accommodation or vergence thus the pupillary mechanism and its responses lie outside the scope of this thesis. In contrast, it is generally accepted that a synergistic link does exist between accommodation and vergence and it is this relationship which will be discussed in this Chapter.

3.2 - ACCOMMODATIVE CONVERGENCE

Müeller was the first to demonstrate synergism between accommodation and convergence in 1826. He, like many subsequent researchers reported that a change in accommodative state is associated with a change in vergence when the two eyes are dissociated (Morgan, 1944b; Fry, 1953; Heath, 1956b and others). The convergence associated with an increase in accommodative demand is known as accommodative convergence (AC). It has been described as 'a blur-driven change in the horizontal position of the eyes' (Ciuffreda and Kenyon, 1983). Although once thought to be a monocular response when assessed under dissociated conditions (Alpern and Ellen, 1956), AC has since been shown to be a binocular response with the movements of both eyes occurring in the direction (but not amplitude) predicted by Herrings Law of Equal Innervation (Kenyon et al., 1978). AC is considered to be the cross-link between the accommodative and vergence mechanisms.

3.3 - THE AC/A RATIO

The AC/A ratio is of particular relevance to this thesis as it represents the gain of AC i.e. the change in magnitude of AC (measured in prism dioptres, Δ) for every dioptre change in accommodation (D). When a change in accommodation represents the change in the *stimulus* to accommodation an assessment of the stimulus AC/A ratio is made. However when the change in accommodation is measured as the change in the *response*, the response AC/A ratio is measured. When measuring the AC/A ratio it is important to distinguish whether it is the stimulus or response ratio as the values obtained do vary (see section 3.3B).

3.3A - AC/A ratio measurement techniques

Various experimental techniques have been used to measure AC/A ratios. To measure AC, the vergence loop has to be open by eliminating the stimulus to fusion. When eliminated, an increase in the accommodative response (AR) is accompanied by an increase in AC. Under closed-loop vergence conditions the increase in AC cannot be easily quantified because the increase in AC is always associated with a decrease in fusional vergence (FV) in order to avoid retinal disparity and maintain a constant aggregate vergence response.

The AC/A ratio can be determined by measuring the vergence of the two eyes under open-loop conditions at two or more different accommodation levels. The change in vergence represents the gain in AC providing that tonic vergence and proximal vergence remain constant. There are three principal techniques for measuring AC/A ratios namely;

i) Heterophoria method
ii) Gradient test
iii) Fixation disparity method

For a more extensive review of the techniques employed to measure AC/A ratios see Borish (1970).

i) Heterophoria method

This method involves measuring the distance and near heterophorias; the AC/A ratio is derived by dividing the difference between the two heterophoria measurements by the change in accommodative level. This technique does assume that the difference in heterophoria is due solely to a change in AC but as already discussed in Chapters 1 and 2 (sections 1.5B and 2.4E, respectively), variations in target distance will produce proximal cues to both accommodation and vergence; therefore this method does not provide an absolute measure of the AC/A ratio.

ii) Gradient test

The gradient test is similar to the heterophoria method in as much as the AC/A ratio is determined by measuring the heterophoria at two accommodative stimulus levels. In order to eliminate proximal effects induced by the target distance, accommodation is stimulated by the use of ophthalmic lenses. However, the variation in lens power does alter the spectacle magnification and thus the induced change in apparent size may still drive proximally-induced accommodation (PIA - see section 1.4B). However, results from Chapter 8 of this thesis suggest that size does not act as a cue to PIA. The AC/A ratio is calculated by subtracting the heterophoria measurements obtained under different accommodative levels and dividing the result by the change in accommodation induced by ophthalmic lenses. For both the heterophoria method and the gradient test, if the change in the *stimulus* to accommodation is used in the calculation, the stimulus AC/A has been measured whereas the response AC/A is measured when the denominator represents the actual change in accommodative *response*.

iii) Fixation disparity method

This technique computes the AC/A ratio by dividing the value of prism required to produce a given fixation disparity by the value of spherical lens power which produces the same magnitude of fixation disparity. There are several advantages to this method, not least the fact that fusion is maintained and thus viewing conditions are more normal. Good subject co-operation and accurate observation is essential when using the fixation disparity technique; ideally the subjects should be trained before commencing data collection which means that this method of assessing AC/A is far more time consuming than either the heterophoria technique or the gradient test.

3.3B - The effect of measurement technique on the AC/A ratio

The value obtained for the AC/A ratio depends upon the type of AC/A ratio measured i.e. stimulus or response and also the measurement technique employed. Several studies have reported mean values of the stimulus AC/A ratio between 3-5 Δ/D (Morgan 1944b, Morgan and Peters, 1951; Ogle and Martens, 1957; Ogle et al. 1967). Mean response AC/A ratios are generally higher, in the order of 4-7 Δ/D (Flom and Takahashi, 1962; Rosenfield and Gilmartin, 1987a). Alpern (1958b) proposed that AC is proportional to the effort of accommodation, thus suggesting that the AC/A ratio is more accurately measured by the response not the stimulus AC/A. Many people regard the response AC/A to reflect more accurately the state of oculomotor balance although the stimulus AC/A ratio is clinically easier to measure and still provides useful information on oculomotor balance.

The degree of dissociation of the eyes affects the value of AC/A ratio obtained (Hebbard, 1960). The measurement techniques which involve assessing heterophoria, namely the

gradient test and heterophoria technique, totally dissociate the eyes thus eliminating the stimulus to fusion and consequently open the vergence loop. In contrast, the vergence loop is not opened for the measurement of fixation disparity; with the exception of two monocular Nonius lines positioned within the central visual field, normal binocular vision is permitted, allowing the stimulus to fusion to act across the peripheral visual field. Under such conditions when both disparity and blur cues are present, AC occurs secondary to FV (see Chapter 2 section 2.4D) thus making it difficult to assess the contribution of AC.

Although the fixation disparity technique more closely mimics normal conditions, it can be argued that because the vergence loop is closed during the measurement of fixation disparity it may not be possible to differentiate AC from other components of the vergence response e.g. FV. The differences in the state of the vergence system (i.e. open- or closed-loop) when the fixation disparity method as opposed to when the gradient test is used to assess AC/A may account for the differences in linearity and magnitude of the AC/A ratio obtained. However, Ogle and Martens (1957) reported a mean AC/A ratio for both the 'phoria method (N = 28) and the fixation disparity method (N = 104) of 3.5 Δ/D ±1.2 implying that the method of measurement does not affect the magnitude of the AC/A ratio. In contrast, Hebbard (1960) obtained a poor correlation between the results of these two techniques.

It has been suggested that the discrepancy in AC/A ratios measured by different techniques is due to an increase in stimulation to both accommodation and disparity vergence under the binocular viewing conditions of the fixation disparity method (Ogle et al., 1967). However, Ramsdale (1979) noted only marginal differences in the accommodative responses of 9 subjects viewing targets under binocular and monocular conditions. In addition, Schor (1983) also felt it unlikely that differences in the accommodative response under monocular and binocular viewing conditions are responsible for the reported discrepancies in AC/A ratios measured under associated and dissociated vergence conditions. He suggested that the discrepancies may be the result of changes in the output of convergent accommodation (CA - see section 3.4) which has been shown by Semmlow and Hung (1979) to increase under closed-loop conditions when a stimulus to vergence produces an increase in FV. A rise in CA will be accompanied by a drop in blur-driven accommodation in order to maintain a stable aggregate accommodative response and the fall in blur-driven accommodation will result in a decrease in AC and hence produces a decrease in AC/A measured with the fixation disparity method.

3.3C - The effect of age on the AC/A ratio

When considering the effect of age on the AC/A ratio large discrepancies between the stimulus and the response AC/A ratios exist because the onset of presbyopia affects the response AC/A to a greater degree than the stimulus AC/A. In fact several workers have reported that the stimulus AC/A does not change significantly with the onset of presbyopia (Tait, 1951; Morgan and Peters, 1951; Alpern and Hirsch, 1960; Breinin and Chin, 1973). Breinin and Chin (1973) report that the stimulus AC/A remains unchanged between the ages of 16-52 years. In contrast, the response AC/A has been found to increase significantly between the ages of 40 - 50 years, coinciding with the onset of presbyopia (Fry,1959; Breinin and Chin, 1973). Fry (1959) measured his own response AC/A using a haploscope optometer and noted that it increased from 5.7 Δ/D at age 29 to 31.5 Δ/D at age 50.

3.3D - Linearity of the AC/A ratio

Both the stimulus and response AC/A ratios are generally considered to be linear throughout the intermediate accommodative range for the majority of people. Moreover, the range over which the AC/A is linear coincides with the linear portion of the stimulus/response curve (Chapter 1 section 1.6A). The AC/A ratio often appears non-linear when positive lenses are used to relax accommodation thus prompting the suggestion that only negative lenses should be used (Ogle and Martins, 1957; Ciuffreda, 1992). This point was considered when choosing the methodology used in this thesis to measure AC/A (see Chapter 6 section 6.2B).

3.3E - The repeatability of the AC/A ratio measurement

Prior to a paper by Manas and Shulman (1954) many workers such as Hofstetter (1942) and Morgan (1944b), had concluded that the AC/A ratio was a stable measurement. However Manas and Shulman (1954) point out that the experimental data of these workers reveal a standard deviation of approximately 40% of the mean AC/A ratio which encouraged them to investigate the constancy or repeatability of the AC/A measurement.

Using 22 experienced observers, Manas and Shulman (1954) measured, using the heterophoria technique and the gradient test the stimulus AC/A ratios twenty times for each subject. They reported that although the ratios were generally correlated between the two methods, the variability of the gradient method was approximately twice that of the heterophoria method. Manas and Shulman used the variability in the measurements (≈ 50%) as evidence that the AC/A ratio is a "psychophysiological variable that will fluctuate in amount depending upon the exigencies of the day and the demands of the environment". They suggested that the magnitude of fluctuation in the AC/A measurement was of the same order as those experienced when measuring the distance and near heterophorias and since 'phoria was not constant, it suggested to them that the

AC/A ratio could not be constant either. Subsequently, Hirsch, (1954) suggested that Manas and Shulman had merely demonstrated that repeated measurements of the AC/A ratio revealed the inherent variability present when any set of measurements of a physiological system are repeated. Whether the variations are due to measurement error or other factors is still open to question although most workers now accept that there is a constant relationship between accommodation and convergence.

3.4 - CONVERGENT ACCOMMODATION

Cross in 1911 was the first person to formulate the concept of convergent accommodation (CA). Fry (1940) defined CA as "that amount of accommodation which is fully associated with convergence when the need for exact focusing has been eliminated". CA is considered to be the cross-link between the vergence and accommodation mechanisms and can be demonstrated if steady-state open-loop accommodation (SOLA) is measured at 2 vergence stimulus levels; an increase in the vergence response will be accompanied by an increase in CA. However, under closed-loop conditions, the increase in CA induced by an increase in the vergence response will be accompanied by a decrease in blur-driven accommodation in order that the aggregate accommodative response remains stable thus making it impossible to determine the contribution of CA.

3.4A - Convergent accommodation versus disparity-induced accommodation

It is important to mention here the difference between disparity-induced accommodation (DIA) and convergent accommodation. CA can only be assessed while the accommodative loop is open. When the accommodative system is in its natural closed-loop condition and normal negative feedback systems are allowed to operate, DIA can be assessed. If the disparity stimulus is modified by the use of prisms or lenses, any change in the accommodative level is referred to as DIA under closed-loop viewing conditions and CA under open-loop viewing conditions. Many workers measure DIA as it is not easy to attain the condition whereby the accommodative loop is open while the vergence loop is closed although a new method of achieving such conditions is described in this thesis (see Chapter 5).

3.5 - THE CA/C RATIO

The CA/C ratio represents the gain of CA due to the change in convergence (Kent, 1958). It can be measured in dioptres/meter angle (D/MA) where 1 MA is equal to the reciprocal

of the distance (m) between the point of fixation assumed to lie on the median line and the base line of the eyes (Millodot, 1986). The disadvantage of this unit of measurement is that 1 MA does not represent the same deviation for all people as it is dependent on the individual's inter-pupillary distance. The CA/C ratio can also be measured in dioptres/prism dioptre (D/Δ) where 1 Δ represents a deviation of 1 cm on a flat surface 1 m away from the prism (Millodot, 1986). As 1 MA ≈ 6Δ, the CA/C ratio is commonly expressed in D/6Δ.

The CA/C ratio has not attracted as much attention as the AC/A ratio primarily because of the difficulties in measuring it; CA only becomes manifest under open-loop accommodative conditions. CA was tentatively measured by Morgan in 1952 and later by Fincham and Walton (1957), Kent (1958) and Balsam and Fry (1959) their results indicate that the average CA/C ratio in young adulthood is approximately 1 D/MA (≈ 1 D/6Δ). More recently, Rosenfield and Gilmartin (1988b) obtained an average CA/C ratio of 0.4 D/6Δ when they measured CA objectively using an IR optometer.

3.5A - CA/C ratio measurement techniques

In order to measure the CA/C ratio, the amount of accommodation stimulated solely by convergence while maintaining fixation has to be determined. Thus the accommodative loop has to be opened while the vergence loop remains closed. Morgan (1954) and later Kent (1958) measured the CA/C ratio using the principle of stigmatoscopy to measure accommodation while simultaneously measuring convergence using the haploscope. In stigmatoscopy, the target is a very small pinpoint of light which does not stimulate the accommodative response; thus the accommodative loop is opened even though disparity cues are still available to the vergence mechanism. Fincham and Walton (1957) and Balsam and Fry (1959) used a haploscope-optometer with artificial pupils to open-loop the accommodative system and measure the CA/C ratio. Rosenfield and Gilmartin used two methods of opening the accommodative loop while maintaining closed-loop vergence responses;

i) the subject viewed near-type at 33 cm through 0.5 mm pinhole pupils

ii) the subject viewed a 0.1 mm diameter spotlight at distances of 33 and 100 cms.

Accommodation responses were measured objectively from the left eye while convergence was stimulated by placing 3 and 6 Δ base-out prisms before the right eye.

3.5B - The effect of age on the CA/C ratio

The most comprehensive study on the CA/C ratio was undertaken by Fincham and Walton (1957). They measured the CA/C ratios of 22 Optometry students using a haploscope-optometer with 0.5 mm exit pupils to open-loop the accommodative system. Fincham and Walton report that up to the age of 24 there is a one-to-one relationship

between CA and convergence when measured in D/MA. However over the age of 24, they reported a steady decrease in CA/C.

Kent (1958) reported that the magnitude of induced CA is dependent upon the amplitude of accommodation; for those subjects with amplitudes in excess of 10 D (determined by the push-up method) convergence is capable of inducing the correct or an excessive amount of accommodation to focus the eyes on the point on which they are converging. As the amplitude of accommodation drops, so does the magnitude of CA, thus other components of the accommodative response become increasingly prominent in the aggregate accommodative response. As it is well known that the amplitude of accommodation decreases with age both these studies and that of Balsam and Fry (1958) show that the CA/C decreases with age which is in contrast to the response AC/A which remains relatively stable up to the age of 45. This point is considered further in Chapter 6 when the magnitudes of the CA/C and AC/A ratios are compared.

3.5C - Linearity of the CA/C ratio

Morgan (1954) obtained results from one subject which suggested the relationship between CA and convergence was not linear, whereas the results obtained by Balsam and Fry (1959), for intermediate CA values, show that the CA/C ratio appears approximately linear. Fincham and Walton (1957) also found the relationship between convergence and CA to be fairly linear, like the relationship between accommodation and AC. Differences between the nature of the AC/A and the CA/C ratio were reported by Fincham and Walton whose measurements showed that whereas convergence can alter accommodation considerably while the stimulus distance is fixed due to the depth-of-focus and other physiological attributes of the eye, the converse does not apply. Modification of the vergence response by accommodation while maintaining single binocular vision is minimal because small amounts of binocular disparity are poorly tolerated.

Accommodation and vergence responses represent the output of two different motor mechanisms; the autonomic nervous system activates ciliary smooth muscle whereas the somatic nervous system initiates contraction of striated skeletal muscle (see Chapters 1 and 2 sections 1.2A and 2.2A respectively). Brecher (1959) suggested that due to differences in the musculature and latencies of accommodation and vergence mechanisms (see section 3.6) one would predict that the AC/A ratio would be non-linear. However as this does not appear to be the case, he concluded that a control feedback mechanism must exist. Indeed the frontal lobes of the brain have the function of coordinating somatic and autonomic function which is what is occurring here. The next section looks at differences in the temporal characteristics of AC and CA which, as mentioned above, are related to the differences in the motor mechanisms involved.

3.6 - TEMPORAL CHARACTERISTICS OF ACCOMMODATIVE CONVERGENCE AND CONVERGENT ACCOMMODATION

3.6A - The dynamics of accommodative convergence

Wilson (1972) reported that both accommodative convergence and accommodative divergence yield similar mean latencies of about 250 ms whereas Semmlow and Wetzel (1979) report asymetrical mean latencies of 300 and 380 msec for convergent and divergent stimuli respectively. In addition, Semmlow and Wetzel measured the time constant, t, which represents the time taken for the response to reach 63% of its final value and like latency, the results were asymmetrical for convergence and divergence (t = 430 and 660 msec respectively).

The latency of FV has been reported by many researchers to be quicker than that of AC. Krishnan et al. (1973) found that the average latency of FV varies between 130-250 msec but is usually around 160 msec. Semmlow and Venkiteswaren (1976) report that FV has a latency period of 160 msec and the time constant is 300 msec. In a more extensive study, Semmlow and Wetzel (1979) determined the latency and time constant for positive fusional vergence to be 180 msec and 200 msec respectively and for negative fusional vergence to be 290 msec and 320 msec respectively.

Many workers originally believed that the vergence response was initiated by AC whereas the role of fusional vergence was to refine the response to eliminate retinal disparity (see Chapter 2 section 2.4D). However, more recently researchers have argued that because the latency of AC is longer that that of FV, AC does not contribute to the initial stages of the vergence response (Semmlow and Wetzel, 1979; Hung et al. 1983). Moreover Hung and his co-workers noted that the initial stimulus to accommodation and vergence consists of a blurred retinal image falling on an eccentric portion of the retina which Semmlow and Tinor (1978) had previously shown to be a poor stimulus to AC because as target eccentricity increases, the effectivety of the target to initiate an accommodative response decreases. As the fusional vergence response brings the target closer to the fovea, it acts as a more potent stimulus to accommodation (and therefore AC) so that the magnitude of AC increases. Hung et al. (1983) suggested that the longer latency of AC compared with FV may relate to the decrease in the effectivety of an eccentric stimulus.

3.6B - The dynamics of convergent accommodation

The dynamics of CA are much more difficult to measure than AC because the rotation of the globe interferes with the measurement of accommodation. Using a dynamic optometer to measure the position of the III Purkinje image on 2 subjects, Krishnan et al (1977) measured the latency of CA for small step changes in disparity and report that the

latency is between 250-300 msec. The time taken to complete the positive CA response after the stimulus onset was between 900-1100 msec; the responses (both latency and response velocity) were found to be slower for negative CA.

The latency of CA appears then to be similar to if not slightly quicker than that of AC and blur induced accommodation (≈360 msec - see section 1.4B). The discrepancy between the latencies of CA and blur-induced accommodation seem to indicate that whenever blur and disparity stimuli occur simultaneously (as in near vision), the disparity driven components i.e. CA and FV are much quicker to respond than those components driven by blur (Hung et al., 1983), which is possibly due to the fact that the initial stimulus falls on an eccentric portion of the retina and target eccentricity degrades the effectivety of the blur-stimulus to accommodation.

3.7 - MODELS OF ACCOMMODATION-VERGENCE INTERACTION

In Chapters 1 and 2 it was explained that both the accommodation and vergence mechanisms are examples of negative feedback systems. This section reviews in more detail the models of accommodation and vergence and in particular the interactions between the two and their relevance to this thesis.

Single interactive models of accommodation and vergence

Early models of the relationship between accommodation and vergence only recognised the existence of one cross-link, either AC or CA hence they are known as single interactive models, the first of which was proposed by Maddox in 1886. Maddox's model recognised that accommodation could drive vergence (AC) but failed to recognise the role of CA as a cross-link between vergence and accommodation. He assumed that AC provided the major drive in the vergence response while FV was used for fine-tuning of the system. In contrast, Fincham and Walton (1957) suggested that the disparity driven components to accommodation and vergence namely FV and CA predominate during near vision, with CA producing most of the required accommodation. Today, it is generally accepted that the interaction between accommodation and vergence is a two-way process with both AC and CA acting as the cross-links between the two systems. However, the major stimulus drive in the binocular response (i.e. blur or disparity) is still disputed.

The dual interactive theory

In contrast to Maddox, Westheimer (1963) suggested that the binocular response was a dual process with separate vergence and accommodation control centres interacting by separate neural pathways. He produced the first block diagram to include both

accommodation and vergence feedback control systems, with the mutual interactions AC and CA shown as cross-links between the two primary oculomotor functions. (see Figure 3.1 below).

Figure 3.1: Diagrammatic representation of Westheimer's model of accommodation-vergence interaction (from Westheimer, 1963).

Many experiments have been performed to support the notion of a dual interactive model. Semmlow and Hung (1981) provided experimental evidence which shows that the mechanisms of CA and AC can simultaneously maintain different magnitudes. Hence it is proposed that they are mediated by separate neural mechanisms, each capable of functioning in isolation but mutually interactive in normal binocular viewing through separate neural pathways. Schor and Narayan (1982) develop further the model proposed by Semmlow and Hung (1980) in which there is mutual interaction between accommodation and vergence motor systems; they suggest that the interaction occurs through separate feed forward cross-links which interact via negative feedback loops. These mutual interactions increase the effective amplitude of the AC/A ratio during binocular viewing conditions (Figure 3.2). A very similar model is also described by Carroll (1982).

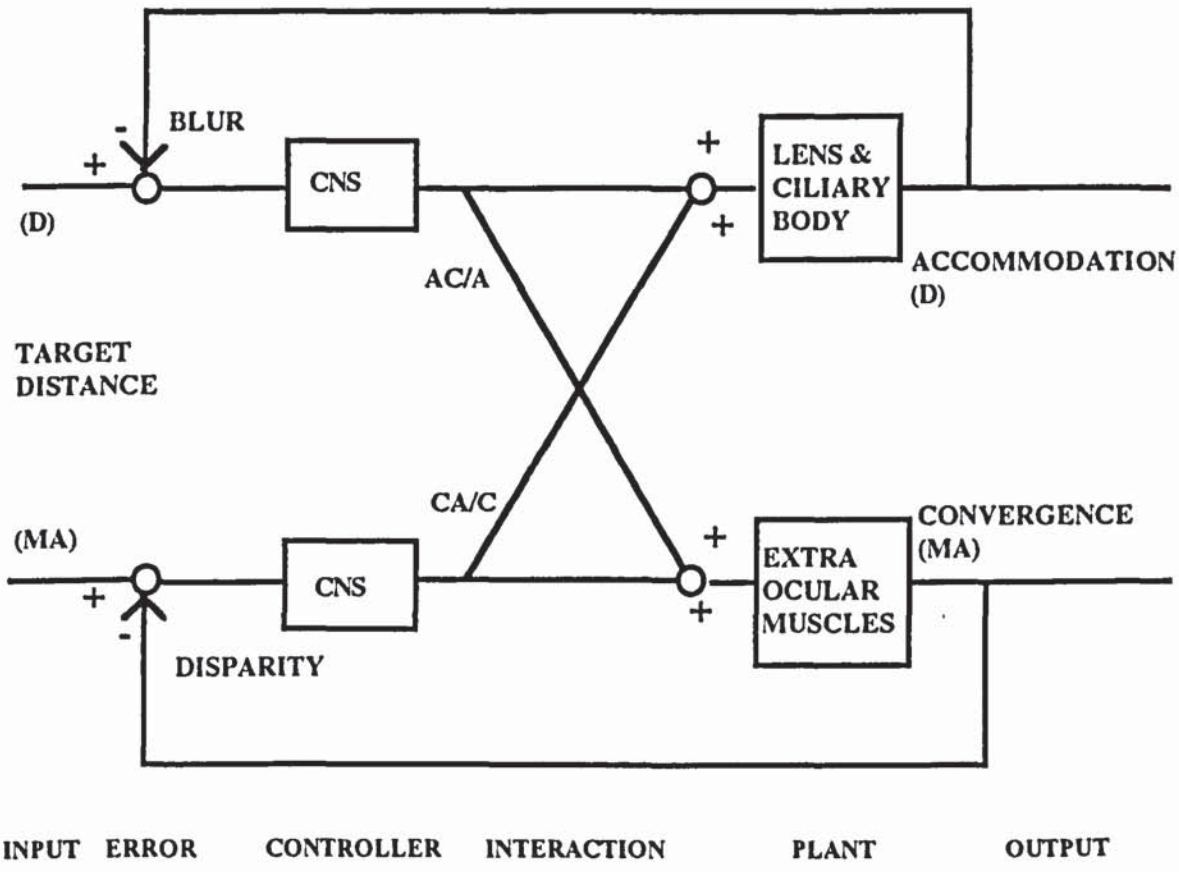

Figure 3.2: Diagrammatic representation of Schor and Narayan's accommodation-vergence interaction model (redrawn from Schor and Narayan, 1982).

Schor (1985) subsequently investigated in more detail the form in which the cross-links should take. He looked at four variations; forward and reverse parallel cross-links and serial cross-links where CA precedes AC and vice versa. The only model which predicted results consistent with experimental findings was the forward parallel cross-links model which was previously suggested by Schor and Narayan in 1982.

The position of the oculomotor cross-links

Obviously the models described so far are very simplified in terms of the accommodation and vergence controller systems. Many different elements to these systems have been described to account for the way in which the accommodative and vergence mechanisms respond under a variety of conditions. Schor (1979a; 1980) suggests that the FV response consists of two components; the fast fusional component (also known as reflex or phasic) which reacts within 1 s to reduce retinal disparity and the slow component (also known as adaptive or tonic) which acts to maintain the net vergence response (see Chapter 2). He later went on to suggest that an analogous system may also exist for accommodation such that reflex accommodation provides a stimulus to adaptive accommodation (Schor, 1986). Hung and Ciuffreda (1988) confirmed the existence of

fast and slow components of the accommodative mechanism whereby smooth ramp movements were observed for low velocity stimuli whereas step responses predominate for high velocity stimuli. Combined step-ramp responses were more prevalent at intermediate target velocities. Further, Hung and Ciuffreda suggested that the fast component of both the vergence and the accommodative systems exhibited pre-programming while the slow components showed continuous feedback control.

Controversy exists as to whether the accommodation-vergence cross-links are situated between or after the reflex and adaptive components of the vergence and accommodation controller systems. If AC and CA are driven by the fast components of accommodation and vergence alone then the cross-links must be situated between them, whereas if the input to AC and CA is derived from both the fast and slow components of these two mechanisms the cross-links must occur after both components.

Rosenfield and Gilmartin (1988a) investigated the influence of within-task disparity induced accommodation on the post- to pre-task shift in SOLA. Schor and Kotulak (1986) had previously observed that after adapting to 8 Δ base out for 5 s while the accommodative loop was open, there was a rapid decay in both vergence and accommodation responses when the negative feedback loops of both systems are opened. However, after adapting to the stimulus for 2 mins, an increase in tonic vergence disparity (TVD) and SOLA was noted and the subsequent decay of these after-effects towards pre-task levels was independent, indicating that the post-task increase in SOLA is not produced by the increase in TVD stimulating accommodation. In contrast, Rosenfield and Gilmartin (1988a) demonstrated that under closed-loop viewing, an increase in FV produced a mean reduction in the accommodative regression in some emmetropes. This observation is consistent with the finding that an increase in blur-driven accommodation under closed-loop conditions produces a reduction in vergence adaptation. Consequently, Rosenfield and Gilmartin suggested that the primary input to the accommodative regression component under closed-loop viewing conditions is derived from the output of blur-driven accommodation only rather than from the output of the oculomotor cross-links as well, implying that the cross-links occur *after* both the reflex (fast) and adaptive (slow) components of the accommodative and vergence mechanisms.

In a later paper, Rosenfield and Gilmartin (1988c) examined the proposal by Schor (1986) that CA is directly dependent upon the proportion of the vergence response driven by reflex vergence. Schor (1986) suggested that if CA is directly dependent on reflex vergence then CA would be inversely proportional to the portion of the response controlled by the adaptive vergence component; from this one may predict that the onset of adaptive vergence would be accompanied by a concomitant reduction in reflex

vergence which in turn would cause the magnitude of CA to decrease. Following their investigation, Rosenfield and Gilmartin (1988c) reported no reduction in the output of CA as the vergence mechanism adapted to 6 Δ base out over a period of 3 mins. Consequently they concluded that CA is not driven exclusively by reflex vergence but rather it is driven by the combined effects of the initial reflex vergence and subsequent adaptive vergence. They also suggested that an analogous system also occurs for the accommodative response so that during periods of sustained near-vision, the cross-link interactions do contribute to the aggregate near response.

The findings of Rosenfield and Gilmartin (1988a, 1988c) are consistent with the model of accommodation-vergence interaction proposed by Ebenholtz and Fisher in 1982 which was based on the work of Krishnan and Stark (1977) and Schor (1979a; 1980). Ebenholtz and Fisher (1982) described a model in which the near response cross-links namely AC and CA occur after the adaptive component of the accommodation and vergence control systems. Rosenfield and Gilmartin (1988c) included a revised version of Ebenholtz and Fisher's model in their paper, which is illustrated in Figure 3.3 below.

Figure 3.3: Model of accommodation and vergence interactions (from Rosenfield and Gilmartin, 1988c)

Hung (1992) developed a model to simulate accurately the accommodative and vergence behaviour under static as well as dynamic adaptive conditions. Like Rosenfield and Gilmartin (1988a; 1988c) and Ebenholtz and Fisher (1982), he positioned the near vision cross-links after both the reflex and the adaptive components of the accommodation and vergence controller systems.

Schor (1986), in contrast to Ebenholtz and Fisher (1982), Rosenfield and Gilmartin (1988a; 1988c) and Hung (1992), proposed a model in which the cross-links occur *between* the reflex and adaptive components of the controller systems of both accommodation and vergence. This proposal was based on the observations that responses to small step stimuli of both AC and CA decay rapidly after the initial reflex response of both accommodation and vergence. Schor proposed that reflex accommodation only is driving AC while reflex vergence is exclusively driving CA. Figure 3.4 shows the model proposed by Schor. In a recent study (Jiang, 1993) evidence to support the model proposed by Schor (1986) is put forward. Jiang found that accommodative adaptation produced a decrease in AC and concluded that the AC cross-link originates before the adaptive component but after the reflex component of the vergence controller.

Figure 3.4: Model proposed by Schor of the accommodative and vergence interactions (from Schor, 1986). It proposes that the two motor systems are interconnected at points in their feed forward paths located between the phasic and tonic neural indicators.

Both accommodation and vergence work on a negative feedback loop with dual interaction occurring between the two systems via the AC and CA cross-links. Although the issue of the position of these cross-links in the accommodative-vergence interaction model remains unsolved, it has been established that the controller system of both accommodation and vergence contains two components namely reflex and adaptive vergence. Models describing fully the interaction between the accommodation and vergence systems have become very complex. Schor et al. (1992) include interactions between the observer and the surrounding environment in their model of the interaction of accommodation and vergence such that spatiotopic cues provide the course-tuning to the oculomotor response and retinotopic cues the fine-tuning. Further discussion regarding these models can be found in Chapters 9 and 11.

CHAPTER 4

THE ROLE OF THE NEAR VISION RESPONSE IN THE DEVELOPMENT OF MYOPIA

4.1 - INTRODUCTION

As this thesis is primarily concerned with the oculomotor responses of emmetropes and myopes, this Chapter is intended to provide a brief review of the role of the near vision response in the aetiology of myopia. In addition, other proposed theories of refractive development are discussed. Literature concerning the aetiology of refractive errors and in particular myopia is vast and many theories have been proposed. This thesis concentrates on the three major ones, namely; the biological-statistical theory, the use-abuse theory and the theory of emmetropization. Extensive reviews of refractive error development may be found elsewhere (e.g. Borish, 1970; McBrien and Barnes, 1984; Weymouth and Hirsch, 1991). Evidence for both hereditary and environmental influences on the development of refractive error will also be considered.

A discussion of the classification of myopia appears in section 4.4, with emphasis on the age of myopic onset. The differential effect of genetic and environmental aspects on various types of myopia is also discussed although pathological/malignant myopia will not be included as it is outside the scope of this thesis. Evidence from studies distinguishing the oculomotor profiles of emmetropes and myopes is included to support the proposals that near work plays a role in myopic development and that myopia can be divided in to groups distinguished by the differential effect of environmental and genetic factors. The final section of this Chapter outlines the aims of the research programme of this thesis with respect to oculomotor function and the development of myopia.

4.2 - THEORIES OF REFRACTIVE DEVELOPMENT

At present no consensus exists regarding the basis for myopia development although over the years many theories have been proposed. Evidence for both inherited and environmentally-induced myopia exists. The suggestion that near vision may play a role in the aetiology of myopia was first made by Ramazzini in 1713, he noticed that people who use there eyes a great deal had a 'weakness of vision' plus changes in the 'tonus of the membranes and fibres of the eye'. Evidence for a genetic basis for refractive development is provided by uniovular twin studies together with studies of the incidence of myopia in ethnic populations.

4.2A - Biological - statistical theory of refractive development

The biological - statistical theory attempts to demonstrate that all refractive errors are due to the way in which components of the eye combine. In 1913 Steiger suggested that the majority of refractive errors could be explained by the interaction of various components of the eye, namely corneal power, anterior chamber depth, lens power and axial length, each of which are normally distributed throughout the population. He proposed that the distribution of refractive error should reflect the distribution of these individual components and thus the refractive state of the eye should be normally distributed.

Later studies by Stenström (1946) and Sorsby et al. (1957) revealed that the distribution of refractive error is not normal, instead marked leptokurtosis is evident in the emmetropic region. The predominance of emmetropia in the normal population is not in keeping with Steiger's suggestion of free association of ocular components; it would appear therefore that an active mechanism designed to correlate the various ocular components exists to produce an abundance of emmetropes or near emmetropes (Sorsby et al., 1957). Sorsby and his co-workers went on to suggest that those people who were ametropic fell into two groups namely:

i) *correlation ametropia* - caused by a failure of the mechanism designed to correlate axial length, corneal power, lens power and anterior chamber depth. This type of ametropia was found predominantly in the +6.0 to -4.0 D range of refractive errors.

ii) *component ametropia* - caused by a particular component (usually axial length) deviating significantly in value of that found in emmetropia. They reported this type of ametropia to predominate outside the ranges of +6.0 to -4.0 D.

4.2B - The theory of emmetropization

As discussed in section 4.2A, the predominance of emmetropia in the normal population has led some workers to suggest that a coordinating mechanism exists to bring about emmetropia (Sorsby, 1967; Straub, 1909; Van Alphen, 1961). This coordinating mechanism was termed 'emmetropization' by Straub (1909), since then Van Alphen (1961; 1990) developed a theory to explain how the process works. This theory is now known as the theory of emmetropization.

In 1961 Van Alphen carried out detailed statistical analysis on the biometric data of Stenström (1946) and discovered 10 significant inter-correlations between the refractive components. Further analysis lead to the identification of 3 independent factors, 2 of which contribute to the development of emmetropia: factor '*S*' (the size factor) determines the combination of corneal curvature and axial length; in emmetropia larger eyes have flatter cornea. Factor '*P*' (the stretch factor) influences the combination of axial length, anterior chamber depth and lens power; large emmetropic eyes were found to have flatter

lenses and deeper anterior chambers. The third factor, '*R*' (the adjustment factor) is responsible for the development of ametropia and represents the resistance offered by the ciliary muscle-choroidal layer to the intraocular pressure (IOP).

Van Alphen (1961) suggested that IOP played a part in determining both corneal curvature and axial length. If the IOP is counterbalanced by both choroidal tension and scleral elasticity, then choroidal tension will be a factor in the determination of axial length. Van Alphen (1961) considered the ciliary muscle-choroidal layer to behave as a continuous elasto-muscular sheet of smooth muscle surrounding the eye. This proposal was confirmed in a later study (Van Alphen, 1986) by showing that axial expansion emanated from ciliary muscle stretch. By considering the choroid and ciliary muscle as functionally continuous, the resistance to changes in IOP will therefore depend on the physiological tonus of the ciliary muscle, with high ciliary muscle tone lowering the tension on the sclera while low ciliary muscle tone would result in scleral stretch.

The eye normally enlarges during the first years of life by a combination of growth and stretch. Growth is determined by genetic factors whereas stretch is determined by the IOP. A growing eye will not enlarge unless a degree of IOP is present (Coulombre and Coulombre, 1956). Van Alphen (1990) thus suggested that as emmetropia predominates in the population, the stretch of the eye must be closely controlled. He proposed a mechanism based on two assumptions:
i) The tension of the choroid which is determined by the tonus of the ciliary muscle regulates the stretch of the sclera by partially resisting IOP, thus it is the nett pressure on the sclera that enlarges the eye.
ii) The macular and brain relay information about the degree of hyperopia to the Edinger Westphal Nucleus and the activity of the Edinger Westphal nucleus is adjusted accordingly (i.e. a continuous feedback loop).

Hence, Van Alphen (1990) proposed that the stretch of the sclera is under both cortical and subcortical control and any interruption of the feedback loop at the level of the cortex or subcortex would interfere with emmetropization (see Figure 4.1). This theory is supported by the observation that emmetropization is rarely achieved in cases of corneal opacities, high astigmatism, congenital nystagmus or mental deficiency (Rabin et al., 1981). In addition many studies have shown that form deprivation can lead to high levels of myopia in a variety of animals (for reviews see Yinon, 1984; Criswell and Goss, 1983) thus supporting the proposal that normal visual stimulation is necessary in order for emmetropization to occur. However, results obtained from a numerical model designed by Brennan et al. (1994) to describe the change in refractive error distribution between birth and adulthood suggest that leptokurtosis is not necessarily evidence for a visually dependent feedback phenomenon.

Figure 4.1: Van Alphen's model of emmetropization. EW represents the Edinger-Westphal nucleus (from Van Alphen, 1990).

4.2C - The use - abuse theory of refractive development

This theory attempts to explain the onset of myopia as an adaptation to the use or misuse of the eyes in prolonged close work. Unlike the biological - statistical theory and, to a certain degree, the theory of emmetropization which imply that refractive error is an inherited trait, this theory suggests that environmental conditions play the major role in the development of refractive error and in particular myopia.

As previously mentioned, an association between close work and myopia had been made as early as 1713 by Ramazzini, although it is Cohn (1886) who is generally acclaimed to be the originator of the theory that near work induces myopia. Cohn found that the incidence of myopia increases with age for children within the educational system who are engaged in increased amounts of near work. Although much evidence presented subsequent to Cohn's theory also points to a correlation between near vision and myopic development, it still remains unclear whether the development of myopia associated with close work results from changes in the accommodative system, the vergence system or the oculomotor cross-links. Evidence provided in subsequent sections supports all three possibilities.

Accommodation and myopia

The suggestion that myopia is correlated with the accommodative response has been made by several people and many theories of how myopia would develop have emerged. Newman (1929) suggested that excessive accommodation would pull on the elastic membrane of the choroid which would increase choroidal tension and lead to a decrease in the nutrition at the choroid which in turn would result in degenerative changes and posterior staphyloma. Recent research (Avetisov and Savitskaya, 1977) has shown that

blood flow in ocular vessels becomes significantly slower as the magnitude of myopia increases.

To investigate the effect of accommodation on myopic progression, Bedrossian (1966) monocularly paralysed the accommodative system of young myopes using atropine. He found that while the myopia in the untreated eyes increased by an average of -0.63 D in one year, the cyclopleged eyes demonstrated an average decrease in myopia of 0.5 D in the same period. Bedrossian claimed that the results of his study support the proposal that accommodation is the important factor in the development of myopia but it should be noted that the use of monocular cycloplegics causes a total dissociation of the eyes for near vision thus altering the vergence requirements and the synkinetic link between accommodation and vergence.

Much of the evidence supporting the proposal that accommodation is an important factor in the development of myopia was provided by Young in the 1960s and 70s. In 1961 he demonstrated that when monkeys were placed in restricted visual environments (of approximately 50 cm distance), after 11 months 70% of the monkeys showed myopic shifts greater than 0.50 D while 50% demonstrated shifts in excess of 1.5 D. In 1965 Young demonstrated that the myopia caused by restricting the visual environment could be arrested by daily instillation of atropine, thus he proposed that accommodation plays a significant role in the development of myopia.

A number of workers have induced myopia in a variety of species by suturing the eye lids to enforce form deprivation. In 1985, Raviola and Wiesel discovered that these myopic shifts were mediated via vitreous chamber elongation; in addition they found that atropine inhibited myopia progression in stump-tailed monkeys (*Macaca arctoides*) but not in Rhesus monkeys (*Macaca mulalla*). This finding is of interest as it demonstrates that caution is needed when applying the results of animal studies to humans.

By the 1970s Young was convinced that accommodation played a vital role in the development of myopia although the actual mechanism which lead to axial elongation was not clear. In 1975 Young developed his "environmental stresses" theory based on the proposal that initially myopia resulted from a temporary increase in lens thickness due to the inability to relax accommodation fully. This was followed by a permanent increase in vitreous chamber depth resulting from an increase in vitreous chamber pressure mediated by accommodation. He tested his theory on monkeys by placing a pressure transducer in the anterior chamber and initiating accommodation responses by altering fixation distances. His results showed that vitreous chamber pressure increased by 6 - 7 mmHg whereas the pressure in the anterior chamber dropped when the monkeys changed their fixation from far distance to 12 inches. Furthermore, this increase in vitreous chamber

pressure was maintained during the period of accommodation and decreased upon relaxation. Young claimed that his theory was sufficient to explain the development of refractive error between the range of low hyperopia to -8.0 D myopia. The results of his experiment may be erroneous though, as the transducer used to measure posterior chamber pressure is likely to have caused an imbalance in the pressure due to its size. Furthermore, the monkeys viewed the fixation target binocularly and thus the increase in IOP following changes in the fixation distance could be due not only to accommodation but also to vergence or their combined affect.

The proposal that myopia was produced by raised intraocular tensions was not new, other workers before Young had also suggested this (Ware, 1813; Donders, 1864). Various studies have shown that IOP changes as accommodative demand increases (Armaly and Burian, 1958; Armaly and Jepson, 1962; Armaly and Rubin, 1961), although the actual mechanism by which accommodation causes scleral stretch remains unclear. Coleman (1970) suggested that accommodation causes an increase in pressure gradient between the anterior and posterior chambers with the higher pressure being present in the vitreous chamber. This pressure gradient may indicate the stress on the sclera during accommodation and thus cause the posterior globe to stretch.

The idea that accommodation is linked with the development of myopia has encouraged some workers to try and eliminate the stimulus to accommodation by fitting children with bifocal glasses and contact lenses. However, the Houston Myopia control study (Grosvenor et al., 1987) failed, like many other studies, to find any reduction in the rate of myopia progression in the majority of children fitted with bifocal glasses.

It should be noted that Van Alphen's model of emmetropization (1961; 1990) does not necessarily support the proposal that accommodation is the main cause of the development of myopia even though his model is based on the stress IOP places on the sclera. Van Alphen suggests that it is the physiological tonus of the ciliary muscle and not ciliary muscle tone associated with accommodation which is crucial to scleral stretch. He suggests that accommodation would actually diminish the pressure on the sclera and thus prevent axial elongation.

Vergence and myopia

A number of workers have suggested that an increase in the axial length of the eye may be related to the action of the extraocular muscles on the globe. Thus forces inducing myopia development may arise from external aspects of the globe rather than from the internal actions of the ciliary muscle.

Stansbury (1948) cited Von Graefe (1854) as being the first to indicate medial and lateral recti muscles may cause stretching and distension of the eyes during sustained near vision. In a later paper Von Arlt (1876) also suggested that myopia may be produced by excessive vergence and postulated that pressures of the extraocular muscles on the globe impeded blood flow through the vortex veins which would cause congestion and result in an increase in IOP. In addition, Stilling (1891) suggested that the development of myopia was related to the anatomical position of the trochlea. He postulated that a low (presumably meaning inferior) pulley position would result in globe compression but other workers were unable to verify this (Stansbury, 1948).

In 1931 Jackson stated that 'excessive convergence in the majority of cases starts myopia and keeps it progressive'. In an attempt to verify this by dissociating the eyes with monocular cycloplegia, Luedde (1932) investigated the effect of atropine on myopic progression. At a later date Bedrossian (1966) completed a very similar experiment (as mentioned in the previous section) and although the results from both experiments were comparable in that a reduction in myopia was noted in the cyclopleged eye, the conclusions drawn by each experimenter were very different. Bedrossian concluded that the results provided evidence for accommodation being the major factor in myopia development whereas Luedde interpreted the results as evidence for the role of excessive convergence in the development of myopia.

Maurice and Mushin (1966) and Tokoro (1970) were able to induce myopia in rabbits by raising temperature and IOP but Mohan et al. (1977) later demonstrated that this myopia was actually dependent on extraocular tension. They found that the induced myopia increased following resection of the four recti muscles whereas free tenotomy of the muscles resulted in a retardation of myopic development.

More recently Greene (1980, 1981) proposed that the extension of the posterior portion of the globe could be due to the action of the extraocular muscles. He noted that the peak force capabilities of the extraocular muscles are 250 times greater than that of the ciliary muscle and consequently hypothesized that the vergence mechanism would dominate the accommodation mechanism in terms of applying pressure to the sclera. Greene also suggested that whilst changes in accommodation may indirectly affect IOP via choroidal tension (Van Alphen, 1961; 1986) the potential IOP changes that may be induced by vergence are larger and may be directly transmitted to the sclera by the extraocular muscles.

Continuing his work, Greene (1980, 1981) calculated that the oblique muscles could exert significant amounts of localized tensile stress on the posterior sclera and together with the increase in IOP present during convergence, this concentrated stress may be

sufficiently large to permanently stretch the sclera out of shape. In addition Greene and McMahon (1979) showed *in vitro* that when elevated stress is applied for moderate periods of time, the sclera will creep permanently out of shape; furthermore Ku and Greene (1981) demonstrated that cyclic pulses of high IOP could cause irreversible deformation of the globe. A study by Perkins (1981) comparing the degree of myopia with the calculated scleral stress was unable to support the proposals that the myopic eye enlarges as a result of mechanical stress on the sclera. However, the method used by Perkins to estimate axial length and thus calculate scleral stress using Laplace's formula (Friedman, 1966) were not particularly accurate and his results should be treated with caution.

Oculomotor cross-links and myopia

It is clear from the results of the studies discussed in the previous sections that it is very difficult to differentiate the actions of accommodation and vergence in the development of myopia due to the strong cross-links that exist between the two systems. Whilst a substantial amount of evidence supports a link between near vision and the development of myopia, it is still unclear which system is responsible. As a consequence of negative feedback mechanisms already known to exist between accommodation and vergence (see Chapters 1 and 2), an alteration in the output of either accommodation or vergence is likely to induce concomitant changes in the other component. The findings of Rosenfield and Gilmartin (1987b; 1987c) suggest that myopia may develop as a result of an alteration in the cross-links of accommodation and vergence. Indeed myopia may be an adaptation undertaken by the eye as a way of maintaining this synkinetic relationship. Birnbaum (1984) also suggested that myopia is caused by stress resulting from the links between accommodation and vergence and proposal that the LOM may actually represent an adaptive change resulting from nearpoint stress.

4.3 - HEREDITARY AND ENVIRONMENTAL ASPECTS OF MYOPIA DEVELOPMENT

Evidence is available to support each of the principal theories of refractive development discussed in section 4.2 even though the basis for each of the theories differ. As already mentioned, the biological - statistical theory supports the view that refractive error is an inherited trait as do aspects of the theory of emmetropization proposed by Van Alphen (1961). Conversely the use - abuse theory is based on environmental factors. The debate as to whether refractive error is genetically or environmentally determined continues; evidence from both sides is presented in the following sections.

4.3A - Heredity and myopia

The two main sources providing evidence for the role of genetic factors in myopia development are the incidence of myopia in uniovular twins and in ethnic populations. Sorsby et al. (1962) employed 78 uniovular twins, 40 binovular twins and 48 unrelated pairs to investigate the role of heredity in the aetiology of myopia. They reported that the agreement between the individual components of refraction and the resulting refractive errors was high in uniovular twins but significantly lower in binovular twins and unrelated pairs. The fact that the refractive error of binovular twins who were reared in the same environmental conditions showed significantly lower concordance rates than uniovular twins led them to suggest that refraction was purely genetically determined. Previous work by Waardenberg (1950) on 300 pairs of uniovular twins and 222 pairs of binovular twins supported Sorsby's findings. Several other studies have also shown that the refractive errors of uniovular twins are significantly more similar than binovular twins, siblings or unrelated pairs (see Borish, 1970 for a review).

Further evidence of the role of heredity in refractive development comes from studies on the incidence of myopia in ethnic populations. Crawford and Hammar (1949) discovered that the incidence of myopia in the indigenous population of Hawaii was 3% whereas it rose to 17% for the Chinese living in Hawaii. It should be noted however, that together with genetic factors, differences in the lifestyles of ethnic minorities may contribute to the development of refractive errors. Taylor (1981) compared the distribution of refractive error in young Europeans aged 20-30 living in Australia with that of Australian Aborigines of the same age and discovered that the Europeans were on average 0.5 D more myopic. Other studies on the incidence of myopia in ethnic populations are reviewed by Bear (1991). Once again it is difficult to conclude from these findings if the differences between the groups are due to genetic or environmental influences as the differences in life-style of these two groups are considerable.

4.3B - Environmental influences and myopia

Various environmental factors have been implicated in the aetiology of myopia. Animal studies have clearly shown that the visual environment can play a vital role and normal visual stimulation is necessary for emmetropization to occur. Moreover, it has been demonstrated that the susceptibility to the myopic shifts caused by visual deprivation is linked to age and maturity (see Yinon, 1984 for a review). Many workers have noted that in addition to a correlation between myopia and near work, other factors such as head posture (Mohan et al., 1988) stress (Van Alphen,1961;) and social class (Goldschmidt, 1968; Mohan et al., 1988) have also been correlated with the incidence of myopia.

The studies on Eskimo populations by Young et al. (1969) provide evidence for environmental influences on the development of myopia. Young and his co-workers

recorded very little myopia in the older generations but in the younger generation, born since the second world war, they reported approximately 68% incidence of myopia. Since heredity influences remained constant across the generations, they attributed this difference to the imposition of compulsory education and postulated that increased amounts of near vision were to blame for the dramatic increase in the incidence of myopia since the second world war. Young and his colleagues discounted the effect of a change in diet on the incidence of myopia as the changes were found to occur in the off-spring but not in the parents. However, it may be wrong to disregard the effect of diet as the degree of susceptibility to myopic change may vary between adults and children as discovered in animal studies (see Yinon, 1984 for a review), although a later study by Young et al. (1973) showed that refractive development of monkeys was not affected by the amount of protein in the diet.

Adams and McBrien (1992) recorded the prevalence of myopia in a cross sectional group of clinical microscopists and found it to be as high as 71% with 49% reporting the onset of myopia after entering this occupation at the age of 21 or older. These prevalence rates are far higher than those found in the general population where incidence of myopia lies between 10 and 30%, with approximately 8% appearing later in life (Goss and Winkler, 1983). In addition, Adams and McBrien report of subjects who showed myopic progression since entering the profession, 56% reported no refractive change for the 5 years before entering the profession. These results indicate that some aspect of the work of a clinical microscopist is linked to myopic development and progression although the authors do recognise there may also be a genetic susceptibility to myopia development. Even if the actual cause of the increased incidence in myopia in these populations is open to debate, evidence supports the proposal that environmental influences have a part to play.

Evidence provided to support both sides of the heredity/environmental basis to myopia debate makes it clear that the two are very difficult to distinguish and as such cannot be considered separately. It is likely therefore that refractive error results from a combination of both genetic predisposition and environmental influences (Goldschmidt, 1968; 1990; Curtin, 1970; Jensen, 1991). The possible predominance of one factor over another has lead investigators to classify myopia into different types. Discussion of the classification of myopia appears in the next section.

4.4 - CLASSIFICATION OF MYOPIA

As mentioned in the previous section many workers now believe that myopia can be classified in terms of differential effects of heredity and environment. Over the years

several other classifications for myopia have been proposed (for reviews see Borish, 1970; Grosvenor, 1987) including physiological versus pathological, structural versus functional or axial versus refractive. This thesis is concerned primarily with the effect of environmental factors on myopic development and as such will concentrate on a classification designed to differentiate myopia in terms of heredity and environmental factors.

Grosvenor (1987) developed a method of classifying myopia by taking into account the age-of-onset. Although no assumptions regarding genetic and environmental factors are made by such a classification, he hoped that it would serve as a framework allowing better understanding of the aetiology of the various categories of myopia. Grosvenor's categorisation of myopia has four groups; congenital, youth onset, early adult onset and late adult onset (see Figure 4.2). For the sake of this thesis, slight modifications to Grosvenor's classification will be made and myopic subjects will be categorised into just 2 groups namely early-onset and late-onset. The prevalence of congenital myopia, which is present at birth and may be present upon entering school is only about 2% and is not considered in this thesis. In addition late-adult onset myopia is not considered in this thesis as the subjects used in the following experiments (Chapters 6-10) are all below the age at which this type of myopia manifests itself.

Figure 4.2: Graphical representation of the prevalence of myopia with age, classified as congenital, youth onset, early adult-onset and late adult onset where the criterion for myopia is -0.50 D or greater (from Grosvenor, 1987).

4.4A - Early-onset myopia

In this thesis early-onset myopia (EOM) is considered to be myopia which has its onset between the ages of 5 and 14 and is approximately equivalent to Grosvenor's 'youth-

onset myopia'. The prevalence of this type of myopia increases with age and thus may be correlated to increased amounts of near work. However the body is also growing rapidly at this time and the myopia may well be linked to bodily growth. The age of cessation of early-onset myopia has been calculated by a number of workers (e.g. Slataper, 1950; Goss and Winkler, 1983) and found to coincide with the cessation ages for increase in height (i.e. around 15 years of age) and when the eye normally attains its adult emmetropic length (Sorsby et al., 1961; Sorsby and Leary, 1970; Larsen, 1971). As height is known to be an inherited trait, the major factor in the aetiology of EOM may be genetic although the effect of environment cannot be totally discounted.

4.4B - Late-onset myopia

It appears from the reports of Goss and Cox (1985) Goss et al. (1985) and Saunders (1986) that a significant number of individuals develop myopia after the age of cessation for childhood myopia (Goss and Winkler, 1983). Myopia which appears after the cessation of childhood myopia will be referred to as late-onset myopia (LOM) in this thesis. LOM appears typically in the late teens or early to middle twenties. It constitutes about 8% of all myopia and has no clear heredity basis (Goss and Winkler, 1983; Grosvenor, 1987; O'Neal and Connon, 1987; National Research Council, 1989; Baldwin et al., 1991). Usually LOM develops over a relatively short period and stabilizes at low dioptric levels of around 1.5 D, nevertheless levels up to 4 D and above have been reported (Adams, 1987). Ocular biometric studies have shown that the principle correlate for both EOM and LOM is elongation of the posterior chamber (McBrien and Millodot, 1987a; Bullimore et al., 1992; Grosvenor and Scott, 1991; 1993) and this is confirmed in this thesis (see Appendix 1).

Attention has been drawn to LOM as its association with prolonged near vision is more clearly defined than in EOM which suggests that its aetiology is environmentally based. The onset of LOM is invariably reported as being directly linked to significantly increased amounts of near vision or to a change in the visual environment in the work-place such as the introduction of VDUs. As LOM has been linked with near vision, several studies have tried to determine whether aspects of oculomotor function differentiate LOMs from EMMs and also EOMs. A brief review of these studies is given in the next section.

Many researchers believe that as the basis for LOM could be environmental, it is possible to halt the progression and even the initiation of myopic development by various means (for reviews see Goss, 1982; Woo and Wilson, 1990). Indeed Trachtman (1978) devised a non-invasive method of myopia therapy designed to reduce the amount of functional myopia by training individuals to gain greater control over their voluntary accommodation. A review of Trachman's work is given by Gilmartin et al. (1991). However most forms of myopia control have met with little success. It may be that once

the physical changes (e.g. axial elongation) have been initiated, it is impossible to alter the course of events. Predicting which emmetropes are likely to develop myopia later in life and initiating preventative therapy before the occurrence of physical change may increase its effectiveness. Furthermore, it may prevent individuals having to have corrective surgery in the form of photorefractive keratectomy (PRK) which, as with all surgical procedures, carries an element of risk and is expensive. In addition, by being able to predict which applicants wishing to pursue careers requiring high standards of unaided vision (e.g. pilots, police and fire fighters) are susceptible to myopic shifts, less money will be wasted on training people who develop myopia and are thus unable to pursue the job for which they have been trained.

4.5 - OCULOMOTOR FUNCTION AND REFRACTIVE ERROR

This section briefly summarises the evidence offered by various workers that LOM can be distinguished from other refractive groups with regard to a variety of oculomotor responses although much of the evidence is equivocal. More detailed reviews of this work appear in Chapters 6 to 10. Further research is required before the full extent of the differences between these oculomotor profiles is known and knowledge of the precise factors (both environmental and physiological) responsible for LOM is gained.

4.5A - Steady-state open-loop accommodation and refractive error

Van Alphen's theory of emmetropization (see section 4.2B) suggests that the eye's ability to resist potential stretching forces which might otherwise produce axial elongation may be proportional to the tone in the ciliary muscle. A high ciliary tone (measured clinically as SOLA) is equated to the development of hyperopia due to increased resistance to IOP changes and thereby lowering the resulting tension on the sclera. Conversely, a low ciliary tone would lead to the development of myopia due to variation in IOP leading to scleral stretch.

Since speculation of a correlation between refractive error and SOLA first arose, several workers have attempted to demonstrate a relationship between SOLA and refractive error although these studies have revealed conflicting results. Suzumura (1979) and Simonelli (1983) indicated that myopes have higher SOLA levels than other refractive groups whereas Maddock et al. (1981), McBrien and Millodot (1987b), Bullimore et al. (1988) and Rosner and Rosner (1989a) reported that myopes have the lowest SOLA levels and hyperopes the highest. Other workers such as Gilmartin et al. (1984), Fisher et al. (1987b) and Whitefoot and Charman (1992) failed to show any significant difference in SOLA between the refractive groups. Sample sizes vary considerably between the studies which may have an effect on the results as this measure is inherently variable (see

Chapter 1 section 1.7E). In a further attempt to resolve the issue, several workers have subdivided their myopic subjects into the early- and late-onset types (e.g. Rosenfield and Gilmartin, 1987b; 1988a; 1989; Bullimore and Gilmartin, 1987b; McBrien and Millodot, 1987b; Bullimore et al. 1988).

Even the results of studies in which the myopes have been subdivided are inconclusive. Lower SOLA levels in LOM have been reported by several researchers (Rosenfield and Gilmartin, 1987b; Bullimore and Gilmartin, 1987b; McBrien and Millodot, 1987b) although other studies have failed to reproduce this observation (Rosenfield and Gilmartin, 1988a; 1989). In addition, whilst myopes were found to have significantly lower SOLA levels than emmetropes and hyperopes, Bullimore et al. (1988) reported no significant difference between the early- and late-onset myopes. On the basis of the studies mentioned here, no consensus exists as to the relationship between SOLA and refractive error which is why an extensive study of SOLA levels in EMMs, EOMs and LOMs appears in Chapter 8 of this thesis.

4.5B - Accommodative regression patterns and refractive error

Additional interest in open-loop accommodation has been provoked by the finding that following a period of sustained near fixation, significant shifts in SOLA can occur which are maintained over a period of time. Ebenholtz (1983) used the term 'accommodative hysteresis' to describe these changes (other terms such as accommodative adaptation and accommodative regression patterns are also used - see section 1.7B). He also suggested that the slow decay of post-task SOLA to its pre-task level may play a part in the aetiology of myopia. As a consequence, several workers have investigated the effect of refractive error on accommodative regression patterns.

Both Bullimore and Gilmartin (1987b), Rosenfield and Gilmartin (1988a; 1989) and Gilmartin and Bullimore (1991) demonstrated that following a period of sustained near-vision, populations of emmetropes and LOMs exhibited different post-task regression patterns. McBrien and Millodot (1988) also reported differences in regression patterns between LOMs, EOMs, EMMs and hyperopes although they did not find any change in SOLA in either the EMMs or EOMs following a 15 min viewing period of a target located at 5 D. However, McBrien and Millodot assessed accommodative regression by sampling post-task SOLA at 1, 7 and 15 mins following task completion whereas several other studies (Bullimore and Gilmartin, 1987b; 1991 Rosenfield and Gilmartin, 1988a; 1988e; 1989) including those undertaken in this thesis (see Chapters 9 and 10) suggest that a substantial proportion of accommodative regression to the pre-task SOLA level is complete within the first minute of the post-task period.

Temporal aspects of accommodative regression in EMMs and LOMs has been assessed by Rosenfield and Gilmartin (1989). After task durations of 10 s, 15 s and 45 s, Rosenfield and Gilmartin found that EMMs show a significant increase in SOLA during the first 10 s of post-task recording which regressed to the pre-task value within a further 20 - 30 s. The LOMs responses were similar to the EMMs after task durations of 15 s and 30 s but after the 45 s duration task, a marked negative shift in SOLA was observed for the LOMs during the 10 - 50 s post-task period (see Figure 4.3). Instillation of Timolol maleate (a β-receptor antagonist) attenuated this shift suggesting that it was mediated via β-adrenergic innervation to the ciliary muscle. This suggestion is investigated in more detail in Chapter 10.

Figure 4.3: Mean post task dioptric shifts in SOLA against time after 3 task durations (from Rosenfield and Gilmartin, 1989).

Several factors have been found to affect accommodative regression patterns such as the magnitude of the adapting stimulus (Ebenholtz, 1985; Owens and Wolf-Kelly, 1987 and others), the composition of the accommodative response (Rosenfield and Gilmartin, 1988a) and monocular versus binocular accommodative response (Fisher et al., 1988; Rosenfield and Gilmartin, 1988e). The effect of different accommodative stimuli on regression patterns of EMMs, EOMs and LOMs is investigated in Chapter 9 to determine whether the composition of the within-task aggregate accommodative response differs between the refractive groups and whether accommodative regression patterns are influenced to a greater extent by particular elements of the within-task accommodative response.

4.5C - Autonomic characteristics of the ciliary muscle and refractive error

The proposal that the autonomic characteristics of the ciliary muscle may be linked to the aetiology of LOM was made following work by Gilmartin and his co-workers (Gilmartin et al., 1984; Gilmartin and Hogan, 1985) which demonstrated that SOLA could be modified by the topical application of drugs known to interfere with the sympathetic innervation of the ciliary muscle (see Gilmartin, 1986, for a review).

Using timolol maleate to block sympathetic innervation, Gilmartin and Bullimore (1987) showed that the rate of regression of some emmetropes (principally those with high SOLA levels) is significantly increased whereas the regression patterns of others remained unaffected. Those emmetropes with a slower regression following timolol instillation demonstrate a sympathetic facility of the ciliary muscle whereas the others do not. Consequently, it was suggested that those EMMs with low SOLA levels who did not demonstrate a facility for sympathetic innervation may be predisposed to the development of LOM because a deficit in sympathetic inhibition may enhance susceptibility to prolonged post task accommodative regression patterns induced by sustained near vision.

Whether a lack of sympathetic innervation constitutes a predisposing factor to LOM in some EMMs is worthy of further research and this is undertaken in Chapter 10 of this thesis. A mechanism linking the incremental accommodative changes to vitreous elongation needs to be established and thus Van Alphen' s (1961) theory that the ciliary muscle and choroid form a continuous elastic capsule around the eye may be of relevance. Further discussion on this topic can be found in Chapters 10 and 11.

4.5D - Aspects of accommodative function and refractive error

McBrien and Millodot (1986b) report that myopes have higher amplitudes of accommodation than emmetropes and hyperopes. They subdivided their myopic subjects and found that LOMs have higher amplitudes of accommodation than EOMs and they suggested that these differences were due differential innervation of the ciliary muscle. Maddock et al. (1981) also observed that LOMs have higher amplitudes of accommodation than both EOMs and EMMs.

McBrien and Millodot (1986a) identified slight differences in the accommodative response (AR) gradients of EMMs, EOMs and LOMs. They reported a significant correlation coefficient between the AR gradient and refraction but the accommodation responses were only significantly different between EMMs and LOMs at high stimulus levels. In a more recent study, Gwiazda et al. (1993) reported higher AR gradients for emmetropic children compared to myopic children. These findings are discussed in more detail in Chapter 6.

Continuing the quest to discover differences in accommodative function between refractive groups, Rosenfield and Gilmartin (1987c) observed that LOMs have significantly higher levels of disparity- and blur-induced accommodation than both EMMs and EOMs under certain conditions. They were also able to demonstrate that EOMs have significantly lower levels of blur-induced accommodation than EMMs. Later, Rosenfield and Gilmartin (1988d) confirmed their earlier findings (1987c) that LOMs display higher levels of disparity-induced accommodation than EMMs. These findings suggest that the components of the aggregate accommodative response combine in different proportions for the different refractive groups.

4.5E - Aspects of the oculomotor cross-links and refractive error

In contrast to predictions made following the results of previous studies (Rosenfield and Gilmartin 1987c; 1988c), Rosenfield and Gilmartin (1988b) did not find any difference in the CA/C ratios of EMMs, EOMs and LOMs. When they investigated another aspect of the oculomotor cross-links, namely the AC/A ratio Rosenfield and Gilmartin (1987b) discovered not only was the AC/A ratio of EOMs higher than the EMMs and LOMs but that this increase was mediated via an increase in accommodative convergence and not via a decrease in the accommodative response. These findings are discussed in more detail in Chapter 6.

4.5F - Aspects of the vergence system and refractive error

Less data is available to compare the vergence systems of emmetropes and myopes, although Goss (1991) reported that near-point 'phorias of a now myopic group prior to myopia development were significantly more esophoric than the emmetropic group. In addition, North et al. (1989) investigated variations in the adaptability of the vergence systems of EMMs, EOMs and LOM following an observation by Rosenfield and Gilmartin (1988d) which led them to suggest that LOMs may adapt less well to induced disparity than EMMs. Although North and her co-workers revealed that the EOMs demonstrated the greatest amount of adaptation after 3.5 min under various stimulus conditions, the differences in the amounts of adaptation at this point between the refractive groups were not statistically significant. However, the choice of statistical analysis rendered a high proportion of the data redundant thus calling into question the validity of the results. As a consequence, an investigation of vergence recovery as well as adaptation together with concurrent objective measures of accommodation in EMMs, EOMs and LOMs is undertaken in Chapter 7 of this thesis.

4.6 - SUMMARY

Much evidence is available from a wide range of experimental studies to support the proposal that the development of myopia and near vision is linked although the mechanism by which near vision leads to axial elongation is unclear. Controversy still exists as to which aspect of near vision or oculomotor function is responsible for the association; accommodation, vergence and the relationship between the two systems have all been implicated at various times. In addition the debate on environmental versus. heredity influences continues. The aim of this thesis is to determine whether EMMs, EOMs and LOMs can be differentiated in terms of various aspects of oculomotor function. Consequently it may be possible to demonstrate the role of certain functions in the aetiology of myopia.

Until now, researchers have often investigated the effect of refractive error on one particular component of the oculomotor system without relating it to any other even though the accommodation and vergence systems are strongly linked. Chapter 6 aims to contrast and cross-correlate various aspects of oculomotor function in order to determine the characteristics of the oculomotor response profiles of EMMs, EOMs and LOMs.

Chapter 7 is concerned primarily with the role of the vergence system in the development of refractive error. Vergence adaptation and recovery is monitored for EMMs, EOMs and LOMs in order to determine whether this aspect of the oculomotor profile can be characterised in terms of the refractive group. Significant differences between the groups responses would suggest a prominent role for the vergence mechanism in the aetiology of myopia.

Chapter 8 aims to resolve the issue of whether a relationship between SOLA and refractive error exists or not. Van Alphen (1961) proposed that ciliary muscle tone is fundamental to the development of refractive error but this is yet to be proven. By measuring SOLA it is hoped that the role of ciliary muscle tone in refractive development will become clearer.

The differences in accommodative regression patterns reported to exist between EMMs and LOMs following sustained near vision are investigated in Chapter 9. Rosenfield et al. (1990) reported that variations in the output of proximally-induced accommodation can significantly influence regression patterns. Consequently, regression patterns of EMMs, EOMs and LOMs are investigated with respect to proximally-induced accommodation. In addition they are also investigated with respect to the autonomic characteristics of the ciliary muscle in Chapter 10, following the proposal that LOM may be due to a deficit in sympathetic inhibition.

CHAPTER 5

METHODOLOGY AND STATISTICAL ANALYSIS

5.1 - INTRODUCTION

This Chapter is designed to give an account of the reasons behind the choice of methodology for the following experimental programme. In addition, specifications of the basic instrumentation and apparatus used in the various investigations are given. Each of the experimental Chapters (6 to 10) includes a section on the methodology specific to that particular investigation. The final section of this Chapter includes a short discussion of some of the statistical analysis techniques employed for the experiments undertaken in this thesis.

5.2 - BIOMETRY AND KERATOMETRY MEASUREMENTS

In addition to the studies undertaken in the experimental programme of this thesis, ocular biometry and keratometry measurements were recorded from the majority of subjects participating in the experimental programme in order to determine the principal physical correlates of myopia. Posterior vitreous chamber depth is generally accepted to be the principal correlate of EOM and LOM but other factors such as corneal curvature and lens thickness have also been implicated. Axial ultrasonic measures were obtained by using a Storz Omega Compu-Scan Biometric Rule, equipped with a 10 MHz focused transducer. The instrument is fully computerised and takes 512 readings within 0.5 s, thus providing a large number of readings and at the same time minimising the effects of eye movement. A footswitch provided with the instrument initiates the measurement procedure. Keratometry measurements were made using a two position Javal-Schiötz keratometer.

Keratometry measurements always preceded biometry measurements. Keratometry readings were taken from the horizontal and vertical meridians from which the mean radius of corneal curvature was calculated. Prior to any biometry readings being taken, the tip of the ultrasound probe was sterilised and the subject's corneas were anaesthetised using 0.4% benoxinate (oxybuprocaine HCl). In order to control accommodation, subjects were instructed to look at a distant target during ultrasound measurements. The probe of the Biometric Rule was kept as steady as possible until at least 10 readings were obtained. If the standard deviation of any of the readings exceeded 0.1 mm, further readings were taken.

Mean biometry and keratometry measurements for all subjects measured appear in Appendix 1 together with the results of statistical analyses. In addition, the biometry and keratometry data from the subjects employed in each separate investigation undertaken in the experimental program of this thesis appear together with the background data in the relevant appendices.

5.3 - MEASUREMENT OF ACCOMMODATION

A substantial part of the research programme of this thesis is concerned with the measurement of accommodation under both open- and closed-loop conditions. The various techniques by which steady-state open-loop accommodation (SOLA) may be measured has been discussed in Chapter 1, section 1.7D but some of these are not suitable for measuring closed-loop accommodation responses. Furthermore, the method of choice needed to be objective and unobtrusive so that SOLA measures were not contaminated by proximal and cognitive influences (see section 1.7D). Considering these factors, infra-red optometry was the method of choice for the following experimental programme.

5.3A - The Canon Autoref R-1 optometer

The Canon Autoref R-1, an infra-red (IR) autorefractor was the instrument of choice for the measurement of accommodation. Although no longer available, it was introduced by Canon Europa in 1981 to provide the clinician with objective measures of refractive error. It is similar in many ways to other infra-red optometers but it has a couple of unique advantages:

i) the subject has an open binocular field of view (18° vertically, 50° horizontally) which helps to minimise instrument myopia (Hennessy, 1975).

ii) The fixation of the subject and alignment of the instrument can be monitored easily, an internal IR video camera transmits a magnified image (8.2x) of the eye to a separate TV screen.

In addition to the advantages mentioned above, the Autoref R-1 produces refraction measurements for either the spectacle plane (12 mm) or the corneal plane (0 mm); in this thesis, all refractions were referred to the corneal plane. The manufactures claim a power range of ± 15.0 D for the sphere and ± 7.0 D for the cylinder. Increments in power are made in 0.12 D steps and cylinder axes in 1° steps. The measurement procedure takes only 0.2 s to complete and measurements are displayed on the TV screen and if required, printed on heat sensitive paper at approximately 1 s intervals. In Chapter 9 when accommodation was being sampled at very regular intervals under open-loop conditions,

the Autoref R-1 was interfaced with an Apple Macintosh Classic computer instead of a printer (details appear in section 5.3B).

Mode of operation of the Autoref R-1

The Autoref R-1 operates on the principle of grating focus, a technique commonly employed by modern IR optometers (Henson, 1983). A target, in this case a projection chart, illuminated by IR light, is imaged on the subject's retina. The image is then reflected back through the pupil and 3 photodiodes positioned 60° apart detect the intensity of the reflected IR light. Focusing lenses are moved along the optic axis of the Autoref R-1 and the position at which each photodiode detects the maximum reflected IR light is determined. The position of the focusing lenses yielding maximum output from the photodiodes corresponds to the optimum image focus on the retina. The measurement cycle takes 0.2 s to complete and the instrument computes a sphero-cylindrical refraction by applying a $\sin^2$ curve. As the relative positions of the lenses corresponding to the peak outputs from the photodiodes are utilized in the measurement of refractive error, the result is not directly dependent on the magnitude of the signal from these diodes. A typical output signal from a single channel is shown in Figure 5.1a. If for some reason the shape of the signal is very flat and the gradient of the 'in-phase slope' and the 'out-of phase-slope' is too shallow, the peak cannot be detected by the photodiode and an error reading will be produced (see Figure 5.1b). This can happen when the subject blinks or moves during the measurement sweep or the instrument is not correctly aligned.

Figure 5.1a: Typical output signal of a single channel as the Canon autorefractor performs one sweep in 'single shot' mode (from Winn al., 1989)

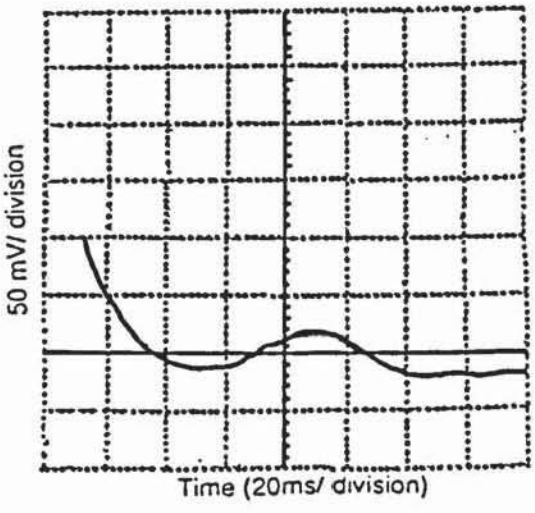

Figure 5.1b Output signal of a single channel when an error reading is produced (redrawn from Winn et al., 1989)

An error reading will also be produced if the pupil becomes so small that insufficient IR light is reflected back through the pupil to locate accurately the peak in the photodetector output. The limiting pupil size for IR optometers is usually in the range 2.5 - 3.0 mm

and the manufacturers state that the limiting pupil diameter is 2.9 mm for the Autoref R-1 in its static mode of operation. Winn et al. (1989) calculated that this figure refers to the exit and not the entrance pupil. As the pupil diminishes in size below 3 mm, the cylindrical component of the refraction increases in magnitude and at 2 mm an error reading will be obtained (Winn et al, 1989). For this reason, all refractive data recorded by the Autoref R-1 in the following experiments containing an unusually large cylindrical component was ignored. However as much of the data was collected on young adults and in conditions of darkness, pupil size was not a significant problem.

Accuracy, repeatability and application of the Autoref R-1

A clinical evaluation of the Autoref R-1 was undertaken by McBrien and Millodot in 1985 to determine the repeatability and the accuracy of the measurements generated compared with those obtained by routine refraction. A total of 93 subjects (186 eyes) were used. Repeatability, both between successive measurements and over a period of time, was found to be very high with a Pearson product-moment correlation coefficient of 0.99 for the spherical equivalent obtained for measurements taken on separate occasions. When compared to subjective refraction where the endpoint criterion was maximum plus with best VA, the Autoref R-1 gave results which were slightly more negative (≈0.39 D best sphere). However, if the endpoint criterion was to balance the subjects on the duochrome, the difference would be negligible. The Autoref R-1 results were slightly less accurate for the cylindrical component of refraction, possibly due to the fact that only three meridians are sampled in the measurement sweep (McBrien and Millodot, 1985). Even so McBrien and Millodot concluded that the Autoref R-1 is a reliable and valid objective autorefractor.

The Autoref R-1 has proved to be a popular research tool for a variety of investigations on the accommodative system. Millodot and Thibault (1985) used it to investigate variations in astigmatism with accommodation . McBrien and Millodot (1986a; 1987b; 1988) have used the Autoref R-1 to assess various aspects of the accommodative system as have Rosenfield and Gilmartin (1987b; 1987c; 1988a; et seq.; 1989; 1990) Bullimore and Gilmartin (1987a; 1987b; 1988) and many others.

5.3B - Interfacing the Autoref R-1 with a Macintosh Classic computer

In Chapter 9, accommodation was sampled in quick succession over a 60 s period with the results printed onto heat sensitive paper. These results then had to be converted by hand into best sphere and entered onto a data base on an Apple Macintosh Classic computer for analysis which was very time consuming. When it became clear that a subsequent experiment (detailed in Chapter 10) also required quick successive sampling of accommodation and similar analysis of data, the possibility of interfacing the Autoref R-1 with the computer was investigated. An interface unit (designed and distributed by

S.W. Spadafore, Franklin and Marshall College, PO Box 3003, Lancaster, PA 17604, USA) was purchased which connected the printer port of the Autoref R-1 to the Macintosh Classic computer such that accommodation could be sampled and recorded successively at 1.5 s intervals.

The software accompanying the interface unit had to be modified (see Appendix 2b) for part of the experiment so that error readings were not ignored but were counted as a reading in order that all the readings were time linked such that in any 60 s period, a total of 40 readings were obtained some of which may be errors. The program supplied with the interface unit (Appendix 2a) was used when assessing within task accommodative levels which did not need to be time-locked and error readings were undesirable.

5.3C - The effect of soft contact lenses on measurements of accommodation obtained with the Canon Autoref R-1 optometer

The Canon Autoref has the disadvantage of being unable to take readings through spectacle lenses unless they are inclined at an angle of about 20° to the subjects face. Even when readings are obtained, they are often very variable. In addition, viewing a target obliquely through a lens can result in less accurate accommodative responses due to enhanced distortion and aberration produced by the lens. Consequently, for all experiments requiring measures of accommodation, myopes were corrected by means of *Acuvue* disposable ultra thin soft contact lenses (Johnson and Johnson, Ltd.).

It was necessary to determine whether the contact lenses affected the readings made by the Canon optometer. Five EMMs were fitted with plano ultra thin contact lenses and their refractions were determined both with and without the contact lenses in place for distance (5 m) and near (30 cm - see Appendix 3). Paired t-tests showed that there was no significant difference between the results obtained both with and without the contact lenses at either target distance for any of the subjects. Hence there was no need to control for the effect of contact lenses during the experimental program thus only myopic subjects were fitted with them.

5.4 - OPENING THE ACCOMMODATIVE LOOP

Many of the investigations undertaken in this thesis required accommodation to be measured under open-loop conditions. To open-loop the accommodative mechanism, the quality of the retinal image has to be independent of the accommodative response i.e. there must be no stimulus to accommodation. Various methods of opening the accommodative loop have been discussed in Chapter 1 (section 1.7C) and some of them such as dark empty field and pinhole pupil have been used. However, alternative

methods of opening the loop had to be found when neither complete darkness or pinhole pupil were appropriate for a particular investigation (see Chapters 6 and 10). The methods of opening the accommodative loop used are described below.

Dark empty field

In order to keep stray light to a minimum, a large black curtain was used to screen the subject from the TV monitor of the Canon. Only very slight modifications had to be made to the Canon optometer before it was suitable to take readings in complete darkness. Green filters had to be placed over the alignment lights of the optometer to ensure they did not distract the subject during periods of complete darkness but they were still visible on the TV monitor to help the experimenter align the optometer.

Pinhole pupil

A 0.5 mm pinhole was made from Kodak Wratten 87 filter which transmits the non-visible IR light from the autrorefractor so that it does not interfere with the measurement process. However, when used in conjunction with the Canon autorefractor, the two light sources (visible red light) producing the corneal (first) Purkinje image used by the experimenter to aid alignment of the Autoref R-1 are reflected by this filter making it very difficult to see the eye on the TV monitor and obtain accurate measures of refraction. To overcome this difficulty the light sources were completely covered up, thus leaving inadequate illumination for the video camera. A separate illumination system was devised using fibre optic cables to direct light to the eye from an external source. The ends of the fibre optic cable were covered with the Wratten filter and affixed to the Autoref R-1 in such a way as to illuminate the eye being measured. Alignment of the Autoref R-1 was still possible using the alignment circle that appears in the centre of the TV monitor.

Diffuse green light

In Chapter 6, a method of opening the accommodative loop whilst maintaining closed-loop vergence responses was required in order to measure the CA/C ratio. Rosenfield and Gilmartin (1988b) used two methods to open the accommodative loop without opening the vergence loop; a 0.1 mm white light source and 0.5 mm pinholes (see section 3.5A). However these methods were not employed in this thesis for a number of reasons; vergence measurements were often not possible to obtain when 0.5 mm pinholes were positioned over both eyes as any sizeable movement of the eyes rendered the pinholes out of alignment with the visual axes of the eyes. Furthermore, several subjects were unable to see the 0.1 mm diameter light in the dark so it was decided to investigate another way of opening the accommodative loop without opening the vergence loop.

A small green light emitting diode (LED) was placed immediately behind a 0.5 mm pinhole. A 1.5 cm gap separated a 3 mm thick piece of ground glass (transmission ≈

90%) from the LED and pinhole. The glass caused a decrease in the luminance and blurring of the edges of the green light so that it appeared to be several millimetres in diameter. In order to check that the accommodative loop was open when subjects viewed this target in an otherwise darkened room, supplementary lenses of varying powers were placed infront of the RE while the left eye was occluded. The occluder was placed ≈ 15 cm from the corneal apex so that objective measures of accommodation could be made with the Canon Autoref. Results showed that the accommodative loop was indeed open (see Appendix 4a)

To check that the vergence loop remained closed whilst viewing the diffuse green light, supplementary prismatic lenses were placed before the RE while the subject binocularly observed the target. Measures of accommodation from the LE were recorded. Significant increases in accommodation were noted when the disparity stimulus (stimulated by prismatic lenses) increased. These increases in accommodation therefore appear to be mediated via the vergence system in the form of convergence accommodation indicating that the vergence loop is indeed open (see Appendix 4b).

Laser speckle

Conditions of complete darkness minimise the non-optical stimuli to accommodation thus measurements of SOLA under such conditions are rather low. This can be a disadvantage when assessing the innervational profile of the ciliary muscle in some individuals (see Chapter 10). For the majority of people, measures of SOLA in darkness do not provide enough background parasympathetic activity to augment sympathetic inhibition, if present. As a result of this, another method of opening the accommodative loop was employed in Chapter 10 in an attempt to raise the SOLA levels to a magnitude whereby sympathetic inhibition would consistently be augmented.

Conditions such as viewing a diffuse green light in a darkroom (Chapter 6) or viewing through a 0.5 mm pinhole (Chapter 8) do increase the measured SOLA levels when compared to those measured in complete darkness. However both these methods failed to raise the LOM's SOLA levels to a magnitude whereby sympathetic augmentation would be expected to occur. Gilmartin et al. (1984) demonstrated sympathetic inhibition on all their subjects (10 EMMs) when they measured SOLA using a subjective laser optometer. The cognitive effort involved in determining laser speckle movement causes the SOLA level to increase significantly compared to darkroom measures but one problem with this method of measuring SOLA is that it is subjective and not objective.

As the presence of a target, even a very dim one, has been shown to increase SOLA a little (see Chapter 6) it was suggested that viewing the speckle target produced by the laser optometer (He-Ne) used by Gilmartin et al. (1984) and Gilmartin and Hogan (1985)

may in itself induce higher SOLA levels. As the laser speckles always appear in focus, regardless of the accommodative state of the observer they will therefore (theoretically) offer little by way of an accommodative stimulus thus rendering the accommodative loop open. Furthermore, laser light, being monochromatic in nature provides no differential chromatic aberration for the accommodative system to use as a cue (see Chapter 1 section 1.5A).

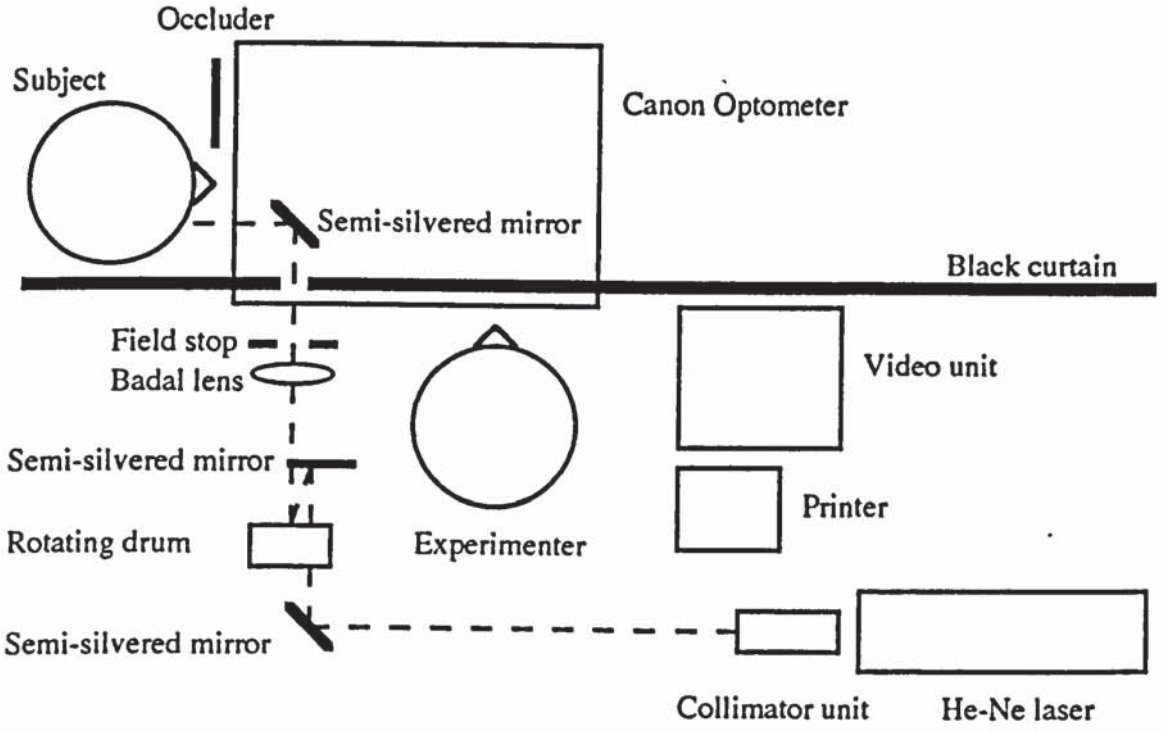

Figure 5.2: Diagrammatic illustration of the experimental set-up used to measure SOLA when viewing the speckle pattern.

A laser speckle target was produced by reflecting laser light from a rotating matt drum (see Gilmartin et al., 1984 for details). Random irregularities of the matt surface introduce a phase difference in the reflected laser light such that interference fringes are produced that differ in phase, orientation, spacing and intensity with the result that the observer perceives a random pattern of laser speckles. Subjects viewed the speckle pattern via a beam splitting mirror (Ealing - Beck 50:50 semi silvered mirror) placed at 45° to the observers eye. A +5.0 D Badal lens was placed 20 cms from the cornea at 90° to the corneal plane and a 25 mm field stop was placed between the Badal lens and the beam splitter (see Figure 5.2).

A pilot study was undertaken by 6 subjects to determine whether viewing the speckle pattern in complete darkness rendered the accommodative loop open or not. The speckle target was placed at various distances from the subject to provide various stimulus levels. Mean sphere accommodation responses were not found to vary significantly with the

with the stimulus level thus it was concluded that the accommodative loop was indeed open (see Appendix 4c)

5.4A - Measuring accommodative regression patterns

When measuring accommodative regression patterns following a period of sustained distance or near viewing (see Chapters 9 and 10) it is important to be able to swap from closed-loop viewing to open-loop conditions very quickly and with minimal effort from the experimenter. To aid this procedure, an Apple IIe computer was programmed to time the period of closed-loop viewing and emit a warning bleep a few seconds before the onset of open-loop conditions. The tungsten lamp used to illuminate the target which the subject viewed during the visual task was then automatically switched off via a CIL Microsystems PCI 6000 interface controlled by the Apple IIe. After 90 s the lamp was illuminated again to signal the end of the accommodative regression pattern recording period. The software used to control the procedure appears in Appendix 5.

5.5 - MEASUREMENT OF VERGENCE

Various aspects of the vergence mechanism (accommodative convergence, heterophoria, tonic vergence disparity and prism adaptation) are investigated in Chapters 6 and 7 of this thesis and thus a suitable method of measuring vergence under a number of conditions was required. The method chosen was the flashed Maddox rod technique as it is very versatile in that it can be used at various testing distances, when lenses (both spherical and prismatic) are placed in front of the subject's eyes and under conditions of complete darkness. In addition, direct comparison between experimental results can be made between studies employing similar methods such as North et al. (1989). One disadvantage to this technique is that it is not objective, it relies on the subject's observation skills. In order to minimise observation errors, all subjects received training in this technique before any data was collected.

5.5A - The flashed Maddox rod technique

The flashed Maddox rod technique requires the subject to estimate the position of the Maddox rod streak on a tangent scale. Measuring different aspects of the vergence system required slight modifications to the basic technique and these are described in the relevant Chapters. In general, the subject monocularly viewed a target for a period of time while one eye was occluded by a closed shutter, behind which was a Maddox rod. The shutter would then open for 125 ms exposing the Maddox rod and the target illumination was extinguished. Simultaneously, a spot light situated at the centre of the tangent scale would be turned on. Following the brief exposure of the Maddox rod, the shutter would remain closed and spot light on for a short time while the Maddox rod was

removed during which time the subject indicated the position of the streak on the tangent scale for the experimenter to record. Subsequently a period of binocular viewing was observed while the shutter remained open.

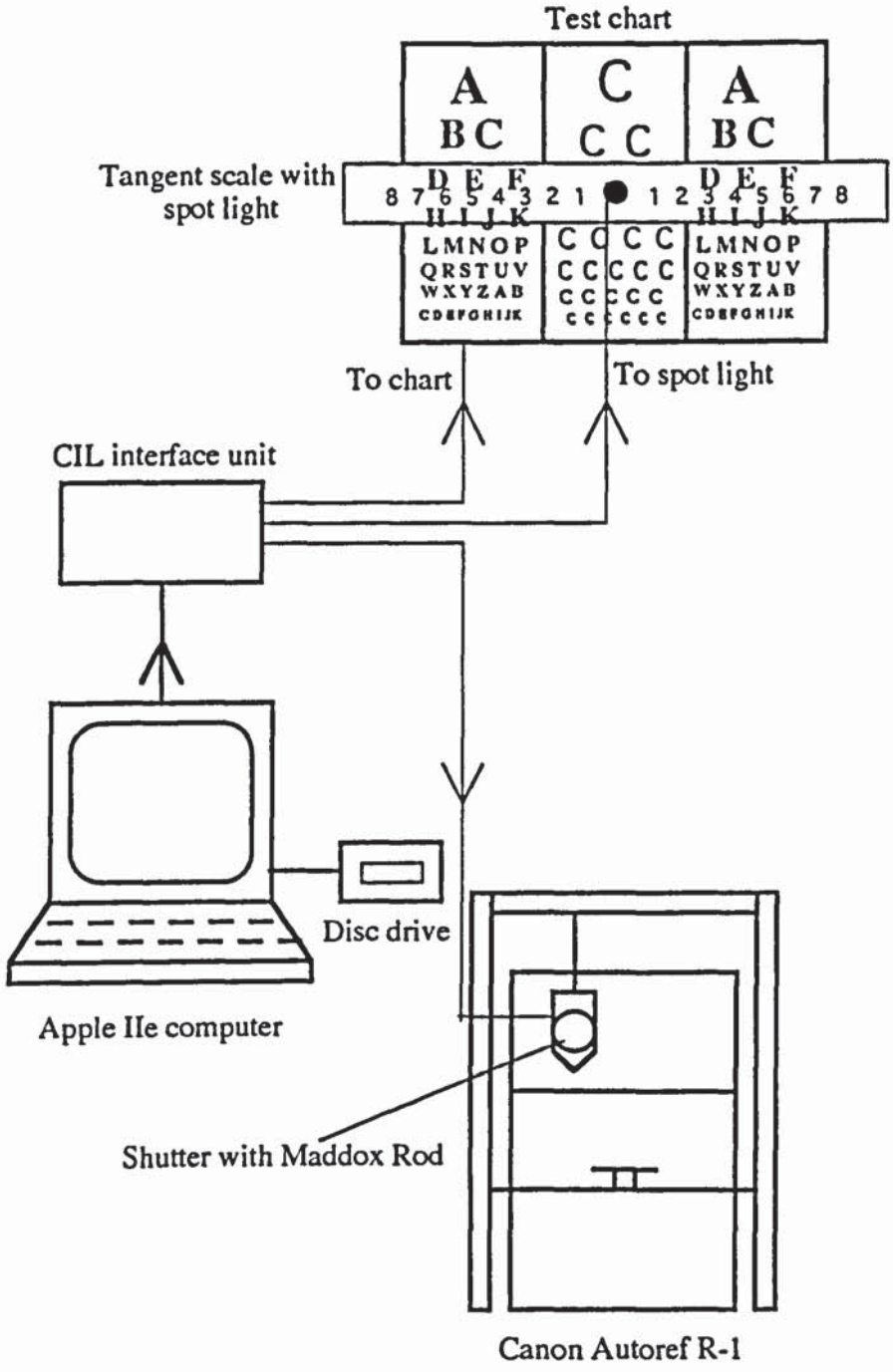

Figure 5.3: Experimental set-up for measuring aspects of the vergence system

The target used for testing distances of 5 m and 2.25 m was a Snellen chart conforming to BS 4274. The chart was internally illuminated having a luminance of 350 cdm^{-2}. The standard Snellen letters and Landolt ring targets ranged from 5/36 to 5/5 in size. A clear perspex tangent scale was attached to the front of the chart, a hole cut in the centre for the spot light. The figures on the tangent scale were equivalent in size to 5/14, they were separated by 5 cm with mid point markers inbetween. The figures and mid point markers

were made from Scotch 3M reflective tape and glued to the back of the perspex enabling them to be illuminated via internal reflection from the central spot light. When this tangent scale was used at a distance of 2.25 m, all readings had to be multiplied by a conversion factor of 2.22 in order to calibrate the scale. The target used to assess vergence at near was made from an adapted Freeman Archer unit, details appear in Chapter 7. More detailed methodology for measuring accommodative convergence, heterophoria, tonic vergence disparity and prism adaptation appears in Chapters 6 and 7.

5.5B - Control of the flashed Maddox rod technique

The flashed Maddox rod procedure was fully controlled by an Apple IIe computer via a CIL Microsystems PCI 6000 interface. The interface has mains voltage rated relays and allowed for independent switching of the chart, spot light illumination and shutter (see Figure 5.3). The programs used to control each experimental condition appear in Appendix 6. Whilst most of the programs were written by the author, the program used for the prism adaptation experiment was written by D L Sculfor (Final year elective study, Aston University 1991).

5.6 - STATISTICAL ANALYSIS OF EXPERIMENTAL RESULTS

Much of the data acquired from the research programme of this thesis could be analysed using standard statistical techniques such as one- and two-way analysis of variance (ANOVA), paired t-tests and correlation coefficients. Such techniques are commonly used in all types of research, hence it is not necessary to discuss them in detail here. However, it was not appropriate to analyse some of the data from the investigations using these techniques therefore additional statistical analyses used in this thesis are described below.

5.6A - Analysis of covariance

Analysis of covariance (ANCOVA) is a technique that combines features of ANOVA and regression. The aim of the ANCOVA is to correct the measurement of one variable from the effect of another variable and to check if the two variables are associated (Armitage, 1971). Regression analysis is not always the best way of determining associations between variables as sometimes much of the data collected is made redundant by this technique. ANCOVA uses all the available data thus reducing the possibility of overlooking some of the subtle interactions and effects.

ANCOVAs are used in Chapter 8 as it was necessary to determine if the magnitude of SOLA measured under pinhole conditions was dependent upon the magnitude of SOLA measured under conditions of darkness for EMMs, EOMs and LOMs. In addition,

ANCOVAs were used to determine if a relationship between SOLA measured with and without concurrent mental effort exists or not for both dark and pinhole conditions. In this thesis ANCOVAs were analysed with the help of a Macintosh Classic computer and the application program 'SuperANOVA'. For more details of ANCOVAs see Snedacor and Cochran (1980).

5.6B - Split-plot analysis of variance

Split-plot designs were first employed in agricultural experiments. The field used in the investigation was divided into 'main plots' in order to compare one factor (or treatment) e.g. irrigation by allocating it in random to the main plots. The main plots were further sub-divided into a number of 'sub-plots'. The sub-plots were exposed at random to another factor (or treatment) e.g. different fertilizers (Armatige, 1971). The effect of the fertilizers could be compared between the sub-plots but would be subject to random variations between these plots and the effects of irrigation could be compared between the main plots.

Similar situations arise in medical and other biological experimentation although these tend to be known as repeated measure designs. The subject can be considered as the main unit receiving each treatment in turn so that the subject is measured repeatedly. Alternatively, each subject may only receive one treatment but the effect of this treatment is subsequently measured repeatedly to study how its effects change as time elapses thus successive measurements cannot be regarded as independent. A similar situation occurs when successive measures of accommodation or vergence are made as in accommodative regression and prism adaptation assessment (see Chapters 7, 9 and 10). Hence split-plot ANOVAs were used in the analysis of data from these measurements. The advantage of using split-plot ANOVAs over normal ANOVAs is that no data is made redundant and separate error terms for both the major and minor factors and interactions are determined. The split-plot ANOVAs were computed with the help of a Macintosh Classic computer and the application program 'Statview 512+™'.

CHAPTER 6

OCULOMOTOR RESPONSES OF EMMETROPES AND MYOPES

6.1 - INTRODUCTION

Chapter 4 described how a number of investigators have proposed that the development of myopia and especially LOM is linked to sustained near vision. Many workers have since tried to provide evidence to support such a proposal although most of the evidence offered has only indirectly supported the hypothesis. It is still not clear yet which aspect of near vision - oculomotor responses (i.e.accommodation, vergence or the cross-links), changes in intraocular pressure or even pupil size is in fact responsible for stimulating myopic onset. This thesis is concerned mainly with a possible link between oculomotor responses and refractive development.

Several researchers have investigated individual aspects of the oculomotor system of emmetropes and myopes such as the amplitude of accommodation (McBrien and Millodot, 1986b), the accommodative response (AR) gradient (McBrien and Millodot, 1986a; Gwiazda et al. 1993;) AC/A and CA/C ratios (Rosenfield and Gilmartin, 1987b; Rosenfield and Gilmartin, 1988b; Jiang and Woessner, 1994), steady-state open-loop accommodation (Ramsdale, 1978; Maddock et al. 1981; McBrien and Millodot, 1987b; Rosenfield and Gilmartin 1987b; Bullimore and Gilmartin, 1987b) and accommodative regression patterns following sustained closed-loop viewing (Gilmartin and Bullimore, 1987; Fisher et al., 1987b; 1987c; Rosenfield and Gilmartin 1988a; Rosenfield and Gilmartin 1989). However such measurements have mainly been taken separately making it difficult to establish a complete oculomotor function profile for the various refractive groups. Nevertheless results of some of the investigations have indicated that differences may exist between the oculomotor responses of various refractive groups which has increased speculation that sustained near vision plays a significant role in the development of LOM. The aim of this thesis is to distinguish which aspects (if any) of oculomotor function vary significantly between the refractive groups of EMMs, EOMs and LOMs and hence determine whether a connection between oculomotor function and the aetiology of LOM indeed exists.

The effect of refractive group on various aspects of *open-loop* accommodation will be dealt with in more detail in Chapters 8, 9 and 10. The aim of this Chapter is to assess several aspects of the oculomotor function of EMMs, EOMs and LOMs such as AC/A

ratios (stimulus and response), AR gradients, CA/C ratios, tonic vergence disparity (TVD), 'phoria and steady-state open-loop accommodation (SOLA).

In attempting to identify differences in oculomotor function between the refractive groups, many workers have compared the closed-loop ARs of EMMs, myopes and occasionally hyperopes to various stimuli. McBrien and Millodot (1986a) found slight differences in the AR gradients (D/D) of EMMs (mean 0.92) compared with EOMs (mean 0.88) and LOMs (mean 0.87) when the target distance was varied thus stimulating both blur-induced accommodation (BIA) and disparity-induced accommodation (DIA - see Chapter 3 section 3.4A). They obtained a statistically significant correlation coefficient between AR gradient and refraction but the actual ARs were only significantly different between the EMMs and LOMs at the 4.00 and 5.00 D stimulus levels. In a study using emmetropic and myopic children, Gwiazda et al. (1993) reported that for similar stimuli, the AR gradients were 0.88 and 0.78 D/D respectively. However when negative lenses were used to stimulate accommodation the AR gradients dropped to 0.61 and 0.20 D/D respectively. In a more recent investigation, Gwiazda et al. (1994) reported that myopes are able to relax their accommodation to maintain clear vision better than EMMs.

Rosenfield and Gilmartin (1987c) examined the ARs of EMMs, EOMs and LOMs to differing forms of accommodative stimuli. The effects of BIA without any concomitant change in the vergence stimulus and of DIA without any concomitant change in the blur stimulus were assessed. For both conditions the effect of proximally-induced accommodation was eliminated by the use of a Badal system. The results showed that LOMs have significantly higher levels of DIA and BIA than both EMMs and EOMs which contradicts the findings of Gwiazda et al. (1993). However although the levels of DIA were similar for both EMMs and EOMs, EOMs had significantly lower levels of BIA than EMMs.

Later Rosenfield and Gilmartin (1988d) confirmed their earlier finding (1987c) that LOMs display higher levels of DIA compared with EMMs. It was suggested that the increase in DIA may be the result of an increase in the CA/C ratio in the LOMs or an altered interaction between DIA and BIA. Interestingly, the condition in which no DIA was stimulated i.e. 0 Δ, the LOMs displayed significantly lower ARs than the EMMs which supports the findings of McBrien and Millodot (1987a) and Gilmartin and Bullimore (1987). Such a reduction in the AR may indicate a greater proportion of DIA in the aggregate AR of LOMs compared with EMMs.

The results of their previous finding (1987c and 1988d) led Rosenfield and Gilmartin (1988b) to investigate the CA/C ratios of 10 EMMs, 10 EOMs, and 10 LOMs. The accommodative loop was opened in two ways: by using 0.5 mm pinholes and by viewing

a 0.1 mm diameter spotlight in darkness. Convergence was stimulated by introducing 3 and 6 Δ base out and accommodation was measured concurrently using an objective IR optometer. The mean CA/C ratios for the different methods of 0.39, 0.41 and 0.38 D/6Δ, for the EMMs, EOMs and LOMs respectively were not found to be significantly different, thus indicating that differences in DIA demonstrated previously under closed-loop conditions between LOMs and EMMs (Rosenfield and Gilmartin, 1987c; 1988d) cannot be accounted for by variations in CA/C. It is possible therefore that the relative proportions of the various accommodative elements such as BIA, DIA, SOLA and PIA within the total accommodative response vary between the refractive groups, while the CA/C ratio remains unaltered.

In attempting to discover whether aspects of the synkinetic link between accommodation and vergence other than the CA/C ratio represent the part of the near vision response associated with the development of myopia, Rosenfield and Gilmartin (1987b) measured the response AC/A ratios of EMMs, EOMs and LOMs. The stimulus levels chosen were 3.00, 3.90 and 4.60 D; the latter two were attained by the use of negative lenses in conjunction with a target placed at 33 cms. EOMs displayed higher AC/A ratios (mean 10.14) than both the EMMs (mean 8.67) and the LOMs (mean 8.91). The raised AC/A of the EOMs was found to be mediated via an increase in accommodative convergence (AC) and not via a decrease in the AR.

In contrast to Rosenfield and Gilmartin, the results from a longitudinal study by Jiang and Woessner (1994) suggest that LOMs and EMMs who show myopic shifts manifest high AC/A ratios and low CA/C ratios compared with EMMs with stable refractions. Jiang and Woessner have therefore suggested that it may be possible to identify the adult EMMs at greatest risk of developing myopia by calculating the ratio of AC/A to CA/C. However, there were only 7 EMMs who showed myopic shifts which may have distorted the results as AC/A ratios have an inherent variability (see section 3.3E).

Less attention has been paid to differences in the vergence systems of EMMs and myopes. North et al. (1989) did investigate variations in the adaptability of the vergence system of EMMs, EOMs and LOM following a suggestion by Rosenfield and Gilmartin (1988d) that LOMs may adapt less well to induced disparity than EMMs. This idea is investigated and discussed in Chapter 7. Goss (1991) analysed the clinical records of several children who had developed myopia between the ages of 6 and 15 and of children who had remained emmetropic throughout this period. He found that the near-point 'phorias of the now myopic group before myopia development were significantly more esophoric than the emmetropic group (mean 1 Δ eso and 2 Δ exo respectively) which suggests that changes in near 'phoria may precede the development of myopia and in

particular EOM. However this study did not include changes in 'phoria preceding the development of LOM.

Very few investigations have reported the effect of refractive group on distance and near heterophoria measurements. Distance 'phoria was once thought to represent the disparity between tonic vergence and the primary position (see Chapter 2 section 2.5C). However this is now known not to be the case but tonic vergence disparity (TVD) and distance 'phoria do seem to be related (O'Shea et al., 1988; Wolf et al., 1990; Rosenfield and Ciuffreda, 1990; Owens and Tyrrell,1992 - see section 2.5C). Owens and Tyrrell (1992) demonstrated that a significant proportion of the discrepancy between the two measures results from a reduction in AC due to relaxation of accommodation. Previous studies have shown that the magnitude of AC is greater for the EOMs than both the LOMs or EMMs under closed-loop conditions (Rosenfield and Gilmartin, 1987b). It may be that the discrepancy between distance 'phoria and TVD is also greater for this refractive group.

Controversy exists still as to whether TVD and SOLA are related (see Chapter 2 section 2.5D). If they are, then it may be reasonable to expect that like SOLA, (see Chapter 8) TVD is also influenced by refractive group. If this is the case it could offer further evidence albeit indirectly of the connection between near work and in particular the vergence system and the aetiology of LOM.

In attempting to discover a connection between near work and the development of LOM, researchers have tended to investigate the effect of refractive error on one particular component of the oculomotor system without relating it to any other. The accommodation and vergence systems cannot be regarded in isolation, due to the strong cross-links that exist between the two especially under closed-loop viewing conditions. This study aims to contrast and cross-correlate various aspects of oculomotor function such as stimulus and response AC/A ratios, stimulus CA/C ratios, AR gradients, 'phoria measurements, TVD and SOLA and analyse them with respect to refractive group in order to determine the characteristics of the oculomotor response profiles of EMMs, EOMs and LOMs.

6.2 - METHODS

6.2A - Subjects

Forty subjects took part in the experiment, 14 EMMs (mean sphere refraction between plano and +0.75 D), 13 EOMs (mean sphere refraction $\geq$ -0.50 D, myopic onset on or before the age of 14) and 13 LOMs (mean sphere refraction $\geq$ -0.50 D, myopic onset on

or after the age of 16). These age classifications were chosen as previous literature has indicated that stabilization of refractive error usually occurs around 15 years of age (Slataper, 1950; Goss and Winkler, 1983 - see Chapter 4 section 4.4). Furthermore, the recollection of myopia onset usually coincides with the first refractive correction and not with the onset of blurred distance vision which may occur at least several months earlier. A gap between the upper limit of myopic onset for the EOMs and the lower limit for the LOMs was enforced to ensure that any overlap between the groups was minimised and that subjects were correctly classified. The criteria for selecting which group a subject should be placed in remains the same throughout the entire experimental programme of this thesis.

Table 6.1 gives details of the subjects used in this study. Biometry and keratometry measurements for the majority of subjects appear in Appendix 7a. All subjects had normal binocular vision, visual acuity in each eye of at least 6/6 and cyls no larger than 0.75 D. Both eyes of all myopic participants were fitted with *Acuvue* disposable soft contact lenses for the duration of the experiment (see Chapter 5 section 5.3C). At least 20 minutes was allowed for adaptation to the contact lenses prior to data collection.

	EMMs	EOMs	LOMs
Number of subjects	14	13	13
Mean age (yrs)	20.43	21.33	22.21
Range of ages (yrs)	18 - 27	18 - 33	18 - 30
Mean refraction	+0.10 D	-4.00 D	-1.42 D
(SEM)	(±0.06)	(±0.66)	(±0.13)
Mean myopic onset	-	10.50	19.28
(SEM)	-	(±0.92)	(±0.78)

Table 6.1 Details of subjects used: emmetropes (EMMs), early-onset myopes (EOMs) and late-onset myopes (LOMs).

6.2B - Measuring AC/A ratios and the accommodative response gradient

Both stimulus and response AC/A ratios were measured simultaneously, the results of which provided data to assess the AR gradient. Vergence was assessed using a flashed Maddox rod technique (described in Chapter 4) while accommodation was measured by the Canon Auto-Ref R-1 objective optometer. The initial accommodative stimulus was provided by a target fixed at 2.25 m and was varied by introducing negative lenses before one eye, thus mimicking the gradient test described in Chapter 3 section 3.3A. This method was chosen as it minimises the proximal stimulus to accommodation compared with the 'phoria method and it is easier and quicker for subjects to perform than the fixation disparity technique.

Subjects sat with their chin on the chin rest of the Canon objective optometer. A lens holder was placed in front of the LE 12 mm from the corneal apex. During the experiment either no lens or negative lenses of powers -1.00, -2.00 or -3.00 D were placed in the lens holder to provide accommodative stimuli levels of -0.44, -1.42, -2.37 and -3.30 D respectively. These stimulus levels were chosen to coincide with the central, flat portion of the S/R curve (see Chapter 1 section 1.6A). A *Blitz* electronic shutter mechanism and lens holder containing the Maddox rod was placed in front of the RE approximately 15 cms from the corneal apex, i.e. behind the semi-silvered mirror. The separation from the eye to the shutter was necessary in order for the optometer to assess the refraction without the shutter interfering with the measurement method. The separation did not affect the position of the Maddox rod seen on the tangent scale by the subject and the shutter and its surround still acted as an effective occluder to the RE.

An Apple IIe computer was programmed (see Appendix 6b) to control the heterophoria measurements via a CIL Microsystems PCI interface. On the experimenters command, the internal chart lights would be extinguished whilst simultaneously the central spot light would be illuminated and the shutter would be opened to expose the Maddox rod. The shutter remained open for 125 ms only, less than the accommodative latency of 370 ms (Campbell and Westheimer, 1959) and the vergence latency of 160 ms (Krishnan et al., 1973; Venkiteswaren, 1976).

Subjects were instructed to view the test chart and keep the smallest targets clear at all times and report any blurring. Meanwhile, refractive error was measured using the Canon at least 5 times. After pressing the command key, the computer would emit a bleep to warn the subject of an imminent 'phoria measurement. At least 5 readings for each stimulus level, imposed in random order, were obtained from each subject. The results had to be multiplied by a constant (2.22) in order to convert the tangent scale which was designed to be used at 5 m to one for use at the test distance of 2.25 m (see Chapter 5 section 5.5A.).

6.2C - Measuring tonic vergence disparity (TVD) and steady-state open-loop accommodation (SOLA)

Tonic vergence disparity (TVD) was measured using a slightly modified version of the flashed Maddox rod technique used for measuring the AC/A ratio. Subjects sat in complete darkness with their chin on the chin rest of the Canon optometer. The shutter was placed in front of the RE, close to the corneal apex so that it was easier to maintain alignment in complete darkness. The Canon assessed darkroom SOLA from the LE during this part of the experiment. The test chart, which was switched off for the duration of the experiment was covered with white paper so that the targets could not be confused with the numbers on the tangent scale during a TVD measurement. Subjects sat

in complete darkness for three minutes prior to data collection to allow for any adaptive effects of both the accommodative and vergence systems to dissipate (see Chapters 1 and 2, sections 1.7E and 2.5B).

The timing of each TVD measurement was controlled by the experimenter, a warning bleep was issued by the computer prior to a measurement. In contrast to the AC/A measurements, the spotlight remained on for only 125 ms (compared to 2 s) after the Maddox rod was flashed in order that the accommodative system remained unstimulated by the measurement. Once again, the readings from the tangent scale had to be modified by multiplying them by the constant 2.22 in order to convert them to a test distance of 2.25 m. The test distance of 2.25 m was specifically chosen as the high SOLA levels of some individuals would have caused the numbers on the tangent scale to appear blurred if used at 5 m. The target distance of 2.25 m is equivalent to 0.44 D which is approximately the average SOLA level when measured using a Canon optometer (see Chapter 8).

6.2D - Measuring the CA/C ratio

To measure CA, the accommodative loop has to be opened while the vergence loop remains closed. The method used to achieve such conditions is described fully in Chapter 5. While sitting in complete darkness subjects were instructed to binocularly view a diffuse green light which was placed at a viewing distance of 64 cms. The target distance of 64 cms was chosen so that for subjects' with an average inter-pupillary distance of 64 mm, the target induced 10Δ convergence when no supplementary lens was present. A lens holder, containing either no lens, 2, 4 or 6 Δ was placed in front of the subjects' RE. The ophthalmic prisms were introduced, in random order, while the subjects kept their eyes closed in order to reduce the effect of prism adaptation (see Chapter 7). Upon opening their eyes and locating the target, the refractive error of the LE was measured by the optometer at least 10 times.

6.3 - RESULTS

All refractive error measurements were analysed as mean spheres. AC/A ratios, CA/C ratios and AR gradients were derived by drawing the best fit line through the data points for each subject and finding its gradient. The group mean results for the measurements of AC/A ratios, AR gradients, CA/C ratios, TVD, 'phoria at 2.25 m and SOLA measured in both darkness and with diffuse green light as the target are shown in Table 6.2, SEMs are given in brackets.

One-way ANOVAs were computed for each condition to determine if the results were significantly influenced by the refractive group. However, the measurements between the refractive groups did not differ significantly for any of the responses even though the group means indicate possible trends. The EOMs show larger mean AC/A ratios and AR gradients than both the LOMs and EMMs respectively, whereas EMMs have larger mean CA/C ratios than both the EOMs and the LOMs. Furthermore, the LOMs mean 'phoria measured at 2.25 m and TVD were both more esophoric than both the EOMs and EMMs respectively. In addition, SOLA measurements were on average higher when the diffuse green light as opposed to complete darkness was used to open the accommodative loop. Moreover, for both conditions the EMMs had higher mean SOLA levels than the EOMs and the LOMs respectively.

Condition	EMMs	EOMs	LOMs
AC/A (stimulus), Δ/D	2.86 (±0.09)	3.65 (±0.10)	3.22 (±0.07)
AC/A (response), Δ/D	6.20 (±0.23)	6.78 (±0.14)	6.47 (±0.15)
AR gradient	0.48 (±0.0001)	0.51 (±0.001)	0.49 (±0.001)
CA/C ratio, D/6Δ (MA)	1.06 (±0.26)	0.78 (±0.14)	0.87 (±0.18)
'Phoria (2.25 m), Δ	0.20 eso (±0.23)	0.83 eso (±0.21)	1.24 eso (±0.23)
TVD, Δ	2.26 eso (±0.16)	3.02 eso (±0.18)	3.20 eso(±0.24)
SOLA (dark), D	0.65 (±0.03)	0.59 (±0.03)	0.53 (±0.03)
SOLA (green light), D	0.85 (±0.04)	0.75 (±0.04)	0.65 (±0.03)

Table 6.2: Group mean results for the various oculomotor responses (SEMs are given in brackets)

Relationships between the various oculomotor response measurements were investigated using correlation coefficients. Significant correlations were found to exist between some of the measurements (see Figure 6.1). SOLA (dark) and SOLA (green light) were found to be positively correlated ($r = 0.72$; $p < 0.001$) as was SOLA (dark) and CA/C ratio ($r = 0.48$; $p = 0.002$). In addition, SOLA (green light) and CA/C ratio were also positively correlated ($r = 0.48$; $p = 0.002$). A significant negative correlation was found to exist between SOLA (green light) and 'phoria ($r = -0.33$; $p = 0.04$). Furthermore, the correlation coefficients of TVD and 'phoria ($r = 0.49$; $p = 0.001$) and AC/A (stimulus) and AC/A (response) were also found to be highly significant (0.85; $p < 0.001$).

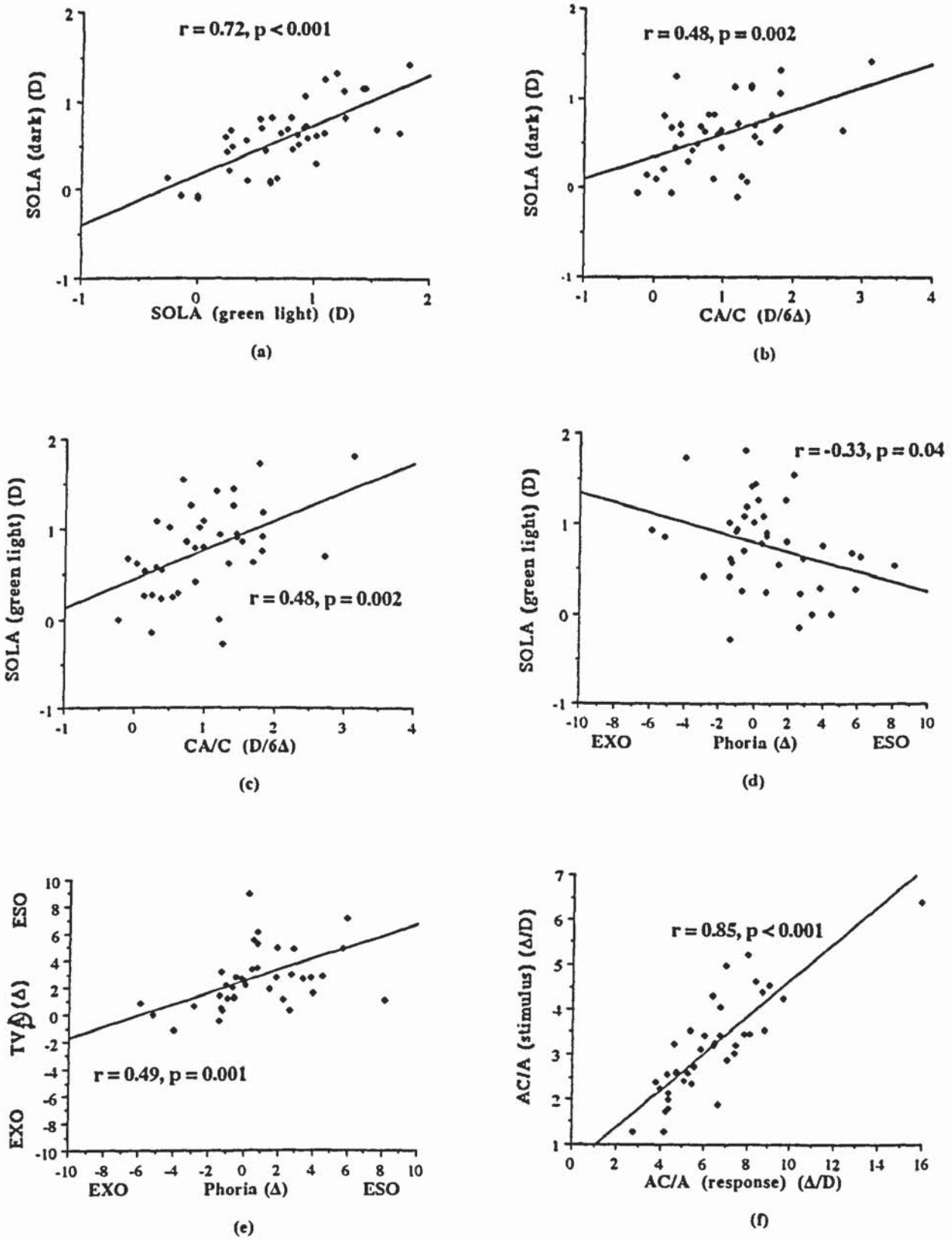

Figure 6.1: Graphs showing the relationships between various oculomotor responses.

6.4 - DISCUSSION

The aim of this investigation was to find whether differences exist between certain oculomotor responses of EMMs, EOMs and LOMs which may help explain the reported connection between sustained near vision and the development of myopia. Although no significant differences between the refractive groups were found for the measures of AC/A and CA/C ratios, AR gradients, TVD, 'phorias measured at 2.25 m or SOLA levels measured under two open-loop conditions, certain trends and correlations were evident.

Unlike the study by Jiang and Woessner (1994), no significant differences were found to exist between the AC/A ratios of EMMs and LOMs. However, similarities exist between the findings reported here and those of Rosenfield and Gilmartin (1987b) in as much as the EOMs had larger AC/A ratios than both the LOMs and the EMMs. Furthermore the stimulus AC/A results were significantly correlated to the response AC/A ratios suggesting that the differences in the ratios are mediated via AC and not the AR which is in agreement with the findings of Rosenfield and Gilmartin. The response AC/A ratios reported here are lower than those reported by Rosenfield and Gilmartin but there are several differences in the methodology of the two experiments which may have given rise to these discrepancies.

In contrast to McBrien and Millodot (1986a), no correlation was found between the AR gradient and refractive error or even refractive group in this study but the ARs at 4 and 5 D stimulus levels were not recorded nor were hyperopes included as a subject group. The magnitudes of the AR gradients obtained in this experiment are very low compared with those of McBrien and Millodot (1986a) and Gwiazda et al. (1993) when the target distance was altered to provide varying accommodative stimulus levels. However, the accommodative stimuli in this experiment were provided by negative lenses and not by altering the target distance which is likely to be the reason behind the smaller gradients reported here as the stimuli to proximal accommodation is much reduced compared to when the target is moved physically. Gwiazda et al. (1993) also found that when the accommodative system was stimulated by negative lenses the AR gradient was much reduced.

Furthermore, the letters on the test ranged in size from 5/36 to 5/5 but with the target distance being only 2.25 m the equivalent target sizes would have ranged from approximately 5/80 to 5/11. It could be argued that they would not have provided a sufficient accommodative stimulus even though the subjects were instructed to keep the smallest letters and Landolt ring targets clear at all times and to report any blurring if it occurred. Even so, the effective size of the targets would have decreased with the introduction of the negative lenses which would, in theory have increased the accuracy of

the accommodative response. Furthermore the best fit lines drawn through the data points showed high correlations, in the order of 0.95 which would suggest that subjects could see the targets clearly. It should also be noted that unlike McBrien and Millodot's study, the subjects viewed the target monocularly throughout therefore eliminating the contribution of CA to the aggregate accommodative response.

The results obtained for the group mean CA/C ratios agree well with those of Rosenfield and Gilmartin (1988b) who also found no significant differences between the refractive groups. The findings of both studies suggest that the CA/C ratio is unlikely to play a role in the aetiology of myopia which is in contrast to the proposal of Jiang and Woessner (1994). Moreover, no correlation was found between AC/A and CA/C ratios which is confirmed by reports that the stimulus AC/A remains relatively constant throughout life and the response AC/A remains relatively constant until around 45 years of age (see Chapter 3, section 3.3C) whereas the CA/C ratio remains steady only until approximately 24 years of age after which it decreases (see Chapter 3, section 3.5B).

The group mean 'phoria measurements show a trend for higher esophoria in LOMs and EOMs than in EMMs. Such a finding is interesting in view of the increased esophoria in EMMs prior to myopic change reported by Goss (1991). However, it should be remembered that the differences between the refractive groups were not statistically significant and therefore without further investigation it is not possible to attach any special importance to them.

The trend of increased esophoria in LOMs compared with EOMs and EMMs reveals itself once again, this time in the measurement of TVD. Although the differences in TVD between refractive groups like those of 'phoria were not significant, a high correlation between TVD and 'phoria was found. In the majority of cases, the TVD was more esophoric than the 'phoria which supports the findings of O'Shea et al. (1988), Wolf et al. (1990), Rosenfield and Ciuffreda (1990) and Owens and Tyrrell (1992). The discrepancy between the two measures is thought to result mainly from a reduction in AC due to relaxation of accommodation when measuring the 'phoria (Owens and Tyrrell, 1992). The discrepancy between 'phoria and TVD appears to be largest for the EOMs which would agree with the suggestion by Rosenfield and Gilmartin (1987b) that the magnitude of AC is greater for EOMs than both LOMs or EMMs.

The trends evident in the SOLA measurements under both open-loop conditions are in agreement with those reported by others (Ramsdale,1978; McBrien and Millodot, 1987b; Rosenfield and Gilmartin, 1987b and Bullimore and Gilmartin, 1987b) with the group mean for EMMs being higher than the group means for the myopes. Interestingly the ranking order of the group means (EMMs, EOMs then LOMs) remained the same for

both conditions even though there were no significant differences between the groups. Analysis of covariance (ANCOVA - see section 5.6A) was computed to determine the effect of the magnitude of SOLA measured in darkness on the magnitude of SOLA measured with the diffuse green light by taking variance of both measures into account. The relationship between the two measurements was found to be significant ($P < 0.001$).. The green light condition inducing higher accommodative levels than complete darkness. The reason for this could be as the vergence loop remained closed during the SOLA (green light) condition, CA contributed to the measured SOLA level.

In view of the fact that the group mean SOLA measurements for EMMs are highest but TVD measurements are the least esophoric of the three groups and LOMs have the lowest SOLA levels but most esophoric TVD measurements of the three groups, it is perhaps not surprising that significant correlations between both SOLA (dark) or SOLA (green light) and TVD were not found as under closed-loop conditions an increase in accommodation is usually associated with an increase in convergence and it is unlikely this relationship would reverse under open-loop conditions. However a negative correlation was found between SOLA (green light) and 'phoria measured at 2.25 m. The reason for this correlation is not clear because when SOLA was measured the vergence loop remained closed while the accommodative loop was opened whereas when the 'phoria was measured it was the accommodative loop which remained closed while the vergence loop was opened; it may be that a reversed relationship between vergence and accommodation exists if only one loop is opened at a time although this would seem unlikely as no other data from the study supports this suggestion. Another surprising correlation was found between SOLA (both dark and green light) and the CA/C ratio. Subjects' CA/C ratios appeared to increase with their measured SOLA levels. However, on inspection of Figure 6.1 (b and c) it appears that a couple of outlying points make it seem as if a correlation does exist between between SOLA and CA/C.

The data presented in this Chapter fails to demonstrate any statistically significant differences in certain aspects of the oculomotor systems of EMMs, EOMs and LOMs. Thus no evidence is provided of a connection between sustained near vision and the development of late-onset myopia from the point of view of oculomotor function. However, the trends noted from the data of this Chapter may indicate ways in which the oculomotor system *adapts* to the development of ametropia.

CHAPTER 7

PRISM ADAPTATION IN EMMETROPIA AND MYOPIA

7.1 - INTRODUCTION

Although no significant differences in certain oculomotor responses were found to exist between EMMs, EOMs and LOMs in Chapter 6, Rosenfield and Gilmartin (1988d) have previously reported that LOMs show significantly higher levels of disparity-induced accommodation (DIA) than EMMs on introduction of 3 Δ and 6 Δ base-out prisms. The increase in accommodative response (AR) due to DIA was maintained over the 10 min course of the task for the LOMs whereas the AR of the EMMs remained unchanged by the introduction of the prisms. As a result, Rosenfield and Gilmartin suggested that the EMMs may have adapted more rapidly to the prism than LOMs.

The possibility that LOMs may not adapt as readily to prisms as other refractive groups was investigated by North et al. in 1989 who examined the adaptation ability of 14 EMMs, 14 EOMs and 14 LOMs to 6Δ base-out and 6Δ base-in at distance (4 m) and near (40 cms). North and her co-workers classified the EOMs as myopic subjects whose onset of myopia was before 15 years of age whereas LOMs were classified as such if the onset of their myopia was at 15 years of age or later. Their results showed that all three refractive groups were capable of adapting to prism-induced deviations at both distance and near. Although the EOMs demonstrated the greatest amount of adaptation after 3.5 mins of binocular viewing in all cases, the differences in the amount of adaptation at this point between the refractive groups were not statistically significant. It is important to note that the level of adaptation achieved after 3.5 min binocular viewing was calculated from the best fitting curve drawn by eye through each set of group mean data for the different refractive groups and this trend was compared for each group using a student's t-test. Such a method of analysis renders a high proportion of the data redundant thus calling into question the statistical validity of the results.

Several different methods of analysis have been used by various workers to interpret the results of prism adaptation curves. As already mentioned, North et al. (1989) compared the final level of adaptation reached after 3.5 minutes of binocular viewing using a students t-test. They also investigated the response over the time period by using Mann Whitney trend analysis. The disadvantages of these techniques have already been discussed. In contrast, Sethi and North (1987) estimated the time constant, t, (the time taken for 63% of the adaptation to be complete) and calculated the adaptation rate from the exponential curve equation of the form $y = P \exp^{-Bx}$ for varying magnitudes of prism-

induced disparities. Although it is useful to know the time constants and rates of adaptation, this data alone does not show if differences between factors are significant or not.

Dowley (1990a, 1990b) used two-factor ANOVAs to analyse the adaptation responses of orthophoric and heterophoric subjects and found a significant interaction with time. Snedecor and Cochran (1980) explain that in experiments of the type detailed here, each subject receives only one treatment per condition but repeated measures are made during the treatment phase so that the change due to the treatment can be studied over time. Consequently, the successive measures made on the same subjects cannot be treated as independent, whereas the measures recorded for different individuals are independent which led them to suggest using a split-plot ANOVA for this type of experiment.

As North et al. (1989) showed that EOMs have a *tendency* to adapt to induced disparity more quickly than EMMs and LOMs, it was decided that a similar investigation using improved methodology and statistical analysis (i.e. split-plot ANOVAs) should be undertaken to clarify the issue. The experiment described below was designed to measure adaptation to *and* recovery from retinal disparity induced by base-out and base-in prisms whilst subjects viewed distance and near targets. The vergence responses of EMMs (N = 20), EOMs (N = 19) and LOMs (N = 20) were recorded; in addition, concurrent measures of accommodation were made from a smaller selection of the subjects used in this investigation.

7.2 - METHODS

Prism adaptation was recorded during a total of 225 s of binocular viewing through a 6 Δ horizontal prism for the four viewing conditions, distance with base-in (DBI) and base-out (DBO) prism and near with base-in (NBI) and base-out (NBO) prism. This was followed by a further 135 s of binocular viewing without prism during which recovery was monitored. Two visits, separated by at least 24 hrs were required to collect data from the subjects in order to avoid fatigue. During each visit, 2 conditions were assessed (in random order), separated by a minimum of 20 min. Baseline 'phorias were measured again before proceeding with the second condition. This was to ensure that no residual vergence adaptation was present.

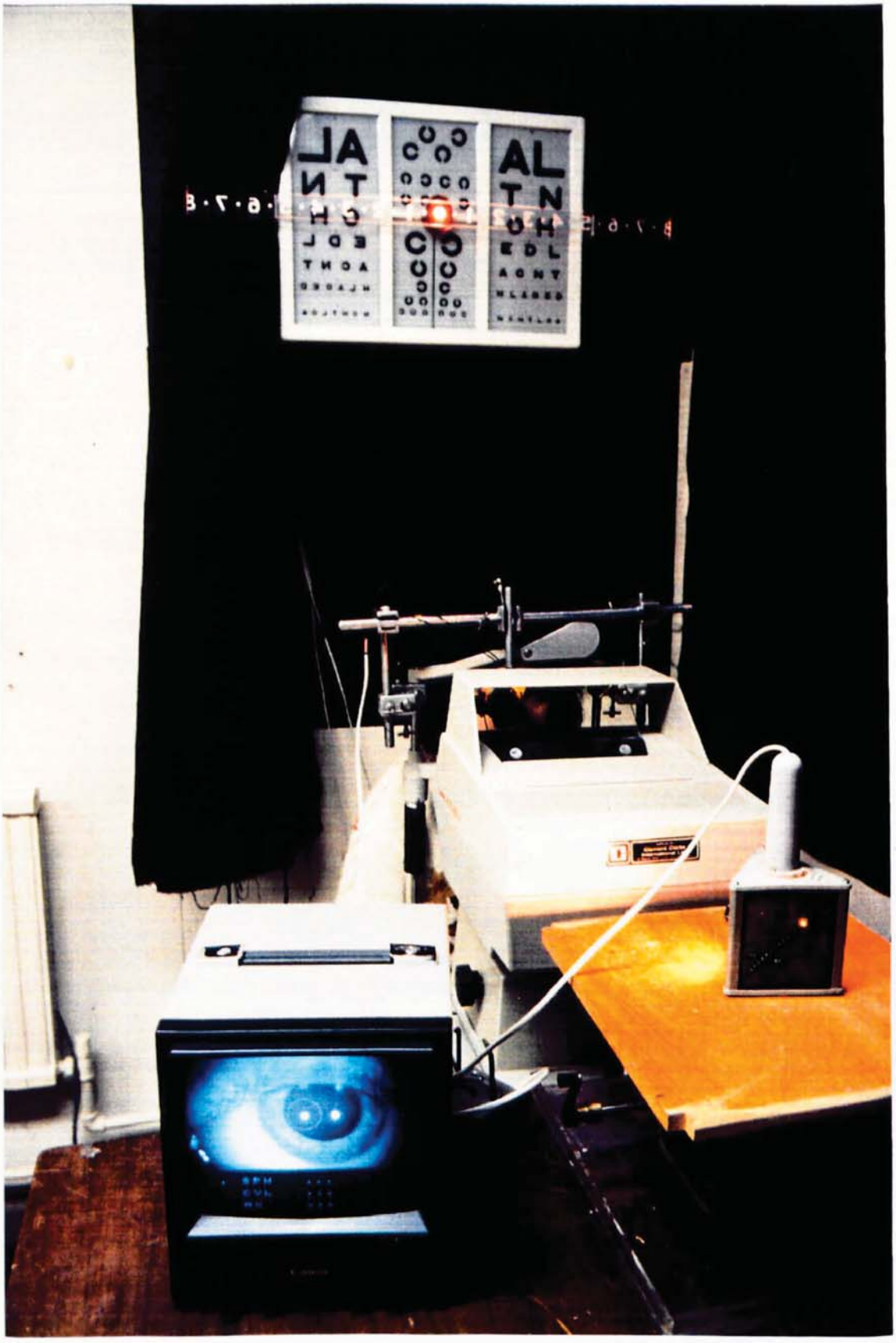

Figure 7.1: Photograph of the experimental set up showing both distance and near targets.

The heterophoria measurements were made using a flashed Maddox rod technique, similar to that used by North et al. (1989) but which was computer, not subject, controlled in an attempt to remove any possible discrepancies between the intersubject experimental conditions. The subject was positioned in the chin and forehead rest of the Canon Auto-Ref R-1 objective IR optometer which was used to record accommodation responses from a sub-set of subjects during the experiment. A *Blitz* electronic shutter was mounted on the forehead rest of the Canon optometer and was positioned in front of the right eye so that when it was closed, it acted as an occluder. A lens holder attached to the front of the shutter was used to hold a red Maddox rod and prism as required. The equipment used in this experiment was computer controlled via a CIL Microsystems PCI 6000 interface (see Figure 7.1 and Chapter 5). An Apple IIe microcomputer previously programmed by D.L. Sculfor in BASIC (see appendix 6d) provided automatic control of the complete test procedure.

7.2A - Procedure for measuring distance heterophoria

The subject viewed via a mirror, a tangent scale mounted at the centre of a standard test chart, the viewing distance was 5 m. A viewing distance of 5 m was chosen in preference to 4 m (used by North et al., 1989) to ensure that accommodation was more relaxed. To determine the subject's baseline 'phoria at this viewing distance, the following measurement subroutine (represented graphically in Figure 7.2) was run three times but if the first three readings were not identical, the mean value of a second run of three measurements was taken as the baseline.

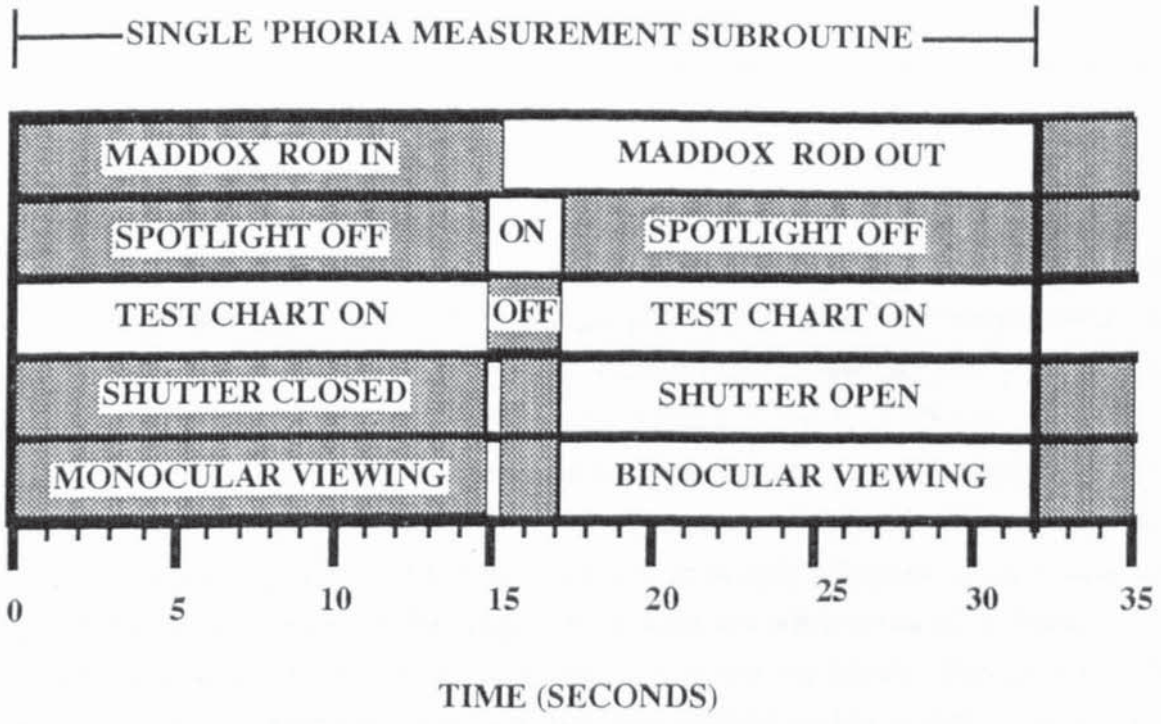

Figure 7.2: Diagram to show a single 'phoria measurement subroutine

1) The shutter was closed for 15 s of monocular occlusion and the Maddox rod was inserted. In order to maintain control of accommodation the subject was encouraged to read the letters on the illuminated chart. One second before the 'phoria measurement was taken, the computer generated a double bleep to alert the subject of the imminent 'phoria measurement.

2) After 15 s of monocular occlusion, the shutter opened for 125 ms to expose the Maddox rod. Simultaneously, the chart light was extinguished and the spotlight illuminated. The condition of monocular occlusion with the spotlight illuminated remained for the next 2 s during which the Maddox rod was removed. The resultant 'phoria measurement was noted with the subjects stating the position of the red streak to the nearest 0.25 Δ.

3) The shutter then opened, the spotlight was extinguished and the test chart illuminated for the next 15 s to permit binocular viewing of the test chart. Subjects were encouraged to read the test chart and maintain clear single vision at all times.

In order to measure adaptation, a 6 Δ lens was placed in the lens holder attached to the front of the electronic shutter. A 'phoria measurement was noted after each brief exposure of the Maddox rod. The first adaptation measurement was therefore taken before any binocular viewing through the prism was permitted (time, t = 0). Following the 15th run, during the period of occlusion the prism was removed. The subsequent 'phoria measurement represented the first recovery value before any binocular viewing without the lens had occurred (t = 225 s). Nine more recovery measurement readings were taken (giving a total of 10 measurements) which concluded the experimental routine for one condition.

7.2B - Procedure for measuring near heterophoria

In contrast to North et al. (1989) who placed their near target at a distance of 40 cm, near 'phoria measurements were assessed for a target placed at 45 cm. The reason being that the near target used in this experiment was an adapted Freeman-Archer near vision testing unit which has a tangent scale calibrated for a testing distance of 45 cm. The unit is triangular in shape with one side displaying various sizes of near type, another side a tangent scale with fixation spot and the third contains a rotating display of various targets for near vision testing. The unit is hand-held and internally illuminated by a tungsten light. Originally, the figures on the tangent scale were red but because a red Maddox rod was used, the colour filter was changed to green to avoid confusion. Furthermore, the handle, originally situated underneath the unit, was secured on top so that the unit could be placed on a flat surface 45 cm from the observer.

During near heterophoria assessment, the shutter was computer controlled in the same manner as for distance viewing. However, in order to switch between the near test type and the tangent scale with the fixation light, the experimenter had to rotate the unit. Initially the subject viewed the near test type; when the double bleep warning the subject of an imminent 'phoria measurement was heard, the experimenter rotated the unit so that the tangent scale faced the subject. The shutter then opened and the subject estimated the position of the Maddox streak to the nearest 0.25 Δ. During the following two seconds of monocular occlusion, the Maddox rod was removed and the near vision unit rotated back to its original position.

Baseline 'phoria, adaptation and recovery measurements were obtained at near using the same basic procedure as that used for distance condition and detailed above. Thus, in addition to a baseline 'phoria measurement, 15 'phoria measurements were recorded with the prism in place followed by 10 measurements once the prism had been removed.

7.2C - Measuring accommodation during adaptation and recovery

Accommodation levels of some EMMs and the myopes who wore soft contact lenses were measured during both the adaptation and recovery periods using a Canon Auto-Ref R-1 objective optometer. It was only possible to assess the accommodation levels of myopes wearing soft contact lenses because consistent measurements were not possible to obtain when subjects wore spectacles or rigid contact lenses (see section 5.3C). It was decided that instead of fitting all the myopes with soft contact lenses, subjects should wear their habitual form of refractive correction as any induced prismatic effects produced by their habitual refractive correction will be fully adapted to whereas the fitting soft lenses may induce further adaptation. Accommodation measures were obtained from the left eye of 20 subjects (6 EMMs, 6 EOMs and 8 LOMs) during the periods of binocular viewing while adapting to and recovering from the effects of induced prism.

7.2D - Subjects

A total of 59 subjects took part in this study, the majority of whom were staff and students from the department of Vision Sciences at Aston University, hence they were experienced at making optometric judgements. The classification of refractive groups used in this study differs slightly to that used by North et al. (1989); subjects were classed as LOMs if they reported myopic onset on or after the age of 16 whereas EOMs were subjects with myopic onset before the age of 14. This classification was chosen in preference to that used by North et al in an attempt to minimise any overlap between the groups (see Chapter 6). The myopes wore their habitual refractive correction (either contact lenses or spectacles) during the experiment and could achieve at least 6/6 visual acuity with each eye. The EMMs had mean sphere refractive errors within the range of -0.25 to +0.75 D with no more than 0.50 D astigmatism and could achieve at least 6/6

unaided with each eye. Subjects were considered myopic if their mean sphere refraction was greater than -0.50 D. All subjects had normal binocular vision. The mean ages of subjects, refractive error and age of onset of myopia are shown in Table 7.1 below.

	EMMs	EOMs	LOMs
Number of subjects	20	19	20
Mean age (yrs)	20.73	20.20	22.13
Range of ages (yrs)	18 - 27	18 - 29	18 - 30
Mean refraction	+0.12 D	-3.75 D	-1.44 D
(SEM)	(±0.06)	(±0.62)	(±0.19)
Mean myopic onset	-	11.87	19.07
(SEM)	-	(±0.62)	(±0.75)

Table 7.1 Details of subjects used: emmetropes (EMMs), early-onset myopes (EOMs) and late-onset myopes (LOMs).

It was not possible for some subjects to maintain single binocular vision for all four conditions and others failed to complete the two visits, as a result out of the 59 subjects used in this experiment only 15 EMMs, 16 EOMs and 17 LOMs completed all four conditions. In contrast, North et al. (1989) reported that all 14 subjects from each of the three refractive groups completed each condition.

7.3 - RESULTS

The adaptation and recovery phases of the four conditions (DBI, DBO, NBI and NBO) were analysed separately using three-factor split-plot ANOVAs (major factors were refractive group and condition, the split-plot i.e. minor factor was time). This particular method of analysis requires equal numbers of subjects in each refractive group, consequently the final analysis was made on 45 sets of data; the data of 15 subjects from each refractive was used to compile the three-factor split-plot ANOVA tables (see Tables 7.2 and 7.4). The subjects excluded from the analysis (1 EOM and 2 LOMs) were chosen at random.

7.3A - Baseline 'phoria measurements

The baseline 'phoria measurements collected before the introduction of the prism for the distance and near viewing conditions were averaged (see Appendix 8b). Using one-way ANOVAs, no significant differences were found between the 'phoria measurements of EMMs, EOMs and LOMs for either the distance or near condition. This is consistent with the results from the previous Chapter where it was reported that no difference was found between the groups for the 'phorias measured at 2.25 m.

7.3B - 'Phoria measurements during the adaptation phase

Figure 7.3 shows all four adaptation and recovery phases for each of the three refractive groups. Figure 7.4 contains the same data as Figure 7.3 but it is displayed so that direct comparisons can be made between the refractive groups for each condition. Each point on the graphs represents the mean response of 15 subjects. Error bars have been omitted for clarity but SEMs were in the order of ±0.25. All the measurements have been adjusted for the subject's baseline 'phoria and therefore show the amount of prism-induced 'phoria as binocular viewing is gained through the prism.

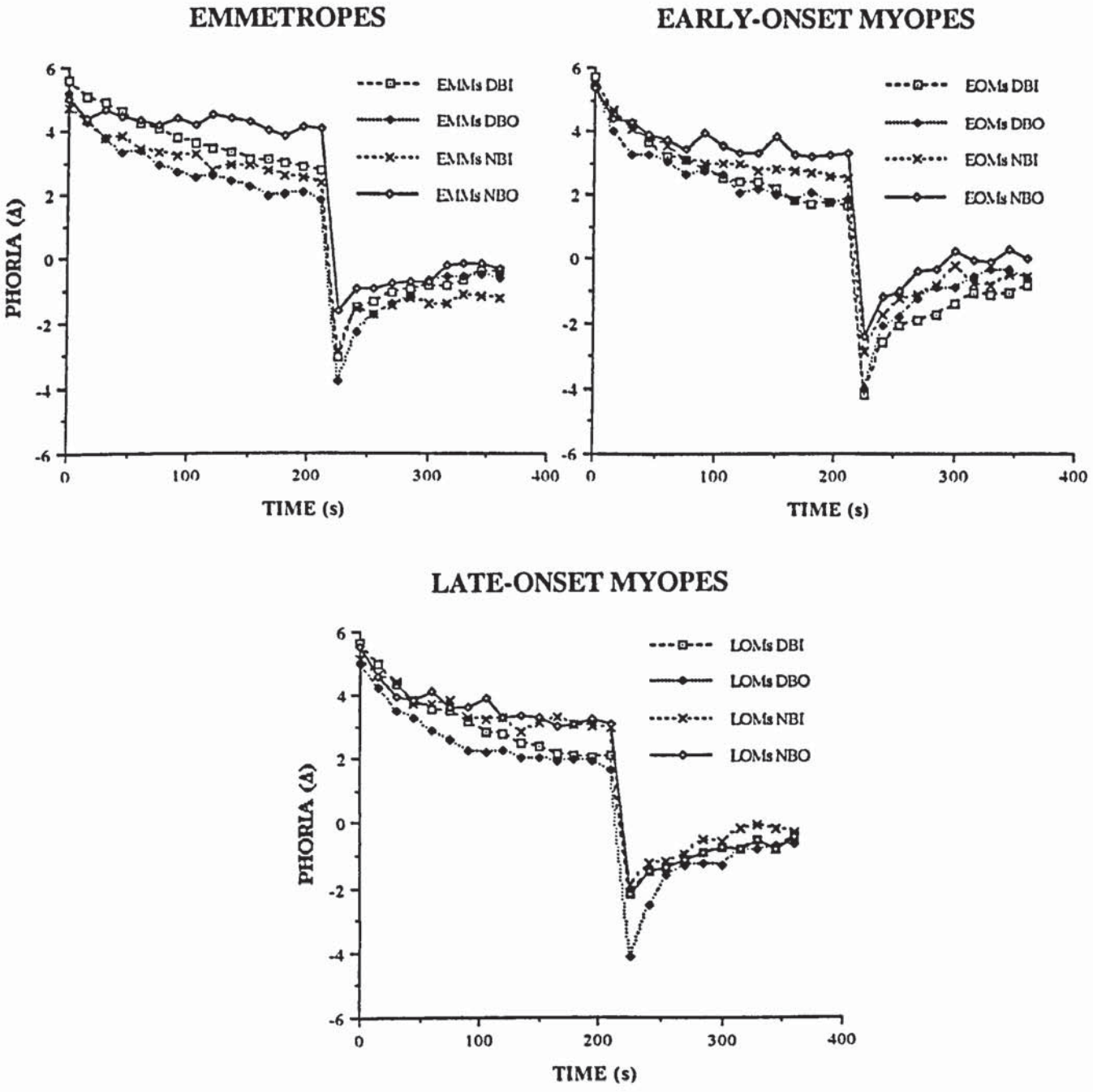

Figure 7.3: The graphs show the differences in the adaptation and recovery responses between the four conditions of induced prism i.e.distance viewing with base-in (DBI) and base-out (DBO) prism and near viewing with base-in (NBI) and base-out (NBO) prism for the three refractive groups. Error bars have been omitted for clarity but errors were of the order ±0.25.

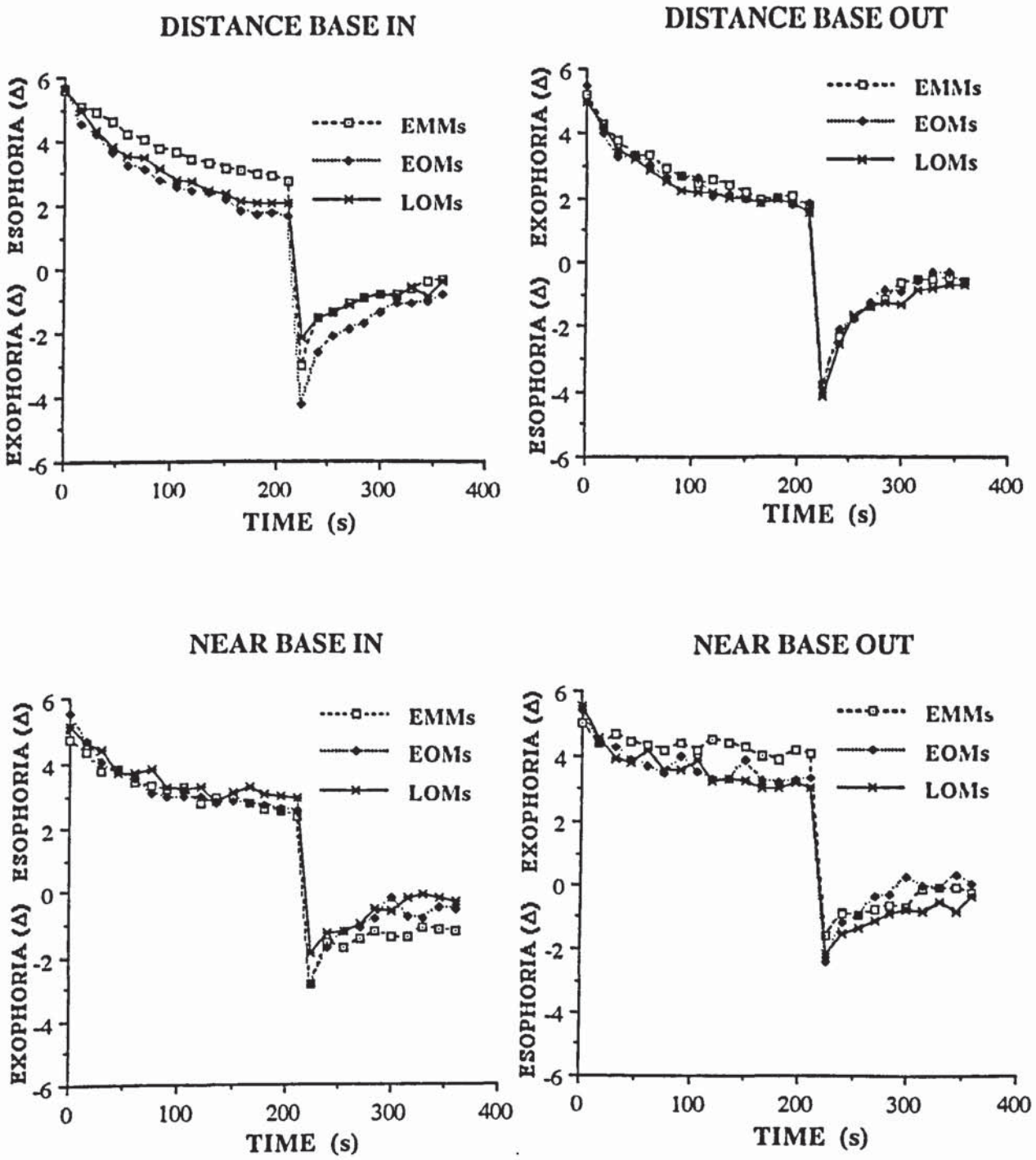

Figure 7.4: Graphs show the differences in adaptation and recovery responses between the refractive groups for the four conditions (i.e. DBI, DBO, NBI and NBO). Error bars have been omitted for clarity but errors were of the order ±0.25.

Table 7.2 shows that for the adaptation phase, the condition has a significant effect on the 'phoria measurements ($p < 0.001$) this is also evident in Figure 7.3. All three groups show the greatest amount of adaptation to 6 Δ BO at distance and the least adaptation to 6 Δ BO at near although *two*-factor split-plot ANOVAs imply that the effect of condition is more significant for the EMMs ($p < 0.001$) than either the EOMs ($p = 0.002$) or the LOMs ($p = 0.036$).

Source	df	Sum of Squares	Mean Square	F-test	P value
Refractive (Rx) group	2	76.862	38.431	2.947	0.0552
Condition (i.e DBI, DBO, NBI, NBO)	3	464.828	154.943	11.88	0.0001
Rx group x Condition	6	98.315	16.386	1.256	0.2803
Subjects w-in groups	168	2191.178	13.043		
Split-plot (Time)	14	1646.625	117.616	232.675	0.0001
Rx group x Time	28	33.478	1.196	2.365	0.0001
Condition x Time	42	150.183	3.579	7.074	0.0001
Rx x Condition x Time	84	39.527	0.471	0.931	0.6561
Condition x Subjects	2352	1188.922	0.505		

Table 7.2: Three-factor split-plot ANOVA table for the adaptation phase

Statistically, the effect of refractive group only just fails to be a significant factor in determining the 'phoria measurements ($p = 0.055$) although Figure 7.4 does show that differences in the responses of EMMs, EOMs and LOMs do exist. A two-factor split-plot ANOVA shows that the responses of the different refractive groups are most similar for the DBO and NBI conditions, whereas they differ significantly for the DBI condition ($p = 0.04$) and appear to differ significantly for the NBO condition but statistically this was found not to be the case ($p = 0.174$).

Analysis of variance (see Table 7.2) shows that there is a significant time trend with prism adaptation which is clearly shown in Figure 7.3 as a reduction in the induced 'phoria with time in an exponential manner. The time trend is significantly effected by the condition as can be seen by the slope of the adaptation plots. The best fitting line was drawn by eye through each set of data points in order to calculate the time constant, t i.e. the time taken for 63% of the adaptation to be complete (Sethi and North, 1987); for the DBO condition, $t = 204$ s, 142 s and 179 s for the EMMs, EOMs and LOMs respectively whereas the NBI and NBO conditionS yielded much longer time constants, $t > 210$ s for all the refractive groups. For the DBI condition, the EOMs adapt more quickly ($t = 142$ s) and to a greater degree than the LOMs ($t = 176$ s) and the EMMs ($t > 210$ s).

The time course of adaptation is affected by the condition as previously mentioned; furthermore ANOVA (Table 7.2) shows that the interaction between refractive group and time is also highly significant ($p < 0.001$). Figure 7.4 demonstrates the effect of refractive error on the time course of adaptation. For the two conditions DBI and DBO for which it was possible to estimate t, the EOMs have the fastest time constants whereas the EMMs have the slowest.

7.3C - Phoria measurements during the recovery phase

The results of the three-factor split-plot ANOVA for the recovery phase is shown in Table 7.3 and the recovery plots appear along with the adaptation plots in Figures 7.3 and 7.4. The first recovery point is taken before any binocular vision is gained without the prism in position and is therefore influenced by the final adaptation measurement; consequently the starting point of recovery varies depending on the adaptation ability of the subject. The variations between the refractive groups in the first recovery measurement can be seen in Figures 7.3 and 7.4. The initial recovery measurement will also affect subsequent 'phoria measurements and therefore the shape of the recovery curve.

Source	df	Sum of Squares	Mean Square	F-test	P value
Refractive (Rx) group	2	1.284	0.642	0.075	0.9274
Condition (i.e DBI, DBO, NBI, NBO)	3	111.078	37.026	4.352	0.0056
Rx group x Condition	6	126.57	21.095	2.479	0.0253
Subjects w-in groups	168	1429.459	8.509		
Split-plot (Time)	9	928.025	103.114	192.094	0.0001
Rx group x Time	18	28.615	1.590	2.962	0.0001
Condition x Time	27	78.124	2.671	4.976	0.0001
Rx x Condition x Time	54	33.211	0.615	1.146	0.2208
Condition x Subjects	1512	811.624	0.537		

Table 7.3: Three-factor split-plot ANOVA table for the recovery phase

In the same way as condition influences adaptation, it also influences the recovery measurements (p=0.006). Figure 7.3 shows variations in the recovery measurements for the different refractive groups. However two-factor split-plot ANOVAs reveal that the condition fails to be a significant factor in determining recovery measurements of LOMs ($p = 0.26$) or EMMs ($p = 0.07$) but is highly significant for EOMs ($p = 0.004$). The discrepancy between the effect of condition on the adaptation and recovery phases of the refractive groups may be the result of differences between the initial recovery measurements and hence subsequent recovery measurements of the three refractive groups.

The effect of time on the recovery measurements was highly significant as can be seen from the results in Table 7.3. The interaction between time and condition was also found to be highly significant ($p < 0.0001$) for the recovery phase. However the estimates of 't' (Table 7.4) show that the time constants of adaptation vary but no particular trend with regard to condition is evident. The advantage of estimating 't' for the recovery phase over calculating ANOVAs is that the differences in the initial recovery measurements are

taken into consideration as 't' represents the time taken to recover by 63% from the first recovery measurement before any binocular vision has taken place. Even though the final recovery measurements are similar for all three refractive groups after 210 s, the time constants vary considerably.

Rx GROUP	DBI	DBO	NBI	NBO
EMMs	34 s	39 s	> 135 s	59 s
EOMs	55 s	27 s	43 s	26 s
LOMs	78 s	76 s	55 s	72 s

Table 7.4: Time constants for the recovery phase

Unlike the adaptation phase where refractive group has a significant effect on the 'phoria measurements, refractive group shows what may be regarded as a highly *insignificant* effect on the 'phoria measurements made during the recovery phase ($p = 0.93$). However the interaction between time and refractive group is highly significant ($p < 0.001$). Figure 7.4 shows that the EOMs recover fastest (the slope of their recovery plot is steepest) while the EMMs and LOMs recover more slowly for all conditions.

7.3D - Accommodation during the adaptation phase

Accommodation responses of 6 EMMs, 6 EOMs and 8 LOMs were assessed during the periods of binocular viewing and Figure 7.5 shows typical responses from each of the refractive groups. Analysis of the accommodation responses will be made by eye as it is impossible to determine exactly the time period when each reading was taken for each subject thus comparisons between subjects cannot be made. Consequently the results presented in this section only represent trends of what may be occurring to the accommodation response during prism adaptation. Unlike Rosenfield and Gilmartin (1988d) who used open-loop viewing conditions, accommodation responses were recorded under normal closed-loop viewing conditions which will act to attenuate large accommodative change.

Most of the subjects showed little difference in accommodation responses to 6 Δ BO and 6 Δ BI for both distance and near although the responses to the target at 45 cm were generally much more variable than those to the distant target (see Figure 7.5). It may be that some 'adaptation' of accommodation has taken place. A minority of subjects showed differences between the responses to the two prism directions, Figure 7.6 shows the responses of some of these subjects. In general these subjects show a slight increase in response to BO prism compared with BI. In contrast subject KJ (a LOM) shows an increase in accommodative response to BI prism at near compared to BO prism.

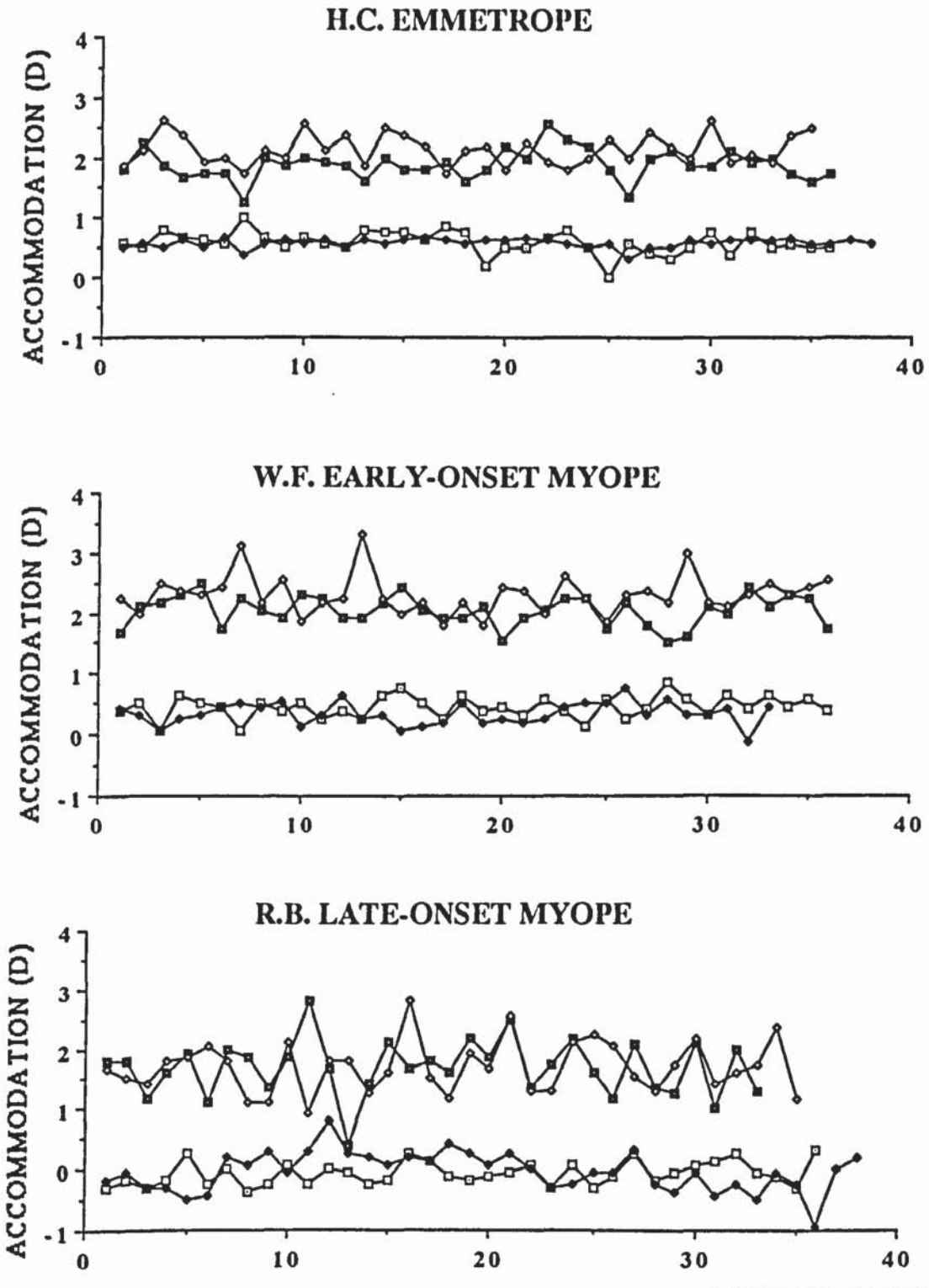

Figure 7.5: Typical accommodation responses during adaptation to prism.
Key: Distance, base-in prism; Near, base-in prism; Distance, base-out prism; Near, base-out prism

There does not appear to be any change in accommodation level over time for any of the subjects studied, which implies that either the accommodation response is not affected by the amount of binocular viewing gained through the prism which is unlikely due to the existance of convergence accommodation, or that the accommodation system itself has adapted in some way.

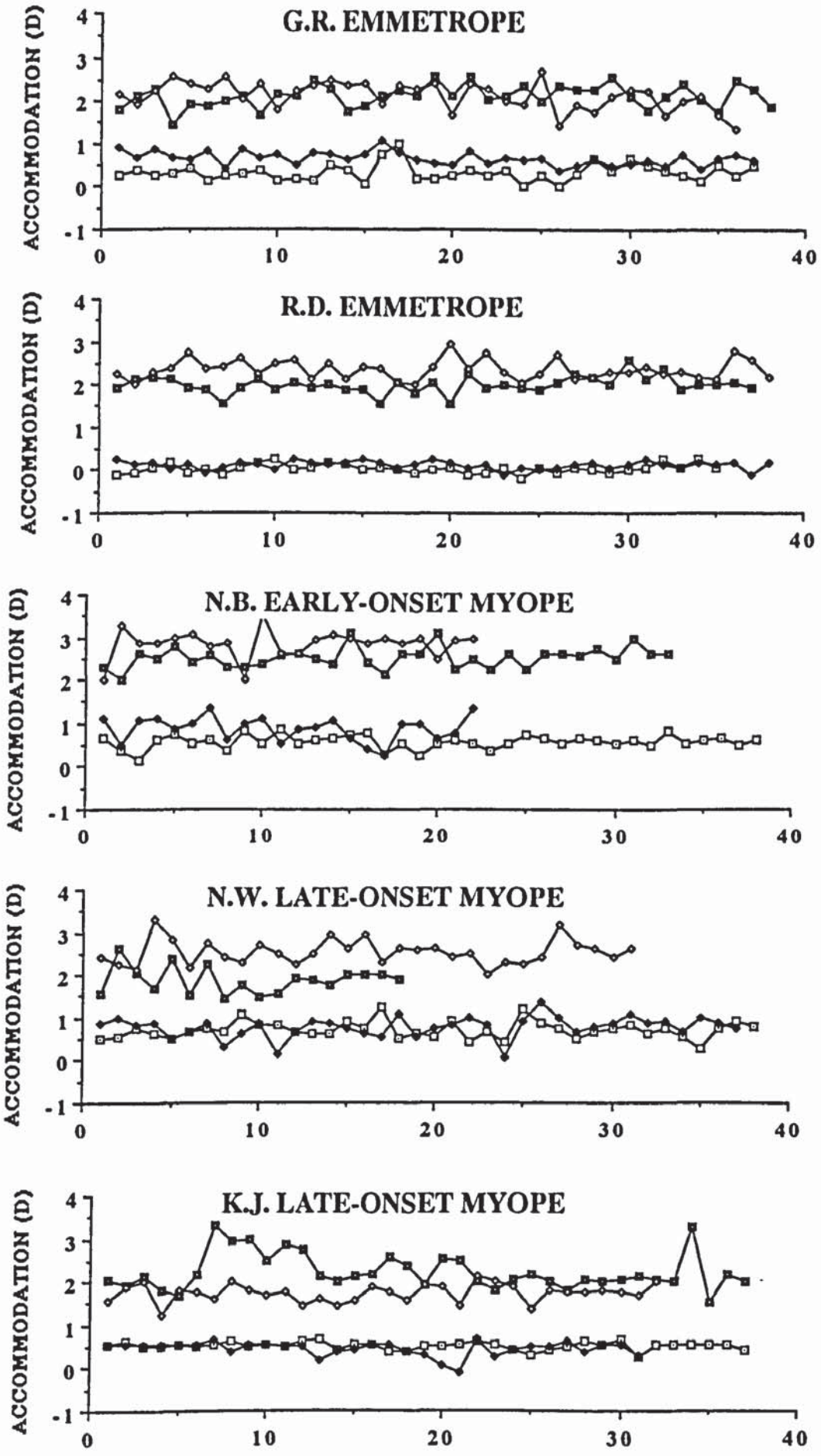

Figure 7.6: Atypical accommodation responses during adaptation to prism (see Figure 7.5 for key)

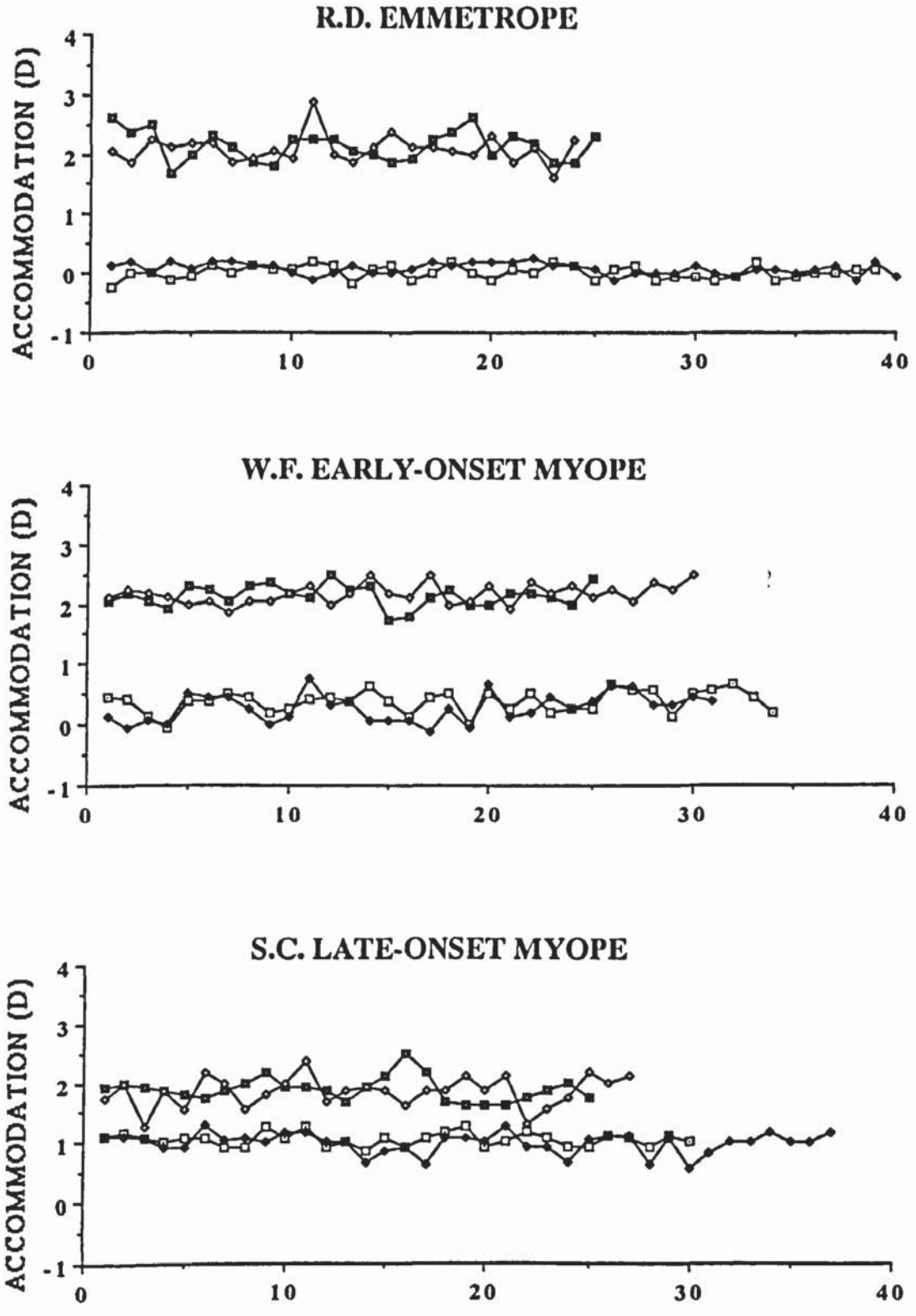

Figure 7.7: Typical accommodation responses during recovery from induced disparity (see Figure 7.5 for key)

7.3E - Accommodation during the recovery phase

Less data is available for the accommodation responses during the recovery phase as the time over which it was measured was significantly shorter than the adaptation phase. As a result the data from some subjects is insufficient to interpret properly. The majority of subjects showed no noticeable differences between the accommodation levels recorded

under the different recovery conditions but the responses recorded for near were generally more variable than those recorded for the distance condition (Figure 7.7). A noticeable difference in accommodative response was detected in a minority of subjects. For example subjects SB and NW tended to have higher accommodation levels recovering from BO prism compared to BI prism for the near condition whereas subject RB showed the opposite effect, the removal of BI prism induced higher accommodative levels at near than the BO prism (see Figure 7.8). All three of these subjects were LOMs.

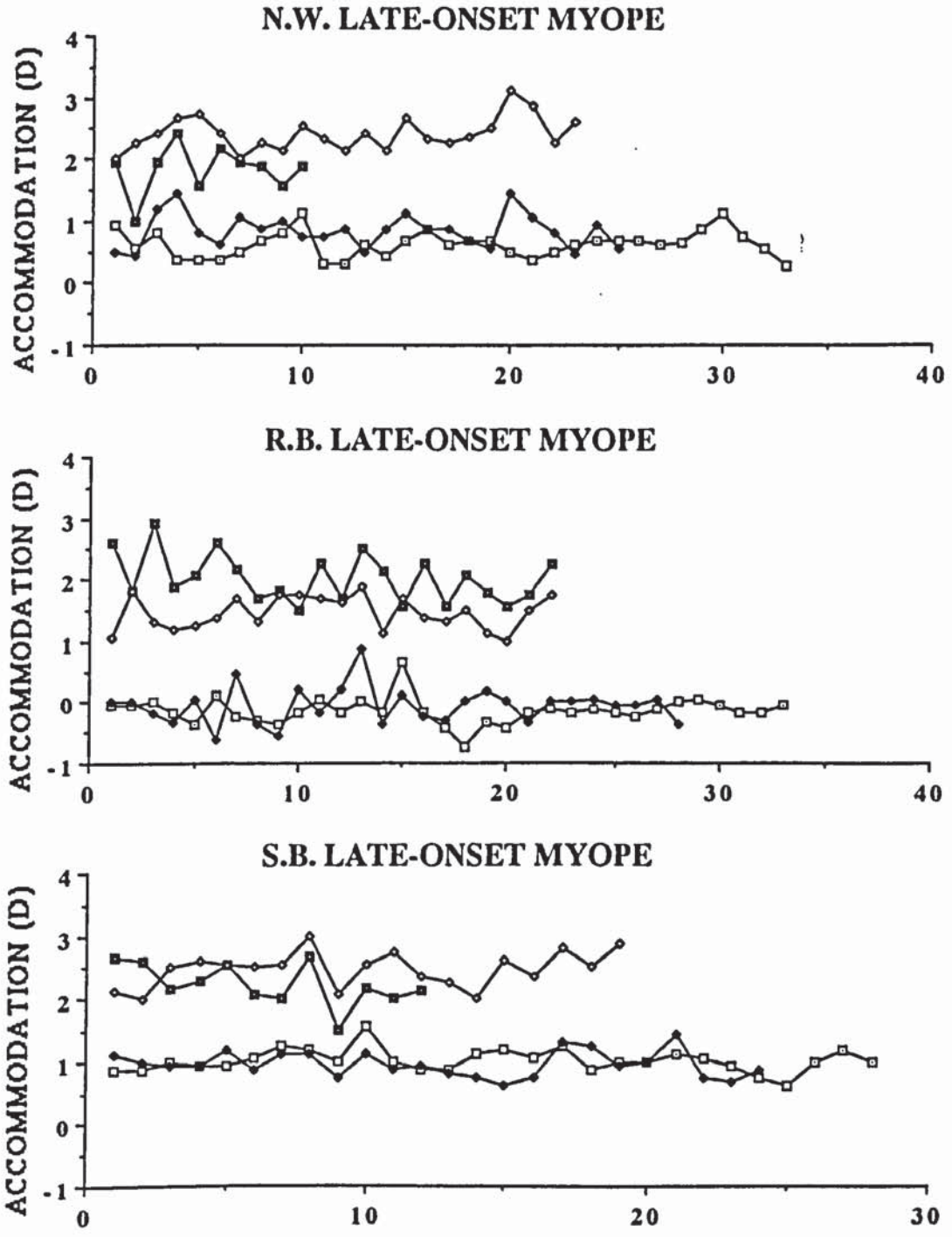

Figure 7.8: Atypical accommodation responses during recovery from induced disparity (see Figure 7.5 for key).

In the same way as for the adaptation phase, time does not seem to effect the accommodation levels during the recovery phase as no consistent increase or decrease in accommodative level is detectable from any of the accommodation graphs but again this could be due to adaptation of the accommodative system.

7.4 - DISCUSSION

The results of this study indicate that the ability to adapt to prism differs between the refractive groups only under certain conditions and is not necessarily manifest as a difference in the level of adaptation after 3.5 mins binocular viewing through the prism. Other aspects of adaptation such as the time constant of both the adaptation and recovery curves have been considered and all the data has been included in statistical analysis to determine which factors affect the ability to adapt to prism.

All three refractive groups show significant differences in the ability to adapt to prism at different testing distances and base direction. All groups adapt most readily to the DBO condition while least adaptation is achieved for the NBI condition. The EOMs were the fastest to adapted to both exo- and eso-disparity when viewing a distant target followed by the LOMs and the EMMs, respectively. Hence the results from this investigation contradict Rosenfield and Gilmartin's (1988d) suggestion that EMMs adapt more quickly to induced disparity than LOMs.

It may be that the ability of the vergence system to adapt to induced disparity is not due to anatomical or physiological differences between the refractive groups but due to the effect of wearing glasses. EOMs tend to have larger amounts of myopia than LOMs and tend to wear their glasses on a full time basis. It may be that they are more used to having to adapt to disparity induced by their glasses due to poor lens centration and increased lens power than the LOMs. For instance, the largest discrepancy between the abilities of the refractive groups to adapt to induced prism occurred when viewing a distant target with a 6 Δ base-in supplementary prism. Often, in order to reduce edge thickness or reduce the size of the lens blank needed to glaze a frame, the optical centres of a glazed frame are further apart than the individuals inter-pupillary distance (IPD). If this is the case, the negative lenses used to correct myopia will induce base-in retinal disparity which the individual will adapt to in order to avoid diplopia; hence EOMs and to a lesser extent LOMs will be more used to having to adapt to induced retinal disparities than EMMs who never wear glasses. Thus, it may well be that the ability to adapt to retinal disparity is correlated to the wearing of glasses and thus is a product of ametropia and not the cause of it. The ability to recovery from induced disparity does not appear to be influenced by

the refractive group of an individual even though the point at which recovery started varied depending on the amount of adaptation achieved at the end of the adaptation phase.

During the recovery phase, although the overall effect of condition is significant, the difference between the recovery measurements for the different conditions is insignificant for both the EMMs and LOMs but highly significant for the EOMs. The recovery measurements are dependent upon the final adaptation measurement which may be why the condition was a significant factor only for EOMs; the EOMs show the greatest amount of adaptation to prism-induced disparities during the adaptation phase, thus the initial recovery measurement is larger for this group than for the other two refractive groups.

The time-constants for each of the conditions were significantly different between the refractive groups, the EOMs consistently showed faster time-constants during both the adaptation and recovery phases; LOMs had the slowest time-constants for three out of the four recovery conditions but for the two distance adaptation conditions, the time constants were faster than those of the EMMs. North et al. (1989) also found that EOMs tend to adapt to induced disparity more quickly than the other two refractive groups.

The recovery phase produced significantly faster time-constants than the adaptation phase which may indicate that although all three refractive groups adapted readily to prism-induced disparities, the adaptation was temporary and as soon as the stimulus was removed, the vergence system quickly reverted back to its original state. Sethi and Henson (1984) suggested that when adaptation is complete, recovery of the 'phoria will be negligible. Furthermore they proposed that the time taken to *recover* from induced disparity gives a much more accurate indication of the adaptation that has taken place as 'phoria and fixation disparity techniques underestimate the time taken to fully adapt to induced prismatic deviations (see section 2.6E).

Considering the suggestions of Sethi and Henson (1984), the results obtained from the experiment detailed here indicate that although EOMs appear to adapt more quickly than the other two groups, the adaptation is only very temporary and by no means complete as the recovery time-constants are also fastest for this group. The LOMs have the slowest recovery time-constants which, according to Sethi and Henson, indicates that they have adapted more fully to the induced disparities than either of the other two groups. It should be remembered that the starting point of the adaptation phase for all three refractive groups is approximately equal to the 6 Δ stimulus and is roughly the same for all three groups once the results have been adjusted for the subjects baseline heterophoria. In contrast, the response to the removal of the 6 Δ in terms of the magnitude of the 'phoria measurement varies considerably due to the varying magnitudes of the proceeding adaptation measurement. Furthermore, the difference between the final adaptation and

the first recovery measurement rarely equals 6 Δ, which represents the magnitude of the stimulus to the vergence system on removal of the prism.

The method of statistical analysis chosen for this study indicates that refractive group only just fails to be a significant factor in determining the vergence response to prism during the adaptation phase although clear differences can be seen for DBI condition (see Figure 7.4). North et al. (1989) failed to find any significant differences between the refractive groups final level of adaptation following 210 s binocular viewing through a prism but the rest of the data proceeding this final point was virtually ignored. This study has shown that differences do exist between the refractive groups but do not necessarily manifest themselves as differences in the level of adaptation achieved after 3.5 mins binocular viewing. The shape of the adaptation and recovery curves is very important as the changes in 'phoria with time give a better indication as to the adaptation ability of a subject than just the final level of adaptation achieved.

It is very difficult to draw conclusions from the accommodation data collected during both the adaptation and recovery phases of this experiment as it is not possible to perform any statistical analysis on it. Slight variations in the accommodative response during the adaptive phase can be detected by eye from Figure 7.6. Although the majority of subjects showed no difference in accommodation levels which may indicate that the accommodative system is adapting to the induced disparity. However, some subjects appear to accommodate more during the BO compared to the BI condition for a certain viewing distance; this is perhaps not surprising as BO prism induces exo-deviation which can be rectified by increasing the vergence response to the target and one method is by increasing the contribution of accommodative convergence.

During the recovery phase, the only subjects which showed a noticeable difference in accommodative level between BO and BI conditions were LOMs. Two showed increased accommodative levels on removal of BO prism while the third showed an increase in accommodative response on removal of BI prism. The reduced amount of data collected during this phase compared to the adaptation phase makes interpretation of the results more difficult. An increase in accommodative level following the removal of BI prism could perhaps be expected because of the relative exo-deviation it produces.

No accommodative trend with time can be seen on any of the plots. Although it is not surprising that these results do not show large variations in accommodative level, small consistent changes may have been expected to occur with time because measures of adaptation to the induced prism are significantly effected by time. As binocular vision is gained through the prism, the slow vergence response is altered which could be expected to influence the magnitude of convergence accommodation. However, it could be that

the accommodative system adapts to this increase in CA thus the accommodative response appears to remain the same for all viewing conditions and for the duration of the induced prism.

Measuring accommodation during prism adaptation has never been reported before. This study has shown that it is possible and although the results obtained proved difficult to analyse statistically, they provide an insight to what is occurring to the accommodative mechanism during adaptation. The results obtained so far suggest that further study on the accommodative mechanism during adaptation and recovery is required. Accommodative measures would need to be taken at specific time slots during the binocular viewing period for all subjects so that the data of different subjects can be compared and analysed statistically.

Refereed published abstract from conference proceedings

Edwards NR and Gilmartin B (1993) Prism adaptation in emmetropia and myopia. Optom. Vis. Sci. (Suppl) 70 (12S): 42

CHAPTER 8

STEADY-STATE OPEN-LOOP ACCOMMODATION IN EMMETROPIA AND MYOPIA

8.1 - INTRODUCTION

It is now well established that under conditions of inadequate visual stimuli, the accommodative mechanism adopts an intermediate resting position, described by the term steady-state open-loop accommodation (SOLA - see sections 1.7A and 1.7B). The magnitude of SOLA depends on many factors especially the methodology used for its measurement (see sections 1.7C and 1.7D). Although differences in mean levels and distributions of SOLA between various refractive groups have been reported (Maddock et al., 1981; McBrien and Millodot, 1987b; Rosenfield and Gilmartin, 1987b; Bullimore and Gilmartin, 1987b), no consensus exists as to whether there is such a relationship. The most consistent finding to date is that EMMs have higher levels and larger ranges of SOLA in darkness than LOMs, the significance of such a finding is yet to be fully understood.

Following reports that refractive error may effect mean ranges and levels of SOLA, Bullimore and Gilmartin (1987b) investigated the effect of mental effort on SOLA using both EMMs and LOMs. Many researchers have shown that mental effort can alter the magnitude of accommodation responses measured under both open- and closed-loop conditions (see section 1.5B) but the results obtained by Bullimore and Gilmartin have shown that the effect is larger for LOMs than EMMs. Furthermore, various workers have highlighted other differences between the accommodative function of EMMs and LOMs, under both open- and closed-loop conditions; LOMs have larger amplitudes of accommodation (McBrien and Millodot, 1986b), smaller AC/A ratios (Rosenfield and Gilmartin, 1987b) and have more sustained accommodative regression effects than EMMs after prolonged near vision (Rosenfield and Gilmartin, 1988; Gilmartin and Bullimore, 1991).

The first part of the study detailed in this chapter aims to compare the magnitudes of SOLA measured on EMMs (N = 43), EOMs (N = 31) and LOMs (N = 30) using two different methods of opening the accommodative loop: complete darkness and pinhole pupil. The study was undertaken for a number of reasons:

i) By using relatively large sample sizes the aim is to resolve the issue of whether there is indeed a correlation between the magnitude of SOLA and refractive error.

ii) The large sample sizes used will also help quantify the effect of opening the accommodative loop using various methods has on the three refractive groups. It is not known if any correlation that may exist between SOLA and refractive error remains intact when the method of opening the accommodative loop is varied.

iii) By including EOMs in the study (many previous studies have failed to do this), any differences found between EMMs and LOMs can be distinguished from differences due to myopia in general. Furthermore, any differences found between EOMs and LOMs will provide indirect evidence to suggest that the origins of these types of myopia differ and that LOMs cannot be regarded simply as EOMs whose myopic onset occurs after the cessation of bodily growth.

The aim of the second part of this study is to quantify the effect of a stimulus independent task (SIT - see section 1.5B) on the levels of SOLA measured in darkness and when viewing through a pinhole for EMMs, EOMs and LOMs. The study by Bullimore and Gilmartin (1987b) omitted examining the responses of EOMs. Consequently, the reported difference between the mean induced positive shifts of EMMs and LOMs may actually reflect a difference between EMMs and myopes in general rather than being a specific trait of LOMs. Moreover, Bullimore and Gilmartin only investigated the effects of mental effort on SOLA levels measured in darkness and not while viewing through a pinhole.

The third part of the investigation examines the effect of the target size on the pinhole SOLA responses of 10 subjects. Target size has been shown by some to provide a stimulus to proximally-induced accommodation (PIA - see section 1.5B) by acting as a cue to the apparent distance of the target. A review of work examining the potency of target size as a cue to both the accommodative and vergence systems is given in section 1.5B. The role of target size in determining the accommodative response is still unclear but the aim of this study is to examine the effects of various letter sizes on the SOLA levels, as opposed to closed-loop accommodation responses.

8.2 - METHODS

Subject groups for the first part of this study consisted of 43 EMMs (mean sphere refraction between plano and +0.75 D), 31 EOMs (myopic onset on or before the age of 14) and 30 LOMs (myopic onset on or after the age of 16). All EOMs and LOMs had a mean sphere refraction of at least -0.50 D and and were fitted with *Acuvue* disposable soft contact lenses for the duration of the experimental work. A subset of 36 EMMs, 25 EOMs and 24 LOMs completed the second part of the experiment while 8 EMMs, 1 EOM and 1 LOM completed all three parts of the experiment. Table 8.1 provides refractive

group data for the first two parts of the experiment only as the subjects participating in the third part were considered as one group. Biometry measurements and keratometry readings for the majority of subjects can be found in Appendix 9a All subjects could achieve at least 6/6 visual acuity with each eye, had normal binocular vision and cyls no larger than 0.75 D.

	EMMs		EOMs		LOMs	
Section of study	1	2	1	2	1	2
Number of subjects	43	36	31	25	30	24
Mean age	20.16	20.43	20.32	20.15	21.72	22.42
	(0.40)	(0.47)	(0.65)	(0.70)	(0.78)	(1.00)
Range of ages (yrs)	18 - 30	18 - 30	18 - 33	18 - 33	18 - 34	18 - 34
Mean refraction	+0.10 D	+0.08 D	-3.63 D	-3.92 D	-1.57 D	-1.41 D
	(0.04)	(0.03)	(0.34)	(0.40)	(0.13)	(0.14)
Mean age of myopic	-	-	11.71	11.04	18.41	18.75
onset (yrs)	-	-	(0.45)	(0.61)	(0.42)	(0.50)

Table 8.1 Details of subjects in each refractive group (SEMs are shown in brackets)

Measurements of accommodation were made under monocular viewing conditions using a Canon Auto-Ref R-1 objective IR optometer in its static recording mode. Two conditions under which the accommodative loop was opened were used;

i) complete darkness

ii) viewing a target through a 0.5 mm pinhole.

For the first condition, subjects sat in complete darkness for at least 3 minutes before data collection began in order to establish a stable SOLA level (McBrien and Millodot, 1987b also see section 1.7E). The subjects were then instructed to look 'straight ahead into the darkness'. A minimum of 20 readings were taken over a two minute recording period to establish the dark SOLA level.

The second open-loop condition involved the use of a 0.5 mm pinhole, shown by Ward and Charman (1987) to open sufficiently the accommodative loop. The pinhole was drilled into a Kodak Wratten 87 gelatine filter and held in place with surgical tape approximately 12 mm from the corneal apex (see section 5.4). The subjects were instructed to look at one letter in a line of N8, high contrast (90%) print under photopic conditions (40 cdm^{-2}). The stimulus was placed in a Badal lens system at zero vergence. Between 5 and 10 initial measurements of accommodation were made under closed-loop conditions to ensure that the response level was at a minimum. After the introduction of the pinhole, a period of 3 mins was allowed before readings were taken to eliminate any

transient fluctuations which may occur. At least 20 readings of accommodation were taken during the 2 min recording period to establish the pinhole SOLA level.

For the second part of the study, SOLA levels were recorded in darkness and with a pinhole while subjects were concurrently performing a stimulus-independent task (SIT). These two conditions will be referred to as dark (SIT) SOLA and pinhole (SIT) SOLA respectively. The task the subjects were asked to perform involved counting backwards (to themselves) in 7's from a three figure number supplied by the experimenter.

The third part of the experiment involved measurements of SOLA only under pinhole conditions. The target used in the previous parts of the study consisted of N8 sized letters. For this part of the experiment, the size of the print was varied to include N8, N10, N15 and N20 sized letters and measurements of SOLA both with and without the SIT being performed were obtained for each target size accordingly.

8.3 - RESULTS

8.3A - Part 1: Dark verses pinhole SOLA levels

Figure 8.1 shows the individual subjects' mean dark and pinhole SOLA levels which have been ranked in ascending order for both conditions for each of the refractive groups. Figure 8.2 shows the relationship between dark and pinhole SOLA measurements. A two-way ANOVA was computed to assess the data; both refractive error ($p = 0.001$) and the method of opening the accommodative loop ($p < 0.001$) were found to significantly affect SOLA levels. The interaction between refractive error and the method of opening the loop was not found to be significant even though the EMMs have the highest mean SOLA levels and the LOMs the lowest for both conditions. Scheffe's contrasts revealed that the SOLA levels of EMMs and LOMs were significantly different ($p < 0.001$) but the differences between EMMs and EOMs and EOMs, and LOMs were not significant.

The effect of the magnitude of SOLA measured in darkness on the magnitude of SOLA measured with a pinhole was determined using a one-way analysis of covariance (ANCOVA - see section 5.6A); the refractive group and the SOLA measured under pinhole conditions were the main effects and the SOLA measured in darkness was the covariant. The results imply that the magnitude of dark SOLA has no effect on the magnitude of pinhole SOLA for any of the refractive groups ($p = 0.69$), thus indicating that no correlation exists between these two measurements.

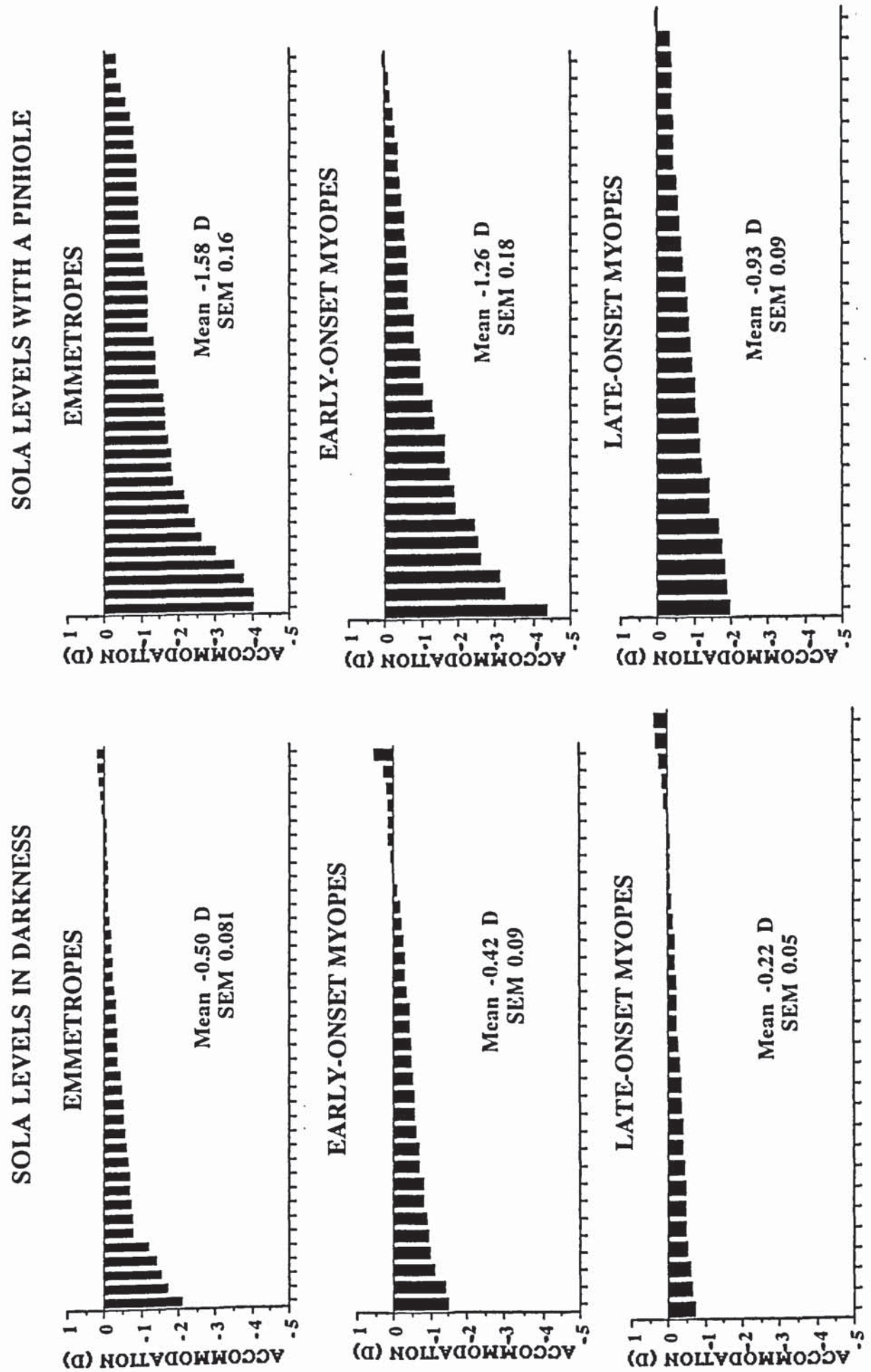

Figure 8.1: Individuals' mean dark and pinhole SOLA levels ranked in ascending order for EMMs, EOMs and LOMs.

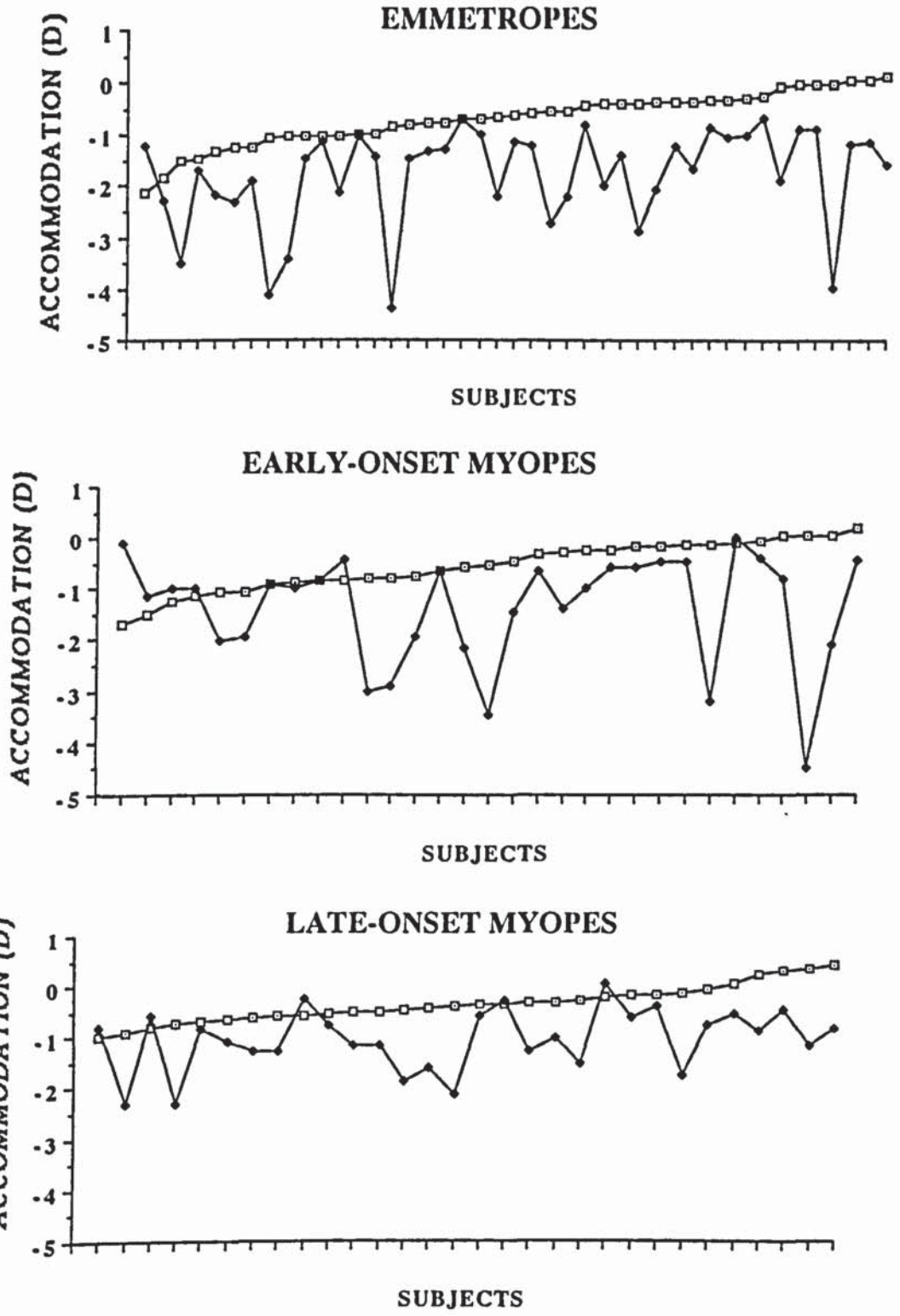

Figure 8.2: Dark SOLA levels have been ranked in ascending order and plotted together with pinhole SOLA levels to show the effect of opening the accommodative loop with a pinhole

Key: —□— Dark SOLA
—◆— Pinhole SOLA

8.3B - Part 2: Dark and pinhole SOLA with and without mental effort

The individual dark and pinhole SOLA levels recorded with concurrent mental effort are ranked in descending order for all three refractive groups in Figure 8.3. Figure 8.4 shows the influence of performing a SIT on both dark and pinhole SOLA measurements.

The mean group values and standard deviations for pinhole and dark SOLA both with and without mental effort are shown in Figure 8.5. SOLA levels when measured while performing a SIT are significantly effected by both refractive error ($p = 0.008$) and the method of opening the accommodative loop ($p = 0.001$). As for the the results from part 1 of this study, Scheffe's contrast reveals significant differences between the SOLA measurements of EMMs and LOMs but not between EMMs and EOMs or EOMs and LOMs. In addition, the influence of mental effort produced significantly higher SOLA levels under pinhole conditions than in complete darkness ($p = 0.001$).

Analysis of the data from parts 1 and 2 of the study (two-way ANOVA) reveals that both refractive error and method of opening the accommodative loop are significant factors in determining SOLA levels both with and without concurrent mental effort ($p = 0.008$ and 0.001 respectively) but the interaction between refractive group and method of opening the accommodative loop was not significant ($p = 0.46$). Once again the results of the EMMs and the LOMs were found to differ significantly whereas when EMMs and EOMs and the two myopic groups were compared no significant differences existed when comparing the data from parts 1 and 2 of the study.

Figure 8.5 shows that the effect of the SIT on SOLA levels is greater for the dark condition compared to the pinhole condition. In fact when the data for both methods of opening the loop were analysed separately, the difference between SOLA with and without the influence of mental effort is insignificant for the pinhole condition ($p = 0.63$) but is highly significant for darkness ($p = 0.001$); the influence of refractive error remained significant ($p = 0.001$) for both conditions.

The results of 2 one-way ANCOVAs suggest a relationship exists between SOLA levels with and without the influence of mental effort; the level of SOLA recorded without concurrent mental effort was found to significantly effect the level of SOLA recorded with the influence of mental effort for both dark and pinhole conditions ($p = 0.012$ and 0.001 respectively). However, this is not immediately apparent on inspection of Figure 8.4.

Dark SOLA was measured on two separate occasions on the majority of subjects in order to assess the repeatability of the measurement. In addition, 13 subjects, 9 EMMs, 2 EOMs and 2 LOMs completed parts 1 and 2 of the experiment twice in order to assess repeatability of all the measurements. Paired student t-tests were used on each measurement and none were not found to vary significantly between trials thus confirming that these measurements are repeatable.

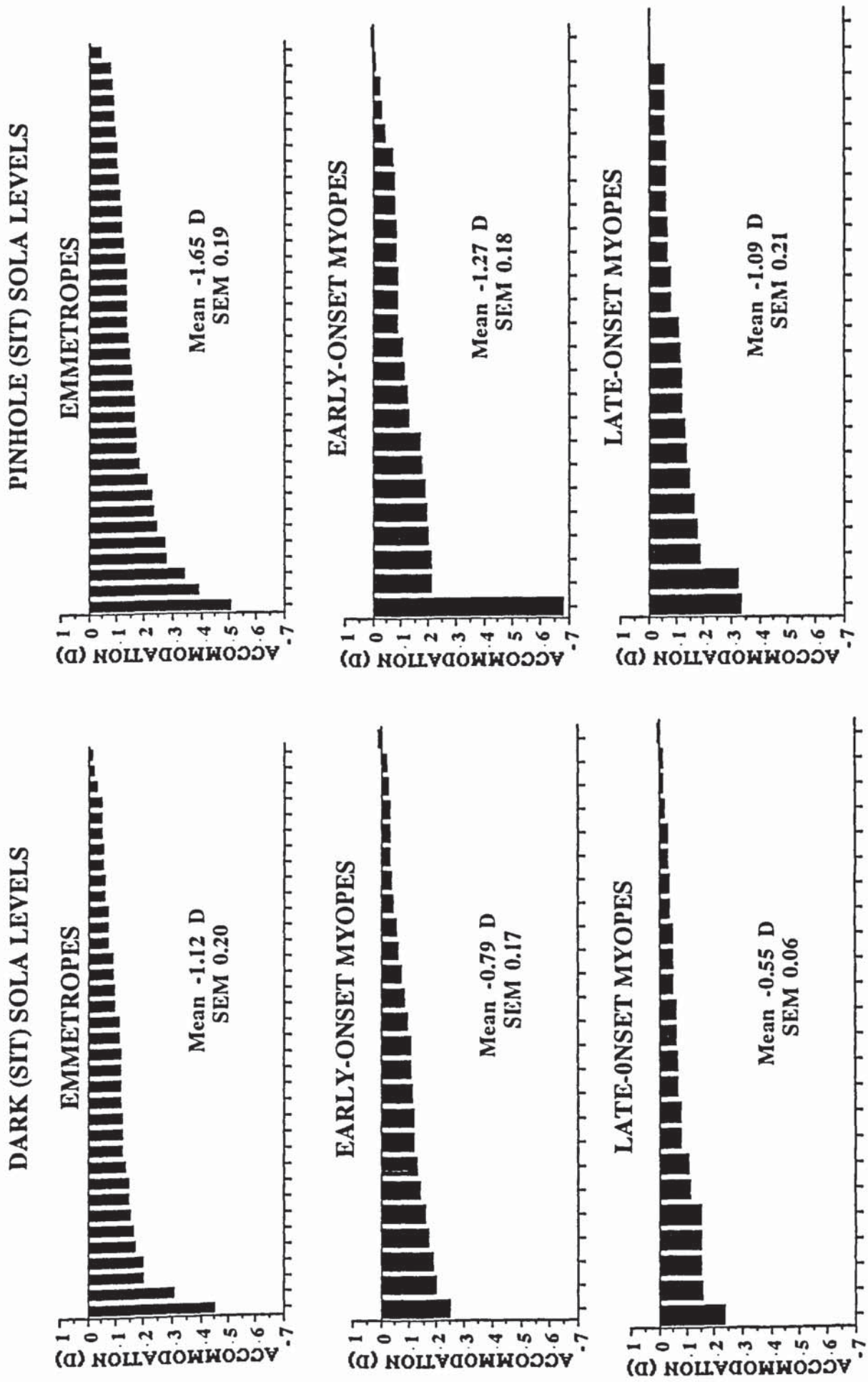

Figure 8.3: Individuals' mean dark (SIT) and pinhole (SIT) SOLA levels ranked in ascending order for EMMs, EOMs and LOMs.

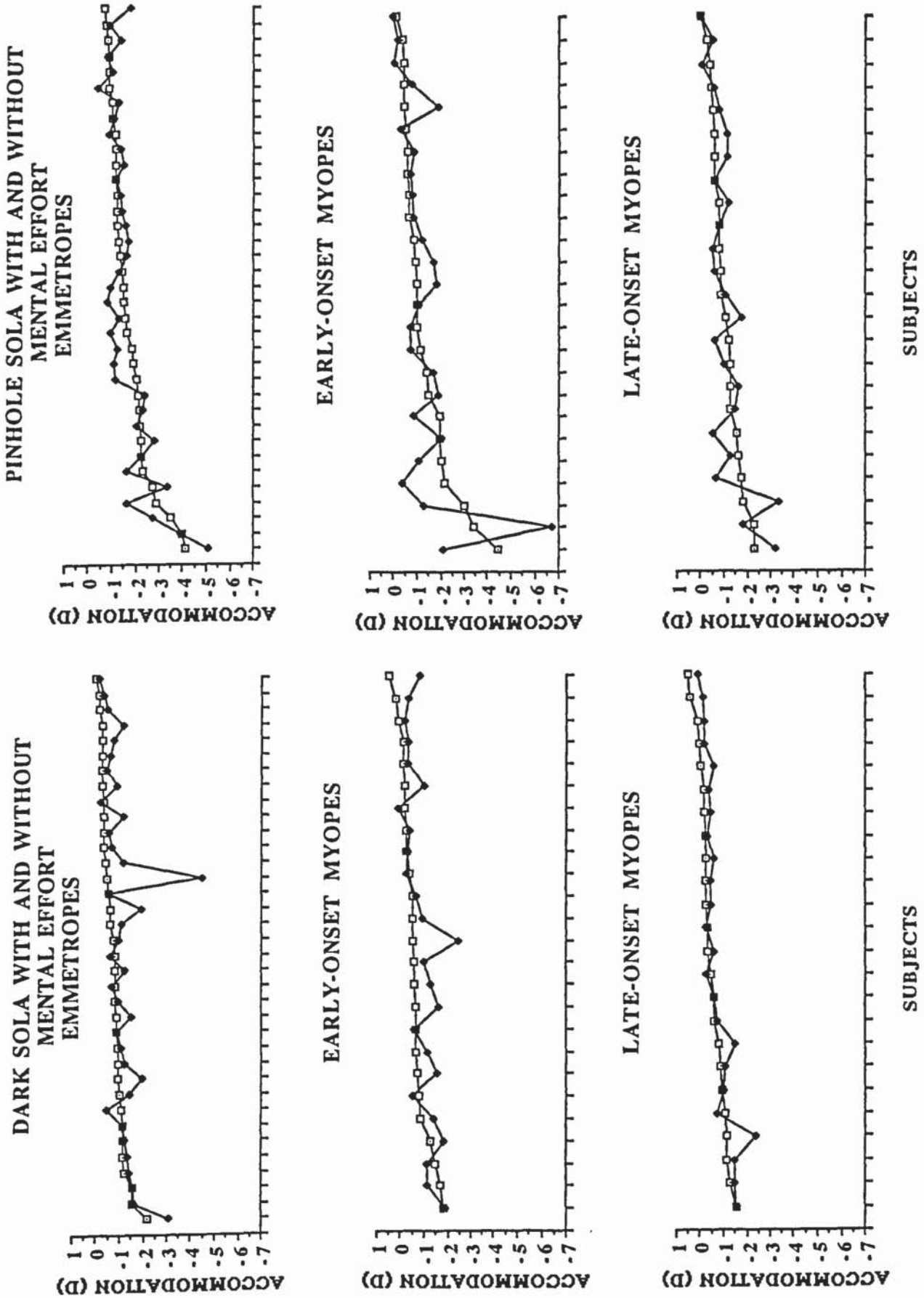

Figure 8.4: Dark and pinhole SOLA levels have been ranked in ascending order and plotted together with dark (SIT) and pinhole (SIT) SOLA levels to show the effect of mental effort on individuals' SOLA levels (see Figure 8.2 for key).

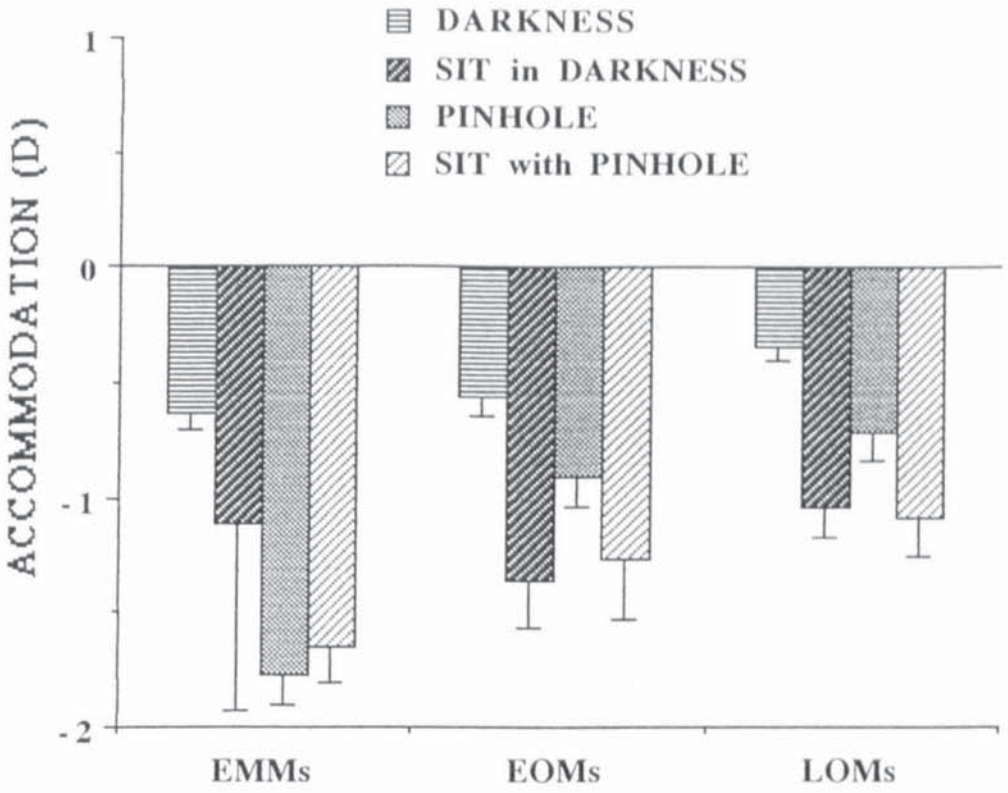

Figure 8.5: Group mean dark and pinhole SOLA levels measured with and without the influence of mental effort. Error bars represent one standard error of the mean.

8.3C - Part 3: Influence of target size on pinhole SOLA measurements

The results from 10 subjects who completed this part of the experiment were analysed together without considering refractive group as a variable because the vast majority of the subjects were in fact EMMs. Figure 8.6 shows the mean levels and standard deviations of SOLA both with and without the influence of mental effort for the target sizes N8, N10, N15 and N20. Individual data is tabled in Appendix 9d One-way ANOVAs were used to establish whether or not target size was a significant factor in determining SOLA levels for the two conditions, i.e. with and without mental effort. The differences between SOLA measurements obtained for the various target sizes were insignificant ($p = 0.99$ for both conditions) and the interaction between the results for each target size and each subject was also insignificant ($p = 0.99$ for both conditions).

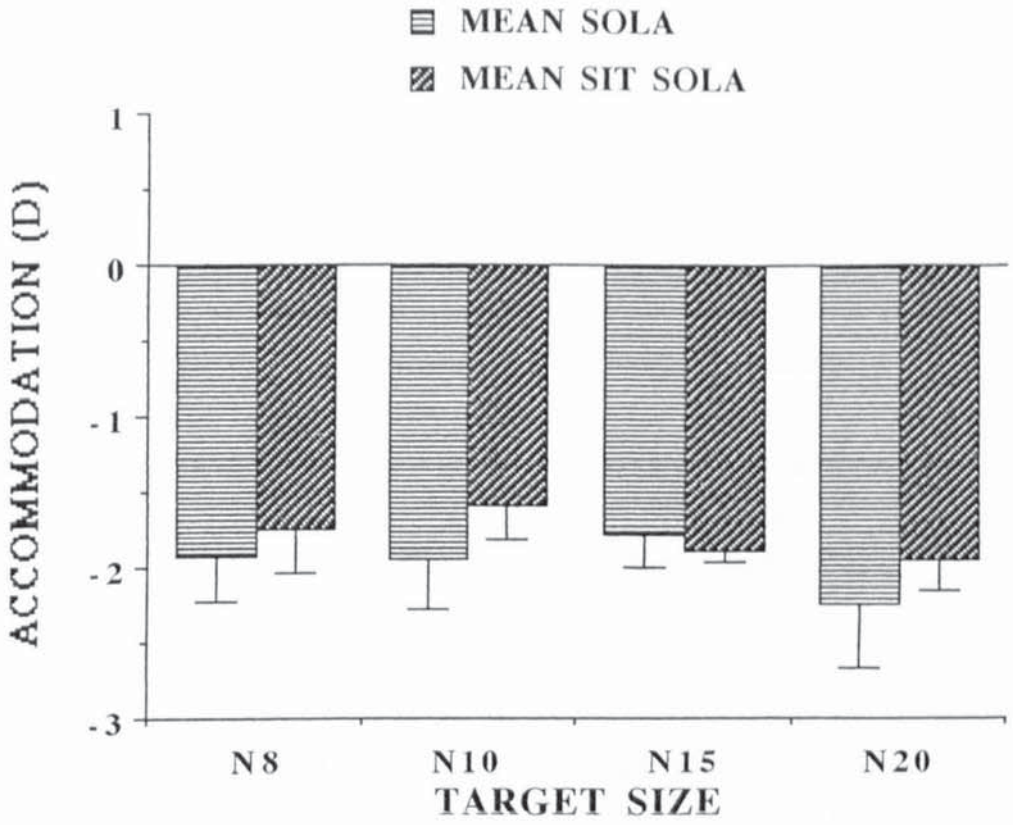

Figure 8.6: Group mean SOLA levels measured with and without the influence of mental effort for various target sizes. Error bars represent 1 standard error of the mean.

8.4 - DISCUSSION

This study supports previous work suggesting that EMMs have higher SOLA levels than LOMs. Furthermore, this difference is still evident when the accommodative loop is opened in two different ways and when a concurrent mental task is performed while under the two open-loop accommodation conditions.

The EOMs' SOLA levels measured both with and without the influence of mental effort were not significantly different from either the EMMs or the LOMs but are intermediate making it difficult to speculate whether the accommodative function of the EOMs is more similar to that of the LOMs or the EMMs. As a result it is difficult to determine conclusively whether the differences between the EMMs and LOMs are due to the refractive classification or due to myopia in general. In addition these results fail to either support or refute the existence of two aetiologically different forms of myopia, but because similar relationships between the refractive groups have been obtained under various open-loop conditions it may well be that EOMs and LOMs are actually two distinct forms of myopia and the difference between EMMs and LOMs is not just due to myopia in general. Furthermore, if the differences between EMMs and LOMs are due

only to myopia then the EOMs' SOLA levels would be expected to be significantly different to the EMMs because the EOMs are generally more myopic than the LOMs.

For all three refractive groups, the mean SOLA level is greater when the accommodative loop is opened using a pinhole as opposed to complete darkness. When the loop is opened with darkness it is the *stimulus* that is degraded in order to eliminate the influence of blur on the accommodative system, whereas when the pinhole is used, it is the subject's *response* to the stimulus that is degraded by increasing the depth-of-focus of the eye to such an extent that blurring of the target is not detected. In addition, the physical presence of the target may induce proximal accommodation and stimulate mental effort in processing the contents of the target in some individuals. Furthermore, Wolfe and O'Connell (1987) proposed that the presence of light in open-loop conditions induces the accommodative system to maintain a more positive vigilant state.

Although the method of opening the loop significantly effects SOLA measurements both with and without concurrent mental effort, the effect is not consistent. In fact for the dark and pinhole SOLA levels no correlation was found thus implying that these two measurements are not related. It is unlikely the factors contributing to SOLA are the same or contribute in the same proportions when the accommodative loop is opened in two fundamentally different ways. The lack of correlation between dark and pinhole SOLA provides further evidence that the accommodative system does not simply rest at its tonic level when open-loop conditions are imposed, instead many factors both psychological and physiological contribute to SOLA.

The effect of mental effort was considerably more marked for the dark condition compared with the pinhole condition for all groups. In fact the pinhole (SIT) SOLA levels were not significantly different from the pinhole SOLA levels. It may be that the higher levels of SOLA and thus parasympathetic activity induced by the pinhole condition are augmenting inhibitory sympathetic action which results in an attenuation of the induced increases in the SOLA level. As a consequence, Chapter 10 investigates the ciliary muscle innervational profiles of EMMs, EOMs and LOMs.

The third part of the study has shown that target size does not effect pinhole SOLA levels when measured either with or without mental effort imposed. The subjects did not respond to changes in apparent distance of the target induced by changes in the actual size of the target which suggests that when assessing pinhole SOLA the target does not necessarily have to be placed within a Badal lens system to control the effect of target size.

The results from the study detailed in this Chapter can be summarised as follows:

1) LOMs have significantly lower SOLA levels than EMMs under conditions of complete darkness and pinhole pupil both with and without concurrent mental effort.

2) Even though SOLA levels under pinhole conditions tend to be higher than those measured under darkness, no relationship was found to exist between the two measures.

3) Concurrent mental effort produces larger accommodative shifts in SOLA under dark conditions compared to pinhole conditions.

4) The size of the target viewed through a pinhole does not effect the magnitude of SOLA.

Supporting publications

Winn B, Gilmartin B, Mortimer LC and Edwards NR (1991) The effect of mental effort on open- and closed-loop accommodation. Ophthal. Physiol Opt. 11: 335-339.

Refereed published abstracts of conference proceedings

Edwards NR, Winn B and Gilmartin B (1991) The influence of non-optical factors on steady-state accommodation. Ophthal. Physiol. Opt. 11: 281.

Edwards NR, Winn B and Gilmartin B (1991) The influence of mental effort on measures of accommodation in emmetropia and late-onset myopia. Ophthal. Physiol. Opt. 11: 400-401.

Edwards NR, Gilmartin B and Winn B (1992) Open-loop accommodation responses in emmetropia and myopia. Optom. Vis. Sci. (suppl) 69: 234-235.

CHAPTER 9

THE EFFECT OF PROXIMITY ON ACCOMMODATION RESPONSES IN EMMETROPIA AND MYOPIA

9.1 - INTRODUCTION

The accommodative response (AR) consists of 4 main components: tonic, convergence, proximal and reflex or blur-induced accommodation (Heath, 1956b). Under normal closed-loop viewing conditions the components combine in different proportions to produce the aggregate AR but under closed-loop viewing conditions it is very difficult to quantify the effect of each component. Furthermore, the relative importance of each component varies from person to person and with the condition such as distance and near viewing. Rosenfield and Gilmartin (1987c) examined the ARs of EMMs, EOMs and LOMs to various accommodative stimuli and discovered that LOMs have higher levels of disparity-induced accommodation (DIA - see Chapter 3 section 3.4A) and blur-induced accommodation (BIA) than both EMMs and EOMs. Nonetheless, the role of the different components in the total accommodative response is not yet fully understood. Moreover, controversy still exists as to whether a change in accommodation due to proximal cues is due to direct accommodative stimulation or due to a change in vergence which then induces convergent accommodation. Rosenfield and Gilmartin (1990) introduced the term proximally-induced accommodation (PIA) to describe accommodative change bought about either directly or indirectly by the apparent nearness or proximity of a target; this terminology will be used in here to describe any change in accommodation stimulated by proximal effects.

In the past, studies have shown that blur, convergence and proximity are all very potent stimuli to accommodation. For instance, when blur is the only stimulus to accommodation the AR will be reasonably accurate (Phillips and Stark, 1977). In addition, Fincham and Walton (1957) suggested that for people up to the age of 24, the AR could be entirely driven by vergence cues. Recent investigations have also suggested a substantial role for PIA in the aggregate AR (Hokoda and Ciuffreda, 1983; Rosenfield and Gilmartin, 1990; Rosenfield et al. 1991; Wick and Currie, 1991; Schor et al. 1992). Rosenfield et al. (1991) found that under open-loop accommodation and vergence conditions PIA is a potent perceptually-driven input to accommodation when the target distance is less than 3 m, furthermore the magnitude of PIA is linearly related to the stimulus distance. Conversely, Hung et al. (1994) have recently devised a model which demonstrates that PIA contributes only a small proportion to the total AR under various closed-loop conditions.

The apparent nearness of an object i.e. the cue to PIA, can be stimulated by either physically changing the target distance, changing the target's apparent distance or altering the target size (see Chapter 1 section 1.5B). As reported in Chapter 8, changing the size of a static target makes no significant difference to the level of SOLA, whereas when the size of the target is altered sinusoidally, Kruger and Pola (1989) found that it presented a powerful stimulus to accommodation at high temporal frequencies (see section 1.4B). However what is not entirely clear is whether the change in accommodation is due solely to the change in target size or to the perceived backwards and forwards movement this size change elicits in some people (Kruger and Pola, 1986). Those subjects who perceive changes in target size as movement of the target show larger responses than those who do not (Kruger and Pola, 1987). Physically changing the targets distance and removing the stimulus to blur appears to give the strongest cue to PIA in all subjects (Rosenfield and Gilmartin, 1990; Rosenfield et al. 1991).

When blur and size cues are placed in conflict, Campbell and Westheimer (1959) found that accommodation is guided more by the changes in target size than by blurring of the target. Kruger and Pola (1989) investigated the effect of changing target size and blur cues in counterphase and reported that at low temporal frequencies blur is particularly effective at stimulating accommodation whereas at moderate or high temporal frequencies size becomes the more effective cue (see section 1.5B). If size and blur cues are allowed to compliment each other, the effectiveness with which the accommodative system is able to follow changes in the position of the target is enhanced (Kruger and Pola, 1986).

In the absence of all stimuli, the accommodative system is focused, not at infinity but at some intermediate position due to the residual tonic innervation of the ciliary muscle when the system is at rest which is known as tonic accommodation (see section 1.7A). The absolute magnitude of tonic accommodation present in the aggregate accommodative response is very difficult to quantify. Even under dark room conditions where both the vergence and accommodative loops are open the measurement is contaminated by factors such as surround propinquity, cognitive effects, visual imagery and method of measurement (see section 1.7). Consequently it has been impossible to determine true levels of tonic accommodation, instead investigators have measured steady-state open-loop accommodation (SOLA) which not only represents tonic accommodation but also the effects of other non-optical stimuli on the accommodative system.

It is now well established that SOLA levels vary both between subjects and between refractive groups (see Chapters 1 and 8); such variations may in turn indicate that the absolute level of tonic accommodation varies in the same way although this is pure speculation at this stage and still has to be proven. If this is the case and the contribution of tonic accommodation to the aggregate accommodative response does vary between individuals and refractive groups, the accommodative profiles of the refractive groups will vary. Evidence has already been offered, albeit equivocal, that distinctions can be made between the refractive groups and in particular between LOMs and EMMs with regard to a variety of oculomotor responses (McBrien and Millodot, 1986a; 1986b; Rosenfield and Gilmartin, 1987a; 1987b; 1987c; Owens et al., 1991) although these were not necessarily confirmed by the experiment detailed in Chapter 6.

One aspect of the accommodative system which has received a lot of attention from researchers is the temporary shift in the pre-task SOLA level following sustained closed-loop near viewing. These near-task induced shifts in SOLA are also termed accommodative hysteresis, accommodative adaptation or accommodative regression patterns (see section 1.8A) and are depicted by successive or continuous measurements of accommodation under open-loop conditions following a sustained closed-loop visual task. The regression patterns represent a delay in the accommodative system in returning to the pre-task SOLA level and have become established as measures of the extent to which the accommodative system can adapt to sustained closed-loop accommodation (Schor and Johnson, 1984; see for reviews, Rosenfield et al., 1992; Rosenfield et al., 1993; 1994).

The time-course and magnitude of the post-task shifts in SOLA vary from person to person; several factors influence the time-course and shape of these regression patterns. The effect of BIA on accommodative regression patterns has been widely demonstrated. Many researchers have proposed that the magnitude of the shift is proportional to the dioptric separation (and hence the target blur) between the SOLA level and the within task accommodative response (Ebenholtz, 1985; Owens and Wolf-Kelly, 1987; McBrien and Millodot, 1988). In contrast, Bullimore and Gilmartin (1989) found that the magnitude of the shift was directly related to the dioptric value, rather than the dioptric separation, of the adapting stimulus although the time-course of the adaptation remained essentially the same.

Variations in the composition of the aggregate accommodative response to the adapting stimulus have been shown to alter the shape and time-course of regression patterns. For example Rosenfield and Gilmartin (1988a) observed that under closed-loop conditions an increase in fusional vergence produced a quicker time-course and mean reduction in the post-task SOLA shifts of EMMs compared with LOMs. This is

consistent with the finding that increased BIA under closed-loop conditions produces a reduction in vergence adaptation (Kran and Ciuffreda, 1988). However, under open-loop conditions many researchers report that convergent accommodation increases the temporary shift in pre-task SOLA (Kran and Ciuffreda, 1988; Schor and Kotulak, 1986; Schor et al., 1986; Wolfe and O'Connell, 1987).

The effect of monocular and binocular closed-loop visual tasks on the subsequent regression patterns has also been investigated (Fisher et al., 1988a; Rosenfield and Gilmartin, 1988e). However, no significant difference between the regression patterns recorded following monocular and binocular viewing were reported even though it would be predicted that for binocular viewing, the output of convergence accommodation would reduce the requirement for BIA compared with that experienced under monocular fixation. It seems unlikely that the magnitude of the SOLA shifts reflects the output of BIA alone.

In 1990 Rosenfield and his co-workers reported that variations in the output of PIA significantly affected the regression patterns of 10 EMMs. PIA was stimulated by changing the target distance while the target size and blur stimulus were kept constant. They found that the shift in SOLA following viewing of the distal target was approximately half that for the near target and that it was inversely correlated with the pre-task SOLA level under both the distal and near target conditions. The results indicate that PIA is a potent stimulus to inducing post-task shifts in SOLA.

Ebenholtz (1983) was the first to suggested that the slow decay of near task-induced shifts in SOLA may act as a precursor to induced myopia, although he failed to put forward a hypothesis as to why this may be the case; many workers have proposed that excessive accommodative effort associated with habitual and sustained periods of near-vision is directly linked to the development of LOM. However it is clear that if such an association does exist, it is likely to be very complex and inextricably linked to hereditary factors (Goldschmidt, 1968; 1990; Curtin, 1970; Sorsby and Benjamin, 1973; Jensen, 1991; also see Chapter 4).

Many workers have investigated the effect of refractive group on accommodative regression patterns. Both Gilmartin and Bullimore (1991) and Rosenfield and Gilmartin (1988a) demonstrated that following a period of sustained near-vision, EMMs and LOMs exhibit different regression patterns. Immediately following the near-task the EMMs showed a larger accommodative shift and a steeper regression gradient than the LOMs. A comprehensive study by McBrien and Millodot (1988) measured differences in the post-task SOLA shifts of EMMs, EOMs, LOMs and hyperopes. Their results showed that LOMs showed increased larger accommodative

shifts 1 min following task completion compared to the other refractive groups. Interestingly, they did not observe any adaptation following a 15 min near vision task located at 5 D in either the EMMs or the EOMs. This finding may be influenced by the time-course of measurements. McBrien and Millodot assessed accommodative adaptation by examining post-task SOLA at 1, 7 and 15 minutes following task completion. Data from several studies has indicated that a substantial proportion of the regression of accommodation is completed within the first minute subsequent to the task (Gilmartin and Bullimore, 1987; Gilmartin and Bullimore, 1991; Rosenfield and Gilmartin, 1988a; 1988e; Rosenfield and Gilmartin, 1989). This may explain the apparent absence of adaptation in EMMs and EOMs reported by McBrien and Millodot.

Clearly several factors are responsible or potentially responsible for the shifts in SOLA that take place following a closed-loop visual task. The association suggested by many workers between intensive close work and the development of LOM may be related to the previously reported variations in regression patterns between refractive groups. However, the influence of other factors on individual refractive groups is not yet known. It may be that the aggregate AR of the various refractive groups is made up of different proportions of tonic, convergent, proximally-induced and blur-induced accommodation and variations in the accommodative regression patterns merely reflect this.

From investigating SOLA in Chapter 8 it seems a logical step to investigate the accommodative regression patterns of subjects from different refractive groups and in the light of the findings detailed above, the effects of different accommodative stimuli on these regression patterns. The aim of the experiment detailed in this Chapter is to determine the effect of PIA on the accommodative regression patterns of EMMs, EOMs and LOMs. In previous investigations, the effects of non-optical stimuli such as surround propinquity, cognitive demand and the influence of changing rapidly from closed to open-loop conditions has on the accommodative system have not been adequately controlled; by measuring adaptation to both 3.00 D and 0.18 D stimuli and subtracting the 0.18 D stimulus regression pattern from the 3.00 D stimulus regression pattern, these non-optical factors should be eliminated and the resulting regression pattern should reflect only the shifts in SOLA generated by blur in the presence or absence of proximal stimuli.

9.2 - METHODS

Thirty six subjects took part in the experiment, 12 EMMs, 12 EOMs and 12 LOMs. The criteria for the subject groups is explained in Chapter 6 (section 6.2A). Table 9.1

provides the details of the subject groups. Biometry and keratometry measurements for the majority of subjects appear in Appendix 10a. All subjects had normal binocular vision, visual acuity in each eye of at least 6/6 and cyls no larger than 0.75 D. All myopic participants were fitted with *Acuvue* disposable soft contact lenses for the duration of the experiment. About 20 minutes was allowed for adaptation to the contact lenses prior to data collection.

	EMMs	EOMs	LOMs
Number of subjects	12	12	12
Mean age (yrs)	20.00	20.08	22.17
Range of ages (yrs)	18 - 27	18 - 29	18 - 30
Mean refraction	+0.06 D	-4.25 D	-1.30 D
(SEM)	(±0.07)	(±0.66)	(±0.10)
Mean myopic onset	-	10.50	19.42
(SEM)	-	(±0.92)	(±0.91)

Table 9.1: Details of subjects used: emmetropes (EMMs), early-onset myopes (EOMs) and late-onset myopes (LOMs).

A Canon Autoref R-1 objective optometer was used to monitor accommodative changes during the experiment (see Figure 9.1). Pre-task SOLA levels were measured prior the commencement of each task condition. Subjects sat in complete darkness for at least 3 minutes before data collection began in order to establish a stable SOLA level (see Chapter 1 section 1.7E). The subjects were then instructed to look 'straight ahead into the darkness'. A minimum of 20 readings were taken over a two minute recording period to establish the pre-task SOLA level. To measure the regression of accommodation following a closed-loop visual task, an Apple IIe computer was programmed (see Appendix 5) to time the task and subsequent period of darkness. The program instructed the computer to emit a bleep at the beginning of the 3 min task period and again about 5 s before the end. At the end of the task, the light used to illuminate the target was extinguished via a relay switch controlled by the computer. After 90 s the light was automatically switched on again. During the period of darkness, refractive error was measured every second (see Appendix 10).

Subjects completed, in random order, 4 task conditions over a 1 hr 45 min period. Between each condition there was a 15 min break to allow for complete dissipation of adaptation effects. During this time, subjects were encouraged to look around the room. As well as preceding each condition with the measurement of SOLA, all conditions incorporated at least 20 measurements of the within-task accommodation level. Fixation was changed several times during the 5 min viewing period to encourage accurate focusing at all times. Four conditions were investigated:

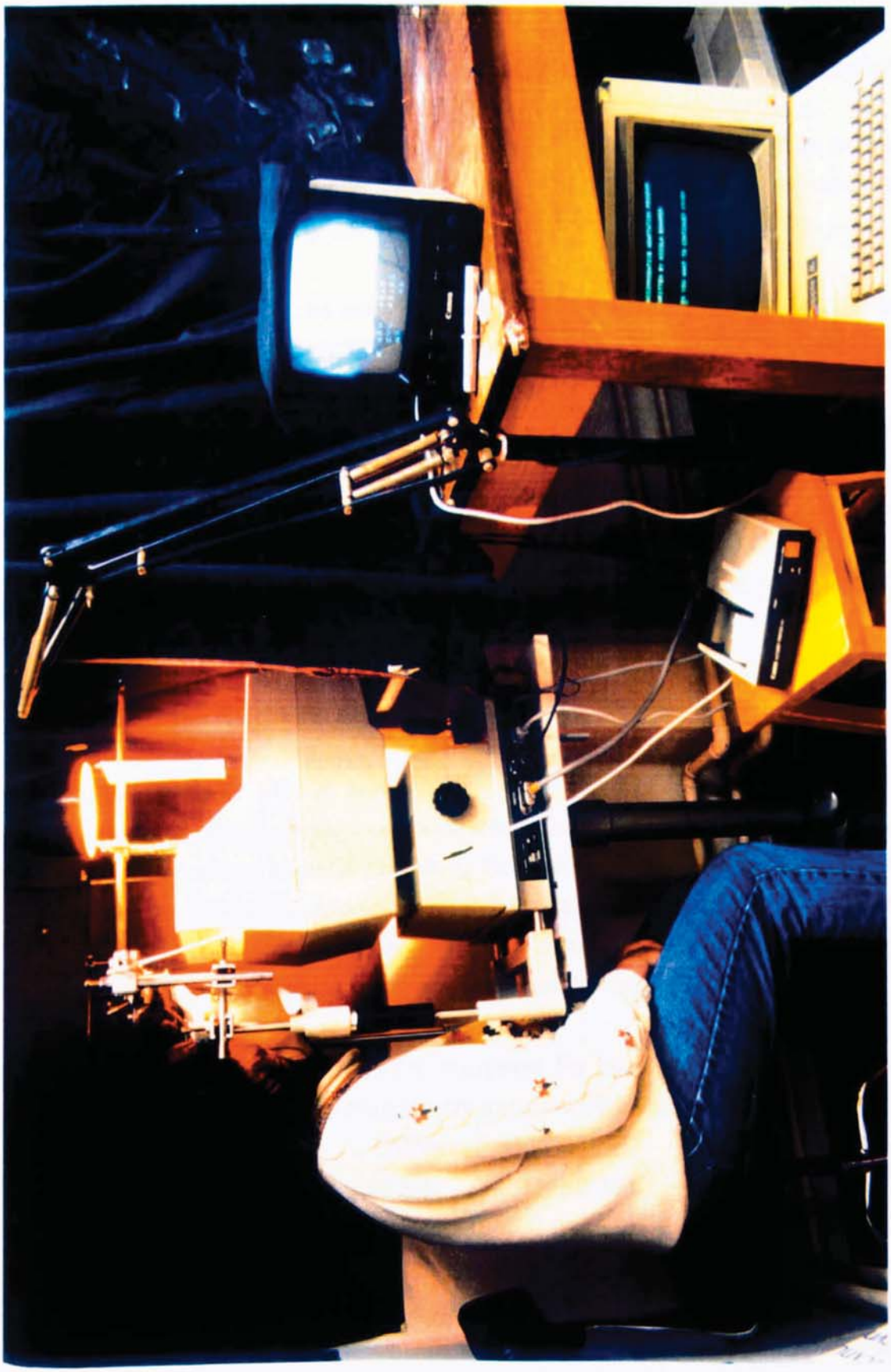

Figure 9.1: Photograph of the experimental set-up

1) Viewing a target at 5.50 m through a plano lens so that no proximal or blur-induced accommodation was stimulated, i.e. distance no blur (DNB).
2) Viewing a target at 5.50 m through a negative lens designed to induce -3.00 D vergence at the eye so that blur accommodation but no PIA was stimulated i.e. distance with blur (DWB).
3) Viewing a target at 33 cms through a plano lens which induced both blur and proximal accommodation i.e. near with blur (NWB).
4) Viewing a target at 33 cms through a positive lens designed to induce 0.18 D accommodation (equivalent to a target distance of 5.50 m) the blur cue to accommodation so that only the proximity cue remained i.e. near no blur (NNB).

All targets consisted of an array of black letters on a white background, the contrast of which was approximately 90%. All letters, when viewed through the lenses were equivalent in size to N8 therefore size changes could not act to stimulate PIA. The lenses for each trial were placed 20 cms from the eye so that the optometer recorded directly from the eye and not through the lens. The power of the lenses needed to provide the necessary vergence at the eye were +7.25 D and -7.75 D. Plano concave and plano convex lenses were obtained so that their magnification effects were easier to calculate. The lenses were edged to fit the lens holder and all tasks were completed monocularly.

9.3 - RESULTS

9.3A - Pre-task SOLA levels

The pre-task SOLA levels were measured prior to each set of conditions as a way of determining when regression resulting from the previous task was complete. For the majority of people, regression of accommodation was complete within 15 minutes. If the initial SOLA level was not reached within 15 minutes, a longer break between conditions was allowed until the SOLA level was similar to the first pre-task SOLA level.

Mean pre-task SOLA levels were computed for each subject and for all conditions. Group means for all the conditions were as follows (SEMs in brackets):

EMMs -0.66 D (±0.11)
EOMs -0.60 D (±0.14)
LOMs -0.66 D (±0.14)

A one-way ANOVA revealed no significant differences in the pre-task SOLA levels between the different refractive groups. This result contrasts with that reported in the previous Chapter where EMMs showed significantly higher SOLA levels in darkness than the LOMs but it should be remembered that the sample sizes were over twice the size of those used here.

9.3B - Within-task accommodation

Table 9.2 shows the mean within task accommodative responses for the EMMs, EOMs and LOMs for all four task conditions. Two-factor ANOVAs were completed on data for the conditions with a 3.00 D blur stimulus and those with no blur stimulus to accommodation. The results indicate that for the two task conditions without a blur stimulus (i.e. DNB and NNB), the levels of within-task accommodation were essentially the same and no significant difference between the refractive groups was noted. In contrast, the conditions with the blur stimulus i.e. DWB and NWB did produce significantly different ($p = 0.02$) within-task accommodation levels. For all the subject groups the group mean within-task accommodation response was lower for the NWB compared to the DWB condition even though by calculation the vergence of light at the eye for both of these conditions was identical. It may be that the additional proximal cue to accommodation present when viewing the near target initiated a drop in accommodation level. However, if this were the case then the same effect of proximity should be evident for the conditions without the blur stimulus. Another possibility for the difference in accommodative levels for the DWB and NWB conditions is that the vergence of light at the eye was not the same even though by calculation this appeared to be the case.

GROUP	DNB	NNB	DWB	NWB
EMM	0.46 D	0.42 D	2.76 D	2.53 D
EOM	0.34 D	0.24 D	2.70 D	2.59 D
LOM	0.21 D	0.29 D	2.64 D	2.57 D

Table 9.2: Mean within-task accommodation levels (DNB distance no blur, NNB near no blur, DWB distance with blur, NWB near with blur).

9.3C - Post-task accommodative regression

Figure 9.2 represents for subject GP, an EOM, actual regression patterns for all four conditions plotted over 60 s of the post-task period preceded by the within-task accommodation level. The rapid regression of accommodation following within-task stimulation of BIA is evident but any effect of proximity alone on the regression patterns is difficult to establish from the raw data plots. In order to control for non-visual accommodative cues such as cognitive effort, surround propinquity and the effect of transfering from open- to closed-loop viewing conditions, the conditions not stimulating blur accommodation (DNB, NNB) were subtracted from those which did (DWB, NWB). The result was four regression patterns, one representing the effect of blur only (DWB-DNB), one representing the effect of blur minus the effect of proximity (DWB-NNA), one representing the combined effects of both blur and proximity (NWB-DNB) and finally, one representing the effect of blur in the presence of proximity but with the effect of proximity removed (NWA-NNA).

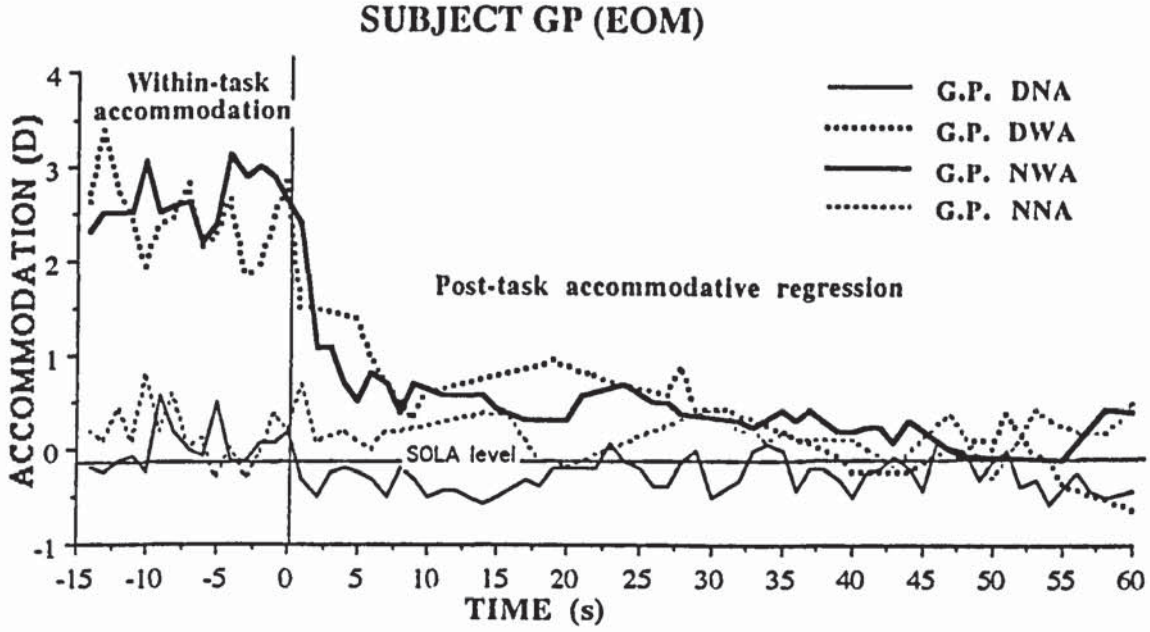

Figure 9.2: Plot of raw data for accommodative regression (all conditions) for subject GP, an early-onset myope. The plot is over 15 s of the within-task period followed by 60 s of the post-task period.

It should be noted that by subtracting one regression pattern from another, the reference level of pre-task SOLA is effectively reduced to zero if the two pre-task SOLA levels are similar. In order to analyse the effect of proximity and blur on these modified regression patterns without the dioptric differences of the within-task ARs influencing the results, the regression patterns were plotted as a percentage of the new within task accommodative response (i.e. the high AR minus the low AR). The percentage plots represent the amount of accommodative regression completed at a particular time so that once the accommodative level has regressed back to zero, the regression is effectively 100% complete; whereas if the post-task accommodative level has only dropped by 20% compared to the within task response, the regression is only 20% complete. Figures 9.3 and 9.4 are percentage regression plots.

A three factor split-plot ANOVA was carried out on the % accommodation regression data resulting from the conditions: DWB-DNB, DWB-NNB, NWB-DNB and NWA-NNB (major factors: refractive group and condition; minor factor: time). As would be expected the variation in % regression over time was highly significant ($p < 0.001$). The effect of refractive group on the regression patterns was also significant ($p = 0.02$) as was the interaction between time and refractive group ($p < 0.001$) thus indicating that the time-course of accommodative regression varies between the refractive groups. This effect can be seen in Figure 9.3. In the majority of cases, EMMs completed their regression before both the LOMs and the EOMs. For two conditions the EOMs and LOMs displayed similar regression patterns but in the remaining two cases the time-course of the EOMs regression patterns was a lot longer than the LOMs indicating that the EOMs post-task shifts in accommodation were sustained for a longer period than the other two refractive groups.

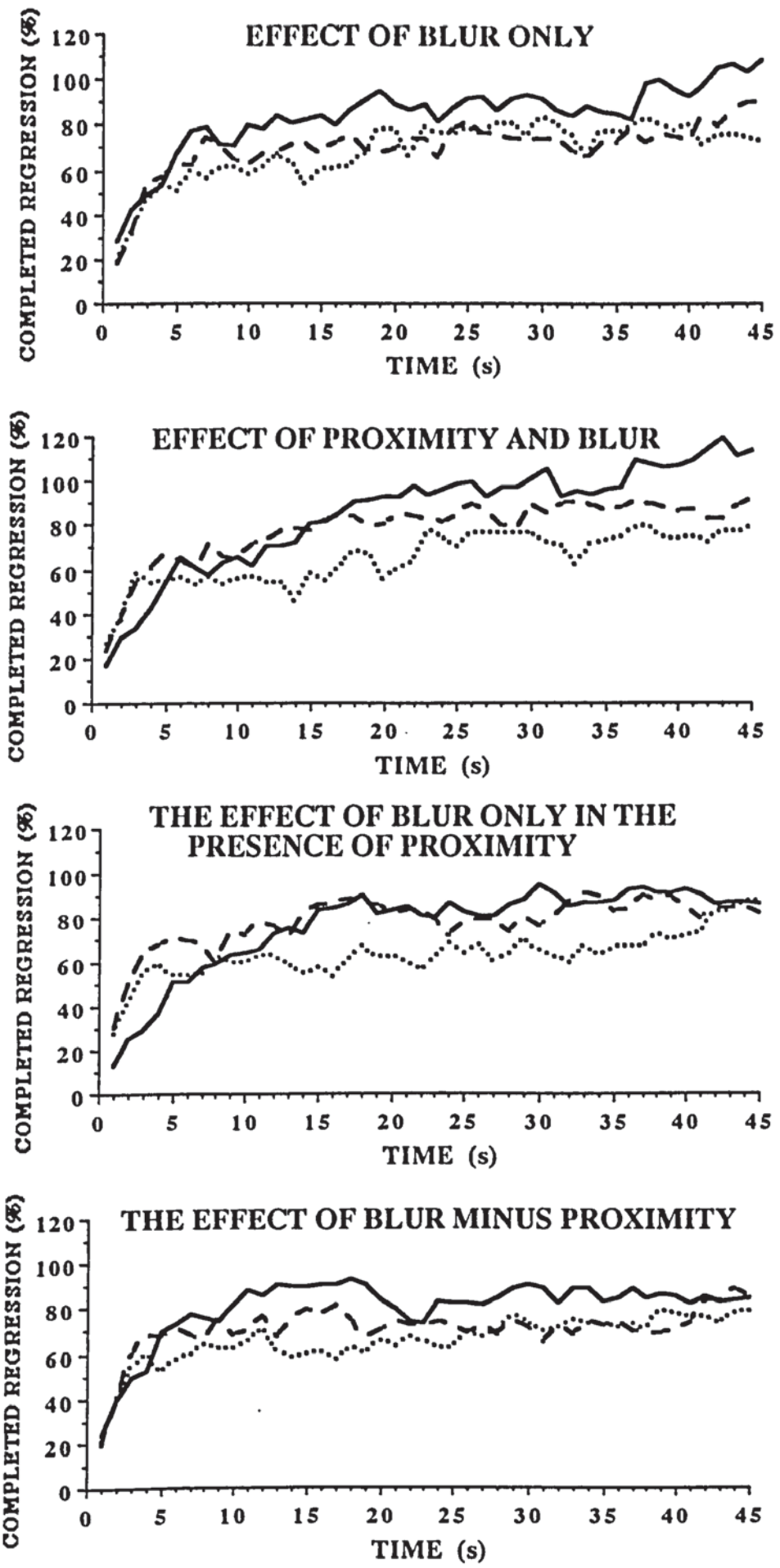

Figure 9.3: The four plots represent the effect of 4 different conditions on the accommodative regression patterns of EMMs, EOMs and LOMs. This Figure highlights the differences in the regression patterns of the different refractive groups.

Key:
——— Emmetropes
..... Early-onset myopes
_ _ _ Late-onset myopes

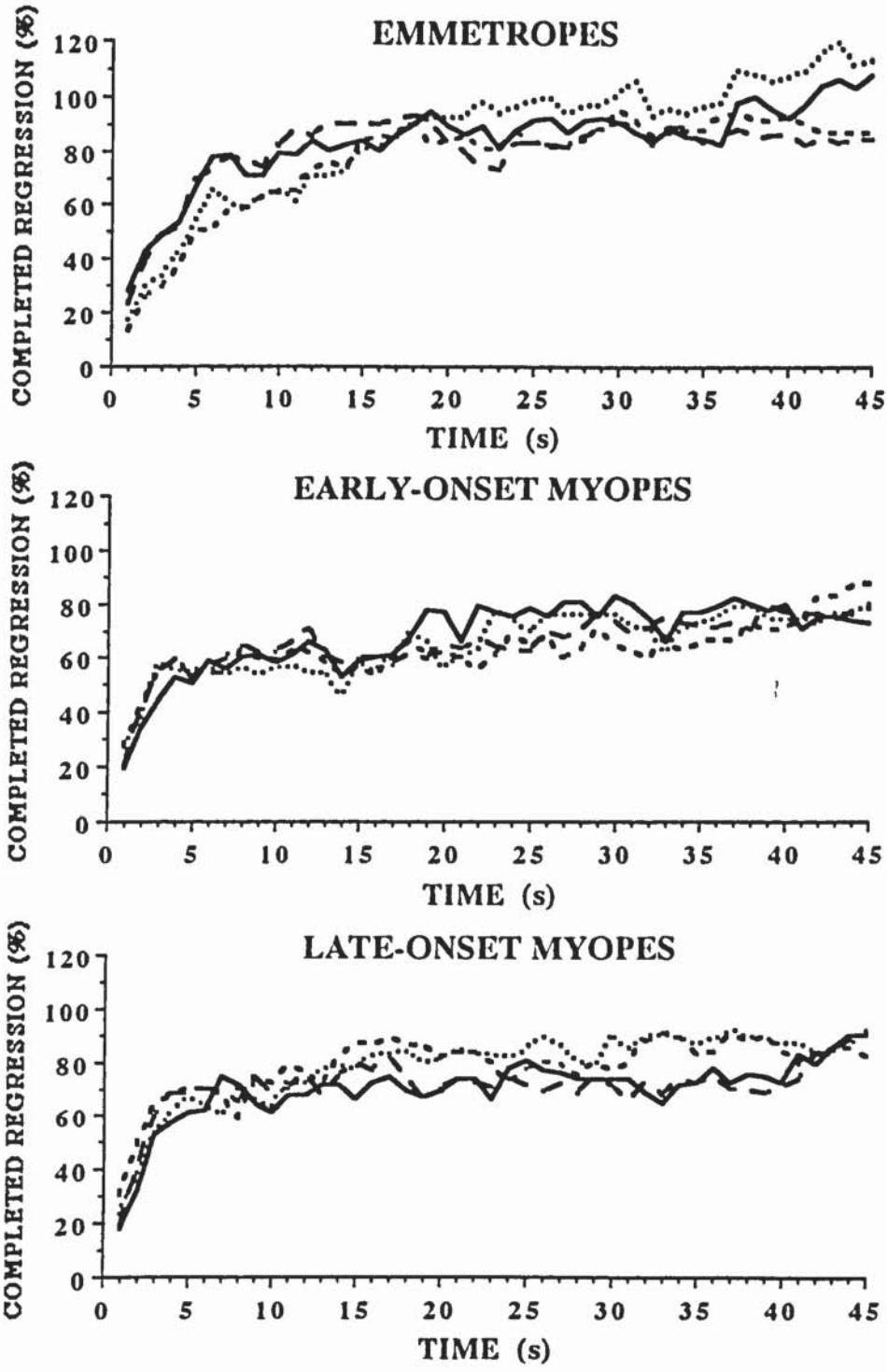

Figure 9.4: The three plots represent the effect of the condition on the regression patterns of EMMs, EOMs and LOMs within the same refractive group. This figure highlights the similarity in the regression patterns resulting from the four different conditions.

Key:
——— Blur only
..... Blur and proximity
- - - - - Blur only in the presence of proximity
_ _ _ Blur minus proximity

The effect of the conditions, as illustrated in Figure 9.4, (blur only, blur and proximity, blur minus proximity and blur in the presence of proximity) was not significant ($p = 0.93$) suggesting that proximal cues do not necessarily influence accommodative regression patterns. Thus support is given to the model devised by Hung et al. (1994) which suggests that the relative contribution of proximity is small under various closed-

loop conditions. In addition, the interactions between refractive group and condition and time and condition were not significant either, indicating further that the effect of blur on the regression patterns is not influenced by the presence or absence of proximal effects.

9.4 - DISCUSSION

The aim of this investigation was to find the effect of proximity on accommodative regression patterns of subjects from three different refractive groups namely EMMs, EOMs and LOMs. In addition, several measures of pre-task SOLA were obtained together with estimates of the effect of proximity on within-task accommodation levels.

The pre-task SOLA levels were not found to vary significantly between the refractive groups, a finding which contrasts with the results of the study detailed in Chapter 8 but sample sizes were very much smaller for this study which may disguise subtle differences between the refractive groups. Pre-task SOLA levels on average were of the order of 0.60 D which agrees with previous workers estimates of the average SOLA level when measured using a Canon optometer (Rosenfield and Gilmartin, 1987c; 1989).

The effect of proximity on closed-loop ARs was demonstrated by measuring within-task ARs. When accommodation is not stimulated by blur it was found that the closed-loop response was not significantly affected by the presence or absence of proximal cues but in the presence of a 3.00 D blur stimulus plus additional proximal cues, a decrease in the AR was noted. These findings suggest that when blur acts on its own the AR obtained is in fact more accurate. However, the effect of looking through a negative lens at a distant target may actually encourage higher levels of accommodative effort than necessary due to the unnatural conditions of the task. The subject may feel more aware of having to accommodate to keep the target in focus and therefore over accommodate slightly. When viewing a near target, proximal cues provide additional information to the accommodative system perhaps enabling it to function more efficiently. Furthermore, it should be remembered that throughout this experiment the vergence loop was open so that if PIA acts primarily via convergent accommodation, the effect of proximity on the AR will be negligible.

In a study also designed to assess the effect of PIA on accommodative adaptation Rosenfield et al. (1990) reported that the mean within-task ARs of the 10 subjects was higher for the condition inducing both proximally-induced and blur-induced accommodation compared to the condition in which only blur was allowed to act as a stimulus. However, the difference between these within-task accommodative levels was not significant. Furthermore, the optometer used to assess accommodation was not of

the objective type; the subject had to indicate when two lines appeared to be in alignment which would have involved some cognitive effort which has previously been shown to affect ARs. Moreover those subjects with a refractive error wore their glasses during the experiment which would produce differential magnification of the target.

The results of the investigation detailed here show that the presence or absence of proximal cues had no significant effect on the accommodative regression patterns. These findings contrast sharply with those reported by Rosenfield et al. (1990) who suggested that proximity has a major role to play in stimulating accommodative shifts; the magnitude of these shifts doubled when the stimulus for the closed-loop task incorporated both blur and proximal cues compared to the blur only stimulus. Many discrepancies between the study detailed here and that of Rosenfield and his co-workers exist which may explain the differences in the results obtained:

1) Rosenfield et al. (1990) employed only 10 subjects of various refractive errors and treated them as one group. 36 subjects were used in the study detailed here and all of them were classified as either EMMs, EOMs or LOMs according to the type and age of onset of refractive error. Unlike the subjects used by Rosenfield et al., all the myopes were fitted with soft contact lenses so that discrepancies in spectacle magnification could not affect the results.

2) The optometer used by Rosenfield and his co-workers to measure accommodation was a subjective Hartinger optometer. The measurement of refractive error by this optometer involves some cognitive effort on behalf of the subject which is known to influence measurements of open-loop accommodation as mentioned previously. Furthermore, the time taken to assess the refractive error with the Hartinger optometer is approximately ten times longer than of the Canon R-1. Consequently, Rosenfield et al. only managed to obtain 6 measures of open-loop accommodation in the 60 s immediately following the closed-loop task compared to the 60 readings obtained when using the Canon optometer. In addition, Rosenfield et al. stated that the exit pupil of the Hartinger was only 1 mm in diameter therefore rendering accommodation open-loop but Ward and Charman (1987) reported that in order to open the accommodative loop sufficiently, a 0.5 mm diameter aperture is required.

3) The experiment conducted by Rosenfield et al. (1990) was not computer-controlled thus the conditions would have varied between trials. Furthermore, Rosenfield and his colleagues did not consider and try to control the effects of non-visual stimuli to accommodation such as surround propinquity, the effect of switching from closed- to open-loop conditions and visual imagery. Accommodative regression patterns following a task with no dioptric demand on the accommodative system were not assessed and thus

the measures of post-task accommodation obtained by them may well be contaminated by these non-visual stimuli which may have influenced the results.

4) Rosenfield and his co-workers claimed to measure accommodative regression following a closed-loop visual task but the effect of time on the post-task open-loop accommodative measurements was not considered even though time is a very important factor in the regression of accommodation to pre-task SOLA levels. Rosenfield et al. simply calculated the mean of the post-task accommodative measurements and subtracted the pre-task SOLA level and claimed that the resulting shift in accommodation represented the magnitude of adaptation. The six post-task accommodative readings were not taken at specific time intervals therefore it is not possible to accurately compare the results from the two conditions. The Canon optometer on the other hand takes only 1 s to record and print out a measurement of refraction thus enabling accurate comparison of measurements between trials as the measurements are time locked.

In summary, the current investigation has demonstrated that proximity does not act as a stimulus to altering either the magnitude or the time-course of post-task accommodative shifts. This study has also shown that the time-course of regression is significantly influenced by refractive group, with the EMMs regressing more quickly than both the LOMs and the EOMs. Such a finding has previously been recognised by several workers. As PIA does not affect the time-course of regression, the cause of differences between the refractive groups cannot therefore be due to differences in their accommodative response profiles to the adapting target but is more likely to be due to differences between some other aspect of the oculomotor system. Pharmacological aspects of accommodative response profiles and SOLA are investigated in the following Chapter in order to discover if the time-course differences of accommodative regression between the refractive groups have an innervational basis.

CHAPTER 10

THE EFFECT OF TOPICAL β-ADRENOCEPTOR ANTAGONISTS ON ACCOMMODATION IN EMMETROPIA AND MYOPIA

10.1 - INTRODUCTION

Chapter 8 showed that EMMs have significantly higher SOLA levels than LOMs, in addition Chapter 9 revealed differences in the time-course of accommodative regression patterns of EMMs, EOMs and LOMs following sustained visual tasks which could not be explained by proximal effects. Although many researchers believe that differences in the accommodative profiles of EMMs and LOMs provides evidence, albeit indirectly, for a link between accommodation and the development of LOM, the actual cause of these differences is unknown at present. Several suggestions have been proposed but it was not until Gilmartin et al. (1984) and Gilmartin and Hogan (1985) demonstrated that SOLA could be modified by topical instillation of drugs which interfered with sympathetic innervation of ciliary smooth muscle (see Gilmartin, 1986 for review) that the proposal that sympathetic inhibitory function might somehow be linked to the aetiology of LOM was made. It was suggested that a deficit in sympathetic inhibition might enhance susceptibility to post-task accommodative hysteresis induced by sustained near vision which could render the individual susceptible to the development of LOM.

The hypothesis subsequently received support from the finding that sustained near vision augments inhibitory sympathetic innervation of the ciliary smooth muscle. Gilmartin and Bullimore (1987) measured accommodative adaptation in a group of young EMMs (N = 15) with reference to pre- and post-task SOLA using the Canon R-1 optometer. They illustrated that post-task accommodation normally regressed to pre-task SOLA levels within 60 s but topical instillation of timolol enhanced significantly the magnitude and duration of post-task increases in SOLA induced by a 5.0 D task. No equivalent effect was evident with timolol for the 0.3 D task. Gilmartin and Bullimore found that the inhibitory effect occurred principally in those EMMs with relatively high pre-task SOLA levels and consequently proposed that EMMs with low levels of pre-task SOLA may prove more susceptible to the development of LOM.

Gilmartin et al. (1984) and Gilmartin and Hogan (1985) had previously demonstrated a sympathetic inhibitory component to SOLA for *all* their subjects using timolol and isoprenaline. However, a subjective laser optometer which induces higher measures of

SOLA due to the cognitive effort involved in assessing the direction of speckle movement (see Chapter 1 section 1.7D) was used. The SOLA levels measured by Gilmartin and Bullimore (1987) using an objective optometer in complete darkness were significantly lower than those reported by Gilmartin and Hogan which could be the reason why sympathetic inhibition became manifest only in those subjects with relatively high SOLA levels under these conditions.

A study completed by McBrien and Millodot (1988) measured differences in adaptation of SOLA in EMMs, EOMs, LOMs and hyperopes. Like Gilmartin and Bullimore (1987) they used the objective Canon R-1 optometer to assess accommodation. They classified the LOMs as those people who developed myopia at 15 years of age or later. The data showed significant increases in SOLA for LOMs (N = 10) following 15 min tasks located at 0.27 D and 5.0 D when compared to EMMs (N = 16). Mean shifts of around +0.35 D were evident at the first 1 min data point and were maintained and somewhat enhanced at the 7 and 15 min data points.

Subsequently, Gilmartin and Bullimore (1991) considered whether the differences reported by McBrien and Millodot (1988) were in fact a sequel to more enhanced differences occurring prior to their 1 min recording point. Using a similar methodology to that used previously (Gilmartin and Bullimore, 1987), the work demonstrated significant differences between post-task regression patterns for EMMs and LOMs which became more marked as accommodation stimulus levels increased. For example, following a 5 D task, the post-task accommodation of EMMs (N=15) reached pre-task levels within 50 s whereas for LOMs (N=15) the initial rapid regression of accommodation to between 0.2 and 0.4 D above pre-task SOLA levels was maintained over most of the 90 s recording period, i.e. the hysteresis effects of the LOMs dissipated at a slower rate than for the EMMs. The differences could not be linked to variations in either within-task accommodative response or pre-task SOLA levels. A recent study (Strang et al., 1994) using similar measurement techniques has confirmed the findings of Gilmartin and Bullimore (1991) as has the work detailed in the previous Chapter which showed that the time-course of regression is shortest for EMMs when compared to EOMs and LOMs.

When considered together, the results of the above studies would give some support to the proposal that the onset of LOM might follow a progressive sequence: first, a specific deficit in sympathetic inhibition of ciliary smooth muscle (possibly associated with the relatively low levels of SOLA evident in LOM - see Chapter 8) second, a subsequent tendency to post-task accommodative shifts or accommodative spasm following sustained near-vision; finally, an accumulation of these micro-adaptational processes to a point whereby axial elongation is induced. Many workers have already

addressed these issues (Gilmartin and Bullimore, 1987; Fisher et al., 1987; McBrien and Millodot, 1988; Ebenholtz, 1988; Ebenholtz, 1992; see for reviews Owens, 1991; Gilmartin et al. 1992).

For the above mentioned sequence to be feasible, the LOMs profile of ciliary muscle response to β-adrenoceptor antagonist agents would have to be significantly different from that of EMMs, in particular enhancement of the magnitude and duration of post-near task positive shifts in SOLA demonstrated with timolol by Gilmartin and Bullimore (1987) on a subset of EMMs.

The present study is divided into two sections; the first part was undertaken to determined the effect of β-adrenoceptor antagonists on SOLA under two different open-loop conditions for EMMs (N = 12), EOMs (N = 10) and LOMs (N = 8). In addition to complete darkness, a laser speckle target was employed in an attempt to increase the SOLA levels of all refractive groups to a magnitude at which augmentation of sympathetic inhibition, if present, will consistently occur . Due to constraints on laboratory time, for the second part of the study a subset of observers (EMMs, N = 6; EOMs, N = 5 and LOMs, N = 5) were carefully chosen from the initial SOLA study to represent a cross-section of responses from each refractive group. The second part of the investigation profiled the post-task accommodative response to β-adrenoceptor antagonist agents using similar techniques to those used in previous reports (Gilmartin and Bullimore, 1987; 1991). The methodology adopted does, however, differ in a number of important respects notably the use, as a control, of betaxolol HCl a β-adrenoceptor antagonist with predominantly β_1 activity. In addition EOMs are included as a refractive group as the myopia is linked principally to hereditary rather than accommodative factors. In this respect EOMs can be distinguished from LOMs and classified with the EMMs but at the same time act as a control with respect to the possibility of myopia in general affecting the results.

10.2 - METHODS

10.2A - Subjects

A total of 30 subjects were used for the initial study, all of whom signed a consent form prior to taking part, following a full explanation of procedures. The criteria used for designating subject groups is explained in Chapter 6 (section 6.2). Monocular visual acuities were at least 6/6 and none of the subjects had any form of visual abnormality. Biometry and keratometry measurements for the majority of subjects appear in Appendix 11a. Cylindrical corrections were never greater than 0.75 D and all myopic subjects were fitted with *Acuvue* disposable soft contact lenses. At least 20 minutes was allowed for

adaptation to the contact lenses prior to data collection. From the original 30 subjects, 16 were chosen to completed the second part of the study. Table 10.1 gives details of the subject groups used for both parts of the study.

Refractive group	EMMs		EOMs		LOMs	
Section of study	1	2	1	2	1	2
Number of subjects	12	6	10	5	8	5
Mean age (yrs)	22.08	22.50	21.40	22.60	21.00	22.00
Range of ages (yrs)	18 - 29	18 - 27	18 - 29	18 - 29	18 - 28	18 - 28
Mean refraction	+0.18 D	+0.17 D	-3.25 D	-3.42 D	-1.68 D	-1.55 D
(SEM)	(±0.06)	(±0.07)	(±0.56)	(±0.76)	(±0.23)	(±0.23)
Mean myopic onset	-	-	11.80	11.20	18.00	18.80
(SEM)	-	-	(±0.84)	(±1.11)	(±0.82)	(±1.20)

Table 10.1 Details of subjects used: emmetropes (EMMs), early-onset myopes (EOMs) and late-onset myopes (LOMs).

All subjects were initially allocated to two trials, each of which lasted approximately 60 min. Some subjects were chosen to complete a further two trials, each of these lasted a minimum of 90 min. All trials was separated by a period of at least two days. The initial two trials comprised a combination of measurements of SOLA under two open-loop conditions prior to and 35 min following the instillation of 1 of the 2 β-adrenoceptor antagonists, timolol maleate 0.5% and betaxolol HCl 0.5%. The final two trials undertaken by a subset of subjects chosen from the initial SOLA experiment involved monitoring accommodative regression patterns for two task locations (far, 0.2 D; near, set approximately 4.0 D above the darkroom SOLA level) prior to and 35 min following the topical instillation of the β-adrenoceptor antagonists timolol maleate 0.5% and betaxolol HCl 0.5%.

10.2B - β-adrenoceptor antagonists employed

For both parts of the study two β-adrenoceptor antagonists were used; betaxolol HCl and timolol maleate. Betaxolol was used as the control agent for timolol in preference to saline which has been used in previous investigations (Gilmartin and Bullimore, 1987). The reason for this lies in the fact that excised human ciliary smooth muscle has been shown pharmacologically to contain predominantly β_2-adrenoceptors (Van Alphen, 1976; Logrando and Reibaldi, 1986; Wax and Molinoff, 1987; Zetterström and Hahnenberger, 1988; also see Chapter 1 section 1.4C), therefore inhibition of the ciliary smooth muscle occurs with the predominantly non-selective (with respect to β_1 or β_2) β-adrenoceptor antagonist timolol but to a much lesser extent, if at all, with the predominantly β_1-adrenoceptor antagonist betaxolol. Both agents will, however, reduce intraocular pressure (IOP) due to β-receptor activity elsewhere in the eye and therefore, unlike

saline, betaxolol serves as a useful control agent with respect to the possibility of interaction between variations in IOP and accommodation.

10.2C - The initial SOLA study

Complete darkness has been employed in previous experiments to access SOLA (see Chapters 6, 8 and 9) and was used in this study but the mean values of SOLA under such conditions tend to be rather low and therefore do not provide enough background parasympathetic activity to augment sympathetic inhibition (if present) in the majority of people. Consequently a second method of opening the accommodative loop was used in an attempt to raise the SOLA levels to a magnitude whereby sympathetic inhibition would be augmented and the action (if any) of β-adrenoceptor antagonists on the ciliary smooth muscle would become apparent. See Chapter 5 (section 5.4) for a full description of opening the accommodative loop with a laser speckle target.

Subjects experienced the open-loop accommodative conditions (either darkroom with no target or with the speckle pattern) for at least 3 minutes prior to data collection in order to establish a stable SOLA level (see Chapter 1 section 1.7E). They were instructed to look either 'straight ahead into the darkness' or to 'look at the red speckles', whichever was appropriate. During the next 2 min approximately 40 readings of accommodation were recorded by the Canon Autoref R-1 (see Chapter 5 for a description of this instrument) and averaged to give the pre-drug SOLA level. After a break of a few minutes the sequence was repeated for the other open-loop condition. See Figure 10.1 for a photograph of the experimental set-up.

IOP measurements were recorded using a non-contact tonometer (American Optical, UK) in order to monitor the well-known ocular hypotensive effects of both timolol and betaxolol. In order to increase absorption and reduce reflex blinking, subjects received 1 drop of the topical anaesthetic benoxinate HCl (0.4%) in each eye, this was followed by either the single instillation (30 μl) of timolol or 2 instillations (60 μl) of betaxolol. The instillations were made using a precision micropipette and were separated by a period of 3 mins. Both eyes received the same drugs and dosages. Pilot studies had indicated that these dosages would induce approximately the same reduction in IOP. Both experimenter and subject were unaware of which agent had been instilled as instillation was arranged via an intermediary. Following drug instillation, subjects were instructed to return after 35 min and not to engage in the intervening period in intensive close work or rigourous exercise. On returning, IOP was measured together with SOLA under both open-loop conditions.

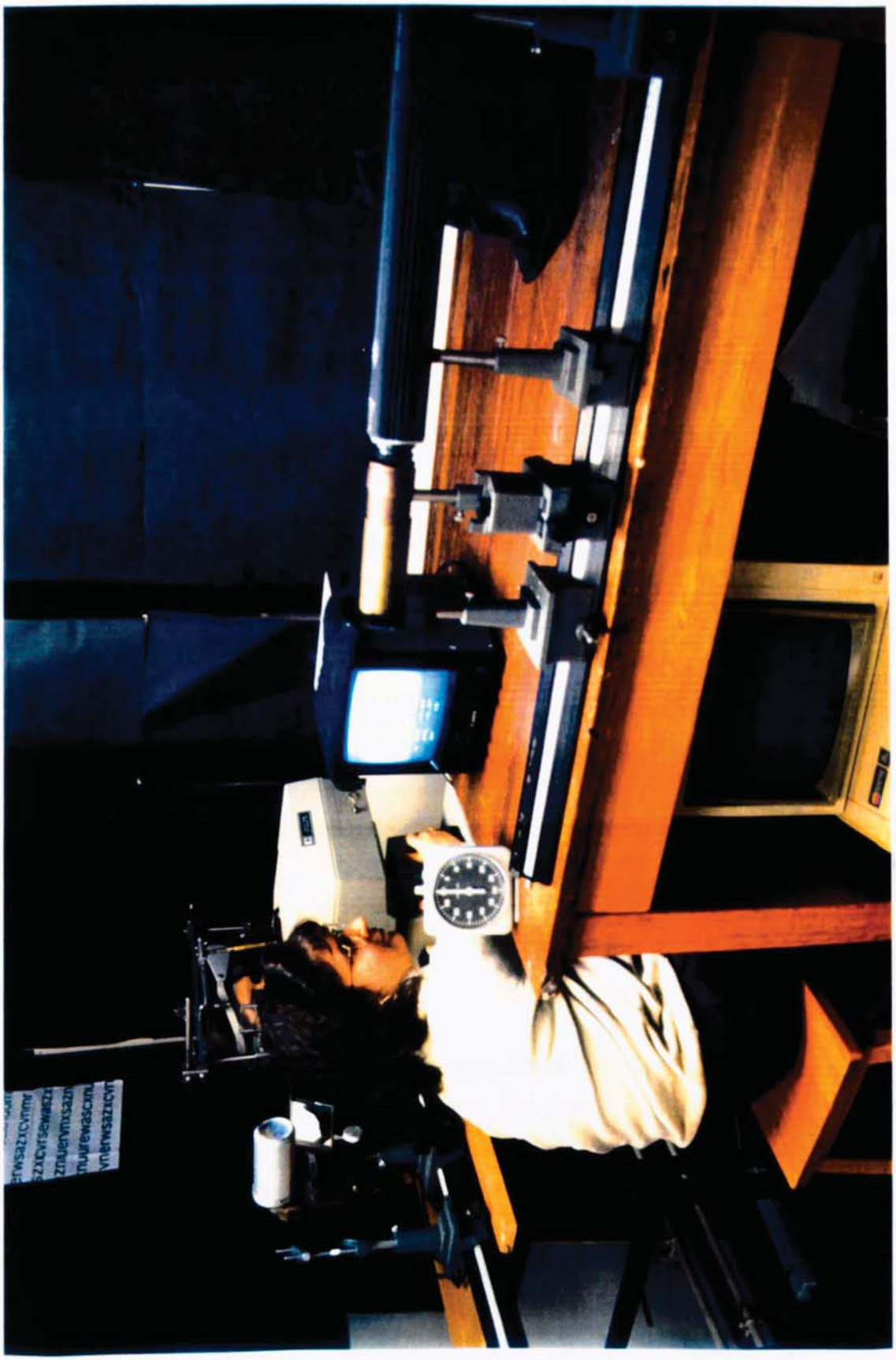

Figure 10.1: Photograph of the experimental set-up.

10.2D -The accommodative regression study

All subjects used in this part of the study had previously completed both parts of the initial study and had signed consent forms following an explanation of procedures. As in the initial study prior to the measurement of SOLA, a period of 3 mins was allowed in complete darkness before any data collection began. During the next 2 min, 20 darkroom accommodation readings were taken and averaged to give a pre-task SOLA value. Subjects then viewed binocularly either the far or near target (randomly allocated) for a 3 min period. The level of accommodation exerted during the task was recorded approximately every 6 s apart from the final 15 s when approximately 9 recordings were taken. A few seconds before the end of this viewing period an auditory signal produced by the Apple IIe computer indicated to the subject the imminent onset of darkness and the need to maintain steady, straight ahead fixation. On extinguishing the lights, accommodation regression was measured at 1.5 s intervals over a 90 s post-task recording period. Following a 10 min break, the procedure was repeated for the other target condition. The time sequencing and data collection was controlled by an Apple IIe computer in conjunction with a CIL PCI 6000 interface unit (see Chapter 5 and Appendix 5). The experimental set-up was similar to that used in Chapter 9 (see Figure 9.1) except that reading from the autorefractor were sent directly to and stored in the Macintosh computer instead of being printed out (see Chapter 5 section 5.3B).

After a 10 min break, IOP was monitored and drugs were topically applied in the same way as for the first part of the study. Following drug installation a period of 35 min elapsed before further IOP measurements and accommodative regression patterns for both target distances were monitored as described above.

10.3 - RESULTS

10.3A- The initial SOLA study

Table 10.2 shows details of the changes in IOP following the instillation of timolol and betaxolol. Figures 10.2a and 10.2b show the group mean SOLA levels under the two open-loop conditions prior to and following the instillation of timolol and betaxolol. In contrast to predictions made earlier, it would appear that when viewing a laser speckle target, the pre-drug SOLA levels are not significantly higher than those measured in complete darkness. This observation is confirmed by the results of 2 two-way ANOVAs comparing the SOLA levels under both complete darkness and when viewing a laser speckle target before the instillations of betaxolol and timolol ($p = 0.95$ and 0.93 respectively). The effect of refractive group on pre-timolol SOLA levels (darkness and laser speckle) only just fails to reach significance ($p = 0.07$) with the EMMs displaying

higher SOLA levels than both the EOMs and the LOMs, confirming the trend reported in Chapter 8. In contrast, the pre-betaxolol measures of SOLA do not demonstrate any significant trends associated with refractive group ($p = 0.18$) which in itself underlines the inherent variability of this measurement.

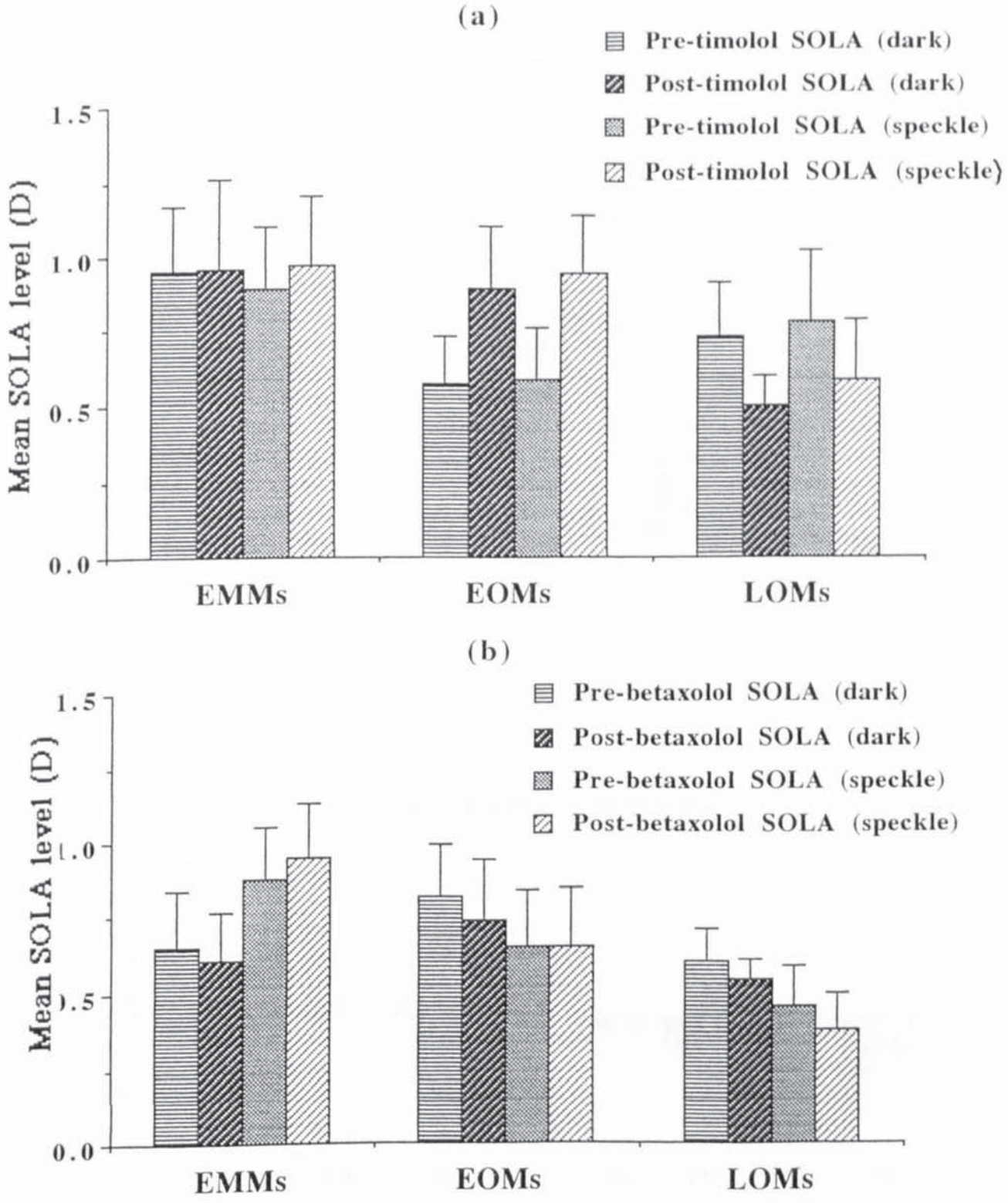

Figure 10.2: Group mean SOLA levels prior to and following the instillation of a) timolol and b) betaxolol measured in complete darkness (SOLA dark) and when viewing a laser speckle pattern in an otherwise darkened room (SOLA speckle)

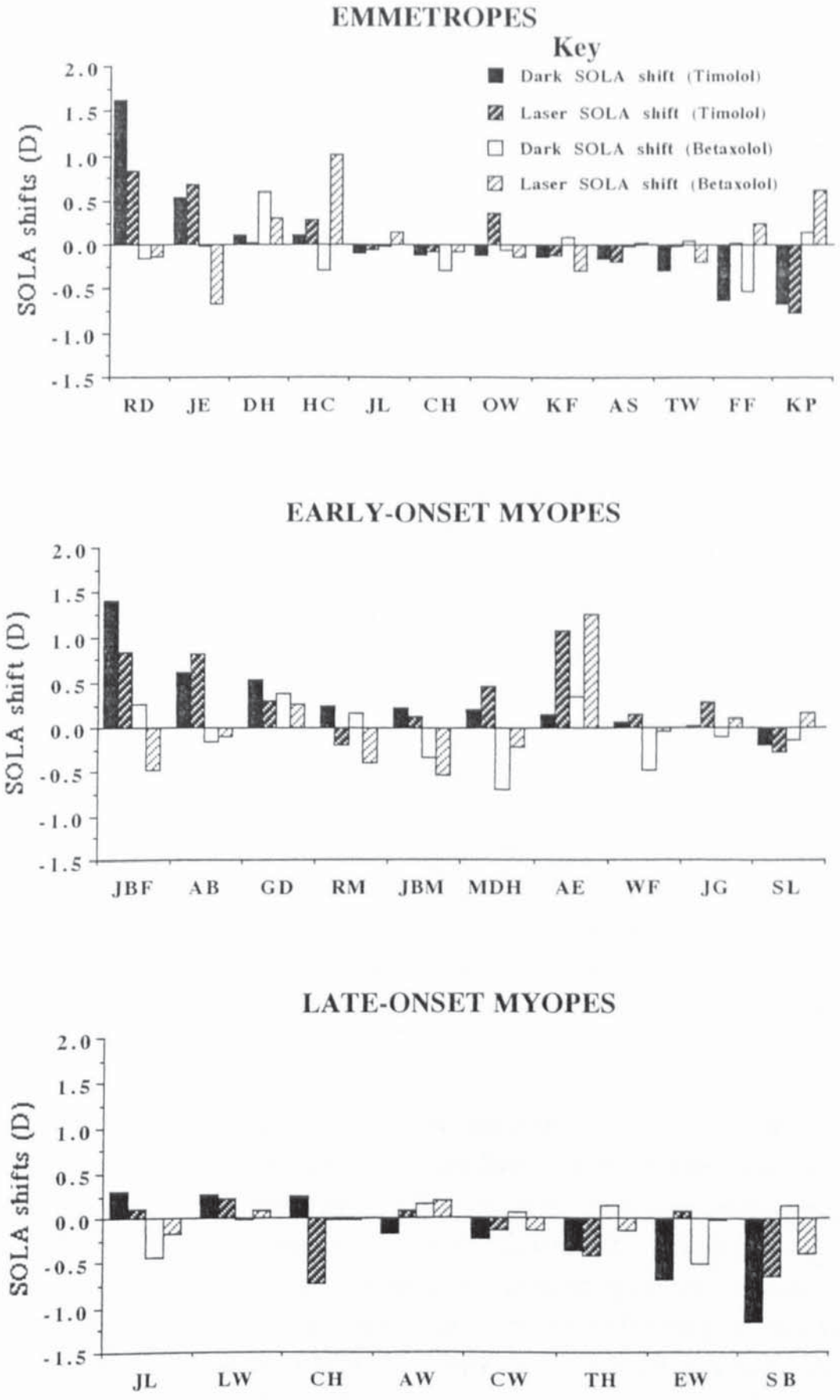

Figure 10.3: Individuals' shifts in SOLA following the instillation of timolol and betaxolol. A positive shift indicates an increase in SOLA whereas a negative shift indicates a decrease.

Refractive groups	EMMs	EOMs	LOMs
Mean IOP reduction with timolol (mmHg) (SEM)	2.88 (0.31)	3.07 (0.30)	2.35 (0.27)
Mean IOP reduction with betaxolol (mmHg) (SEM)	1.55 (0.18)	2.39 (0.27)	2.26 (0.43)

Table 10.2: Group mean changes in IOP following the instillation of timolol and betaxolol.

It appears that timolol has little effect on either of the mean SOLA levels of EMMs whereas the EOMs demonstrate a mean increase and LOMs a mean decrease in both SOLA levels (Figure 10.2a). In contrast, the effect of betaxolol is less marked for all refractive groups (Figure 10.2b) as was predicted earlier. The results were analysed using two-way ANOVAs and neither timolol ($p = 0.76$) nor betaxolol ($p = 0.57$) were found to significantly affect SOLA levels when viewing a laser speckle pattern or when in complete darkness. Figure 10.3 shows the shifts in SOLA for individual observers; positive shifts indicate an increase in SOLA whereas negative shifts indicate a decrease. The marked variations in these shifts, evident across all refractive groups, highlights the reason why mean SOLA levels were not significantly affected by either drug condition.

The fact that all refractive groups demonstrate similar variations in terms of positive and negative shifts indicates that the innervational profiles for each group are very similar, this fact was borne out by the second part of the study. However, it is impossible at this stage to rule out completely an innervational basis in the development of LOM as the SOLA levels for some observers were not of an adequate magnitude to augment sympathetic inhibition.

Subjects whose SOLA shifts represented the full spectrum of effects of timolol and betaxolol on the ciliary muscle and who were known to be reliable were chosen to complete the second part of the study in order to determine, in an alternative way, the innervational profiles of the refractive groups. Subjects RD, JE (EMMs), JBF, AB (EOMs) and JL (LOM) were chosen as they all demonstrate significant increases in both SOLA measurements following the instillation of timolol which suggests they exhibit sympathetic inhibition. Subjects FF, KP (EMMs), SL (EOM), EW and SB (LOMs) all demonstrate significant negative shifts following the topical application of timolol but subject SL declined to act as an observer for the second part of the study. Some subjects demonstrated significant negative shifts with betaxolol such as FF, JE (EMMs), JBM, MD (EOMs) JL, EW and SB (LOMs), all of whom agreed to act as observers for the next part of the study as did KP who showed an increase in SOLA following the instillation of

betaxolol. Other subjects from the three refractive groups were chosen on the basis that their results from this part of the study showed no particular or consistent influence of either drug on SOLA levels and they were known to be reliable subjects.

10.3B - The accommodative regression study

Figure 10.4 represents for subject EW, a LOM, actual regression patterns for all conditions following both far and near plotted over 60 s of the post-task period. The rapid regression of accommodation following the near task is evident for all conditions apart from timolol where a marked attenuation of regression is clearly evident compared to the control betaxolol condition. Pre-timolol and pre-betaxolol regressions are very similar.

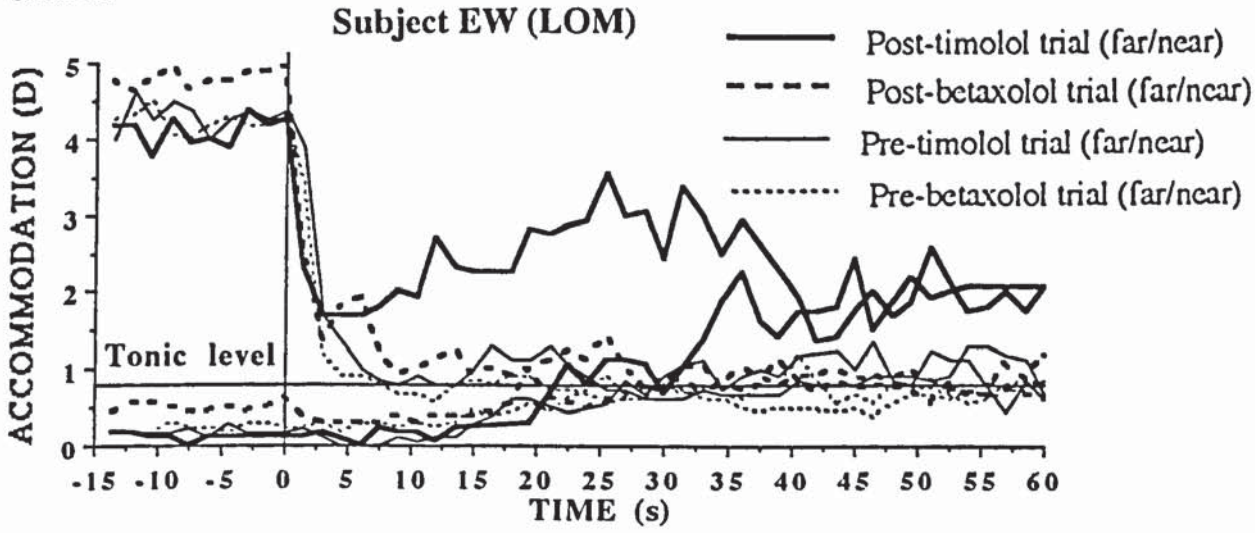

Figure 10.4: Actual regression patterns for subject EW, a late-onset myope.

In previous reports (Gilmartin and Bullimore, 1987; 1991; McBrien and Millodot, 1988) post-task accommodative regression patterns have been measured with respect to pre-task levels of SOLA and thus these measures have represented relative shifts in pre-task SOLA levels. There are limitations to this approach relating principally to the uncertainty regarding both the short-term stability of SOLA (see previous section) and the final resting levels that occur when comparing regression from a far task with regression from a near task, that is there is a resting zone which can extend to 1.0 D (Baker et al., 1983; Morse, 1991). Furthermore, it is probable that regression patterns can be modified by a variety of influences which are extraneous to the actual level of within-task accommodation (see Chapter 9). In this study the accommodative regression patterns resulting from the minimal level of accommodation associated with the far task is taken as the control condition. Thus data points that constitute the far regression are each subtracted from those for the near regression for each condition (similar to the way in which data was analysed in Chapter 9). The difference between near and far regressions is then plotted as a percentage of the difference between mean levels of near and far accommodation occurring during the final 15 s of the task period. This procedure accounts for the variation in far and near accommodation levels that inevitably occurred in

this study between subjects and between conditions due to the differences in SOLA levels. Table 10.3 shows the mean task accommodative levels for the three refractive groups together with the reduction in IOP caused by timolol and betaxolol.

Refractive groups	EMMs	EOMs	LOMs
Task accommodation near - far (D) (SEM)	4.2 (0.16)	4.05 (0.22)	3.97 (0.18)
Mean IOP reduction with timolol (mmHg) (SEM)	2.47 (0.39)	1.83 (0.36)	2.90 (0.33)
Mean IOP reduction with betaxolol (mmHg) (SEM)	1.94 (0.52)	1.93 (0.41)	2.30 (0.43)

Table 10.3: Group means for the within-task accommodation levels (near - far) and IOP reduction following the instillation of timolol and betaxolol.

Three factor split-plot ANOVAs were carried out on the % accommodation regression data collected for pre- and post- timolol and betaxolol trials (major factors: drug and refractive group; minor factor: time) and for the pre-drug condition between timolol and betaxolol trials. As would be expected the variation in % regression over time was highly significant for all conditions. The drug effect was not significant for either the timolol trial ($p = 0.69$) or the betaxolol trial ($p = 0.28$). Differences in regression patterns between refractive groups was just significant for the timolol trial ($p = 0.04$) but not for the betaxolol trial ($p = 0.69$). No significant interaction effects were evident for any of the trials.

The % accommodation regression data was condensed for a subset of subjects to produce Figures 10.5a, 10.5b and 10.5c. The mean of each of the 7 mean sphere readings located symmetrically about the 10, 20, 30 and 40 s data points was computed. The initial 2 or 3 readings were not included as they were difficult to assess owing to the transient nature of the regression and the need on occasion to realign the instrument. The upper plots demonstrate the inter-subject variation shown in previous studies (Gilmartin and Bullimore, 1987; 1991) and the general finding that regression to base-line levels usually occurs within 60 s. The differences between pre- and post- drug regressions shown in the lower plots illustrate the similarity of drug effects for each refractive group. Thus subjects KP, JG and EW show for timolol (relative to betaxolol) an increase in the time constant of regression; subjects OW, AB and CH equivalent regressions; subjects HC, MD and JL faster regressions.

EMMETROPES

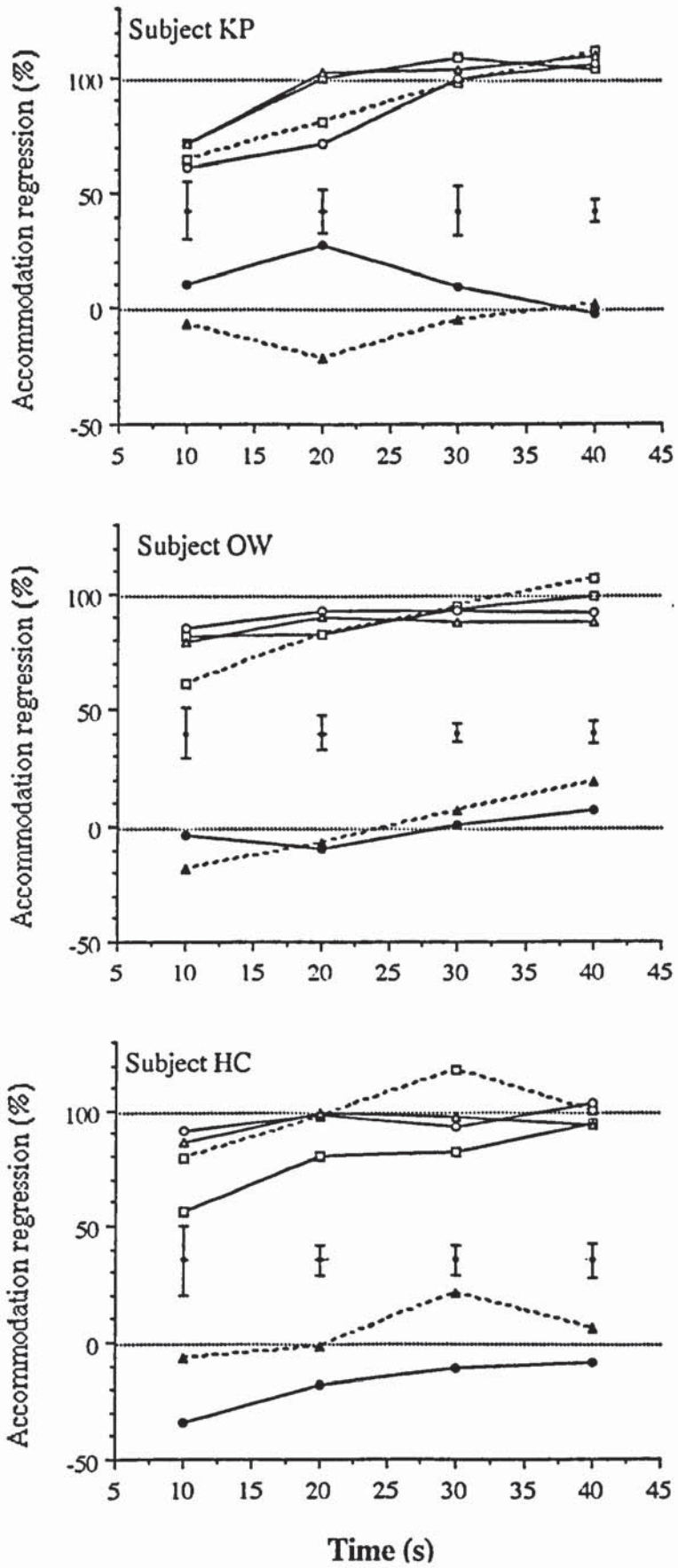

Figure 10.5a: Upper plots: Condensed % accommodation regression data for 3 subjects drawn from the emmetropic group. The error bars represent, for each time period, the mean standard deviation (derived from each separate set of 7 data points) for all conditions. Lower plots: The difference, derived from each respective upper plot, between pre- and post-drug regression for timolol and betaxolol. Key: —□— Pre-timolol trial ---□--- Pre-betaxolol trial —○— Post-timolol trial —△— Post-betaxolol trial. —●— (Pre-) - (Post-) timolol. ---▲--- (Pre-) - (Post-) betaxolol.

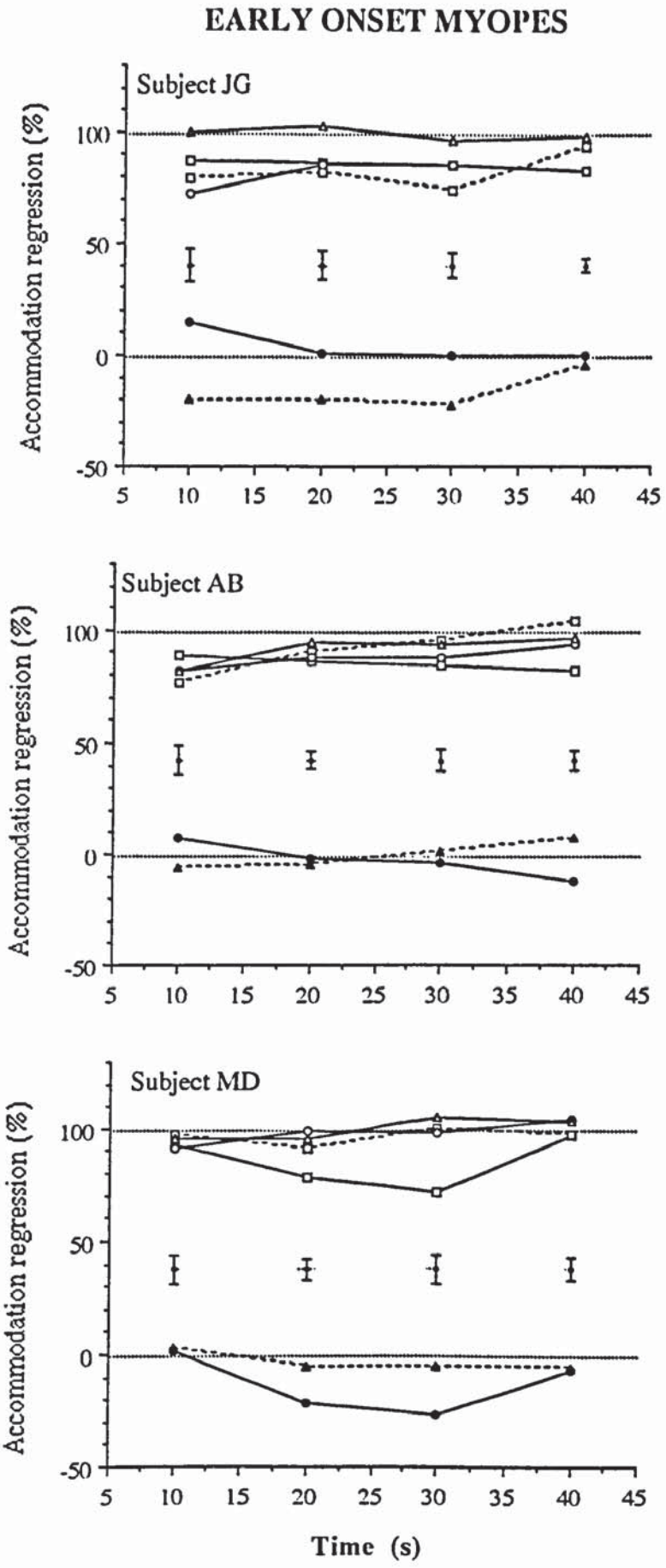

Figure 10.5b: Data for 3 subjects drawn from the early-onset myopia group (see Figure 10.5a legend)

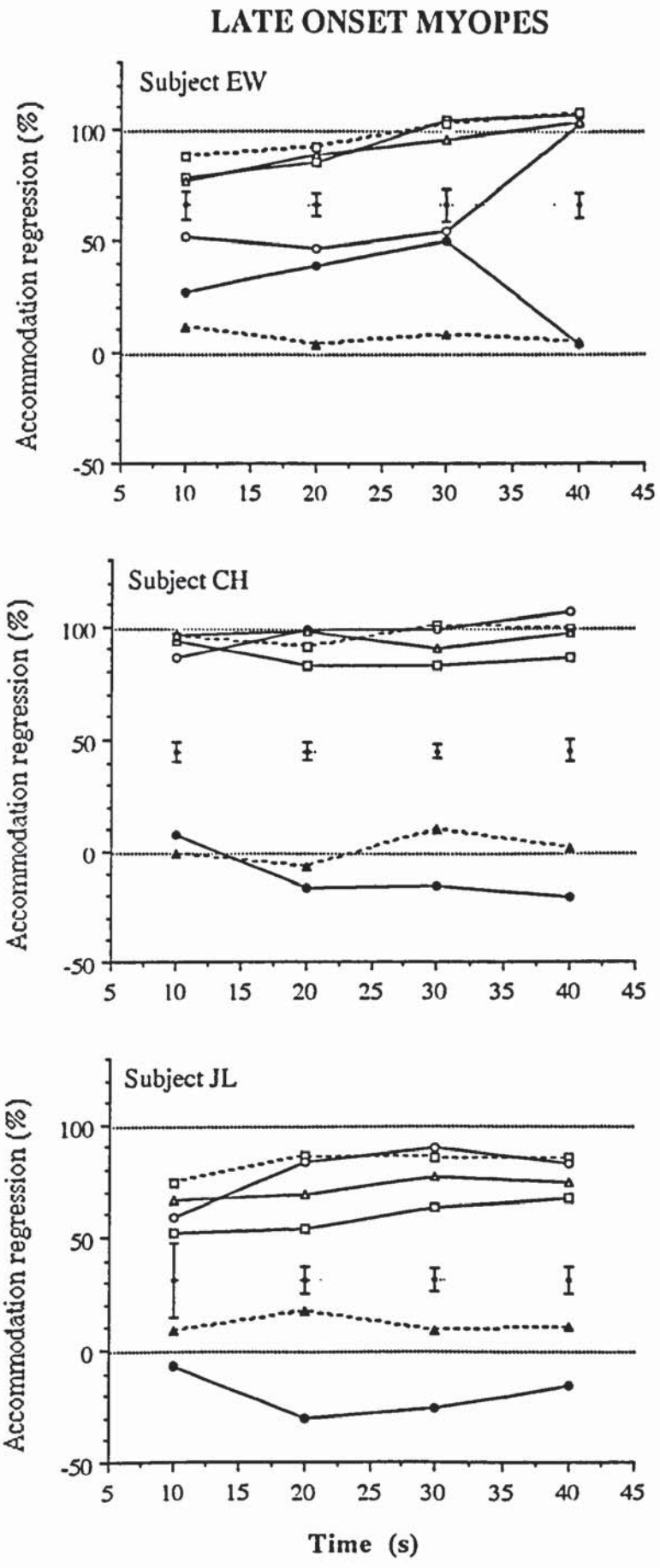

Figure 10.5c: Data for 3 subjects drawn from the late-onset myopia group (see Figure 10.5a legend)

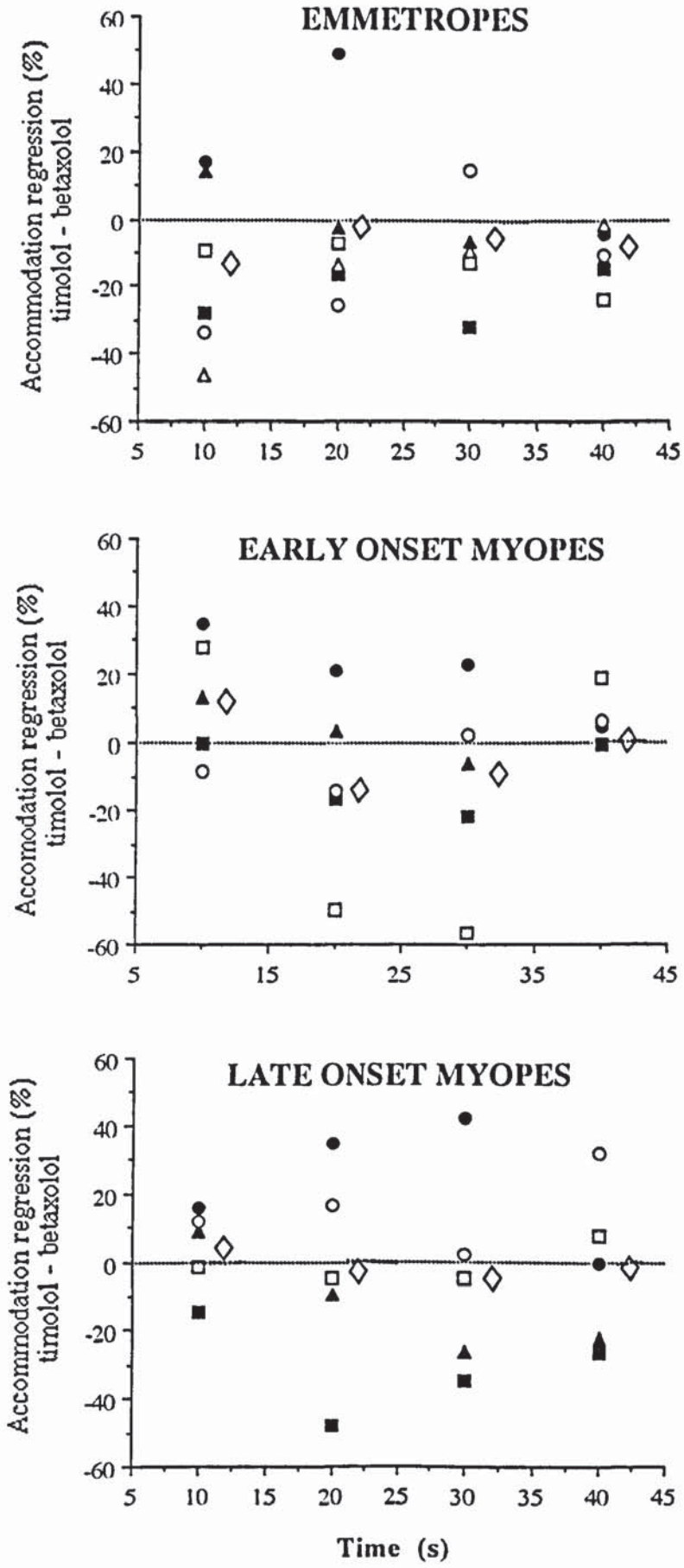

Figure 10.6: The plots are derived from the subtraction, for all subjects, of the lower plots illustrated in Figure 5 (timolol - betaxolol) for each refractive group. Positive and negative values thus represent respectively the relative enhancement and attenuation of post-task hysteresis with timolol. Different symbols are assigned to each subject within refractive groups. The group mean (◊) is displaced for clarity.

Data illustrated in Figure 10.6 condenses the data in Figure 10.5 further by subtracting, for all subjects used, the lower plots (timolol - betaxolol) to give a net drug effect. Positive and negative values thus represent respectively the relative enhancement and attenuation by timolol of post-task regression patterns. Inspection of the distribution of these differences across time demonstrates further that the profile of response to β-adrenoceptor antagonism is similar for each of the refractive groups.

Figure 10.7 plots mean % accommodation regressions for the pre-drug data for each refractive group so that comparison could be made, albeit for a smaller sample size, with the findings of Gilmartin and Bullimore (1987) and Strang et al. (1994). As was reported in Chapter 8, EOMs as well as LOMs show an increase in the time constant of accommodative regression. The pre-drug differences failed, however, to reach statistical significance (two-factor split-plot ANOVA: $p = 0.27$).

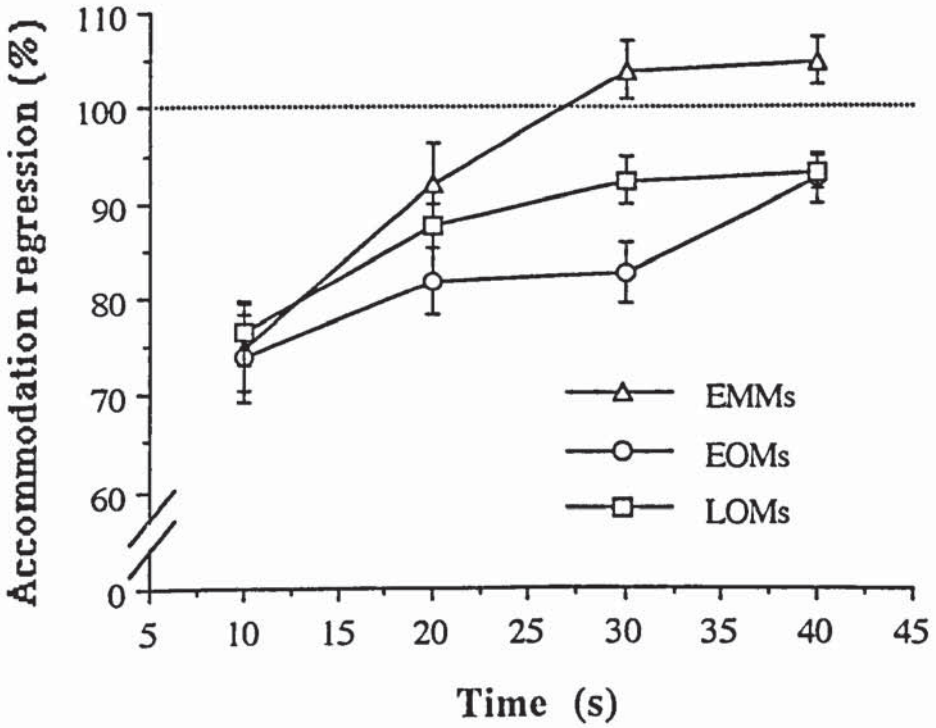

Figure10.7: Mean % accommodation regression data (condensed, see Figure 10.5a legend) for the pre-drug conditions for each refractive group. The error bars represent, for each time period, the mean SEM (derived from each separate set of 7 data points).

10.4 - DISCUSSION

The results from both parts of this study demonstrate that the accommodative responses to β-adrenergic antagonists of EMMs, EOMs and LOMs are similar in profile. All three refractive groups showed evidence of both the presence and absence of sympathetic innervation of the ciliary muscle thus the proposal that a deficit in sympathetic innervation is a precursor to the development of LOM is rejected. In addition, the differences in mean SOLA levels evident between EMMs and LOMs (see Chapter 8) cannot readily be explained by variations in the innervational characteristics of the ciliary muscle.

It is important to note that the study detailed in this Chapter adopted a very simple methodology in order to assess the effect of β-adrenoceptor antagonists on the accommodative mechanism of humans *in vivo*. However, the effect that the drugs employed may have had on ocular structures other than the ciliary smooth muscle such as the ciliary processes, choroidal and retinal vasculature as a result of systemic absorption is fully appreciated. It is possible that the effect of β-blockers on these structures has an indirect effect on the measured accommodation responses (Owens et al., 1991; Vuori et al., 1993). In addition, the potential cross-linkage that can occur between systemic transmitters and systemic receptors at pre-synaptic sites further complicates the issue of determining the functional actions of β-adrenoceptor antagonists in the eye (Starke et al., 1989).

Indeed, Lütjen-Drecoll and Kaufman (1986a; 1986b) found that following the prolonged use of timolol in the eyes of cynomolgus monkeys, evidence for pathophysiological changes to certain ocular structures was found. The ciliary processes demonstrated changes consistent with decreased aqueous secretion and in some regions, the trabecular meshwork appeared degenerated. In addition, the timolol treated animals (N = 6) were found to be significantly more myopic than those animals treated with epinephrine, a combined α- and β-adrenergic agonist (N = 2) after 6 months of treatment. Although Lütjen-Drecoll and Kaufman concluded that the increase in myopia could be mediated solely by blockade of the β-adrenergic receptors of the ciliary smooth muscle it is possible that the changes present in the ciliary processes and the trabecular meshwork have a role to play. Furthermore, it has recently been suggested (Tamm et al., 1991; Kaufman, 1992) that elongation of the vitreous chamber could be mediated via extralenticular elastic components of the eye such as Brüch's membrane.

Recently, Jensen (1991) carried out an extensive study of myopia progression in young school children which included the topical use of timolol maleate 0.5% over a two-year period. Timolol was used due to its ocular hypotensive effects rather than on its ability to antagonise inhibitory β_2-adrenoceptors. No significant differences were found between

the rate of myopia development in those children who received the timolol and in the controls. Further insight into the possible influence of sympathetic inhibition on the eye may be gained from the recent demonstration of such inhibition in the chick eye (Troilo et al., 1993) and its incorporation into animal models of myopia development.

The homogeneity of response profile to β-adrenoceptor antagonists demonstrated by both parts of this study will clearly need to be verified for larger sample sizes which include hyperopes and individuals drawn from non-academic populations. Although this study would appear to discount a link between the sympathetic system and myopia development mediated by an anomaly of accommodative function, a longitudinal or large cross-sectional investigation designed to test the correlation between response profiles and ametropic status would be of interest.

Supporting publications

Gilmartin B and Winfield NR (1994) The effect of topical β-adrenoceptor antagonists on accommodation in emmetropia and myopia. Vis. Res. (in press).

CHAPTER 11

REVIEW OF EXPERIMENTAL RESULTS AND PROPOSALS FOR FUTURE WORK

11.1 - INTRODUCTION

It has been proposed that early-onset myopia (EOM) i.e. myopia onset before the age of 15 is primarily inherited whereas late-onset myopia (LOM) i.e. myopia onset from the age of 16 is induced by environmental factors, principally sustained near vision. No consensus exists as to which aspect of the near vision response; accommodation, vergence or their synergistic cross-links promotes LOM development. Furthermore, the mechanism by which near vision could induce axial elongation is obscure although there is evidence to show that interactions between ciliary muscle tone, choroidal tension, scleral rigidity and intraocular pressure play an important role.

The role of accommodation is to maximise the contrast and quality of the foveal image, whereas alignment of the visual axes so that the image falls on corresponding points of the two retinae is attained by the vergence mechanism. Clear, single binocular vision is achieved via negative accommodative and vergence feedback loops. Under normal closed-loop viewing conditions, both the accommodative and vergence responses represent the aggregate of several components. The accommodative response principally comprises of tonic accommodation, blur-induced accommodation, proximally-induced accommodation and convergent accommodation. The vergence response comprises of tonic vergence, fusional vergence, proximal vergence and accommodative convergence. In addition, both systems have fast, reflex phases and slower, adaptive phases.

The proposal that LOM results from sustained near vision was investigated with respect to the hypothesis that anomalous oculomotor function precipitates myopic change. Emmetropes (EMMs), EOMs and LOMs participated in all the investigations undertaken in this thesis. Biometry (Storz Omega Compu-Scan Biometric rule) and keratometry (Javal Schiötz keratometer) were recorded from the majority of subjects to determine which ocular components are responsible for LOM. Measurements of accommodation, made with a Canon Autoref R-1 objective IR optometer, vergence, made using a flashed Maddox rod and tangent scale technique together with standard optometric measures were obtained from subjects during the research programme. A summary of the findings of this research programme is given below as a series of research questions.

11.2 - REVIEW OF EXPERIMENTAL RESULTS

Chapter 5 and Appendix 1

What are the principal physical correlates of late-onset myopia?

It is important to know the mechanism behind the development of myopia so that preventative measures can be directed at the cause. By undertaking axial ultrasonic measures and corneal curvature measures from the majority of subjects used in the experimental programme, this thesis is able to confirm that the degree of both EOM and LOM is correlated principally to an increase in posterior vitreous chamber depth and also, to a lesser extent anterior chamber depth but not to an increase in corneal curvature or to a decrease in lens thickness as suggested by some workers (Goss and Erickson, 1987; Zadnik et al., 1991).

Chapter 6

Are anomalous oculomotor responses responsible for the development of LOM?

Some investigations have indicated that differences exist between the oculomotor responses of various refractive groups thus prompting the proposal that anomalous oculomotor responses provide the trigger to myopic development. A study was undertaken to contrast and cross-correlate various oculomotor responses of EMMs, EOMs and LOMs in an attempt to identify any anomalies in the response profile which may be responsible for precipitating myopic change. Measurements of accommodative convergence / accommodation ratios (stimulus and response), convergent accommodation / convergence ratios, accommodative response gradients, tonic vergence disparity and heterophoria (measured at 2.25 m) and steady-state open-loop accommodation (SOLA) were obtained from the subjects.

The results did not support the proposal the anomalous oculomotor responses provide the trigger to myopic development as no significant differences were found between the responses of EMMs, EOMs and LOMs for any of the measures. However, certain trends were observed; EMMs tended to have higher mean SOLA levels than the EOMs and the LOMs respectively. In addition, EOMs tended to have higher accommodative convergence / accommodation ratios than both EMMs and LOMs and the group mean 'phoria measurements showed a trend for higher esophoria in the two myopic groups compared with the EMMs. These results suggest that the oculomotor responses can be altered as a *result* of the development of refractive error rather than being the *cause* of it.

Chapter 7

Is the ability of the vergence mechanism to adapt to induced retinal disparity correlated with refractive group?

It has been suggested that EMMs adapt more quickly to induced disparity than LOMs (Rosenfield and Gilmartin, 1988d). North et al. (1989) tested this hypothesis by measuring the adaptation to horizontal prisms of EMMs, EOMs and LOMs at viewing distances of 4 m and 40 cm. They showed that EOMs tended to adapt more quickly than EMMs and LOMs. However, the statistical analysis used by these workers to interpret their results was inappropriate and rendered the vast majority of the data redundant. Thus a study was undertaken to measure both adaptation to and recovery from prismatically-induced exo- and eso-disparity at viewing distances of 5 m and 45 cm. Subjects employed in the experiment consisted of 20 EMMs, 19 EOMs and 20 LOMs.

The results were analysed using a three-factor split-plot ANOVA (see Chapter 5 section 5.6B). The EOMs adapted more quickly than both the LOMs and the EMMs respectively to both exo- and eso-disparity when viewing a distant target. Hence the results from this study fail to support the suggestion by Rosenfield and Gilmartin (1988d) that EMMs adapt more quickly to induced disparity than LOMs. It is possible that the ability of the vergence system to adapt to induced disparity is not due to anatomical or physiological differences between the refractive groups but due to the effect of wearing or not wearing glasses. EOMs are usually more myopic than LOMs and invariably wear their glasses on a full time basis. It is possible that they are more used to having to adapt to the retinal disparity induced by their glasses when viewing a near target. Furthermore, in order to reduce the edge thickness of a lens or the size of lens blank required to glaze a frame, the optical centres of the lenses in a glazed frame are further apart than the individuals inter-pupillary distance (IPD). If this is the case, the negative lenses used to correct myopia will induce base-in retinal disparity which individuals will frequently adapt to; hence EOMs and to a lesser extent LOMs will be more used to adapting to induced retinal disparities than EMMs who never wear glasses.

It is thus proposed that the ability to adapt to induced retinal disparities is correlated with the wearing of glasses rather than with refractive group. This suggestion is supported by the fact that the largest discrepancy between the abilities of the refractive groups to adapt to induced prism i.e. when viewing a distant target with induced eso-disparity which mimics the situation produced when the optical centres of negative lenses are further apart than the individuals IPD. To test fully the proposal that the ability of the vergence mechanism to adapt to induced retinal disparity is correlated with the wearing of glasses, adaptation plots of LOMs and EOMs with the same magnitude of refractive error who wear glasses on a full time basis and those who wear contact lenses or glasses on a part time basis only should be compared.

Is the ability of the vergence mechanism to recover from induced retinal disparity correlated with refractive group?

When adaptation is complete, recovery of the 'phoria following removal of the prism will be negligible (Sethi and Henson, 1984) thus recovery measurements give an indication to the level of adaptation achieved by an individual. Recovery was measured following the removal of the supplementary prism for all subjects participating in the investigation. Results indicate that the ability to recover from induced retinal disparity is not influenced by the refractive group of an individual even though the point at which recovery started varied depending on the amount of adaptation achieved at the end of the adaptation phase.

How does the accommodative mechanism respond to vergence adaptation?

As the accommodative and vergence mechanisms are so closely linked via the oculomotor cross-links, the way in which the accommodative mechanism responds during vergence adaptation is of interest. Accommodation was measured during vergence adaptation for a subgroup of the subjects participating in the investigation to determine vergence adaptation abilities. Some of these individuals showed evidence of an increase in accommodation levels when adapting to base-out compared to base-in prism at viewing distances of 5 m. It is probable that this increase in accommodation is the result of convergent accommodation being stimulated by exo-disparity. No differences in the profile of accommodative responses was found to exist between the refractive groups. However, accommodation was measured under closed-loop conditions and thus large changes in convergent accommodation would have been masked by changes in blur-induced accommodation in order to maintain a steady aggregate accommodative response.

Chapter 8

Does a relationship exist between steady-state open-loop accommodation (SOLA) and refractive group?

Many investigators have reported a relationship between SOLA and refractive group but conflicting results means that no consensus as to this relationship exists. In an attempt to resolve the issue, SOLA was measured under two different open-loop conditions on relatively large numbers of subjects (EMMs, N = 43, EOMs, N = 31, LOMs, N = 30). Under both conditions of complete darkness and pinhole pupil, LOMs displayed significantly lower mean SOLA levels than EMMs which supports previous findings (Maddock et al., 1981; McBrien and Millodot, 1987b; Rosenfield and Gilmartin, 1987b; Bullimore and Gilmartin, 1987b, Rosner and Rosner, 1989a). The results of the EOMs lay inbetween those of the EMMs and the LOMs but they were not found to differ significantly from either. However, the relationship between SOLA and refractive group was not always evident when smaller subject groups were used (see Chapter 9).

As the relationship between SOLA and refractive group is not *always* evident it is probable that SOLA levels are altered as a *result* of ametropic development rather than being the *cause* of it. A more direct relationship between refractive group and SOLA would be expected if SOLA had a major part to play in the development of ametropia. Indeed results of a longitudinal study by Adams and McBrien (1993) support this hypothesis. The mechanism behind a reduction in SOLA level with the onset of LOMs is not clear; a correlation between the degree of myopia and SOLA level has not been found. Whether it is the tonus of the ciliary muscle or the contribution of various non-optical stimuli to SOLA which decreases with the onset of LOM needs to be determined by conducting a longitudinal study whereby each of the non-optical stimuli to SOLA (e.g. surround propinquity, mental effort and visual imagery) is manipulated individually.

What is the relationship between steady-state open-loop accommodation measured under various open-loop conditions?

Many workers have opened the accommodative loop in a number of ways to assess SOLA. In order to collate all the information on SOLA it is important to determine whether measures of SOLA under various open-loop conditions are comparable or not. An experiment designed to measure SOLA levels under pinhole conditions and in complete darkness revealed that pinhole conditions induce significantly higher SOLA levels. Under pinhole conditions it is the accommodative *response* which is degraded whereas under conditions of complete darkness, the *stimulus* to accommodation is degraded. It is this fundamental difference in opening the accommodative loop which is responsible for the differences in SOLA levels obtained.

An interesting result from this investigation was that the SOLA levels in darkness were *not* found to influence those measured under pinhole conditions i.e. there was no correlation between the two measures. However when the accommodative loop was opened with a diffuse green light (Chapter 6) or a laser speckle pattern (Chapter 10), the level of SOLA measured in darkness was correlated to the level of SOLA measured under these two conditions. It is reasonable to suggest that SOLA measured under conditions whereby the accommodative response and not the stimulus is degraded (i.e. pinhole conditions) is contaminated to a much greater extent by psychological and physiological factors than when it is measured under alternative open-loop condition. Furthermore, it is proposed that SOLA measured under pinhole conditions reflects less accurately the tonus of the ciliary muscle compared with other open-loop conditions.

What is the effect of mental effort on the SOLA levels of EMMs, EOMs and LOMs?

It was previously suggested that the contribution of non-optical factors to SOLA may vary between refractive groups and provide the source of the discrepancy in the levels of SOLA between EMMs and LOMs. To investigate this proposal, SOLA levels of EMMs, EOMs and LOMs were measured under dark and pinhole conditions both with and without the imposition of concurrent mental effort. The relationship between SOLA and refractive group reported above was still evident when concurrent mental effort was imposed thus implying that the contribution of mental effort to the aggregate SOLA response does not vary significantly between the refractive groups. However, the effect of mental effort was considerably more marked for all refractive groups when the accommodative loop was opened under conditions of complete darkness as opposed to pinhole pupil. Under pinhole conditions, due to the higher baseline SOLA levels, the parasympathetic activity is greater than in complete darkness. Thus augmentation of inhibitory sympathetic is more likely to occur under pinhole conditions and it is this sympathetic inhibition which may account for the attenuation of the mentally-induced shifts in SOLA under pinhole conditions.

Chapter 9

What is the effect of proximity on the closed-loop accommodative response of EMMs, EOMs and LOMs?

A recent model (Schor et al., 1992) of the accommodative and vergence system have suggested that spatiotopic cues (e.g. proximity) are used to initiate the near response (coarse-tuning) whereas retinotopic cues (e.g. blur and disparity) refine and complete the response (fine-tuning). The importance of proximity as a stimulus to the accommodative system was tested by investigating the closed-loop accommodation responses of EMMs, EOMs and LOMs to targets in which the blur and proximity cues had been manipulated by the use of supplementary lenses. Subjects viewed in random order a target which provided both blur and proximal cues, blur cues only, proximal cues only and a target which did not provide either proximal or blur cues to accommodation.

The results showed that when proximity cues (in the absence of blur cues) are present, the accommodative response remains unaffected compared to the condition when blur and proximity act together. In contrast, when blur acts in the absence of proximity, the accommodative response is higher than when proximity and blur act together. Hence it is proposed that blur acts as the primary stimulus to accommodation but the accommodative response is further refined by proximal cues which is in direct contrast to the model proposed by Schor et al. (1992). The results are in agreement with the model of

accommodation and vergence devised by Hung et al. (1994) in which the contribution of proximal accommodation is relatively small under conditions other than dual open-loop.

What is the effect of proximity on the accommodative regression patterns of EMMs, EOMs and LOMs?

Following sustained closed-loop near visual tasks, a temporary shift in pre-task SOLA level occurs in the majority of individuals. Many researchers have shown that the regression of this shift varies between refractive groups. Rosenfield et al. (1990) suggested that proximity has a major role to play in stimulating the post-task accommodative shifts thus it is proposed that the differences in the regression patterns of the refractive groups is due to differential effects of proximity. To investigate this proposal, EMMs, EOMs and LOMs viewed a selection of targets designed to stimulate blur only, proximity only, blur and proximity and neither blur or proximity. The closed-loop visual task lasted for 3 mins for each condition. Subsequently, complete darkness was imposed to open the accommodative loop and successive measurements of accommodation were recorded over a 90 s period. Non-visual stimuli were controlled by subtracting regression patterns obtained without any blur stimulus to accommodation from those in which accommodation was stimulated by blur.

Unlike Rosenfield et al. (1990), proximity was not found to significantly influence the regression patterns recorded in this study. However, a relationship between the time-course of regression and refractive group was found to exist which confirms previous reports that EMMs' post-task accommodative levels regress more quickly than both EOMs and LOMs. However, this study has shown that the basis for retardation of accommodative regression in myopes is not due to differential effects of proximal stimuli. Further investigation regarding the retardation of regression is required as it is considered by some to be the precursor to myopic development.

Chapter 10

How are steady-state open-loop accommodation levels of EMMs, EOMs and LOMs affected by β-adrenergic receptor antagonists?

The suggestion that LOM is mediated via a deficit in sympathetic inhibition of the ciliary muscle was investigated by measuring the SOLA distributions of EMMs, EOMs and LOMs. SOLA levels recorded under two open-loop conditions before and after the instillation of β-adrenergic antagonists timolol maleate and betaxolol HCl. Betaxolol was used as the control agent for timolol instead of saline as it is a predominantly β_1-selective adrenoceptor antagonist and thus while reducing intraocular pressure in a similar manner to timolol, it will have minimal effect on the β_2-adrenoceptors of the ciliary muscle. The accommodative loop was opened by imposing darkroom conditions and, in an attempt to

raise the SOLA levels to produce a level of parasympathetic activity likely to augment sympathetic inhibition, subjects viewed a laser speckle target in an otherwise darkened room.

Unfortunately the laser speckle target failed to raise SOLA to a level whereby sympathetic augmentation would consistently be expected to occur in all the subjects. However, evidence for the occurrence of sympathetic inhibition was shown by an increase in SOLA levels following the instillation of timolol maleate. A selection of subjects from each of the three refractive groups displayed the effects of sympathetic inhibition. In addition, some subjects again from each of the refractive groups failed to display the effects of sympathetic inhibition. These results suggest that the variation in SOLA is not readily explained by differences in ciliary muscle innervation as the profile of SOLA measurements following the instillation of β-blockers was similar for all three refractive groups.

Is the retardation of accommodative regression in myopes induced by a deficit in sympathetic inhibition of the ciliary muscle?

Following the proposal that LOM is precipitated by a retardation of accommodative regression which could be induced by a deficit in sympathetic inhibition of the ciliary muscle, the effect of β-adrenoceptor antagonists on accommodative regression patterns of EMMs, EOMs and LOMs was investigated. The β-blockers employed were those used in the experiment described above i.e. timolol maleate and betaxolol HCl. Measures of accommodation were taken prior to and 35 min following the instillation of the drug during the 90 s period following the distant and near closed-loop visual tasks. Non-visual stimuli were controlled by subtracting the regression pattern obtained for distance viewing condition (5 m) from that recorded immediately following the task in which the target was placed at a stimulus level of 4.0 D above the baseline SOLA level.

A retardation of post-task accommodative regression was evident following the instillation of timolol in some subjects from all three refractive groups thus suggesting that the presence of sympathetic inhibition is likely to be a general feature of accommodative function rather than one which is specific to a particular group. In addition, there was evidence for a lack of sympathetic innervation in some subjects from each of the refractive groups. Hence the profile of accommodative regression patterns to β-adrenergic antagonists appears similar for all three refractive groups, thus the findings do not support the proposal that differences in the characteristics of autonomic innervation of the ciliary muscle is the basis for myopia development.

11.3 - DISCUSSION AND PROPOSALS FOR FUTURE WORK

Group samples

It is pertinent to note that most of the subjects used in the research programme were undergraduate students from the department of Vision Sciences, ranging in age between approximately 18 to 24 years. Hence the subjects used in this thesis were not randomly selected, indeed the samples are very selective in as much as they all have relatively similar backgrounds, levels of intelligence, aspirations and knowledge of optometry. It is also pertinent to note that the definition of LOM used in this thesis is an arbitrary one and represents an approximation in an attempt to divide subjects into those whose myopia is more likely to be due to environmental factors and those in which heredity plays the prominent role. An important point should be made about environmentally-induced myopia in that genetic factors establish the potentialities whereas the environment establishes the actualities.

Furthermore, the LOMs used in this thesis would have been myopic for a considerably shorter period than most of the EOMs. If the LOMs and EOMs had been matched for the duration of myopia, the results from the investigations may have been different if the proposal that differences in oculomotor function are the result of ametropic development rather than the cause of it is correct. However, due to practical difficulties in obtaining sufficient numbers of older LOMs or younger EOMs, together with the gradual loss of accommodative facility with age, subjects of student age were used for all investigations described in this thesis.

Future work proposed as a consequence of the experimental programme

The results of the experimental programme of this thesis provide little evidence to suggest that oculomotor dysfunction is responsible for the development of LOM. Indeed it may be that any differences between the oculomotor responses of the different refractive groups are the *consequence* of ametropia development rather than the *cause* of it. However, longitudinal studies are required to assess whether the profile of oculomotor function changes before or with the development of ametropia if at all. In order to investigate both EOM and LOM individuals really need to participate in a longitudinal study from childhood (before puberty) through to adulthood (about mid 20s) when most people who are susceptible have developed myopia. Alternatively, susceptible age groups could be studied intensively such as ages 6 - 10 years for EOM and 14 - 18 years for LOM.

Epidemiological studies suggest that undertaking intensive near work places people at risk from developing myopia. However, myopic shifts have been noted in all refractive groups (including hyperopes) when there is a substantial increase in the amount of near

work undertaken by an individual. However, the susceptibility to these myopic shifts is more pronounced in existing myopes (O'Neal and Connon, 1987; National Research Council, 1989). As a result, it may be more profitable to identify elements of oculomotor function of EMMs, EOMs and LOMs which are similar rather than disparate in order to discover the factors involved in the aetiology of myopic shifts.

The research undertaken in this thesis appears to discount a link between the innervational profile of the ciliary muscle and the development of myopia. However only small numbers of subjects were able to be used for the cross-sectional study described in Chapter 10. A larger cross-sectional study is required together with a longitudinal study to verify the homogeneity of the response profile of β-adrenoceptor antagonists across all refractive groups (including hyperopes) before a link between sympathetic function of the ciliary muscle and the development of myopia can be categorically discounted.

The modulation of axial elongation

The actual causative mechanism for LOM still remains unclear. It is generally thought to be due to an increase in axial length (McBrien and Millodot, 1987a; Bullimore et al., 1992) although corneal steepening has also been suggested (Goss and Erickson, 1987). However biometry results reported in this thesis indicate that LOM is mediated by anterior and posterior chamber enlargement and not by corneal steepening. Although the mechanism which produces axial elongation is still somewhat obscure, it is likely to involve synergism between ciliary and choroidal smooth muscle tonus, resistance to intraocular pressure (IOP) and scleral stretch (Van Alphen, 1986; 1990; Van Alphen and Graebel, 1991; Tamm et al. 1991).

Van Alphen (1986; 1990) has suggested that the ciliary muscle - choroidal layer is functionally continuous and the resistance to scleral stretch emanates directly from the tone of the ciliary muscle. Van Alphen predicted that hyperopes would have high ciliary tone and thus resist stretch whereas myopes would display a low ciliary tonus which would render the eyeball susceptible to scleral stretch. It would be useful to determine the tonus of the ciliary muscle in order to investigate this hypothesis. It is thought that SOLA gives us only limited information regarding the tonus of the ciliary muscle due to contamination by psychological and physiological factors. This thesis has demonstrated that for large subject groups a relationship between SOLA and refractive group does exist with LOMs displaying significantly lower SOLA levels than EMMs which indirectly supports Van Alphen's hypothesis. However this relationship does not necessarily hold for small sample sizes. A more direct way of assessing ciliary muscle tonus may be by measuring refractive error on two separate occasions under cycloplegia induced by:
i) atropine, which abolishes all accommodative responses including ciliary muscle tonus
ii) cyclopentolate which does not abolish ciliary tonus.

Hence the difference between the two measurements would give an indication of the magnitude of the ciliary tonus and these could be compared across the refractive groups. It may be difficult to obtain ethical approval to use atropine as this drug can be very toxic and some people may experience side effects although a greater problem may be experienced in recruiting subjects due to the long term cycloplegic effects of atropine.

Van Alphen's model proposes an active role for IOP in the development of ametropia therefore it would be of value to assess changes in IOP induced by sustained near vision to determine if it is this aspect of the near vision response which is responsible for the development of LOM. The vergence and the accommodative components of the near response could be isolated to determine which of them is responsible for any changes in IOP. If variations in the change of IOP with near fixation are observed between the refractive groups it may be worthwhile investigating ways of avoiding changes in IOP induced by sustained near vision by manipulating the near vision response with prisms or lenses. Furthermore, if the degree of scleral rigidity can be measured and is found to vary between different refractive groups, then this may provide information relating to the causative mechanisms that lead to the development of ametropia.

Van Alphen's model of emmetropization (1990) suggests that stretch of the sclera is under both cortical and subcortical control. Evidence suggests that atropine prevents deprivation myopia, not by acting on the accommodative or vergence mechanisms as originally proposed, but via a retinal mechanism (Stone et al., 1991; McBrien et al., 1993) or by direct action on the sclera (Marzani et al., 1994). It appears that the atropine, a non-selective muscarinic antagonist acts on the M1 receptors of the retina and sclera in addition to acting on the M3 receptors of the ciliary muscle.

Recent studies (Stone et al., 1991; McBrien and Cottrial, 1993; McBrien et al., 1993; Rickers et al., 1994) investigating ways of controlling myopia developed as a result of visual deprivation or lens induced refractive errors have employed selective muscarinic antagonists e.g. Pirenzepine (an M1 selective antagonist), methoctramine (an M2 selective antagonist) and 4-diphenylacetoxy-N-methylpiperidine methiodide (4-DAMP an M3 selective antagonist) to deduce which type of receptors are responsible for mediating the elongation of the posterior chamber. Results show that both the non-selective antagonist atropine and the M1 selective antagonist pirenzepine attenuate the excessive axial elongation of chicks (Stone et al., 1991) and tree shrews (McBrien and Cottrial, 1993) caused by visual deprivation. Rickers et al. (1994) demonstrated that low doses of pirenzepine enhance deprivation myopia whereas at toxic levels, myopia development is suppressed by pirenzepine. In contrast, lens-induced refractive development is not affected by toxic levels of pirenzepine. In addition. neither methoctramine nor 4-DAMP had any effect on axial elongation of visually deprived eyes (Stone et al., 1991). Further,

it has recently been proposed that atropine may prevent myopia development by directly reducing scleral proteoglycan synthesis and that acetylcholine acts as a growth signal from the retina to the sclera (Marzani et al., 1994).

Further evidence of local retinal control in the development of myopia is also available from animal experiments. Workers have shown that using shaped occluders to deprive part of the visual field of chicks, myopia development is restricted to the deprived parts of the visual field (Wallman et al., 1987). Research into the role of muscarinic receptors of the eye in the development of myopia is still in its very early stages with all the work so far having been carried out on animals. Although M1 receptors appear to control axial elongation caused by visual deprivation in animals, the axial elongation of human eyes that occurs with the development of physiological myopia is probably mediated in a very different way. Extensive investigation is required to determine whether myopia development in humans can be controlled or prevented pharmacologically. However, it is important to mention that whatever the proposal for the mechanism underlying myopic development, it has to be able to take account of the condition of anisometropia which at present remains an enigma.

This thesis has investigated various aspects of oculomotor function in an attempt to determine the oculomotor correlates of myopic development. The results presented demonstrate that it is unlikely that those individuals susceptible to LOM can be distinguished from those who are not with regard to oculomotor responses or innervational characteristics of the ciliary muscle. The aetiology of LOM may be associated with ciliary muscle function but account needs to be taken of interactions between the ciliary muscle, choroid, sclera and IOP.

REFERENCES

Abraham SV (1951) The nature of heterophoria. Am. J. Ophthalmol. 34: 1007-1015.

Adams AJ (1987) Axial length elongation, not corneal curvature, as the basis of adult onset myopia. Am. J. Optom. Physiol. Opt. 64: 150-151.

Adams DW and McBrien NA (1992) Prevalence of myopia and myopic progression in a population of clinical microscopists. Optom. Vis. Sci. 69: 467-473.

Adams DW and McBrien NA (1993) A longitudinal study of the relationship between tonic accommodation (dark focus) and refractive error in adulthood. Invest. Ophthalmol. Vis. Sci. 34: 1308.

Alpern M (1958a) Vergence and accommodation. I Can change in size induce vergence movements? Arch. Ophthalmol. 60: 355-357.

Alpern M (1958b) Vergence and accommodation. II Is accommodative vergence related merely to the accommodative stimulus? Arch. Ophthalmol. 60: 358-360.

Alpern M (1969a) Accommodation. In: The eye. Vol. 3, 2nd Ed. Muscular mechanisms. Ed. Davson H. Academic Press, London, UK.

Alpern M (1969b) Movements of the eyes. In: The eye. Vol 3 2nd Ed. Muscular Mechanisms. Ed. Davson H. Academic Press, London, UK.

Alpern M and Ellen P (1956) A quantitative analysis of the horizontal movements of the eyes in the experiment of Johannes Müeller. I Methods and results. Am J Ophthalmol 42: 289-296.

Alpern M and Hirsch MJ (1960) Age and the stimulus AC/A (unpublished) Cited in Alpern and Larson (1960).

Alpern M and Larson BF (1960) Vergence and accommodation. IV. Effect of luminance quality on the AC/A. Am. J. Ophthalmol. 49: 1140-1149.

Alpern M and Walter JR (1956) The relation of horizontal saccadic and vergence eye movements. Arch. Ophthalmol. 56: 685-690.

Armaly MF and Burian HM (1958) Changes in the tonomogram during accommodation. Arch. Ophthalmol. 60: 60-69.

Armaly MF and Jepson NC (1962) Accommodation and the dynamics of the steady-state intraocular pressure. Invest. Ophthalmol. 1: 480-483.

Armaly MF and Rubin ML (1961) Accommodation and applanation tonometry. Arch. Ophthalmol. 65: 415-423.

Armitage P (1971) Statistical methods in medical research. Blackwell Scientific Publications, Oxford, UK.

Avetisov ES and Savitskaya MB (1977) Some features of ocular microcirculation in myopia. Annals Ophthal. 67: 1261-1264.

Bach-y-Rita P and Ito F (1966) In vivo studies of fast and slow muscle fibres in cat extraocular muscles. J. Gen. Physiol. 49: 1178-1198.

Baker B, Brown B and Garner L (1983) Time course and variability of dark focus. Invest. Ophthalmol. Vis. Sci. 24: 1528-1531.

Baker JR (1966) Experiments on the function of the eye in light microscopy. J. Royal Microscopic. Soc. 85: 231-254.

Baldwin WR (1981) A review of the statistical studies of relations between myopia and ethnic, behavioural and physiological characteristics. Am. J. Optom. Physiol. Opt. 58: 516-527.

Baldwin WR, Adams AJ and Flattau P (1991) Young adult myopia. In: Refractive anomalies: research and clinical applications. Eds Grosvenor T and Flom MC Butterworth-Heinemann, Boston, USA.

Ball GV (1951) Twilight myopia. International Optical Congress pp92-103. British Optical Association, London.

Balsam MH and Fry GA (1959) Convergence accommodation. Am. J. Optom. Arch. Am. Acad. Optom. 36: 567-575.

Bear JC (1991) Epidemiology and genetics of refractive anomalies. In: Refractive anomalies: research and clinical applications. Eds Grosvenor T and Flom MC Butterworth-Heinemann, Boston, USA.

Bedrossian RH (1966) Treatment of progressive myopia with atropine. In: Proceedings of the XX International Congress of Ophthalmology pp 612-617. Excerpta Medica Foundation, New York, USA.

Behr C (1924) Die lehre v. der pupillenbewegungen. In: Graefe - Saemisch handbuch der gesamten augenheilkunde £rd Ed. Berlin. (cited by Duke-Elder, 1971).

Bennett AG and Rabbetts RB (1984) Clinical visual optics. Butterworths, London, UK.

Birnbaum MH (1984) Nearpoint visual stress: a physiological model. J. Am. Optom. Assoc. 11: 825-835.

Bohman CE and Saladin JJ (1980) The relation between night myopia and accommodative convergence. Am. J. Optom. Physiol. Opt. 57: 551-558.

Borish IM (1970) Clinical refraction. 3rd Ed. Professional Press Inc. Chicago, USA.

Bowman WC and Rand MJ (1980) Textbook of Pharmacology. Blackwell, Oxford, UK.

Brecher GA (1959) Discussion following Martens and Ogle (1959). Am. J. Ophthalmol. 47: 462-463.

Breinin GM and Chin NB (1973) Accommodation, convergence and aging. Doc. Ophthalmol. 34: 109-121.

Brennan NA, McKendrick AM and Gordon I (1994) A model for the change in refractive error distribution between birth and adulthood. Invest. Ophthalmol. Vis. Sci. 35: 1805.

Brown NP (1973) The change in shape and internal form of the lens of the eye on accommodation. Exp. Eye Res. 15: 441-459.

Bullimore MA and Gilmartin B (1987a) Tonic accommodation, cognitive demand and ciliary muscle innervation. Am. J. Optom. Physiol. Opt. 64: 45-50.

Bullimore MA and Gilmartin B (1987b) Aspects of tonic accommodation in emmetropia and late-onset myopia. Am. J. Optom. Physiol Opt. 64: 499-503.

Bullimore MA and Gilmartin B (1988) The accommodative response, refractive error and mental effort: 1. The sympathetic nervous system. Doc. Ophthalmol. 69: 385-397.

Bullimore MA and Gilmartin B (1989) The measurement of adaptation of tonic accommodation under two open-loop conditions. Ophthal. Physiol. Opt. 9: 72-75.

Bullimore MA, Boyd T, Mather HE and Gilmartin B (1988) Near retinoscopy and refractive error. Clin. Exp. Optom. 71: 114-118.

Bullimore MA, Gilmartin B and Hogan RE (1986) Objective and subjective measurement of tonic accommodation. Ophthal. Physiol. Opt. 5: 57-62.

Bullimore MA, Gilmartin B and Royston J (1992) Steady-state accommodation and ocular biometry in late-onset myopia. Doc. Ophthalmol. 80: 143-155.

Campbell FW and Primrose JAE (1953) The state of accommodation of the human eye in darkness. Trans. Ophthal. Soc. UK 73: 353-361.

Campbell FW and Westheimer G (1959) Factors influencing accommodation responses of the human eye. J. Opt. Soc. Am. 49: 568-571.

Campbell FW and Westheimer G (1960) Dynamics of accommodation responses of the human eye. J. Physiol. 151: 285-295.

Carpenter RHS (1977) The movement of the eyes. Pion, London, UK.

Carroll JP (1982) Control theory approach to accommodation and vergence. Am. J. Optom. Physiol. Opt. 59: 658-669.

Carter DB (1963) Effects of prolonged wearing of prism. Am. J. Optom. Arch. Am. Acad. Optom. 40: 265-273.

Carter DB (1965) Fixation disparity and heterophoria following prolonged wearing of prisms. Am. J. Optom. Arch. Am. Acad. Optom. 42: 141-152.

Charman WN (1982) The accommodative resting point and refractive error. Oph. Opt. 469-473.

Charman WN (1983) The retinal image in the human eye. In: Prog. Ret. Res. 2: 1-50.

Charman WN (1986) Static accommodation and the minimum angle of resolution. Am. J. Optom. Physiol. Opt. 63: 915-921.

Charman WN and Heron G (1979) Spatial frequency and the dynamics of the accommodation response. Optica Acta 26: 217-228.

Charman WN and Jennings JAM (1979) Properties of annular artificial pupils. Vis. Res. 19: 947-949.

Charman WN and Tucker J (1977) Dependence of accommodation responses on the spatial frequency spectrum of the observed object. Vis. Res. 17: 129-139.

Charman WN and Tucker J (1978) Accommodation as a function of object form. Am. J. Optom. Physiol. Opt. 55: 84-92.

Chiu NN and Rosenfield M (1994) Tonic accommodation, tonic vergence and surround propinquity. Ophthal. Physiol. Opt. 14: 290-292.

Ciuffreda KJ (1991) The Glenn A Fry Invited lecture. Accommodation to gratings and more naturalistic stimuli. Optom. Vis. Sci. 68: 243-260.

Ciuffreda KJ (1992) Components of clinical near vergence testing. J. Behavioral. Optom. 3: 3-13.

Ciuffreda KJ and Hokoda SC (1985) Effect of instruction and higher level control on the accommodative response spatial frequency profile. Ophthal. Physiol. Opt. 5: 221-223.

Ciuffreda KJ and Kenyon RV (1983) Accommodative vergence and accommodation in normals, amblyopes and stabismics. In: Vergence eye movements: Basic and clinical aspects. Eds. Schor CM and Ciuffreda KJ. Butterworths, Boston, USA.

Coakes RL and Brubaker RF (1978) The mechanism of timolol in lowering intraocular pressure in the norman eye. Arch. Ophthalmol. 96: 2045-2048.

Cogan DG (1937) Accommodation and the autonomic nervous system. Arch. Ophthalmol. 18: 739-766.

Cogan DG (1956) Neurology of ocular muscles. 2nd Ed. Charles C Thomas, Springfield, Illanois, USA.

Cohn H (1886) The hygiene of the eye in schools, an English translation. Ed Turnbull WP. Simpkin Marshall, London, USA.

Coleman DJ (1970) Unified model for accommodative mechanism. Am. J. Ophthalmol. 69: 1063-1079.

Cooper S, Daniel PM and Whitteridge D (1955) Muscle spindles and other sensory endings in the extrinsic eye muscles; the physiology and anatomy of these receptors and their connections with the brain-stem. Brain 78: 564-583.

Cotlier E (1987) The lens. In: Adler's physiology of the eye: Clinical application. 8th Ed. Eds. Moses RA and Hart WM. Mosby, St. Louis, USA.

Coulombre AJ and Coulombre JI (1956) The role of intraocular pressure in the development of the chick eye. I. Control of eye size. J. Exp. Zool. 133: 211-225.

Crawford HE and Hammar GE (1949) Racial analysis of ocular deformaties in schools in Hawaii. Med. J. 9: 90 (cited in Borish, 1970).

Criswell MH and Goss DA (1983) Myopia development in nonhuman primates. A literature review. Am. J. Optom. Physiol. Opt. 60: 250-268.

Cross AJ (1911) Dynamic skiametry in theory and practice. New York Cross Optical Co. (cited by Schor and Narayan, 1982).

Curtin BJ (1970) Myopia: a review of its aetiology, pathogenesis and treatment. Surv. Ophthalmol. 15: 1-17.

Davson H (1980) Physiology of the eye. 4th Ed. Churchill Livingstone, London UK.

Dharamshi BG (1983) Adaptation to prism induced comitant and incomitant disparities. Ph.D. Thesis (unpublished). University of Wales Institute of Science and Technology, Cardiff (cited by Sethi, 1986b).

Donders FC (1864) On the anomalies of accommodation and refraction of the eye. Trans. Moore WD. The New Sydenham Soc., London, UK.

Dowley D (1990a) Heterophoria amd monocular occlusion. Ophthal. Physiol. Opt. 7: 29-32.

Dowley D (1990b) Heterophoria. Optom. Vis. Sci. 67: 456-460.

Drucker AP, Sadove MS and Unna KR (1951) Ophthalmic studies of curare and curare-like drugs in man. Am. J. Ophthalmol. 5: 865-877.

Duke-Elder S (1946) Text-book of Ophthalmology. Vol. 1. The C.V. Mosby Co., St. Louis, USA.

Duke-Elder S (1971) Neuro-Ophthalmology. Vol. XII of Systems of Ophthalmology. Henry Kimpton, London, UK.

Duncalf D and Jampel RS (1961) The action of d-tubocurarine on the extraocular muscles in strabismus. Arch. Ophthalmol. 65: 366-368.

Eakins KE and Katz RL (1967) The role of the autonomic nervous system in extraocular muscle function. Invest. Ophthalmol. 6: 253-260

Ebenholtz SM (1983) Accommodative hysteresis: a precursor for induced myopia? Invest. Ophthalmol. Vis. Sci. 8: 513-515.

Ebenholtz SM (1985) Accommodative hysteresis: relation to resting focus. Am. J. Optom. Physiol. Opt. 62: 755-762.

Ebenholtz SM (1988) Long term endurance of adaptive shifts in tonic accommodation. Ophthal. Physiol. Opt. 8: 427-431.

Ebenholtz SM (1992) Accommodation hysteresis as a function of target - dark focus position. Vis. Res. 32: 925-929.

Ebenholtz SM and Fisher SK (1982) Distance adaptation depends upon plasticity in the oculomotor control system. Percept. Psychophys. 31: 551-560.

Ellerbrock VJ (1950) Tonicity induced by fusional movements. Am. J. Optom. Arch. Am. Acad. Optom. 27: 8-20.

Emsley HH (1953) Visual optics. Vol. 1, 5th Ed. Butterworths, London UK.

Epstein D (1983) Accommodation as the primary cause of low-luminance myopia. Experimental evidence. Acta Opthalmol. 61: 424-430.

Epstein D, Björk A and Glansholm D (1986) Low-luminance myopia and dark vergence. Acta Ophthalmol. 64: 318-322.

Fincham EF (1937) The mechanism of accommodation. Br. J. Ophthalmol. Monograph suppl. No.VIII. Pulman, London, UK.

Fincham EF (1951) The accommodative reflex and its stimulus. Br. J. Ophthalmol. 35: 381-393.

Fincham EF (1962) Accommodation and convergence in the absence of retinal images. Vis. Res 1: 425-440.

Fincham EF and Walton J (1957) The reciprocal actions of accommodation and convergence. J. Physiol. 137: 488-508.

Fisher RF (1969a) The elsctic constraints of the human lens capsule. J. Physiol. 201: 1-20.

Fisher RF (1969b) The significance of the shape of the lens and capsular energy changes in accommodation. J. Physiol. 210: 21-47.

Fisher RF (1982) The vitreous and lens in accommodation. Trans. Ophthal. Soc. UK. 102: 318-322.

Fisher RF (1983) Is the vitreous necessary for accommodation in man? Br.J. Ophthalmol. 67: 206.

Fisher RF (1986) The ciliary body in accommodation. Trans. Ophthal. Soc. UK. 105: 208-219.

Fisher RF and Pettet BE (1973) Presbyopia and the water content of the human crystalline lens. J. Physiol. 234: 443-447.

Fisher SK, Ciuffreda KJ and Bird JE (1988a) The effect of monocular versus binocular fixation on accommodative hysteresis. Ophthal. Physiol. Opt. 8: 438-442.

Fisher SK, Ciuffreda KJ and Bird JE (1990) The effect of stimulus duration on tonic accommodation and tonic vergence. Optom Vis Sci 67: 441-449.

Fisher SK, Ciuffreda KJ and Hammer S (1987a) Intraocular equality of tonic accommodation and consensuality of accommodative hysteresis. Ophthal. Physiol. Opt. 7: 17-20.

Fisher SK, Ciuffreda KJ and Levine S (1987b) Tonic accommodation, accommodative hysteresis and refractive error. Am. J. Optom. Physiol. Opt. 64: 700-809.

Fisher SK, Ciuffreda KJ, Levine S and Wolf-Kelly KS (1987c) Tonic adaptation in emmetropia and late-onset myopia. Am. J. Optom. Physiol. Opt. 64: 333-343.

Fisher SK, Ciuffreda KJ, Tannen B and Super P (1988b) Stability of tonic vergence. Invest. Ophthalmol. Vis. Sci. 29: 1577-1581.

Fleming DG (1957) The role of the sympathetics in visual accommodation. Am. J. Ophthalmol. 43: 789.

Flom MC and Takahashi E (1962) The AC/A ratio and undercorrected myopia. Am. J. Optom. Arch. Am. Acad. Optom. 39: 305-312.

Friedman B (1966) Stress upon the ocular coats: effects of scleral curvature, scleral thickness and intraocular pressure. Eye, Ear, Nose and Throat Monthly. 45: 59-66.

Fry GA (1940) Skiametric measurement of convergent accommodation. Optom. Weekly 31: 353-356.

Fry GA (1953) Research in accommodation and convergence. Am. J. Optom. 30: 169-176.

Fry GA (1959) The effect of age on the AC/A ratio. Am. J. Optom. Arch. Am. Acad. Optom. 36: 200-203.

Gilmartin B (1986) A review of the role of sympathetic innervation of the ciliary muscle in ocular accommodation. Ophthal. Physiol. Opt. 6: 23-37.

Gilmartin B and Bullimore MA (1987) Sustained near vision augments inhibitory sympathetic innervation of the ciliary muscle. Clin. Vis. Sci. 1: 197-208.

Gilmartin B and Bullimore MA (1991) Adaptation of accommodation to sustained visual tasks in emmetropia and late-onset myopia. Optom. Vis. Sci. 68: 22-26.

Gilmartin B and Hogan RE (1985) The relationship between tonic accommodation and ciliary muscle innervation. Invest. Ophthalmol. Vis. Sci. 69: 1024-1029.

Gilmartin B, Bullimore MA, Rosenfield M, Winn B and Owens H (1992) Pharmacological effects on accommodative adaptation. Optom. Vis. Sci. 69: 276-282.

Gilmartin B, Gray LS and Winn B (1991) The amelioration of myopia using biofeedback of accommodation: a review. Ophthal. Physiol. Opt. 11: 304-313.

Gilmartin B, Hogan RE and Thompson SM (1984) The effect of timolol maleate on tonic accommodation, tonic vergence and pupil diameter. Invest. Ophthalmol. Vis. Sci. 25: 763-770.

Goldschmidt E (1968) On the etiology of myopia. Acta Ophthalmol. (Suppl) 98: 1-172.

Goldschmidt E (1990) Myopia and the control of eye growth. Ciba Foundation Symp. 155 pp 222-234. Jonn Wiley and Sons, London, UK.

Goss DA (1982) Attempts to reduce the rate of increase of myopia in young people - a critical literature review. Am. J. Optom. Physiol. Opt. 59: 828-841.

Goss DA (1991) Clinical accommodation and heterophoria findings preceding juvenile-onset myopia. Optom. Vis. Sci. 68: 110-116.

Goss DA and Cox VD (1985) Trends in the change of clinical refractive error in myopes. J. Am. Optom. Assoc. 56: 608-613.

Goss DA and Erickson P (1987) Meridional corneal components of myopia progression in young adults and children. Am. J. Optom. Physiol. Opt. 64: 475-481.

Goss DA and Winkler RL (1983) Progression of myopia in youth: age of cessation. Am. J. Optom. Physiol. Opt. 60: 651-658.

Goss DA, Erickson P and Cox VD (1985) Prevalence and pattern of adult myopia progression in a general optometric practice population. Am. J. Optom. Physiol. Opt. 62: 470-477.

Gray LS, Winn B, Gilmartin B and Eadie AS (1993) Objective concurrent measures of open-loop accommodation and vergence under photopic conditions. Invest. Ophthalmol. Vis. Sci. 34: 2996-3003.

Greene PR (1980) Mechanical considerations in myopia: Relative effects of accommodation, convergence, intraocular pressure and extraocular muscles. Am. J. Optom. Physiol. Opt. 57: 902-914.

Greene PR (1981) Myopia and the extraocular muscles. Doc. Ophthal. Proc. Series. 28: 163-169.

Greene PR and McMahon TA (1979) Scleral creep vs. temperature and pressure in vitro. Exp. Eye Res. 29: 527-537.

Grosvenor T (1987) A review and suggested classification system for myopia on the basis of age-related prevalence and age of onset. Am. J. Optom. Physiol. Opt. 64: 545-554.

Grosvenor T, Perrigin DM, Perrigin J, Maslovitz B (1987) Houston myopia control study: A rendomised clinical trial. Part II. Final report by the patient care team. Am. J. Optom. Physiol. Opt. 64: 482-498.

Grosvenor T and Scott R (1991) A comparison of refractive components in youth-onset and early adult-onset myopia. Optom. Vis. Sci. 68: 204-209.

Grosvenor T and Scott R (1993) Three-year changes in refraction and its components in youth and adult-onset myopia. Optom. Vis. Sci. 68: 677-683.

Grut EH (1889) A contribution to the pathology of concomitant squinting (convergent and divergent): The Bowman lecture. Trans. Oph. Soc. UK. 10: 1

Gwiazda JE, Bauer JA, Thorn F and Held R (1994) Myopic children can effectively use blur cues to relax but not increase accommodation. Invest. Ophthalmol. Vis. Sci. 35: 1806.

Gwiazda JE, Thorn F, Bauer J and Held R (1993) Myopic children show insufficient accommodative response to blur. Invest. Ophthalmol. Vis. Sci. 34 690-694.

Heath GG (1956a) The influence of visual acuity on the accommodative responses of the eye. Am. J. Optom. 33: 513-524.

Heath GG (1956b) Components of accommodation. Am. J. Optom. Arch. Acad. Optom. 33: 569-579.

Heath GG (1962) The time course of night and space myopia. Aerospace Medical Division 6570th Aerospace Med. Res. Lab., Wright-Patterson Airforce Base, Ohio. Report No. AMRL-TOR-62-80.

Hebbard FW (1952) Measuring tonic convergence. Am. J. Optom Arch. Am .Acad. Optom. 25: 221-230.

Hebbard FW (1960) Foveal fixation disparity measurements and their use in determining the relationship between accommodative convergence and accommodation. Am J Optom Arch Am Acad Optom 37: 3-26.

Helmholtz H (1855) Uber die akkommodation des anges. Albrecht v. Graefes Arch. Ophthal. 1: 1-74.

Helmholtz H (1909) Handbuch der physiologischen optik. Vol 1. Translated and edited from the third German edition by Southall JPC (1962) as Helmholtz's treatise on physiological optics. Vol. 1, Dover Publications, New York, USA.

Henke W (1860) Der mechanisms der accommodation fur nahe und ferne. Albrecht v. Graefes Arch. Ophthal. 6: 53-72. (Cited by Helmholtz, 1909)

Hennessy RT (1975) Instrument myopia. J. Opt. Soc. Am. 65: 1114-1120.

Hennessy RT, Iida T, Shiina K and Leibowitz HW (1976) The effect of pupil size on accommodation. Vis. Res. 16: 587-589.

Henson DB (1983) Optometric instrumentation. Butterworths, London UK.

Henson DB and Dharamshi BG (1982) Oculomotor adaptation to induced heterophoria and anisometropia. Invest. Ophthalmol. Vis. Sci. 22: 234-240.

Henson DB and North RV (1980) Adaptation to prism-induced heterophoria. Am. J. Optom. Physiol. Opt. 57: 129-137.

Heron G, Smith AC and Winn B (1981) The influence of method on the stability of dark focus position of accommodation. Ophthal. Physiol. Opt. 1: 79-90.

Hess A and Pilar G (1963) Slow fibres in the extraocular muscles of cat. J. Physiol. 169: 780-798.

Hirsch MJ (1954) Editorial footnote to Manas and Shulman (1954). Am J. Optom Arch Am Acad Optom 31: 395-396.

Hofstetter HW (1942) The proximal factor in accommodation and convergence. Am. J. Optom. Arch. Am. Acad. Optom. 19: 67-76.

Hofstetter HW (1950) Accommodation, convergence and their relation of apparent distance. J. Psychol. 30: 393-394.

Hofstetter HW (1951) The relatioship of proximal convergence to fusional and accommodative convergence. Am. J. Optom. Arch. Am. Acad. Optom. 28: 300-308.

Hogan MJ, Alvarado JA and Wedell JE (1971) Histology of the human eye: an atlas and text book. WB Saunders, Philadelphia, USA.

Hogan RE (1985) Aspects of tonic accommodation and tonic vergence. Ph.D. Thesis (unpublished). University of Aston in Birmingham, UK.

Hokoda SC and Ciuffreda KJ (1983) Theoretical and clinical importance of proximal vergence and accommodation. In Vergence eye movements: basic and clinical aspects. Eds. Schor CM and Ciuffreda KJ. Butterworths, Boston, UK.

Hung GK (1992) Adaptation model of accommodation and vergence. Ophthal. Physiol. Opt. 12: 319-326.

Hung GK and Ciuffreda KJ (1988) Dual-mode behaviour in the human accommodation system. Ophthal. Physiol. Opt. 8: 327-332.

Hung GK and Semmlow JL (1980) Static behavoir of accommodation and vergence: Computer simulation of an interactive dual-feedback system. Trans. Biomed. Eng. 27: 439-447.

Hung GK, Ciuffreda KJ and Rosenfield M. (1994) Static model of proximal accommodation and vergence. Invest. Ophthalmol. Vis. Sci. 34: 1280.

Hung GK, Semmlow JL and Ciuffreda KJ (1983) Identification of accommodative vergence contributions to the near response using response variance. Invest. Ophthalmol. Vis. Sci. 24: 772-777.

Hurwitz BS, Davidowitz J, Chin NB and Breinin GB (1972a) The effects of the sympathetic nervous system on accommodation I. Beta sympathetic nervous system. Arch. Ophthalmol. 87: 668-674.

Hurwitz BS, Davidowitz J, Pachter BR and Breinin GB (1972b) The effects of the sympathetic nervous system on accommodation II. Alpha sympathetic nervous system. Arch. Ophthalmol. 87: 675-678.

Ittleson WH and Ames AA (1950) Accommodation, convergence and their relation to apparent distance. J. Psychol. 30: 43-62.

Ivanoff A (1947) On the influence of accommodation on spherical aberration in the human eye, an attempt to interpret night myopia. J. Opt. Soc. Am. 37: 730-731.

Ivanoff A (1955) Night binocular convergence and night myopia. J Optical Soc Am 45: 769-770.

Ivanoff A and Bourdy C (1954) Le comportement de la convergence en nocturne. Ann. Optique Oculaire 3: 70-75.

Jackson E (1931) Norms of refraction. Trans. Sec. Ophth. Am. Med. Ass. (cited in Luedde, 1932).

Jampel RS (1967) Multiple motor systems in extraocular muscles of man. Invest. Ophthalmol. 6: 288-293.

Jenkins TCA (1963a) Abberations of the eye and their effects on vision: Part 1. Br. J. Physiol. Opt. 20: 59-91.

Jenkins TCA (1963b) Aberrations of the eye and their effects on vision: Part 2. Br. J. Physiol. Opt. 20: 161-203.

Jensen H (1991) Myopia progression in young school children. Acta Ophthalmol. (Suppl.) 200: 1-79.

Jessop WH (1886) On the anatomy, histology and physiology of the intraocular muscles of mammals. Proc. Royal Soc. 40: 478-484.

Jiang BC (1993) The accommodative vergence crosslink originates between phasic and tonic components of the accommodative controller. Optom Vis Sci (suppl) 12s: 149-150.

Jiang BC and Woessner W (1994) A high AC/A ratio and/or a low CA/C ratio characterize the young adult onset myope. Invest. Ophthalmol. Vis. Sci. 35: 1280.

Johnson CA, Post RB and Tsuetaki TK (1984) Short-term variability of the resting focus of accommodation. Ophthal. Physiol. Opt. 4: 319-326.

Kato T (1938) Uber histologische untersuchungen der augenmusketen von menschen und scugetieren. Okajamas Folia Anatomicae Japonicae 16: 131-145 (cited by Carpenter, 1977).

Kaufman PL (1992) Accommodation and presbyopia: neuromusculature and biophysical aspects. In: Adler's Physiology of the eye. 9th Ed. Ed. Hart MH , Mosby-Year Book, St Louis, USA..

Keller EL (1973) Accommodative vergence in the alert monkey. Vis. Res. 13: 1565-1575.

Kent PR (1958) Convergence accommodation. Am. J. Optom. Arch. Am. Acad. Optom. 35: 393-406.

Kenyon RV, Ciuffreda KJ and Stark L (1978) Binocular eye movements during accommodative vergence. Vis. Res 18: 545-555.

Kern R (1968) Uber die adrenergischen receptoren der extraocularen muskeln des rhesusaffen. Albrecht Von Graefes Archive fur Klinische und Exp. Ophthalmol. 174: 278-286.

Kern R (1970) Die adrenergischen receptoren der intraocularen muskeln des menschen. Albrecht v Graefes Arch. fur Klinischs Exp. Ophthalmol. 180: 231-248.

Knoll HA (1959) Proximal factors in convergence: A theoretical consideration. Am. J. Optom. Arch. Am. Acad. Optom. 36: 378-381.

Koretz JH and Handleman GH (1982) Model of the accommodative mechanism in the human eye. Vis. Res. 22: 917-924.

Koretz JH and Handleman GH (1983) A model for accommodation in the young human eye: the effects of lens elastic anisotrophy on the mechanism. Vis. Res. 23: 1679-1686.

Koretz JH, Handleman GH and Phelps-Brown N (1984) Analysis of the human crystalline lens curvature as a function of accommodative state and age. Vis. Res. 24: 1141-1151.

Kotulak JC and Schor CM (1986a) The dissociability of accommodation from vergence in the dark. Invest. Ophthalmol. Vis. Sci. 27: 544-551.

Kotulak JC and Schor CM (1986b) The accommodative response to subthreshold blur and to perceptual fading during the Troxler phenomenon. Perception 15: 7-15.

Kotulak JC and Schor CM (1987) The effects of optical vergence, contrast and luminance on the accommodative response to spatially bandpass filtered targets. Vis. Res. 27: 1797-1806.

Kran BS and Ciuffreda KJ (1988) Non congruent stimuli and tonic adaptation. Am. J. Optom. Physiol. Opt. 65: 703-709.

Krishnan VV and Stark L (1977) A heuristic model for the human vergence eye movement system. IEEE Trans. Biochem Eng BME-24: 44-49.

Krishnan VV, Phillips S and Stark L (1973) Frequency analysis of accommodation, accommodative vergence and disparity vergence. Vis. Res. 13: 1545-1554.

Krishnan VV, Shirachi D and Stark L (1977) Dynamic measures of vergence accommodation. Am. J. Optom. Physiol. Opt. 54: 470-473.

Kruger PB (1980) The effect of cognitive demand on accommodation. Am. J. Optom. Physiol. Opt. 57: 440-445.

Kruger PB and Pola J (1985) Changing target size is a stimulus for accommodation. J. Opt. Soc. Am. 75: 1832-1835.

Kruger PB and Pola J (1986) Stimuli for accommodation: blur, chromatic aberration and size. Vis. Res. 26: 957-971.

Kruger PB and Pola J (1987) Dioptric and non-dioptric stimuli for accommodation: target size alone and with blur and chromatic aberration. Vis. Res. 27: 555-567.

Kruger PB and Pola J (1989) Accommodation to size and blur changing in counterphase. Optom. Vis. Sci. 66: 455-458.

Kruger PB, Mathews S. Sanchez N and Addarwala KP (1991) Chromatic aberration and focus. Fincham revisited. Invest. Ophthalmol. Vis. Sci. (suppl) 32: 1124.

Krumholtz DM, Fox DS and Ciuffreda KJ (1986) Short-term changes in tonic accommodation. Invest. Ophthalmol. Vis. Sci. 27: 552-557.

Ku DN and Greene PR (1981) Scleral creep in vitro resulting from cyclic pressure pulses: application to myopia. Am. J. Optom. Physiol Opt. 58: 528-535.

Kuntz A (1929) The autonomic nervous system. Lea and Fabunger, Philadelphia, USA.

Larsen JS (1971) The saggital growth of the eye. Pt. III - Ultrasonic measurement of the posterior segment from birth to puberty. Acta Ophthalmol. 49: 441-453.

Leibowitz HW and Owens DA (1975) Anomalous myopias and the intermediate dark focus of accommodation. Science 189: 646-648.

Leibowitz HW and Owens DA (1978) New evidence for the intermediate position of relaxed accommodation. Doc. Ophthalmol. 46: 133-147.

Leigh RJ and Zee DS (1983) Vergence eye movements. In: The neurology of eye movement. FA Davis Co., Philadelphia, USA.

Levy J (1969) Physiological position of rest and phoria. Am. J. Ophthalmol. 68: 706-713.

Linksz A (1958) Optics and visual physiology. Arch. Ophthalmol. 59: 901-969.

Lograno MD and Reibaldi A (1986) Receptor-responses in fresh human ciliary muscle. Br. J. Pharmacol. 87: 379-385.

Luckiesh M and Moss FK (1937) The avoidance of dynamic accommodation through the use of brightness contrast threshold. Am. J. Ophthalmol. 20: 469-478.

Ludlam WM, Wittenburg S, Giglio, EJ and Rosenberg, R. (1968) Accommodative responses to small changes in dioptric stimulus. Am. J. Optom. Arch. Am. Acad. Optom. 45: 483-506.

Ludvigh E, McKinnon P and Zaitzeff L (1964) Temporal course of the relaxation of binocular duction (fusion) movements. Arch. Ophthalmol. 71: 389-399.

Luedde WH (1932) Monocular cycloplegia for the control of myopia. Am. J. Ophthalmol. 15: 603-609.

Lütjen-Drecoll E and Kaufman PL (1986a) Long-term timolol and epinephrine in monkeys. 1. Functional morphology of the ciliary processes. Trans. Ophthalmol. Soc. U.K. 105: 180-195.

Lütjen-Drecoll E and Kaufman PL (1986b) Long-term timolol and epinephrine in monkeys. 2. Morphological alterations in trabecular meshwork and ciliary muscle. Trans. Ophthalmol. Soc. U.K. 105: 196-207.

Maddock RJ, Millodot M, Leat L and Johnson CA (1981) Accommodation responses and refractive error. Invest. Ohthalmol. Vis. Sci. 20: 387-391.

Maddox EE (1886) Investigations on the relationship between convergence and accommodation of the eyes. J. Anat. 20: 475-505, 565-584.

Maddox EE (1893) The clinical use of prisms and the decentration of ophthalmic lenses. 2nd Ed. John Wright and Co., Bristol, UK.

Maier A, de Santis M and Eldred E (1974) The occurence of muscle spindles in the extraocular muscles of various vertebrates. J. Morphol. 143: 397-408.

Majoras J (1935) Totenstarre der angenmuskein. Arch F. Ophth. 134: 112.

Malmström FV and Randle RJ (1976a) Effects of visual imagery on the accommodation response. Percept. Psychophysics 19: 450-453.

Malmström FV, Randle RJ, Bendix JS and Weber RJ (1980) The visual accommodation response during concurrent mental activity. Percpt. Psychophysics 28: 440-448.

Manas L and Shulman P (1954) The variation in the accommodative-convergence accommodation (ACA) ratio upon periodic retesting. Am. J. Optom. Arch. Am. Acad. Optom 31: 385-395.

Mandlebaum J (1960) An accommodation phenomenon. A. M. A. Arch. Ophthalmol. 63: 923-926.

Marzani D, Lind GJ, Chew SJ and Wallman J (1994) The reduction of myopia by muscarinic antagonists may involve a direct effect on scleral cells. Invest. Ophthalmol. Vis. Sci. 35: 1801.

Maurice DM and Mushin AS (1966) Production of myopia in rabbits by raised body-temperature and increased intra-ocular pressure. Lancet 2: 1160-1162.

McBrien NA and Barnes DA (1994) A review and eveluation of theories of refractive error development. Ophthal. Physiol. Opt. 4: 201-213.

McBrien NA and Cottrial CL (1993) Pirenzepine reduces axial elongation and myopia in monocularly deprived tree shrews. Invest. Ophthalmol. Vis. Sci. (suppl) 34: 1210.

McBrien NA and Millodot M (1985) Clinical evaluation of the Canon Autoref R-1. Am. J. Optom. Physiol. Opt. 62: 786-792.

McBrien NA and Millodot M (1986a) The effect of refractive error on the accommodative response gradient. Ophthal. Physiol. Opt. 6: 145-149.

McBrien NA and Millodot M (1986b) Amplitude of accommodation and refractive error. Invest. Ophthal. Vis. Sci. 27: 1187-1191.

McBrien NA and Millodot M (1987a) A biometric investigation of late-onset myopic eyes. Acta Ophthalmol. 65: 461-468.

McBrien NA and Millodot M (1987b) The relationship between tonic accommodation and refractive error. Invest. Ophthalmol. Vis. Sci. 20: 387-391.

McBrien NA and Millodot M (1988) Differences in adaptation of tonic accommodation with refractive state. Invest. Ophthalmol. Vis. Sci. 29: 460-469.

McBrien NA, Moghaddam HO and Reeder AP. (1993) Atropine reduces experimental myopia and eye enlargement via a non-accommodative mechanism. Invest. Ophthalmol. Vis. Sci. 34: 205-215.

Mellerio J (1966) Ocular refraction at low illuminations. Vis. Res. 6: 217-237.

Melton CE, Purnell EW and Brecher GA (1955) The effect of sympathetic nerve impulses on the ciliary muscle. Am. J. Ophthalmol. 40: 155-162.

Mershon DH and Amerson TL (1980) Stability of measures of the dark focus of accommodation. Inves. Ophthalmol. Vis. Sci. 19: 217-221.

Meyers MP (1951) The position of the eyes under general anaesthesia. Am. J. Ophthalmol. 34: 1749-1752.

Miller RJ (1978) Temporal stability of the dark focus of accommodation. Am. J. Optom.Physiol. Opt. 55: 447-450.

Miller RJ (1987) Nonius alignment apparatus for measuring vergence. Am. J. Optom. Physiol. Opt. 64: 458-466.

Miller RJ and Takahama M (1988) Arousal-related changes in dark focus accommodation and dark vergence. Invest. Ophthalmol. Vis. Sci. 29: 1168-1178.

Miller RJ, Pigion RG, Wesner MF, Patterson JG (1983) Accommodation fatigue and dark focus. Percept. Psychophys. 34: 532-540.

Millodot M (1986) Dictionary of Optometry. 1st Ed. Butterworths, London, UK.

Millodot M and Thibault T (1985) Variation of astigmatism with accommodation and its relationship with dark focus. Ophthal. Physiol. Opt. 5: 297-301.

Mitchell AM and Ellerbrock VJ (1955) Fixational disparity and the maintainence of fusion in the horizontal meridian. Am. J. Optom. Arch. Am. Acad. Optom. 32: 520-534.

Mohan M, Pakrasi S and Garg SP (1988) The role of environmental factors and hereditary predisposition in the causation of low myopia. Acta Ophthalmol. (suppl) 185: 54-57.

Mohan M, Rao VA and Dada VK (1977) Experimental myopia in the rabbit. Exp.Eye Res. 25: 33-38.

Morat JP and Doyon M (1891) Le grand sympathetique, nerf de l'accommodation pour la vision des objects eloignes. Ann. d'oculaires. 106: 28-30 (cited by Alpern, 1969a).

Morgan DL and Proske U (1984) Vertebrate slow muscle: its structure, pattern of innervation and mechanical properties. Physiol. Rev. 64: 103-169.

Morgan MW (1944a) The nervous control of accommodation. Am. J. Optom. Arch. Am. Acad. Optom. 21: 87-93.

Morgan MW (1944b) Accommodation and its relationship to convergence. Am. J. Optom. Arch. Am. Acad. Optom. 21: 183-195.

Morgan MW (1947) The direction of visual lines when fusion is broken as in duction tests. Am. J. Optom. 24: 8-12.

Morgan MW (1952) Relationship between accommodation and convergence. A. M. A. Arch. Ophthal. 47: 745-759.

Morgan MW (1954) The ciliary body in accommodation and accommodative convergence. Am. J. Optom. Arch. Am.Acad. Optom. 31: 219-229.

Morgan MW (1957) The resting state of accommodation. Am. J. Optom. Arch. Am. Acad. Optom. 34: 347-353.

Morgan MW (1960) Anomolies of the visual neuromuscular system of the aging patient and their correction. In: Vision of the aging patient. Eds. Hirsch, MJ and Wick RE. Chilton Co., Philadelphia, USA (cited by Carter, 1963).

Morgan MW (1962) Effect of perceived distance on accommodation and convergence. Trans. Int. Opt. Cong. Hafner Publishing Co., New York, USA.

Morgan MW (1968) Accommodation and vergence. Am. J. Optom. Arch. Am. Acad. Optom. 7:417-454.

Morgan MW (1980) The Maddox classification of vergence eye movements. Am. J. Optom. Physiol. Opt. 57: 537-539.

Morgan MW and Peters HB (1951) Accommodative-convergence in presbyopia. Am. J. Optom. Arch. Am. Acad. Optom. 28: 3-10.

Morgan MW, Olmstead JMD and Watrous WG (1940) Sympathetic action in accommodation for far vision. Am. J. Physiol. 128: 588-591.

Morse SE (1992) Implications of describing dark focus as a "zone" of resting focus. Proc. Am. Acad. Optom. Orlando, Florida.

Moses RA (1987) Accommodation. In: Adler's Physiology of the Eye: clinical application. 8th Ed. Eds Moses RA, Hart WM, CV Mosby Co., St Louis, USA.

Müeller J (1826) Elements of physiology (Trans. Baly W) Vol II. Taylor and Walton, London, UK.

Mutti DO, Zadnik K and Adams AJ (1991) A revised equivalent refractive index of the crystalline lens based on *in vivo* measurements from the Orinda longitudinal study of myopia. Invest. Ophthalmol. Vis. Sci. (suppl) 32: 1201.

Nakoa S, Ono T, Nagata R and Iwata K (1969) The distribution of refractive indicies in the human crystalline lens. Jap. J. Clin. Ophthalmol. 23: 903-906.

Nathanson JA (1980) Adrenergic regulation of IOP: Identification of β_2-adrenergic stimulated adenylate cyclase in ciliary process epithelium. Proc. Nat. Acad Sci USA 77: 7420-7424.

Nathanson JA (1981) Human ciliary process adrenergic receptors: Pharmacological characterization. Invest. Ophthalmol. Vis. Sci. 21: 798-804.

National Research Council (1989) Myopia: Prevalence and progression. National Acad. Press, Washington DC, USA.

Newman FA (1929) Aquired axial myopia. Am. J. Ophthalmol. 12: 714-719.

North RV and Henson DB (1981) Adaptation to prism-induced heterophoria in subjects with abnormal binocular vision or asthenopia. Am. J. Optom. Physiol. Opt. 58: 746-752.

North RV and Henson DB (1985) Adaptation to lens-induced heterophorias. Am. J. Optom. Physiol. Opt. 62: 774-780.

North RV, Sethi B and Henson DB (1986) Effects of prolonged forced vergence upon the adaptation system. Ophthal. Physiol. Opt. 6: 391-396.

North RV, Sethi B and Owen K (1989) Adaptation ability of subjects with different refractive errors. Optom. Vis. Sci. 66: 296-299.

North RV, Sethi, B and Owen K (1990) Prism adaptation and viewing distance. Ophthal. Physiol. Opt. 10: 81-55.

O'Neal MR and Connon TR (1987) Refractive error change at the United States Air Force Academy - class of 1985. Am. J. Optom. Physiol. Opt. 62: 344-354.

O'Shea WF, Ciuffreda KJ, Fisher SK, Tannen B and Super P (1988) Relation between distance heterophoria and tonic vergence. Am. J. Optom. Physiol. Opt. 65: 787-793.

Ogle KN (1966) The accommodative convergence accommodation ratio and its relation to the correction of refractive error. Trans. Am. Acad. Ophthalmol. Otolaryngol. 70: 322-330.

Ogle KN and Martens TG (1957) On the accommodative convergence and the proximal convergence. A. M. A. Arch. Ophthalmol. 57: 702-715.

Ogle KN and Prangen A deH (1953) Observations on vertical divergences and hyperphorias. A. M. A. Arch. Ophthalmol. 49: 313-334.

Ogle KN, Martens TG and Dyer JA (1967) Oculomotor imbalance in binocular vision and fixation disparity. Lea and Fabiger, Philadelphia, USA.

Olmstead JMD (1944) The role of the autonomic nervous system in accommodation for far and near vision. J. Nervous Mental Dis. 99: 794-798.

Otero JM and Duran A (1942) Continuacion del estudio de la miopia nocturna. Anales Fisica Quimica 38: 236-248 (cited by Mellerio, 1966).

Owens DA (1979) The Mandlebaum effect: evidence for an accommodative bias toward intermediate viewing distances. J. Opt. Soc. Am. 69: 646-652.

Owens DA (1980) A comparison of accommodative responsiveness and contrast sensitivity for sinusoidal gratings. Vis. Res. 20: 159-167.

Owens DA (1991) Young adult myopia. In: Refractive anomalies: Research and clinical applications. Eds Grosvenor T and Flom MC. Butterworth-Heinemann, Boston, USA.

Owens DA and Leibowitz HW (1976) Oculomotor adjustments in darkness and the specific distance tendency. Percept. Psychophys. 20: 2-9.

Owens DA and Leibowitz HW (1980) Accommodation, convergence, and distance perception in low illumination. Am. J. Optom. Physiol. Opt. 57: 540-550.

Owens DA and Leibowitz HW (1983) Perceptual and motor consequences of tonic vergence. In: Vergence eye movements: Basic and clinical aspects. Eds. Schor CM and Ciuffreda KJ. Butterworths, Boston, USA.

Owens DA and Tyrrell RA (1992) Lateral 'phoria at distance: Contributions of accommodation. Invest. Ophthalmol. Vis. Sci. 33: 2733-2743.

Owens DA and Wolf-Kelly K (1987) Near work, visual fatigue and variations of oculomotor tonus. Invest. Ophthalmol. Vis. Sci. 28: 743-749.

Owens DA, Mohindra I and Held R (1980) The effectiveness of a retinoscope beam as an accommodative stimulus. Invest. Ophthalmol. Vis. Sci. 19: 942-949.

Owens H, Winn B, Gilmartin B and Pugh JR (1991) The effect of topical beta-adrenergic antagonists on the dynamics of steady-state accommodation. Ophthal. Physiol. Opt. 11: 99-104.

Owens RL and Higgins KE (1983) Long term stability of the dark focus of accommodation. Am. J. Optom. Physiol. Opt. 60: 32-38.

Perkins ES (1981) Myopia and scleral stress. Doc. Ophthalmol. Proc. Series. 28: 121-127.

Phillips SR (1974) Ocular neurological control systems: accommodation and the near response triad. Ph.D. dissertation (unpublished) University of california, Berkley (cited by Ciuffreda KJ and Kenyon RV, 1983).

Phillips SR and Stark L (1977) Blur: a sufficient accommodative stimulus. Doc. Ophthalmol. 43: 65-69.

Pilar G (1963) Further study of the electrical and mechanical responses of slow fibres in cat extraocular muscles. J. Gen. Physiol. 50: 2289-2300.

Pipe DM and Rapley LJ (1984) Ocular anatomy and histology. Association of British Dispensing Opticians, London, UK.

Post RB, Johnson CA and Tsuetaki TK (1984) Comparison of laser and infra-red techniques for measurement of the resting focus of accommodation. Mean differences and long term variability. Ophthal. Physiol. Opt. 4: 327-332.

Provine RP and Enoch JM (1975) On voluntary ocular accommodation. Percept. Psychophys. 17: 209-212.

Rabin J, Van Sluyters RC and Malach R (1981) Emmetropization: a vision dependent phenomenon. Invest. Ophthalmol. Vis. Sci. 20: 561-564.

Ramazzini B (1713) Diseases of workers (Trans. Wright WC) University of Chicago Press, Chicago, USA (cited by Owens and Wolf-Kelly, 1987).

Ramsdale C (1978) A study of binocular and monocular accommodation. MSc. Thesis, University of Manchester, U.K.

Ramsdale C (1979) Monocular and binocular accommodation. Oph. Opt. 19: 606-622.

Ramsdale C and Charman WN (1989) A longitudinal study of the changes in the static accommodation response. Ophthal. Physiol. Opt. 9: 255-263.

Rashbass C and Westheimer G (1961) Disjunctive eye movements. J. Physiol. 159: 339-360.

Raviola E and Wiesel TN (1985) An animal model of myopia. New Eng. J. Med. 312; 1609-1615.

Rayleigh JWS (1883) On the visibility of small objects in bad light. Proc. Cambridge Philosophical Soc. 4: 324 (cited by Mellerio, 1966).

Rickers M, Schaeffel F, Hagel G and Zrenner E (1994) Dose-dependant effects of intrvitreal pirenzepine on deprivation myopia and lens-induced refractive errors in chicks. Invest. Ophthalmol. Vis. Sci. 35: 1801.

Ripps H, Chin N, Seigael IM and Breinin G (1962) The effect of the pupil size on accommodation, convergence and the AC/A ratio. Invest. Ophthalmol. Vis. Sci. 1: 127-135.

Robertson KM and Williams TD (1986) Orthophorisation after occlusion-induced exophoria. Am. J. Optom. Physiol. Opt. 63: 757-763.

Robinson DA (1966) The mechanisms of human vergence eye movements. J. Pediatric Ophthalmol. 3: 31-39.

Rohen JW and Rentsch FJ (1969) Der konstructive bau des zonulaaparates beim menschen und dessen funktionelle bedentung. Albrecht v. Graefes Arch. Ophthalmol. 178: 1-19.

Rosenfield M (1989) Comparison of accommodative adaptation using laser and infra-red optometers. Ophthal. Physiol. Opt. 9: 431-436.

Rosenfield M and Ciuffreda KJ (1990) Distance heterophoria and tonic vergence. Optom. Vis. Sci. 67: 667-669.

Rosenfield M and Ciuffreda KJ (1991) Effect of surround propinquity on the open-loop accommodative response. Invest. Ophthalmol. Vis. Sci. 32: 142-147.

Rosenfield M and Gilmartin B (1987a) Oculomotor consequences of beta-adrenoceptor antagonism during sustained near vision. Ophthal. Physiol. Opt. 7: 127-130.

Rosenfield M and Gilmartin B (1987b) Effect of a near vision task on the response AC/A of a myopic population. Ophthal. Physiol. Opt. 7: 225-233.

Rosenfield M and Gilmartin B (1987c) Synkinesis of accommodation and vergence in late-onset myopia. Am. J. Optom. Physiol. Opt. 64: 929-937.

Rosenfield M and Gilmartin B (1988a) Accommodative adaptation induced by sustained disparity vergence. Am. J. Optom. Physiol. Opt. 65: 118-126.

Rosenfield M and Gilmartin B (1988b) Assessment of the CA/C in a myopic population. Am. J. Optom. Physiol. Opt. 65: 168-173.

Rosenfield M and Gilmartin B (1988c) The effect of vergence adaptation on convergence accommodation. Ophthal. Physiol. Opt. 8: 172-177.

Rosenfield M and Gilmartin B (1988d) Disparity induced accommodation in late-onset myopia. Ophthal. Physiol Opt. 8: 172-177.

Rosenfield M and Gilmartin B (1988e) Accommodative adaptation to monocular and binocular stimuli. Am. J. Optom. Physiol. Opt. 65: 862-866.

Rosenfield M and Gilmartin B (1989) Temporal aspects of accommodative adaptation. Optom. Vis. Sci. 66: 229-234.

Rosenfield M and Gilmartin B. (1990) Effect of target proximity on the open-loop accommodative response. Optom. Vis. Sci. 67: 74-79.

Rosenfield M, Ciuffreda KJ and Gilmartin B (1992) Factors influencing accommodative adaptation. Optom. Vis. Sci. 69: 270-275.

Rosenfield M, Ciuffreda KJ and Hung GK (1991) The linearity of proximally-induced accommodation and vergence. Invest. Ophthalmol. Vis. Sci. 32: 2985-2991.

Rosenfield M, Ciuffreda KJ, Hung GK and Gilmartin B (1993) Tonic accommodation: A review I. Basic aspects. Ophthal. Physiol. Opt. 13: 266-284.

Rosenfield M, Ciuffreda KJ, Hung GK and Gilmartin B (1994) Tonic accommodation: A review II. Accommodative adaptation and clinical aspects Ophthal. Physiol. Opt. 14: 265-277.

Rosenfield M, Ciuffreda KJ, Ong E and Azimi A (1990a) Proximally-induced accommodation and accommodative adaptation. Invest. Ophthalmol. Vis. Sci. 31: 1162-1167.

Rosenfield M, Gilmartin B, Cunningham E and Dattani N (1990b) The influence of alpha-adrenergic agents on tonic accommodation. Curr. Eye Res. 9: 267-272.

Rosner J and Rosner J (1989a) Relation between clinically measured tonic accommodation and refractive status in 6- to 14- year-old children. Optom. Vis. Sci. 66: 436-439.

Rosner J and Rosner J (1989b) Relation between tonic accommodation and visual perceptual skills development in 6- to 12-year-old children. Optom. Vis. Sci. 66: 526-529.

Ruskell GL (1973) Sympathetic innervation of the ciliary muscle in monkeys. Exp. Eye Res. 16 183-190.

Ruskell GL (1978) The fine structure of innervated myotendinous cylinders in extraocular muscles of Rhesus monkeys. J. Neurocytol. 7: 693-708.

Ruskell GL (1979) The incidence and variety of Golgi tendon organs in extraocular muscles of the Rhesus monkey. J. Neurocytol. 8: 639-653.

Ruskell GL and Griffiths T (1979) Peripheral nerve pathway to the ciliary muscle. Exp. Eye Res. 28: 277-284.

Ruskell GL and Wilson J (1983) Spiral nerve endings and dapple motor end plates in monkey extraocular muscles. J Anat. 136: 85-95.

Sanghvi IS (1967) Effects of cholinergic and adrenergic agents and their antagonists at the neuromuscular junction of the cat extraocular muscles. Invest. Opthalmol. 6: 269-276.

Saunders H (1986) Age of cessation of the progression of myopia. Ophthal. Physiol. Opt. 6: 243-244.

Schiffendecker P (1905) Z Augenheilk 14: 186 (cited by Wolff, 1976)

Schober HAW, Dehler H and Kassel R (1970) Accommodation during observations with optical instruments. J. Opt. Soc. Am. 60: 103-107.

Schor CM (1979a) The influence of rapid prism adaptation on fixation disparity. Vis. Res 19: 757-765.

Schor CM (1979b) The relationship between fusional vergence eye movements and fixation disparity. Vis. Res 19: 1359-1367.

Schor CM (1980) Fixation disparity: A steady-state error of disparity-induced vergence. Am. J. Optom. Physiol. Opt. 57: 618-631.

Schor CM (1983) Fixation disparity and vergence adaptation. In: Vergence eye movements: Basic and clinical aspects. Eds. Schor CM, Ciuffreda KJ. Butterworths, Boston, USA.

Schor CM (1985) Models of mutual interactions between accommodation and convergence. Am. J. Optom. Physiol. Opt. 62: 369-374.

Schor CM (1986) Adaptive regulation of accommodative vergence and vergence accommodation. Am. J. Optom. Physiol. Opt. 63:587-609.

Schor CM and Johnson CA (1984) Adaptation of tonic accommodation. Ophthal. Physiol. Opt. 4: 133-137.

Schor CM and Kotulak JC (1986) Dynamic interactions between accommodation and convergence are velocity sensitive. Vis. Res 26: 927-942.

Schor CM and Narayan V (1982) Graphical analysis of prism adaptation, convergence accommodation and accommodative convergence. Am. J. Optom. Physiol. Opt. 59: 774-784.

Schor CM and Tsuetaki TK (1987) Fatigue of accommodation and vergence changes their cross-linked interactions. Invest. Ophthalmol. Vis. Sci. (suppl). 28: 103.

Schor CM, Alexander J, Cormack L and Stevenson S (1992) Negative feedback control model of proximal convergence and accommodation. Ophthal. Physiol. Opt. 12: 307-318.

Schor CM, Johnson CA and Post RB (1984) Adaptation of tonic accommodation. Ophthal. Physiol. Opt. 4: 133-137.

Schor CM, Kotulak JC and Tsuetaki TK (1986) Adaptation of tonic accommodation reduces accommodative lag and is masked in darkness. Invest. Ophthalmol. Vis. Sci. 27: 820-827.

Schubert G (1943) Grundlangen der beidaugigen motorishen koordindation P. flügers. Arch Ges. Physiol. 247: 279-291.

Semmlow JL (1981) Oculomotor response to near stimuli: the near triad. In: Models of oculomotor behavior and control. Ed. Zuber BL. CRC Press, Miami, USA.

Semmlow JL and Hung GK (1979) Accommodative and fusional components of fixation disparity. Invest. Ophthalmol. Vis. Sci. 18: 1082-1086.

Semmlow JL and Hung GK (1981) Experimental evidence for separate mechanisms mediating accommodative vergence and vergence accommodation. Doc. Ophthalmol. 51: 209-224.

Semmlow JL and Hung GK (1980) Binocular interactions of vergence components. Am. J. Optom. Physiol. Opt. 57: 559-565.

Semmlow JL and Tinor T (1978) Accommodative convergence response to off-foveal retinal images. J. Opt. Soc. Am. 68: 1497-1501.

Semmlow JL and Venkiteswaran N (1976) Dynamic accommodative vergence components in binocular vision. Vision Res 16: 403-411.

Semmlow JL and Wetzel P (1979) Dynamic contributions of the components of binocular vision. J. Opt. Soc. Am. 69: 639-645.

Sethi B (1986a) Heterophoria: A vergence adaptive position. Ophthal. Physiol. Opt.. 6: 151-156.

Sethi B (1986b) Vergence adaptation: A review. Doc. Ophthalmol. 63: 247-263.

Sethi B and Henson DB (1984) Adaptive changes with prolonged effect of comitant and incomitant vergence disparities. Am. J. Optom. Physiol. Opt. 61: 506-512.

Sethi B and North RV (1987) Vergence adaptative changes with varying magnitudes of prism-induced disparities and fusional amplitudes. Am. J. Optom. Physiol. Opt. 64: 263-268.

Siebeck R and Kruger P (1955) Die histologische struktur der ausseren augenmuskeln als ausdruck ihrer funktion. Graefs Arch. Ophthalmol. 156: 637-652.

Simonelli NM (1983) The dark focus of the human eye and its relationship to age and visual defect. Human Factors. 25: 85-92.

Slataper FJ (1950) Age norms of refraction and vision. Arch. Ophthalomol. 43: 466-481.

Snedecor GW and Cochran WG (1980) Statistical methods. 7th Ed. The Iowa State University Press, Iowa, USA.

Sorsby A (1967) The nature of spherical refractive errors. In report of the workshop on refractive anomolies of the eye. NINDB Monograph 5, US Dept. Health, Education and Welfare, Washington DC, USA.

Sorsby A and Benjamin B (1973) Modes of inheritance of errors of refraction. J. Med. Gen. 10: 161-164.

Sorsby A and Leary GA (1970) A longitudinal study of refraction and its components during growth. Med. Res. Coun. Spec. Report Ser. No. 309 H.M.S.O., London, UK.

Sorsby A, Benjamin B and Sheridan M (1961) Refraction and its components during growth of the eye from the age of three. Med. Res. Coun. Sec. Report Ser. No. 301 H.M.S.O., London, UK.

Sorsby A, Benjamin B, Davey JB, Sheridan M and Tanner JM (1957) Emmetropia and its abberations. Spec. Report Ser. Med. Res. Coun. No. 293. H.M.S.O., London, UK.

Sorsby A, Sheridan M and Leary GA (1962) Refraction and its components in twins. Spec. Report Ser. Med. Res. Coun. No. 303 H.M.S.O., London, UK.

Spencer RF and Porter DJ (1988) Structural organization of the extraocular muscles. In: Neuroanatomy of the oculomotor system. Ed. Büttner-Ennever JA. Elsevier, Amsterdam.

Stansbury FC (1948) Pathogenesis of myopia. A new classification. Arch. Ophthalmol. 39: 273-299.

Stark L (1987) Presbyopia in the light of accommodation. In: Presbyopia: Recent research and reviews from the third international symposium. Eds. Stark L and Obrecht G. Fairchild Publications, New York, USA.

Stark L and Takahashi Y (1965) Absence of an odd-error signal mechanism in human accommodation. IEEE Trans. Biomed. Eng. BME-12: 138-146.

Stark L, Kenyon RV, Krishnan VV and Ciuffreda KJ (1980) Disparity vergence: A proposed name for a dominant component of binocular vergence eye movements. Am. J. Optom. Physiol. Opt. 57: 606-609.

Starke K, Gothert M and Kilbinger H (1989) Modulation of neurotransmitter release by presynaptic autoreceptors. Physiol. Rev. 69: 864-989.

Steiger A (1913) Die entstehung der spharischen refracktionen des menschlichen auges. Karger, Berlin.

Stenström S (1946) Investigation of the variation and correlation of the optical elements of human eyes (trans Woolf D, 1948). Am. J. Optom. Monograph 58: 218-232.

Stilling J (1891) Ueber das wachsthum der orbita und dessen beziehungen zur refraction. Arch. fur Augenh. 22: 47-60.

Stone RA, Lin T and Laties AM (1991) Muscarinic antagonist effects on experimental chick myopia. Exp. Eye Res. 52: 755-758.

Strang NC, Winn B and Gilmartin B (1994) Repeatability of post-task regression of accommodation in emmetropia and late-onset myopia. Ophthal. Physiol. Opt. 14: 88-91.

Straub M (1909) Uber die aetiologie der brechungsonmalien des auges und den ursprung der emmetropie. Albrecht v Graefes Arch Ophthalmol 70: 130-199.

Streeten BW and Licari PA (1983) The zonules and the elastic microfibrillar system in the ciliary body. Invest. Ophthalmol. Vis. Sci. 24: 667-681.

Suzumura A (1979) Accommodation in myopia. J. Arch. Med. Univ. Ass. 7: 6-15.

Switkers E, Bradley A and Schor C (1990) Readily visible changes in colour contrast are insufficient to stimulate accommodation. Vis. Res. 30: 1367-1376.

Tait EF (1951) Accommodative convergence. Am. J. Ophthal. 34: 1093-1107.

Tamm E, Lütjen-Drecoll E, Jungkuntz W and Rohen J W (1991) Posterior attachment of the ciliary muscle in young, accommodating old, presbyopic rhesus monkeys. Invest. Ophthalmol. Vis. Sci. 32: 1678-1692.

Tan RKT (1986) The effect of accommodation response on the dark focus. Clin. Exp. Optom. 69: 156-159.

Taylor HR (1981) Racial variations in vision. Am. J. Epidemiol. 113: 62-80.

Toates FM (1972) Accommodation function of the human eye. Physiol Rev. 52: 828-863.

Toates FM (1974) Vergence eye movements. Doc. Ophthalmol. 37: 153-214.

Tokoro T (1970) Experimental myopia in rabbits. Invest. Ophthalmol. 9: 926-934.

Törnqvist G (1966) Effect of cervical sympathetic stimulation on accommodation in monkeys. Acta Physiologica Scandinavica 67: 363-372.

Törnqvist G (1967) The relative importance of the parasympathetic and sympathetic nervous systems for accommodation in monkeys. Invest. Ophthalmol. 6: 612-617.

Trachtman JN (1978) Biofeedback of accommodation to reduce functional myopia: a case report. Am. J. Optom. Physiol. Opt. 55: 400-406.

Troelstra A, Zuber BL, Miller D and Stark L (1964) Accommodative tracking: a trial and error function. Vis. Res. 4: 585-594.

Troilo D, Li T and Howland HC (1993) Negative accommodation occurs in the chick and may be mediated by sympathetic input. Invest. Ophthalmol. Vis. Sci. (Suppl.) 34: 1310.

Tsuetaki TK and Schor CM (1987) Clinical method of measuring adaptation of tonic accommodation and vergence accommodation. Am. J. Optom. Physiol. Opt. 64: 437-449.

Van Alphen GWHM (1961) On emmetropia and ametropia. Ophthalomol. (suppl) 142: 1-92

Van Alphen GWHM (1976) The adrenergic receptors of the intraocular muscles of the human eye. Invest. Ophthalmol. Vis. Sci. 15: 502-505.

Van Alphen GWHM (1986) Choroidal stress and emmetropization. Vis. Res. 26: 723-734.

Van Alphen GWHM (1990) Emmetropization in the primate eye. In: Myopia and the control of eye growth. Ciba Foundation Symposium 155 pp 115-120. John Wiley and Sons Chichester, UK.

Van Alphen GWHM and Graebel WP (1991) Elasticity of tissues involved in accommodation. Vis. Res. 31: 1417-1438.

Van Alphen GWHM, Kern R and Robinette SL (1965) Adrenergic receptors on the intraocular muscles. Arch. Ophthalmol. 74: 253-259.

Von Arlt (1876) Ueber die Ursachen und die Entstehung der Kurzsichtigkeit, Wilhelm Braumüller, Vienna.

Von Graefe A (1854) Beiträge zur Physiologie und Pathologie der schiefen Augenmuskeln Arch. Ophth. 1: 1-167.

Vuori M-L, Ali-Melkkilä T, Kaila T, Iisalo E and Saari KM (1993) β_1 and β_2 - antagonist activity of topically applied betaxolol and timolol in the systemic circulation. Acta Ophthalmol. 71: 682-685.

Waardenburg PJ (1950) Twin research in ophthalmology. Doc. Ophthalmol. 4: 154-200.

Wald G and Griffin DR (1947) The change in refractive power of the human eye in dim and bright light. J. Optical Soc. Am. 37: 321-336.

Wallman J, Gottlieb MD, Rajaram V and Fugate-Wentzek LA (1987) Local retinal regions control local eye growth and myopia. Science 237: 73-77.

Ward PA and Charman WN (1985) Effect of pupil size on steady-state accommodation. Vis. Res. 25: 1317-1326.

Ward PA and Charman WN (1987) On the use of small artificial pupils to open-loop the accommodative system. Ophthal. Physiol. Opt. 7: 191-193.

Ware J (1813) Observations relative to the near and distance sight of different persons. Phil. Trans. Royal. Soc. London. pp 31.

Warwick R (1956) Oculomotor organisation. Ann. Royal Coll. Surg. 19: 36-52.

Wax MB and Molinoff PB (1987) Distribution and properties of β - adrenergic receptors in human iris-ciliary body. Invest. Ophthalmol. Vis. Sci. 28: 420-430.

Weale RA (1979) Sex, age and birefringence of the human crystalline lens. Exp. Eye Res. 29: 449-461.

Westheimer G (1963) Amphetamine, barbituates and accommodative-convergence. Arch Ophthalmol. 70: 830-836.

Westheimer G and Blair SM (1973) The parasympathetic pathways to the internal eye muscles. Invest. Ophthalmol. 12: 193-197.

Westheimer G and Mitchell AM (1956) Eye movement responses to convergent stimuli. Arch. Ophthalmol. 55: 848-856.

Weymouth W and Hirsch MJ (1991) Theories, definitions and classifications of refractive errors. In: Refractive anomalies: Research and clinical applications. Eds. Grosvenor T and Flom MC. Butterworth-heinemann, Boston, USA.

Whitefoot H and Charman WN (1992) Dynamic retinoscopy and accommodation. Ophthal. Physiol. Opt. 12: 8-17.

Whiteside TCD (1952) Accommodation of the human eye in a bright and empty visual field. J. Physiol. 118: 65.

Wick B (1985) Clinical factors in proximal vergence. Am. J. Optom. Physiol. Opt. 62: 1-18.

Wick B and Currie D (1991) Dynamic demonstration of proximal vergence and proximal accommodation. Optom. Vis. Sci. 68 163-167.

Wilson D (1972) Accommodation-accommodative vergence synkinesis in the human visual system. Ph.D. thesis (unpublished). University of California, Berkeley.

Winn B, Pugh JR, Gilmartin B and Owens H (1989) The effect of pupil size on static and dynamic measures of accommodation using an infra-red optometer. Ophthal. Physiol. Opt. 9: 277-283.

Wolf KS, Bedell HE and Pedersen SB (1990) Relations between accommodation and vergence in darkness. Optom. Vis. Sci. 67: 89-93.

Wolf KS, Ciuffreda KJ and Jacobs SE (1987) Time course and decay of effects of near work on tonic accommodation and tonic vergence. Ophthal. Physiol. Opt. 7 131-135.

Wolfe JM and O'Connell KM (1987) Adaptation of the resting states of accommodation. Invest. Ophthalmol. Vis. Sci. 28 992-996.

Wolfe JM and Owens DA (1981) Is accommodation colour blind? Focusing chromatic contors. Percept. 10: 53-62.

Wolff E (1976) Anatomy of the eye and orbit 7th Ed. HK Lewis, London, UK.

Woo GC and Wilson MA (1990) Current methods of treating and preventing myopia. Optom. Vis. Sci. 67: 719-727.

Yinon U (1984) Myopia induction in animals following alteration of the visual input during development: a review. Curr. Eye Res. 3: 677-690.

Young FA (1961) The effect of restricted visual space on the primate eye. Am. J. Ophthalmol. 52: 799-806.

Young FA (1965) The effect of atropine on the development of myopia in monkeys. Am. J. Optom. Arch. Am. Acad. Optom. 42: 439-449.

Young FA (1975) The development and control of myopia in human and subhuman primates. Contacto 19: 16-31.

Young FA, Leary GA, Baldwin WR, West DC, Box RA, Harris E and Johnson C (1969) The transmission of refractive errors within Eskimo families. Am. J. Optom. Arch. Acad. Optom. 49: 676-685.

Young FA, Leary GA, Zimmerman RR and Strobel DA (1973) Diet and refractive characteristics. Am. J. Optom. Arch. Am. Acad. Optom. 3: 226-233.

Zadnik K, Mutti DO and Adams AJ (1991) Two-year refractive error and axial dimension results from the Orinda longitudinal study on myopia. Invest. Ophthalmol. Vis. Sci. (suppl) 32: 1201.

Zetterström C (1988) Effects of adrenergic drugs on accommodation and distance refraction in daylight and darkness. Acta Ophthalmol. 66: 58-64.

Zetterström C and Hahnenberger R (1988) Pharmacological characterization of human ciliary muscle adrenoceptors *in vitro*. Exp. Eye Res. 46: 421-430.

Zimmerman TJ, Harbin R, Pett M and Kaufman HE (1977) Timolol and facility of outflow. Invest. Ophthalmol. Vis. Sci. 16: 623-624.

APPENDICES

APPENDIX 1

BIOMETRY AND KERATOMETRY IN EMMETROPIA AND MYOPIA

1a) Biometry and keratometry measurements

Subjects' right eye data for mean sphere refractive error (Rx), keratometry ('K'), axial length (A.L.), anterior chamber depth (A.C.D.), lens thickness (L.T.), vitreous chamber depth (V.D.C.) and age of subject.

EMMETROPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)
AC	-0.12	8.05	24.02	3.65	3.61	16.76	19
AD	0.12	7.78	23.40	3.73	3.48	16.19	20
AJ	0.50	7.93	24.50	3.96	3.45	17.09	19
AS	0.25	7.78	23.42	3.86	3.73	15.83	23
BS	0.12	7.33	22.00	3.25	3.19	15.56	18
DH	0.37	8.15	24.65	3.91	3.14	17.60	19
FF	-0.12	7.83	23.33	3.78	3.62	15.93	22
FS	-0.12	7.78	23.41	3.49	3.49	16.43	20
GP	-0.25	7.55	23.06	3.95	3.35	15.76	19
HC	0.25	7.88	23.69	3.68	3.42	16.56	27
HO	0.25	7.65	24.03	3.73	4.30	16.00	30
HP	0.25	7.58	22.45	3.30	3.70	15.45	18
JE	0.37	7.48	22.16	3.86	3.68	14.62	21
JL	0.25	7.63	22.46	3.15	3.94	15.37	18
JS	-0.12	7.45	23.93	3.89	3.85	16.19	18
JS	-0.25	7.60	23.56	2.86	3.73	16.90	20
KF	0.25	7.70	23.28	3.46	3.48	16.34	20
KK	0.00	7.68	23.20	3.68	3.71	15.81	19
KP	0.00	8.98	25.77	3.26	3.58	18.93	18
LB	0.00	8.20	24.30	3.44	3.36	17.50	18
LM	0.00	7.83	23.62	3.84	3.75	16.55	23
LR	0.12	7.60	22.64	3.41	3.58	15.65	19
MH	0.50	7.63	22.63	3.61	3.38	15.24	20
MH	0.12	8.18	24.14	3.71	3.66	16.76	19
MR	-0.25	7.93	23.96	3.78	3.20	16.98	21
NJ	-0.12	7.73	23.23	3.45	3.28	16.50	25
NW	0.00	7.90	23.10	3.50	3.74	15.86	18
OW	0.25	7.83	23.46	3.98	3.55	15.93	22
PP	0.50	7.55	22.65	3.65	3.41	15.59	19
RD	0.25	7.83	23.91	3.30	3.71	16.90	25
RL	0.25	7.83	22.79	3.31	3.87	15.61	18
RS	0.25	7.70	23.99	3.63	3.66	16.69	23
SD	0.12	8.03	23.79	3.91	3.84	16.05	18
SP	0.75	7.83	22.21	3.66	3.61	14.94	20
SR	0.12	7.63	23.62	3.45	3.62	16.55	22
TW	-0.25	7.88	23.47	3.83	3.72	15.92	21
WI	0.00	8.43	23.99	3.31	4.00	16.67	18
ZJ	-0.12	8.00	24.13	3.90	3.74	16.48	20
Mean	**0.12**	**7.82**	**23.47**	**3.61**	**3.61**	**16.25**	**20.45**
SEM	**0.04**	**0.05**	**0.12**	**0.04**	**0.04**	**0.13**	**0.45**

EARLY-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Onset (years)
AB	-2.37	7.40	23.81	3.87	3.73	16.21	20	13
AD	-4.87	7.85	25.54	3.37	3.75	18.42	19	11
AH	-3.75	8.05	26.06	4.13	3.44	18.51	18	13
AN	-6.12	7.50	25.64	3.90	3.69	18.05	18	7
AS	-5.12	7.75	26.67	3.91	3.64	19.11	23	14
CG	-2.00	7.55	23.41	3.47	3.76	16.18	18	13
CW	-1.75	8.00	25.80	3.79	4.16	17.48	20	14
EW	-2.00	8.15	24.15	3.47	3.40	17.23	18	12
GP	-8.50	7.60	26.48	3.45	3.47	19.56	21	5
HR	-1.75	7.95	24.76	3.75	3.85	17.16	19	13
JB	-2.75	7.90	26.34	3.20	3.91	19.22	22	14
JB	-4.25	7.95	27.15	3.69	3.63	19.83	20	12
JG	-1.75	8.10	24.18	3.76	3.32	17.10	19	13
JL	-4.62	7.68	24.78	3.88	3.53	17.37	18	13
JM	-1.12	7.40	24.27	3.70	3.52	17.05	18	14
KL	-3.00	7.95	25.11	3.41	3.42	18.28	23	12
MD	-6.00	8.08	27.04	3.99	3.71	19.34	29	7
MP	-1.75	7.40	23.48	3.65	3.36	16.47	20	11
NE	-4.37	7.50	24.45	3.78	3.68	16.99	23	14
NE	-6.75	8.00	25.49	3.98	3.56	17.95	18	8
PH	-2.50	7.98	25.27	3.84	3.92	17.57	33	12
PJ	-4.50	7.98	25.59	3.84	3.98	17.77	29	10
PP	-4.75	7.73	24.97	3.87	3.65	17.45	19	14
RH	-5.12	7.50	24.76	3.77	4.46	16.53	19	12
RJ	-2.87	7.65	24.35	3.35	3.51	17.49	18	14
RM	-6.25	7.98	26.05	3.68	3.44	18.93	18	7
RS	-1.50	7.65	23.57	3.72	3.53	16.32	18	8
SL	-3.25	7.13	24.01	3.98	3.61	16.43	19	14
SS	-3.37	7.60	24.51	3.71	3.57	17.23	19	10
SP	-4.87	7.83	25.40	3.88	3.28	18.24	19	14
TB	-6.62	7.33	25.54	3.67	4.09	17.79	20	11
WF	-0.75	7.15	22.66	3.66	3.48	15.52	18	14
WS	-3.00	7.50	24.68	3.95	3.56	17.18	21	12
ZR	-4.25	7.75	25.88	3.94	3.38	18.56	20	14
Mean	**-3.77**	**7.72**	**25.05**	**3.74**	**3.65**	**17.66**	**20.41**	**11.73**
SEM	**0.32**	**0.05**	**0.19**	**0.04**	**0.04**	**0.18**	**0.60**	**0.44**

LATE-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Onset (years)
AR	-1.25	7.98	24.26	3.68	3.71	16.87	20	19
AS	-2.50	7.78	24.73	3.84	3.45	17.45	20	16
AW	-1.50	7.58	23.66	3.78	3.23	16.65	19	18
AW	-1.37	7.60	24.40	3.75	4.02	16.63	20	17
BW	-3.00	8.10	24.96	3.16	4.06	17.78	34	23
CP	-1.75	8.00	24.51	3.69	3.72	17.10	21	17
CR	-1.00	7.68	24.28	3.87	3.63	16.78	20	19
CW	-1.12	8.05	25.06	3.94	3.35	17.75	18	16
EF	-0.87	7.90	24.44	3.93	3.44	17.08	19	17
EW	-2.75	7.90	25.75	3.96	3.61	18.17	26	19
HJ	-0.75	7.73	23.92	3.26	3.39	17.28	20	17
JH	-1.00	7.50	23.44	3.29	3.66	16.46	22	21
JL	-0.87	7.50	22.71	3.95	3.45	15.32	18	17
JP	-3.37	8.15	25.78	3.85	3.52	18.41	19	16
KD	-1.50	8.50	25.94	3.79	3.34	18.80	18	16
KJ	-0.75	7.53	24.09	3.68	3.63	16.78	20	18
LW	-2.50	7.20	25.60	3.72	3.51	18.37	18	16
MC	-1.50	7.80	24.91	3.86	3.48	17.57	21	19
MV	-1.25	7.85	24.31	3.42	3.87	17.02	21	18
NB	-1.50	7.93	25.08	3.85	3.61	17.62	30	25
NB	-2.50	8.15	27.05	3.77	3.46	19.82	19	17
NH	-1.50	7.50	24.24	3.86	3.63	16.76	23	19
NO	-0.50	7.70	23.72	3.71	3.56	16.45	19	18
NW	-0.87	7.45	23.78	3.89	3.36	16.52	28	24
PK	-2.50	7.63	24.23	3.39	3.46	17.38	23	18
RB	-1.25	7.33	23.19	3.89	3.38	15.92	19	18
SB	-1.75	8.08	24.49	3.50	3.94	17.05	20	19
SB	-2.12	8.48	25.26	3.71	3.68	17.87	20	17
SC	-2.75	7.93	24.62	3.80	3.48	17.34	34	19
TH	-1.87	7.98	24.57	3.79	3.66	16.89	20	17
Mean	**-1.66**	**7.82**	**24.57**	**3.72**	**3.58**	**17.26**	**21.63**	**18.33**
SEM	**0.14**	**0.06**	**0.16**	**0.04**	**0.04**	**0.16**	**0.80**	**0.42**

One-way analysis of variance (ANOVA) revealed that the only axial length ($p<0.001$), mediated via anterior chamber depth ($p=0.05$) and vitreous chamber depth ($p<0.001$) are significantly correlated to refractive error. In contrast to other workers, neither corneal curvature ($p=0.27$) nor lens thickness ($p=0.48$) were correlated to refractive error.

APPENDIX 2

SOFTWARE FOR THE MACINTOSH CLASSIC COMPUTER FOR USE WITH THE CASI INTERFACE UNIT AND CANON OPTOMETER

2a) The Canon Auto-Ref Interface program.

The program was written by Steve Spadafor in MicroSoft BASIC and was designed to ignor 'Error" readings and collect a specific number of valid refraction readings for various conditions and store them in the Macintosh computer.

```
'   Canon Auto-Ref Interface program
'   Steve Spadafore   8/10/92
'   Copyright ©1992 Franklin & Marshall College
'
'   Adapted from AUTO-REF and GET AUTO-REF Applesoft BASIC
'   programs developed by Rick Tyrrell of Franklin & Marshall
'   College 1987
init:
    WINDOW 1,,(5,30)-(500,330),4
    MENU 1,0,1,"File"                    'set up menus
    MENU 1,1,1,"AutoRef"
    MENU 1,2,1,"View/Print File"
    MENU 1,3,1,"Quit"
    ON MENU GOSUB HandleMenu
    MENU ON
    WHILE 1 : WEND                       'wait for command
HandleMenu:                              'menu handler routine
    MENU
    ON MENU(1) GOSUB AutoRef,Getfile,Quit
    RETURN
AutoRef:
    OPEN "COM1:1200,n,8,1" AS #2   'open modem port at 1200 baud, no parity, 8bits
    flush$ = INPUT$(LOC(2),2)           'comm buffer, flush it
    CLS : LOCATE 5,1
    INPUT "HOW MANY CONDITIONS"; NC%
    INPUT "HOW MANY TRIALS/CONDITION"; NT%
     DIMC$(NC%),EY$(NC%,NT%),SP(NC%,NT%),CY(NC%,NT%),AX(NC%,NT%)
    PRINT
    FOR i% = 1 TO NC%                    'enter condition names
    PRINT "NAME FOR CONDITION #";i%;"?"
    INPUT C$(i%)
    NEXT i%
    CLS : LOCATE 5,1
    INPUT "Press 'RETURN' when Canon is on.", Z$
    '
    '   data collection loop
    '
    FOR C% = 1 TO NC%:                   'CONDITION LOOP
    FOR T% = 1 TO NT%:                   'TRIAL LOOP
CollectData:
    S$ = ""                              ' null the string
    CLS : LOCATE 5,1
    PRINT "     READY TO COLLECT "; C$(C%)
    PRINT "         TRIAL #"; T%
    FOR i% = 1 TO 20                     'read in 20 characters/line from Canon
    S$ = S$ + INPUT$(1,2)
    NEXT i%
    SP$ = MID$(S$,4,5)                   'extract sphere data
    IF SP$ = " ERR " THEN                'test for error message from Canon
    BEEP : BEEP : BEEP                   'error alert beeps
    GOTO CollectData                     'repeat same condition and trial
```

```
    END IF
    IF SP$ = "      " THEN CollectData        'check for switch from eye to eye & ignor it
    EY$(C%,T%) = MID$(S$,2,1)                 'extract eye data
    SP(C%,T%) = VAL(SP$)                      'convert sphere data
    CY(C%,T%) = VAL(MID$(S$,10,5))            'extract and convert cylinder data
    AX(C%,T%) = VAL(MID$(S$,16,3))            'extract and convert axis data
    NEXT T%
    BEEP                                      'beep when done with condition
    NEXT C%
    '
    '   save data to disk file
    '
savedata:
    filename$ = FILES$(0,"Save data as:")
    IF filename$ = "" THEN
    CLS
    INPUT "Do you wish to quit without saving the data?",ans$
    ans$ = UCASE$(ans$)
    IF ans$ = "Y" THEN leaveprog ELSE GOTO savedata
    END IF
    OPEN filename$ FOR OUTPUT AS #1
    '
    ' parameters are delineated by commas in disk file
    '
    PRINT#1, NC%; ","; NT%
    FOR C% = 1 TO NC%
    PRINT#1, C$(C%)
    FOR T% = 1 TO NT%
    PRINT#1, EY$(C%,T%); ","; SP(C%,T%); ",";CY(C%,T%); ","; AX(C%,T%)
    NEXT T%
    NEXT C%
leaveprog:
    CLOSE                                     'close all files
    CLS
    ERASE C$,EY$,SP,CY,AX                     'release dynamic array storage
    RETURN
Getfile:
    F$ = FILES$(1,"TEXT")                     'get the filename
    IF F$ = "" THEN RETURN
    OPEN F$ FOR INPUT AS #2
    INPUT#2, NC%,NT%                          'load # OF CONDITIONS, # OF TRIALS
     DIMEY$(NC%,NT%),SP(NC%,NT%),CY(NC%,NT%),AX(NC%,NT%),C$(NC%)
    FOR C% = 1 TO NC%
    INPUT#2, C$(C%)                           'get condition name
    FOR T% = 1 TO NT%
    '
    '   get eye, sphere, cylinder, axis data
    '
     INPUT#2, EY$(C%,T%),SP(C%,T%),CY(C%,T%),AX(C%,T%)
    NEXT T%
    NEXT C%
    CLOSE #2
    CLS : LOCATE 5,1
hardcopy:
    INPUT "WANT A HARD COPY? (Y/N)"; ans$
    CLS
    ans$ = UCASE$(ans$)
    IF ans$ = "Y" THEN
    OPEN "LPT1:" FOR OUTPUT AS #1     'open printer
    WINDOW OUTPUT #1
    ELSEIF ans$ = "N" THEN
```

```
    'fall through
    ELSE
    GOTO hardcopy
    END IF
    '
    '   print the data by redirecting screen output to printer as well
    '
    PRINT "        EYE SPH  CYL  AXIS"
    PRINT "         ================="
    PRINT
    FOR C% = 1 TO NC%
    PRINT C$(C%)
    R = 0
    FOR T% = 1 TO NT%
    PRINT "        ";EY$(C%,T%);"  ";SP(C%,T%);"  ";CY(C%,T%);"  ";AX(C%,T%)
    R = R + (SP(C%,T%) + (.5 * CY(C%,T%)))  'Cumulative refractive error
    NEXT T%
    MR = R/NT%                              'Mean refractive error
    PRINT "      MEAN SPHERE = "; MR
    PRINT
    PRINT
    NEXT C%
    IF ans$ = "Y" THEN WINDOW OUTPUT 1: CLOSE #1
    ERASE EY$,SP,CY,AX,C$                   'release dynamic array storage
repeat:
    PRINT
    INPUT "WANNA DO IT AGAIN? (Y/N)"; ans$
    ans$ = UCASE$(ans$)
    IF ans$ = "N" THEN CLS : RETURN
    IF ans$ = "Y" THEN Getfile
    GOTO repeat:
Quit:
    SYSTEM
```

2b) The Auto-Ref AR (accommodative regression) program.
This program was written by the author in MicroSoft BASIC and is designed to collect a specific number of refractions including 'Error" readings and store them in the Macintosh Classic computer. It was necessary to modify the original program writted by Steve Spadafor so that when assessing accommodative regression patterns error readings were not ignored and therefore did not disrupt the time slots of all the other readings.

```
'  Canon Auto-Ref AR program
'  Written by Nicola Edwards
'  Adapted from Auto-Ref MicroSoft BASIC program written by Steve Spadafor,
   Franklin & Marshall College, 1992.
init:
    WINDOW 1,,(5,30)-(500,330),4
    MENU 1,0,1,"File"                   'set up menus
    MENU 1,1,1,"AutoRef"
    MENU 1,2,1,"View/Print File"
    MENU 1,3,1,"Quit"
    ON MENU GOSUB HandleMenu
    MENU ON
    WHILE 1 : WEND                      'wait for command
HandleMenu:                             'menu handler routine
    MENU
    ON MENU(1) GOSUB AutoRef,Getfile,Quit
    RETURN
AutoRef AA:
    OPEN "COM1:1200,n,8,1" AS #2    'open modem port at 1200 baud, no parity, 8bits
    flush$ = INPUT$(LOC(2),2)        'comm buffer, flush it
```

```
    CLS : LOCATE 5,1
    INPUT "HOW MANY CONDITIONS"; NC%
    INPUT "HOW MANY TRIALS/CONDITION"; NT%
     DIMC$(NC%),EY$(NC%,NT%),SP(NC%,NT%),CY(NC%,NT%),AX(NC%,NT%)
    PRINT
    FOR i% = 1 TO NC%                    'enter condition names
    PRINT "NAME FOR CONDITION #";i%;"?"
    INPUT C$(i%)
    NEXT i%
    CLS : LOCATE 5,1
     INPUT "Press 'RETURN' when Canon is on.", Z$
    '
    '   data collection loop
    '
    FOR C% = 1 TO NC%:                   'CONDITION LOOP
    FOR T% = 1 TO NT%:                   'TRIAL LOOP
CollectData:
    S$ = ""                              ' null the string
    CLS : LOCATE 5,1
    PRINT "     READY TO COLLECT "; C$(C%)
    PRINT "        TRIAL #"; T%
    FOR i% = 1 TO 20                     'read in 20 characters/line from Canon
    S$ = S$ + INPUT$(1,2)
    NEXT i%
    SP$ = MID$(S$,4,5)                   'extract sphere data
    END IF
    EY$(C%,T%) = MID$(S$,2,1)            'extract eye data
    SP(C%,T%) = VAL(SP$)                 'convert sphere data
    CY(C%,T%) = VAL(MID$(S$,10,5))       'extract and convert cylinder data
    AX(C%,T%) = VAL(MID$(S$,16,3))       'extract and convert axis data
    NEXT T%
    BEEP:BEEP:BEEP                       'beep when done with condition
    NEXT C%
    '
    '   save data to disk file
    '
savedata:
    filename$ = FILES$(0,"Save data as:")
    IF filename$ = "" THEN
    CLS
    INPUT "Do you wish to quit without saving the data?",ans$
    ans$ = UCASE$(ans$)
    IF ans$ = "Y" THEN leaveprog ELSE GOTO savedata
    END IF
    OPEN filename$ FOR OUTPUT AS #1
    '
    ' parameters are delineated by commas in disk file
    '
    PRINT#1, NC%; ","; NT%
    FOR C% = 1 TO NC%
    PRINT#1, C$(C%)
    FOR T% = 1 TO NT%
    PRINT#1, EY$(C%,T%); ","; SP(C%,T%); ",";CY(C%,T%); ","; AX(C%,T%)
    NEXT T%
    NEXT C%
leaveprog:
    CLOSE                                'close all files
    CLS
    ERASE C$,EY$,SP,CY,AX                'release dynamic array storage
    RETURN
Getfile:
```

```
    F$ = FILES$(1,"TEXT")                    'get the filename
    IF F$ = "" THEN RETURN
    OPEN F$ FOR INPUT AS #2
    INPUT#2, NC%,NT%                         'load # OF CONDITIONS, # OF TRIALS
     DIMEY$(NC%,NT%),SP(NC%,NT%),CY(NC%,NT%),AX(NC%,NT%),C$(NC%)
    FOR C% = 1 TO NC%
    INPUT#2, C$(C%)                          'get condition name
    FOR T% = 1 TO NT%
    '
    '   get eye, sphere, cylinder, axis data
    '
     INPUT#2, EY$(C%,T%),SP(C%,T%),CY(C%,T%),AX(C%,T%)
    NEXT T%
    NEXT C%
    CLOSE #2
    CLS : LOCATE 5,1
hardcopy:
    INPUT "DO YOU WANT A PRINT OUT? (Y/N)"; ans$
    CLS
    ans$ = UCASE$(ans$)
    IF ans$ = "Y" THEN
    OPEN "LPT1:" FOR OUTPUT AS #1    'open printer
    WINDOW OUTPUT #1
    ELSEIF ans$ = "N" THEN
    'fall through
    ELSE
    GOTO hardcopy
    END IF
    '
    '   print the data by redirecting screen output to printer as well
    '
    PRINT "        EYE SPH  CYL  AXIS"
    PRINT "         ================="
    PRINT
    FOR C% = 1 TO NC%
    PRINT C$(C%)
    R = 0
    FOR T% = 1 TO NT%
    PRINT "         ";EY$(C%,T%);"  ";SP(C%,T%);"  ";CY(C%,T%);"  ";AX(C%,T%)
    R = R + (SP(C%,T%) + (.5 * CY(C%,T%)))   'Cumulative refractive error
    NEXT T%
    MR = R/NT%                               'Mean refractive error
    PRINT "       MEAN SPHERE = "; MR
    PRINT
    PRINT
    NEXT C%
    IF ans$ = "Y" THEN WINDOW OUTPUT 1: CLOSE #1
    ERASE EY$,SP,CY,AX,C$                    'release dynamic array storage
repeat:
    PRINT
    INPUT "DO YOU WANT TO REPEAT THE PROCESS? (Y/N)"; ans$
    ans$ = UCASE$(ans$)
    IF ans$ = "N" THEN CLS : RETURN
    IF ans$ = "Y" THEN Getfile
    GOTO repeat:
Quit:
    SYSTEM
```

APPENDIX 3

THE EFFECT OF PLANO ULTRA THIN SOFT CONTACT LENSES ON ACCOMMODATION RESPONSES OF EMMETROPES

3a) For distance viewing (5 m)

Mean sphere refractions of emmetropes viewing a distant target both wearing (CL) and not wearing (No CL) plano contact lenses

	AS		OW		TW		HC		RS	
	No CL	CL	No CL	CL	No CL	CL	No CL	CL	No CL	CL
1	-0.25	-0.31	-0.37	-0.37	-0.12	0.00	0.25	0.25	-0.25	-0.37
2	-0.37	-0.31	-0.50	-0.50	-0.12	0.00	0.37	0.37	-0.37	-0.37
3	-0.37	-0.31	-0.50	-0.50	-0.12	0.00	0.25	0.50	-0.50	-0.37
4	-0.37	-0.25	-0.37	-0.25	-0.12	0.00	0.25	0.43	-0.25	-0.37
5	-0.37	-0.31	-0.25	-0.43	-0.12	0.00	0.37	0.43	-0.43	-0.50
6	-0.25	-0.31	-0.25	-0.43	-0.12	0.12	0.37	0.56	-0.56	-0.25
7	-0.25	-0.25	-0.50	-0.50	0.00	-0.12	0.50	0.56	-0.25	-0.25
8	-0.25	-0.25	-0.50	-0.43	0.00	0.00	0.37	0.50	-0.50	-0.56
9	-0.25	-0.18	-0.37	-0.37	-0.12	0.12	0.50	0.50	-0.25	-0.50
10	-0.31	-0.25	-0.25	-0.37	0.00	-0.12	0.50	0.43	-0.37	-0.25
11	-0.31	-0.31	-0.25	-0.50	0.00	-0.12	0.37	0.62	-0.43	-0.50
12	-0.31	-0.31	-0.50	-0.37	0.00	0.00	0.37	0.50	-0.50	-0.25
13	-0.31	-0.31	-0.50	-0.37	-0.12	-0.12	0.37	0.25	-0.43	-0.25
14	-0.31	-0.31	-0.37	-0.37	-0.12	0.00	0.50	0.56	-0.25	-0.37
15	-0.31	-0.31	-0.37	-0.25	-0.25	0.00	0.18	0.12	-0.37	-0.37
16	-0.31	-0.37	-0.50	-0.31	-0.12	-0.12	0.37	0.37	-0.37	-0.43
17	-0.31	-0.31	-0.25	-0.37	0.00	-0.12	0.37	0.43	-0.37	-0.43
18	-0.37	-0.31	-0.43	-0.37	0.00	-0.06	0.37	0.25	-0.25	-0.25
19	-0.37	-0.18	-0.50	-0.25	-0.12	0.00	0.37	0.50	-0.25	-0.37
20	-0.25	-0.25	-0.43	-0.37	-0.25	0.00	0.25	0.18	-0.25	-0.25
X	**-0.31**	**-0.29**	**-0.40**	**-0.38**	**-0.09**	**-0.03**	**0.36**	**0.41**	**-0.36**	**-0.35**
SD	**0.05**	**0.05**	**0.10**	**0.08**	**0.08**	**0.08**	**0.09**	**0.14**	**0.10**	**0.10**

3b) For near viewing (30 cm)

Mean sphere refractions of emmetropes viewing a near target both wearing (CL) and not wearing (No CL) plano contact lenses

	AS		OW		TW		HC		RS	
	No CL	CL	No CL	CL	No CL	CL	No CL	CL	No CL	CL
1	-2.62	-3.12	-2.62	-2.93	-2.62	-2.75	-2.56	2.68	-2.62	-2.50
2	-3.00	-3.00	-2.93	-3.25	-2.75	-2.81	-3.31	-2.50	-2.62	-2.81
3	-3.00	-2.87	-2.87	-3.00	-2.50	-2.81	-3.06	-2.62	-2.87	-2.43
4	-3.00	-3.06	-3.00	-3.12	-2.75	-2.81	-2.93	-2.56	-2.68	-2.56
5	-3.06	-3.12	-2.93	-3.00	-3.00	-2.50	-2.75	-2.81	-2.43	-2.62
6	-2.62	-3.00	-3.00	-2.87	-2.87	-2.56	-2.81	-2.50	-2.37	-2.37
7	-2.93	-2.93	-2.93	-3.00	-2.75	-2.75	-2.62	-2.43	-2.37	-2.93
8	-3.12	-2.81	-2.81	-3.18	-2.50	-2.87	-2.62	-2.25	-2.50	-2.43
9	-3.12	-3.06	-3.00	-3.06	-2.37	-2.87	-2.62	-2.31	-2.62	-2.62
10	-3.12	-2.87	-2.93	-3.00	-2.12	2.75	-2.50	-2.81	-2.31	-2.43
11	-3.00	-3.06	-3.18	-3.12	-2.87	2.81	-2.50	-2.62	-2.93	-2.37
12	-3.12	-3.25	-2.87	-3.12	-2.75	2.56	-2.37	-2.62	-2.93	-2.56
13	-3.00	-3.12	-3.12	-3.00	-2.62	2.43	-2.43	-2.93	-3.06	-2.62
14	-2.87	-2.87	-3.12	-3.06	-3.25	2.62	-2.50	-2.87	-3.12	-2.75
15	-3.06	-3.00	-3.43	-3.06	-2.87	2.56	-2.50	-2.81	-2.56	-2.81
16	-3.00	-3.06	-3.12	-3.06	-3.12	2.81	-2.62	-2.68	-3.18	-2.81
17	-3.00	-3.12	-3.18	-2.50	-2.50	2.93	-2.56	-2.93	-2.87	-3.12
18	-2.87	-3.06	-2.93	-2.50	-2.62	2.87	-2.25	-2.81	-2.68	-2.62
19	-2.75	-3.18	-3.06	-2.81	-2.50	3.00	-2.80	-2.62	-2.80	-2.87
20	-2.87	-2.81	-2.87	-2.87	-2.68	2.75	-2.93	-2.50	-2.68	-3.00
X	**-2.96**	**-3.02**	**-2.99**	**-2.97**	**-2.70**	**-2.74**	**-2.66**	**-2.64**	**-2.71**	**-2.66**
SD	**0.15**	**0.12**	**0.17**	**0.19**	**0.26**	**0.15**	**0.25**	**0.19**	**0.25**	**0.22**

APPENDIX 4

OPENING THE ACCOMMODATIVE LOOP WITH A DIFFUSE GREEN LIGHT OR A LASER SPECKLE TARGET IN AN OTHERWISE DARKENED ROOM

4a) Checking the accommodative loop is open when viewing the diffuse green light in an otherwise darkened room

Average mean sphere open-loop accommodation measurements recorded while viewing the diffuse green light in an otherwise darkened room through a supplementary lens (S. lens).

S. lens	BS	TW	JH	JE	JG	OW	AS
+1.75	-0.40	-4.09	-1.90	-1.62	-0.80	-1.08	-1.15
+1.00	-0.65	-4.15	-1.42	-1.45	-0.34	-0.85	-1.07
0.00	-0.95	-4.11	-1.85	-1.82	-0.64	-0.92	-0.72
-1.00	-0.54	-3.95	-1.55	-1.55	-0.75	-1.07	-1.18
-2.00	-0.22	-4.23	-1.49	-1.59	-1.16	-1.05	-0.89
-3.00	-0.77	-4.24	-1.54	-1.54	-0.72	-0.79	-1.02

4b) Checking that the vergence loop remains closed when viewing the diffuse green light in an otherwise darkened room.

Average mean sphere accommodation measurements recorded while viewing the diffuse green light in an otherwise darkened room through a supplementary prismatic lens (S. lens) which induces convergent accommodation when the vergence loop is closed.

S. lens	AS	JE	JH	JG	BS	JS	AN
0.00	-0.94	-0.53	-0.67	-0.42	-0.70	-1.08	-0.93
2.00Δ	-1.33	-0.53	-0.45	-1.04	-0.97	-1.10	-1.07
4.00Δ	-1.54	-0.50	-0.35	-0.68	-0.58	-1.37	-1.32
6.00Δ	-1.62	-0.63	-0.63	-1.00	-2.32	-1.52	-1.50

4c) Checking the accommodative loop is open when viewing a laser speckle target in an otherwise darkened room

Average mean sphere open-loop accommodation measurements recorded using the Canon Autoref R-1 optometer while viewing the laser speckle target in an otherwise darkened room. The target was placed at different distances from the subject to give various stimulus levels.

Stimulus	CR	TW	FF	RD	JG
0.00	-2.39	-4.61	-1.37	-0.79	-1.03
-0.85	-2.65	-4.36	-1.10	-0.80	-1.24
-1.35	-2.37	-4.24	-1.22	-0.65	-1.35
-3.06	-1.92	-3.94	-1.44	-0.68	-1.23
-8.11	-2.58	-4.90	-1.63	-0.73	-1.37

APPENDIX 5

SOFTWARE FOR THE APPLE IIe COMPUTER TO CONTROL THE EXPERIMENTAL CONDITIONS FOR MEASURING ACCOMMODATIVE REGRESSION PATTERNS

The software was written by the author in Applesoft BASIC. The program begins by timing the period of closed-loop viewing (3 mins) but a few seconds before the end of this viewing period an audiable signal is emited to warn the experimenter and the subject of the imminent onset of darkroom conditions. The computer controls an interface unit which switches on and off the lamp illuminating the target. After the 3 minute period of closed-loop viewing, the lamp is automatically switched off. Following a further 90 s, the lamp is automatically switched on again to mark the end of the measurement of accommodative regression.

```
10    HOME                                              'Clears screen
20    PR# 4: PRINT CHR$ (41); "<R31>": : PR#0           'Lamp on
30    PRINT "ACCOMMODATIVE REGRESSION PROGRAM"
40    PRINT : PRINT : "WRITTEN BY NICOLA EDWARDS"
50    PRINT : PRINT : "DO YOU WANT TO CONTINUE? (Y/N)"
60    GET A$
70    IF A$ = "Y" OR A$ = "N" THEN 100
80    PRINT : "INVALID ENTRY, TYPE Y OR N"
90    GOTO 60
100   IF A$ = "N' THEN 230
110   GOTO 120
120   HOME                                              'Clears screen
130   FOR PAUSE = 1 TO 2500 : NEXT PAUSE                'Pausing for a few seconds
140   PRINT CHR$ (7)                                    'Bleeping to indicate start of
                                                        closed-loop viewing period
150   FOR PAUSE = 1 TO 120000 : NEXT PAUSE              'Pausing for 3 minutes
160   PRINT CHR$ (7) : PRINT CHR$ (7)                   'Double bleep to indicate
                                                        imminent onset of darkness
170   FOR OAUSE = 1 TO 2000 : NEXT PAUSE                'Pausing for 5 seconds
180   PRINT CHR$ (7)                                    'Bleep to indicate onset of
                                                        darkness
190   PR# 4 : PRINT CHR$ (41); <R30>" : PR#0            'Lamp off
200   FOR PAUSE = 1 TO 60000 : NEXT PAUSE               'Pausing for 90 secons
210   PRINT CHR$ (7)                                    'Bleep to indicate end of
                                                        regression measurement
220   GOTO 10
230   PR#4 : PRINT CHR$ (41) : <R30> : PR#0             'Lamp off
240   STOP
```

APPENDIX 6

SOFTWARE FOR THE APPLE IIe WHEN USING THE FLASHED MADDOX ROD TECHNIQUE TO MEASURE VERGENCE

6a) Program to demonstrate the flashed Maddox rod routine to new subjects.

This program was adapted by the author from part of the prism adaptation program written by Dave Sculfor written in Applesoft BASIC. The exposure of the Maddox rod is longer during the demonstration (≈ 0.5 s) than when measuring vergence under experimental conditions (125 ms) so that the subjects can familiarise themselves with the technique.

```
10    REM DEMONSTRATION PROGRAM
20    PR# 4: PRINT CHR$ (41);"<R10,R20,R31>': PR# 0   'Chart on, spotlight off
                                                       and shutter closed
30    HOME                                             'Clears screen
40    PRINT "DEMONSTRATING THE FLASHED MADDOX ROD PROCEDURE"
50    FOR PAUSE = 1 TO 1000 : NEXT PAUSE               'Pausing for a while
60    HOME                                             'Clears screen
70    PRINT "THE SHUTTER CAN ONLY BE OPENED FOR A" : PRINT:
80    PRINT "CERTAIN TIME BEFORE IT OVER HEATS, SO IF": PRINT :
90    PRINT "YOU NEED TO DEMONSTRATE THE MADDOX ROD": PRINT :
100   PRINT "USE A TRIAL FRAME AND PRESS 'S' WHICH" : PRINT :
120   PRINT "WILL TURN THE SPOTLIGHT ON AND THE CHART" :PRINT :
130   PRINT "OFF WITHOUT OPENING THE SHUTTER": PRINT:
140   PRINT "PRESS 'S' FOR THE SPOTLIGHT: :PRINT :
150   PRINT "OR 'F' TO DEMONSTRATE THE FULL PROCEDURE"
160   GET E$
170   IF E$ = "S" OR E$ = "F" THEN 230
180   HOME
190   PRINT "INVALID ENTRY - PRESS "R" FOR THE ": PRINT :
200   PRINT "SPOTLIGHT OR "C' TO DEMONSTRATE THE" : PRINT :
210   PRINT "FULL PROCEDURE"
220   GOTO 160
230   IF E$ = "S" THEN 250
240   GOTO 270
250   PR# 4: PRINT CHR$ (41);"<R30,R21>": PR# 0       'Chart off, spotlight on
260   HOME                                             'Clears screen
270   PRINT "THE SPOTLIGHT SHOULD NOW BE ON AND THE ": PRINT :
280   PRINT "CHART OFF": PRINT : PRINT
290   PRINT "TO DEMONSTRATE THE FULL PROCEDURE": PRINT :
300   PRINT "PRESS ANY KEY"
310   GET F$
320   PR# 4: PRINT CHR$ (41);"<R31,R20>": PR# 0       'Chart on, spotlight off
330   D = 7000:E = 200:F = 7000                        'Setting time constants
340   R$ = "INSERT THE MADDOX ROD"                     'Flashing instruction
350   S$ = "REMOVE THE MADDOX ROD"                     'Flashing instruction
360   U = 1:T$ = "":N = 1:V = 10                       'Setting counter
370   HOME                                             'Clears screen
380   PRINT "THE PROCEDURE WILL NOW BE DEMONSTRATED"; CHR$ (13);
      CHR$ (13); "AT A SLOWER SHUTTER SPEED TO ALLOW THE"; CHR$
      (13); CHR$ (13); "SUBJECT TO VIEW THE SPOTLIGHT": PRINT :
390   PRINT "WHEN INSTRUCTED, MOVE THE MADDOX ROD": PRINT :
400   PRINT "IN FRONT OF THE RIGHT EYE"; PRINT : PRINT
410   PRINT "AT THE DOUBLE BLEEP BE READY TO REMOVE": PRINT :
420   PRINT "THE MEADDOX ROD AS SOON AS THE SHUTTER": PRINT :
430   PRINT "HAS FIRED, FOR A 15 SECOND PERIOD OF" : PRINT :
440   PRINT "BINOCULAR VIEWING": PRINT : PRINT.
450   PRINT : "PRESS ANY KEY TO CONTINUE INSTRUCTIONS"
460   GET J$                                           'Continuing instructions
470   HOME                                             'Clears screen
```

```
480   PRINT "TELL THE PATIENT TO READ THE LETTERS ON": PRINT :
490   PRINT "THE CHART UNTIL THEY HEAR THE DOULBLE": PRINT :
500   PRINT "BLEEP, THEN LOOK AT THE SPOTLIGHT FOR": PRINT :
510   PRINT "THE PHORIA MEASUREMENT".:PRINT : PRINT :
520   PRINT "IF THE SUBJECT IS READY, PRESS ANY KEY": PRINT :
530   PRINT "TO START (NOTE:- BEGINS WITH OCCLUSION)"
540   GET G$                                          'To continue procedure
550   GOSUB 600
560   PR# 4: PRINT CHR$ (41);"<R10>": PR# 0
570   STOP
600   HOME
605   NEXT N
610   FLASH : PRINT R$: PRINT : PRINT : NORMAL        'Flashing message
620   PRINT T$:
630   PRINT : PRINT "RUN NUMBER";N;" OF ";U           'No. of runs completed
640   FOR PAUSE = 1 TO 1000: NEXT PAUSE               'Pausing for ≈4 s
650   FOR PAUSE = 1 TO D: NEXT PAUSE                  'Pausing for ≈3 s
660   PRINT CHR$ (7): PRINT CHR$ (7)                  'Double bleep
670   FOR PAUSE = 1 TO 700: NEXT PAUSE                'Pausing for ≈3 s
680   PR# 4: PRINT CHR$ (41);:<R30,R11,R21>": PR# 0   'Spotlight on, chart off,
                                                      shutter open
690   FOR PAUSE = 1 TO E: NEXT PAUSE                  'Exposing MR for 0.5 s
700   HOME                                            'Clears screen
710   FLASH : PRINT S$: NORMAL                        'Flashing message
720   PR# 4: PRINT CHR$ (41);"<R10>": PR# 0           'Close shutter
730   HOME
740   FLASH : PRINT S$; NORMAL : PRINT : PRINT :      'Flashing message
750   PRINT "RUN NUMBER ";N;" OF ";U                  No. of runs completed
760   FOR PAUSE = 1 TO 1340: NEXT PAUSE               'Pausing for ≈ 5 s
770   PR# 4: PRINT CHR$ (41);"<R20,R31>": PR# 0       'Spotlight off, chart on
780   IF N = V THEN GOTO 560                          'Checks no. repeats =10
790   RETURN                                          'If not, repeat until 10
                                                      measurements obtained
```

6b) Program for measuring 'phoria and accommodative convergence.
This program was written by the author in AppleSoft BASIC and is designed to measure 'phorias and accommodative convergence in order to assess the AC/A ratio. The Maddox rod was exposed for 125 ms.

```
10    REM 'PHORIA AND ACCOMMODATIVE CONVERGENCE PROGRAM
20    PR# 4: PRINT CHR$ (41);"<R10,R20,R30>": PR# 0   'Chart off, spotlight off
                                                      and shutter closed
30    HOME                                            'Clears screen
40    PRINT "'PHORIA AND ACCOMMODATIVE CONVERGENCE
      MEASUREMENT PROGRAM"
50    PRINT
60    PRINT "WRITTEN BY NICOLA EDWARDS'
70    PR# 4: PRINT CHR$ (41);"<R31>": PR# 0           'Turns chart on
80    FOR PAUSE = 1 TO 25000: NEXT PAUSE              'Pausing for ≈10 s
90    HOME                                            'Clears screen
100   PRINT CHR$ (7): PRINT CHR$ (7)                  'Emits warning bleep
110   FOR PAUSE = 1 TO 600: NEXT PAUSE                'Pausing for 2 seconds
120   PR# 4: PRINT CHR$ (41);"<R11,R21,R30>": PR# 0   'Chart off, spotlight on,
                                                      shutter open
130   FOR PAUSE = 1 TO 76: NEXT PAUSE                 'Pauses for 125 ms
140   PR#4: PRINT CHR$ (41);"<R10>": PR# 0            'Shutter closes
150   FOR PAUSE = 1 TO 600: NEXT PAUSE                'Pauses for ≈2 s
160   PR# 4: PRINT CHR$ (41);"<R20,R31>": PR# 0       'Spotlight off, chart on
170   PRINT "DO YOU WANT TO CONTINUE? Y/N"
180   GET A$
190   IF A$ = "Y" GOTO 80
```

```
200   IF A$ = "N" GOTO 240
210   PRINT CHR$ (7)                                    'Bleep
220   PRINT "INVALID ENTRY - PLEASE TYPE Y OR N"         'Checking input
230   GOTO 180
240   PR# 4: PRINT CHR¢ (41);"<R30>": PR# 0: STOP        'Chart off, program
      finished
```

6c) Program for measuring tonic vergence disparity (TVD).
This program was written by the author in AppleSoft BASIC and is similar to the 'phoria and accommodative convergence program however the period of time the spotlight remains on following the flashed Maddox Rod is reduced to 125 ms from 2 s to avoid the initiation of an accommodative response, ensuring the accommodative loop remains open throughout the whole measurement procedure. In addition, as TVD is measured in complete darkness, the chart illumination remains off.

```
10    REM  TONIC VERGENCE DISPARITY PROGRAM
20    HOME                                               'Clears screen
30    PR# 4: PRINT CHR$ (41);"<R10,R20,R30>": PR# 0      'Chart off, spotlight off
                                                         and shutter closed
40    PRINT "TONIC VERGENCE DISPARITY PROGRAM"
50    PRINT
60    PRINT "WRITTEN BY NICOLA EDWARDS'
70    FOR PAUSE = 1 TO 800: NEXT PAUSE                   'Pausing for ≈ 2 s
80    PRINT : PRINT
90    PRINT "PRESS ANY KEY TO CONTINUE"                  'Instructing continuation
                                                         of the computer program
100   GET A$
110   HOME                                               'Clears screen
120   FOR PAUSE = 1 TO 7500: NEXT PAUSE                  'Pausing for a while
130   PRINT CHR$ (7): PRINT CHR$ (7)                     'Emits warning bleep
140   FOR PAUSE = 1 TO 600: NEXT PAUSE                   'Pausing for ≈ 2 s
150   PR# 4: PRINT CHR$ (41);"<R11,R21>": PR# 0          'Spotlight on shutter open
160   FOR PAUSE = 1 TO 76: NEXT PAUSE                    'Pauses for 125 ms
170   PR#4: PRINT CHR$ (41);"<R10>": PR# 0               'Shutter closes
180   FOR PAUSE = 1 TO 76: NEXT PAUSE                    'Pauses for 125 ms
190   PR# 4: PRINT CHR$ (41);"<R20>": PR# 0              'Spot light off
200   GOTO 110                                           'Loop to continue taking
                                                         measurements
```

6d) Program for measuring prism adaptation.
This program was written by Dave Sculfor in AppleSoft BASIC and includes a practice session, baseline 'phoria measurements and option of 15 adaptation only or 15 adaptation and 10 recovery measurements to induced prism.

```
10    REM SBR 2000=DEMO, 3000=BASELINE, 4000=ADAPTATION,
      6000=SHUTTER/CHART CONTROL
20    REM VARIABLES ARE D=OCCLUSION PERIOD, E=SHUTTER TIME, F=
      BINOCULAR VIEWING PERIOD
30    POKE 33, 40
40    PR# 4: PRINT CHR$ (41);"<R10,R20,R31>": PR# 0
50    HOME : PRINT : PRINT : PRINT : PRINT
60    PRINT "PRISM ADAPTATION PROGRAM
70    PRINT
80    PRINT "WRITTEN BY DAVE SCULFOR"
90    PRINT
100   PRINT "OCTOBER 1990"
110   FOR PAUSE = 1 TO 2500: NEXT PAUSE
180   CLEAR : HOME : PRINT "TO DEMONSTRATE THE PROCEDURE TO THE
      " PRINT "SUBJECT PRESS 'D'": PRINT : PRINT : PRINT : "OR" PRINT :
      PRINT : PRINT "TO GO STRAIGHT TO THE PHORIA MEASUREMENT":
      PRINT "PRESS 'C'": PRINT
```

```
200   GET C$
210   IF C$ = "D" OR C$ = "C" THEN 230
220   HOME : PRINT "INVALID ENTRY-": PRINT : PRINT "CHECK THAT THE
      CAPS LOCK IS ON": PRINT : PRINT : PRINT " PRESS 'D' TO
      DEMONSTRATE OR": PRINT : PRINT "PRESS 'C' FOR MEASUREMENT":
      GOTO 200
230   IF C$ = "D" THEN GOSUB 2000 : GOTO 300: REM ALLOWS DEMO THEN
      GOES TO BASELINE
300   GOSUB 3000: REM GOES TO BASELINE
310   HOME : PRINT "IF THE FIRST THREE READINGS WERE THE": PRINT:
      PRINT "SAME, GO ON TO THE ADAPTATION PROCEDURE": PRINT :
      PRINT "BY PRESSING 'A'": PRINT: PRINT: PRINT "OR" :PRINT : PRINT
320   PRINT "PRESS 'R' TO REPEAT THE BASELINE": PRINT : PRINT
      "MEASUREMENTS AND AVERAGE THESE THREE"
330   GET I$
340   IF I$ = "A" OR I$ = "R" THEN 360
350   HOME : PRINT "INVALID ENTRY PRESS 'R' TO REPEAT"; CHR$ (13);
      CHR$ (13); "BASELINE MEASUREMENTS OR 'A' TO GO ONTO"; CHR$
      (13); CHR$ (13); "THE ADAPTATION PROCEDURE': GOTO 330
360   IF I$ = "R" THEN GOSUB 3000 : REM REPEATS BASELINE
      MEASUREMENTS
370   GOSUB 4000: REM FINDS ADAPTATION THEN RETURNS TO CHECK
      WHETHER RECOVERY REQUIRED
380   IF W = 0 THEN GOTO 180: REM ENDS RUN AND RETURNS TO START
      OR GOES ON TO RECOVERY MEASUREMENT
390   D = 8040:E = 76:F = 9855:R$ = "REMOVE THE PRISM & INSERT THE
      MADDOX ROD":U = 10:N = 1: V = 10: REM RECOVERY PROCEDURE
400   T$ = "NOW MEASURING RECOVERY (TEN REPEATS)"
420   S$ = "REMOVE THE MADDOX ROD"
430   GOSUB 6000
440   D = 8045:E = 76:F = 9855:R$ = "INSERT MADDOX ROD":S$ = "REMOVE
      MADDOX ROD":U = 10:T$ = "";V = 10
450   FOR N = 2 TO 10
460   GOSUB 6000
470   NEXT N
480   GOTO 180: REM ENDS RUN
2000  HOME : PRINT "DEMONSTRATING THE PROCEDURE": PRINT
      "**************************************************"
2010  FOR PAUSE = 1 TO 1000 : NEXT PAUSE
2020  HOME : PRINT "THE SHUTTER CAN ONLY BE OPENED FOR A" : PRINT:
      PRINT "CERTAIN TIME BEFORE IT OVER HEATS, SO IF": PRINT :
      PRINT "YOU NEED TO DEMONSTRATE THE MADDOX ROD": PRINT :
      PRINT "USE A TRIAL FRAME AND PRESS 'R' WHICH" : PRINT
2030  PRINT "WILL TURN THE SPOTLIGHT ON AND THE CHART" :PRINT :
      PRINT "OFF WITHOUT OPENING THE SHUTTER": PRINT: PRINT
2040  PRINT "PRESS 'R' FOR THE SPOTLIGHT: :PRINT : PRINT "OR 'C' TO
      DEMONSTRATE THE FULL PROCEDURE"
2050  GET E$
2060  IF E$ = "R" OR E$ = "C" THEN 2080
2070  HOME : PRINT "INVALID ENTRY - PRESS "R" FOR THE ": PRINT :
      PRINT "SPOTLIGHT OR "C" TO DEMONSTRATE THE" : PRINT : PRINT
      "FULL PROCEDURE": GOTO 2050
2080  IF E$ = "R" THEN 2100
2090  GOTO 2140
2100  PR# 4: PRINT CHR$ (41);"<R30,R21>": PR# 0
2110  HOME: PRINT "THE SPOTLIGHT SHOULD NOW BE ON AND THE ":
      PRINT : PRINT "CHART OFF: PRINT : PRINT
2120  PRINT "TO DEMONSTRATE THE FULL PROCEDURE": PRINT : PRINT
      "PRESS ANY KEY"
2130  GET F$
2140  PR# 4: PRINT CHR$ (41);"<R31,R20>": PR# 0
```

```
2150  D = 7000:E = 200:F = 7000:R$ = "INSERT THE MADDOX ROD":S$ =
      "REMOVE THE MADDOX ROD": U = 1:T$ = "":N = 1:V = 10
2160  HOME : PRINT "THE PROCEDURE WILL NOW BE DEMONSTRATED";
      CHR$ (13); CHR$ (13); "AT A SLOWER SHUTTER SPEED TO ALLOW
      THE"; CHR$ (13); CHR$ (13); "SUBJECT TO VIEW THE SPOTLIGHT":
      PRINT : PRINT
2170  PRINT "WHEN INSTRUCTED, MOVE THE MADDOX ROD": PRINT :
      PRINT "IN FRONT OF THE RIGHT EYE"; PRINT : PRINT
2180  PRINT "AT THE DOUBLE BLEEP BE READY TO REMOVE": PRINT :
      PRINT "THE MEADDOX ROD AS SOON AS THE SHUTTER": PRINT :
      PRINT "HAS FIRED, FOR A 15 SECOND PERIOD OF" : PRINT : PRINT
      "BINOCULAR VIEWING": PRINT : PRINT.
2190  PRINT : PRINT "PRESS ANY KEY TO CONTINUE INSTRUCTIONS"
2200  GET J$: HOME
2210  PRINT "TELL THE PATIENT TO READ THE LETTERS ON": PRINT :
      PRINT "THE CHART UNTIL THEY HEAR THE DOULBLE": PRINT :
      PRINT :BLEEP, THEN LOOK AT THE SPOTLIGHT FOR": PRINT : PRINT
      "THE PHORIA MEASUREMENT"
2220  PRINT : PRINT : PRINT "IF THE SUBJECT IS READY, PRESS ANY KEY":
      PRINT : PRINT "TO START (NOTE:- BEGINS WITH OCCLUSION)"
2230  GET G$
2240  GOSUB 6000
2250  PR# 4: PRINT CHR$ (41);"<R10>": PR# 0
2260  HOME: PRINT "TO REPEAT THE DEMONSTRATION PRESS 'D'": PRINT :
      PRINT "OR": PRINT : PRINT "TP RUN THE ADAPTATION PROCEDURE":
      PRINT : PRINT "PRESS 'C'"
2270  GET H$
2280  IF H$ = "D" OR H$ = "C" THEN 2300
2290  HOME : PRINT "INVALID ENTRY": GOTO 2260
2300  IF H$ = "D" THEN HOME : GOTO 2140
2310  RETURN : REM RETURNS TO GO ONTO BASELINE
3000  HOME : PRINT "FINDING THE BASELINE PHORIA": PRINT
      "*****************************************"
3010  FOR PAUSE = 1 TO 1500: NEXT PAUSE: HOME
3020  PRINT "WHEN THE COMPUTER INDICATES, INSERT": PRINT : PRINT
      "THE MADDOX ROD BEFORE THE RIGHT EYE": PRINT : PRINT : PRINT
      "WHEN IT BLEEPS TWICE, REMOVE THE MADDOX": PRINT : PRINT
      "ROD AS SOON AS THE SHUTTER HAS FIRED": PRINT ; PRINT
3030  PRINT "TELL THE PATIENT TO READ THE LETTERS ON": PRINT :
      PRINT "THE CHART UNTIL THEY HEAR THE DOUBLE": PRINT : PRINT
      "BLEEP, THEN LOOK AT THE SPOTLIGHT FOR": PRINT : PRINT "THE
      PHORIA MEASUREMENT": PRINT : PRINT
3040  PRINT : PRINT "PRESS ANY KEY TO CONTINUE INSTRUCTIONS."
3050  GET K$
3060  HOME : PRINT "IF THE SUBJECT IS READY, PRESS ANY KEY": PRINT :
      PRINT "TO START THE SEQUENCE WHICH REPEATS": PRINT : PRINT
      "THREE TIMES AND STARTS WITH OCCLUSION"
3070  GET B$
3080  D = 8045:E - 76:F = 9855:R$ = "INSERT MADDOX ROD":S$ = "REMOVE
      MADDOX ROD":T$ = "":U = 3:V = 3
3090  FOR N = 1 TO 3
3100  GOSUB 6000
3110  NEXT N
3120  PR# 4: PRINT CHR$ (41);"<R10>": PR# 0
3130  RETURN
4000  HOME : PRINT "FINDING THE ADAPTATION"
4010  PRINT "*****************************": PRINT : PRINT
4020  FOR PAUSE = 1 TO 1500: NEXT PAUSE
4030  HOME : PRINT "THE ADAPTATION PROCEDURE IS SIMILAR TO: PRINT
      : PRINT "THE BASELINE PHORIA MEASUREMENT, BUT THE":
```

```
      PRINT"SUBJECT WILL VIEW THROUGH THE PRISM: PRINT : PRINT
      "ALL THE TIME": PRINT : PRINT
4040  PRINT "BEFORE STARTING PLACE THE PRISM IN THE": PRINT : PRINT
      "LENS HOLDER": PRINT : PRINT "WHEN INDICATED PLACE THE
      MADDOX ROD IN": PRINT : PRINT "THE LENS HOLDER ALSO": PRINT :
      PRINT
4060  PRINT : PRINT "PRESS ANY KEY TO CONTINUE INSTRUCTIONS."
4070  GET J$: HOME
4080  PRINT "AT THE DOUBLE BLEEP BE READY TO REMOVE": PRINT :
      PRINT "THE MADDOX ROD AS SOON AS THE SHUTTER": PRINT :
      PRINT "HAS FIRED, FOR A 15 SECOND PERIOD OF": PRINT : PRINT
      "BINOCULAR VIEWING": PRINT : PRINT
4090  PRINT "TELL THE PATIENT TO READ THE LETTERS ON": PRINT :
      PRINT "THE CHART UNTIL THEY HEAR THE DOUBLE": PRINT : PRINT
      "BLEEP, THEN LOOK AT THE SPOTLIGHT FOR": PRINT : PRINT "THE
      PHORIA MEASUREMENT": PRINT : PRINT
4100  PRINT "PRESS ANY KEY TO CONTINUE INSTRUCTIONS": GET T$
4110  HOME : PRINT "IF YOU WANT TO MEASURE RECOVERY AFTER":
      PRINT : PRINT "ADAPTATION PRESS 'R'": PRINT : PRINT : PRINT "OR":
      PRINT : PRINT : PRINT "FOR ADAPTATION ONLY PRESS 'A'"
4120  GET N$
4130  IF N$ = "R" OR N$ = "A" THEN 4150
4140  HOME : PRINT "INVALID ENTRY - PRESS 'R' TO MEASURE": PRINT :
      PRINT "RECOVERY AFTER ADAPTATION OR 'A' FOR": PRINT : PRINT
      "ADAPTATION ONLY"; GOTO 4120
4150  IF N$ "R" THEN W = 1:V = 20: GOTO 4170
4160  W = 0:V = 15
4170  PRINT : PRINT : PRINT "IF THE SUBJECT IS READY, PRESS ANY KEY":
      PRINT : PRINT : "TO START THE SEQUENCE WHICH REPEATS 15":
      PRINT : PRINT "TIMES AND STARTS WITH OCCLUSION"
4180  GET L$
4190  D = 8045:E = 76:F = 9855:R$ = "INSERT MADDOX ROD";S$ = "REMOVE
      MADDOX ROD":T$ = "":U = 15
4200  FOR N = 1 TO 15
4210  GOSUB 6000
4220  NEXT N
4230  RETURN
6000  HOME : FLASH : PRINT R$: PRINT : PRINT : NORMAL : PRINT T$: PRINT
      : PRINT : PRINT : PRINT "RUN NUMBER";N;" OF ";U
6010  FOR PAUSE = 1 TO 1000: NEXT PAUSE
6020  FOR PAUSE = 1 TO D: NEXT PAUSE
6030  PRINT CHR$ (7): PRINT CHR$ (7): REM DOUBLE BLEEP
6040  FOR PAUSE = 1 TO 700: NEXT PAUSE
6050  PR# 4: PRINT CHR$ (41);:<r30,r11,r21>": PR# 0 : REM FLASH SPOT,
      CHART OFF, SHUTTER OPEN
6060  FOR PAUSE = 1 TO E: NEXT PAUSE
6065  HOME : FLASH : PRINT S$: NORMAL
6070  PR# 4: PRINT CHR$ (41);"<R10>": PR# 0: REM CLOSE SHUTTER
6075  HOME : FLASH : PRINT S$; NORMAL : PRINT : PRINT : PRINT : PRINT :
      PRINT : PRINT "RUN NUMBER ";N;" OF ";U
6080  FOR PAUSE = 1 TO 1340: NEXT PAUSE
6100  PR# 4: PRINT CHR$ (41);"<R20,R31>": PR# 0: REM SPOTLIGHT OFF,
      CHART ON
6103  IF N = V THEN RETURN
6105  PR# 4: PRINT CHR$ (41);"<R11>": PR# 0: REM OPEN SHUTTER
6110  FOR PAUSE = 1 TO F: NEXT PAUSE
6120  PR# 4: PRINT CHR$ (41);"<R10>": PR# 0: REM CLOSE SHUTTER
6130  RETURN
7000  POKE 33,40: PR# 1: LIST : REM LISTING SUBROUTINE ONLY
7010  PR# 0: POKE 33, 33
7020  STOP
```

APPENDIX 7

OCULOMOTOR RESPONSES OF EMMETROPES AND MYOPES

7a) Background data

Presented here are individuals' right eye data for mean sphere refractive error (Rx), Keretometry ('K'), axial length (A.L.), anterior chamber depth (A.C.D.), lens thickness (L.T.), vitreous chamber depth (V.C.D.) and age of subject. For the early- and late-onset myopes the age of myopic onset has been included.

EMMETROPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)
AS	0.25	7.78	23.42	3.86	3.73	15.83	23
BS	0.12	7.33	22.00	3.25	3.19	15.56	18
GJ	-0.12						20
GP	-0.25	7.55	23.06	3.95	3.35	15.76	19
HC	0.25	7.88	23.69	3.68	3.42	16.56	27
HP	0.25	7.58	22.45	3.30	3.70	15.45	18
JE	0.37	7.48	22.16	3.86	3.68	14.62	21
JS	-0.12	7.45	23.93	3.89	3.85	16.19	18
JS	-0.25	7.60	23.56	2.86	3.73	16.90	20
KP	0.00	8.98	25.77	3.26	3.58	18.93	18
PP	0.50	7.55	22.65	3.65	3.41	15.59	19
RD	0.25	7.83	23.91	3.30	3.71	16.90	25
SR	0.12	7.63	23.62	3.45	3.62	16.55	22
WI	0.00	8.43	23.99	3.31	4.00	16.67	18
Mean	**0.10**	**7.77**	**23.40**	**3.51**	**3.61**	**16.27**	**20.43**
SEM	**0.06**	**0.12**	**0.26**	**0.09**	**0.06**	**0.28**	**0.76**

EARLY-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AH	-3.75	8.05	26.06	4.13	3.44	18.51	18	13
AN	-6.12	7.50	25.64	3.90	3.69	18.05	18	7
CW	-1.75	8.00	25.80	3.79	4.16	17.48	20	14
GP	-8.50	7.60	26.48	3.45	3.47	19.56	21	5
JB	-4.25	7.95	27.15	3.69	3.63	19.83	20	12
JG	-1.75	8.10	24.18	3.76	3.32	17.10	19	13
KL	-3.00	7.95	25.11	3.41	3.42	18.28	23	12
MD	-6.00	8.08	27.04	3.99	3.71	19.34	29	7
PH	-2.50	7.98	25.27	3.84	3.92	17.57	33	12
RM	-6.25	7.98	26.05	3.68	3.44	18.93	18	7
SS	-3.37	7.60	24.51	3.71	3.57	17.23	19	10
WF	-0.75	7.15	22.66	3.66	3.48	15.52	18	14
Mean	**-4.00**	**7.83**	**25.49**	**3.75**	**3.59**	**18.12**	**21.33**	**10.50**
SEM	**0.66**	**0.08**	**0.37**	**0.06**	**0.07**	**0.35**	**1.39**	**0.92**

LATE-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AW	-1.50	7.58	23.66	3.78	3.23	16.65	19	18
AW	-1.37	7.60	24.40	3.75	4.02	16.63	20	17
CH	-1.25						28	23
CR	-1.00	7.68	24.28	3.87	3.63	16.78	20	19
CW	-1.12	8.05	25.06	3.94	3.35	17.75	18	16
EF	-0.87	7.90	24.44	3.93	3.44	17.08	19	17
EW	-2.75	7.90	25.75	3.96	3.61	18.17	26	19
JH	-1.00	7.50	23.44	3.29	3.66	16.46	22	21

KD	-1.50	8.50	25.94	3.79	3.34	18.80	18	16
NB	-1.50	7.93	25.08	3.85	3.61	17.62	30	25
NH	-1.50	7.50	24.24	3.86	3.63	16.76	23	19
NW	-0.87	7.45	23.78	3.89	3.36	16.52	28	24
SB	-1.75	8.08	24.49	3.50	3.94	17.05	20	19
TH	-1.87	7.98	24.57	3.79	3.66	16.89	20	17
Mean	**-1.42**	**7.82**	**24.55**	**3.78**	**3.57**	**17.17**	**22.21**	**19.28**
SD	**0.14**	**0.09**	**0.22**	**0.05**	**0.07**	**0.02**	**1.18**	**0.84**

7b) Data for AC/A ratios (stimulus and response) and AR gradients
The accommodative stimulus appears in bold type at the top of each table, the average accommodative response for each subject is given in mean sphere below. Corresponding 'phoria measurements appear below the 'Δ' symbol. 'S' denotes an esophoric reading, 'X' represents an exophoric reading.

EMMETROPES

Subjects	**-0.44D**	**Δ**	**-1.42D**	**Δ**	**-2.37D**	**Δ**	**-3.30D**	**Δ**
AS	-0.31	0.92X	-0.95	0.80S	-1.52	3.70S	-1.83	5.58S
BS	-0.10	0.56X	-0.47	2.50S	-1.37	5.10S	-1.71	9.44S
GJ	-0.64	1.60S	-1.11	3.74S	-1.66	8.44S	-1.83	11.28S
GP	-0.33	0.02X	-0.48	3.72S	-1.32	6.56S	-1.53	8.88S
HC	-0.49	1.24X	-0.87	0.68S	-1.36	3.82S	-1.78	6.94S
HP	-0.50	3.62X	-1.09	4.24S	-1.56	6.66S	-1.81	6.50S
JE	-0.09	8.00S	-0.76	8.82S	-1.40	11.72S	-1.58	13.5S
JS	-0.40	0.54X	-1.25	1.90S	-1.73	3.84S	-2.24	5.68S
JS	-0.58	0.96X	-0.99	7.38S	-1.38	11.40S	-1.73	16.00S
KP	-0.76	0.50X	-1.22	1.76S	-1.82	3.06S	-2.03	6.94S
PP	-0.42	1.22X	-1.10	0.48S	-1.56	3.25S	-1.55	2.88S
RD	-0.37	2.66X	-1.12	0.60X	-1.59	0.12S	-1.93	2.80S
SR	-0.45	5.28S	-1.14	7.60S	-1.48	11.36S	-1.78	14.25S
WI	-0.38	0.62S	-1.13	3.54S	-1.33	4.68S	-1.63	7.02S

EARLY-ONSET MYOPES

Subjects	**-0.44D**	**Δ**	**-1.42D**	**Δ**	**-2.37D**	**Δ**	**-3.30D**	**Δ**
AH	-0.55	1.14X	-0.90	1.00S	-1.38	3.50S	-1.80	7.44S
AN	-0.20	5.34X	-0.90	3.18X	-1.38	3.44S	-1.77	5.74S
CW	-0.31	2.42S	-1.03	5.94S	-1.35	12.4S	-1.73	16.50S
GP	-0.13	4.00S	-0.67	8.40S	-1.27	10.14S	-1.50	12.78S
JB	-0.30	0.42S	-0.73	2.16S	-1.26	5.92S	-1.69	5.28S
JG	-0.17	1.32X	-1.18	3.34S	-1.61	6.34S	-2.13	10.00S
KL	-0.64	0.16S	-1.32	2.00S	-1.72	5.66S	-2.02	8.14S
MD	-0.37	3.00S	-0.99	4.20S	-1.34	4.84S	-1.79	10.30S
NB	-1.16	0.20X	-1.33	0.28S	-1.63	1.38S	-2.04	3.10S
PH	-0.13	3.56S	-1.02	7.84S	-1.47			
RM	-0.03	1.72S	-0.81	6.44S	-1.49	12.84S	-1.89	14.54S
SS	-0.89	2.04S	-1.35	4.34S	-1.75	5.62S	-2.02	10.34S
WF	-0.04	0.40S	-0.80	3.00S	-1.45	7.50S	-1.91	9.00S

LATE-ONSET MYOPES

Subjects	-0.44D	Δ	-1.42D	Δ	-2.37D	Δ	-3.30D	Δ
AW	-0.63	4.70X	-1.11	5.38X	-1.58	4.28X	-1.90	1.92X
AW	-0.54	0.65S	-0.87	2.10S	-1.13	3.84S	-1.38	5.46S
CH	-0.30	0.62S	-0.98	5.96S	-1.48	7.66S	-2.01	
CR	-0.08	2.58S	-0.83	6.56S	-1.21	9.06S	-1.65	10.64S
CW	-0.81	0.44X	-1.36	2.64S	-1.72	4.44S	-2.01	8.90S
EF	-0.70	3.40S	-1.57	6.88S	-1.54	10.44S	-1.84	14.38S
JH	-0.03	5.08S	-0.75	8.58S	-1.15	9.32S	-1.70	12.40S
KD	-0.73	0.00	-1.25	2.86S	-1.70	3.22S	-2.04	5.62S
NB	-0.10	1.28X	-0.75	0.18S	-1.34	1.22S	-1.72	5.80S
NH	-0.14	2.36S	-1.16	4.82S	-1.68	8.62S	-2.08	10.3S
NW	-0.80	1.32S	-1.08	4.40S	-1.78	6.56S	-2.04	7.56S
SB	-0.61	5.56S	-1.08	9.86S	-1.63	13.42S	-2.03	17.36S
TH	-0.68	0.60S	-1.20	4.00S	-1.67	7.56S	-2.13	12.02S

7c) Data for CA/C ratios

Individuals' mean open-loop accommodation measurements for each vergence stimulus are given in mean sphere form.

EMMETROPES

Subjects	10Δ base-out	12Δ base-out	14Δ base-out	16Δ base-out
AS	-0.94	-1.33	-1.54	-1.62
BS	-0.70	-0.97	-0.58	-2.32
GJ	-1.25	-1.78	-1.87	-1.98
GP	-1.02	-1.28	-1.33	-1.51
HC	0.27	0.14	-0.17	-0.33
HP	-1.73	-2.59	-2.9	-2.58
JE	-0.53	-0.53	-0.56	-0.63
JS	-0.92	-1.40	-1.51	-1.88
JS	-1.08	-1.10	-1.37	-1.52
KP	-1.81	-2.71	-3.34	-3.81
PP	-0.62	-0.56	-0.54	-0.64
RD				
SR	-0.27	-0.38	-0.43	-0.38
WI	-0.85	-1.10	-0.93	-1.21

EARLY-ONSET MYOPES

Subjects	10Δ base-out	12Δ base-out	14Δ base-out	16Δ base-out
AH	-0.57	-0.82	-0.65	-0.78
AN	-0.93	-1.07	-1.32	-1.50
CW	-0.23	-0.14	-0.31	-0.36
GP	0.00	-0.02	-0.36	-0.55
JB	-1.08	-1.13	-1.02	-1.28
JG	-0.42	-1.04	-0.68	-1.00
KL	-1.26	-1.66	-1.63	-1.70
MD	0.00	-0.07	0.07	0.10
NB	-1.41	-1.57	-1.67	-2.00
PH	-0.76	-0.83	-1.72	-1.48
RM	-0.54	-0.84	-0.93	-1.04
SS	-1.54	-1.68	-1.88	-1.83
WF	-0.56	-0.55	-0.82	-0.95

LATE-ONSET MYOPES

Subjects	10Δbase-out	12Δbase-out	14Δbase-out	16Δbase-out
AW	-0.86	-0.94	-1.47	-1.52
AW	-0.24	-0.31	-0.48	-0.47
CH	-0.26	-0.29	-0.16	-0.36
CR	-0.62	-1.03	-1.08	-1.36
CW	-1.18	-1.53	-1.93	-2.04
EF	-0.28	-0.35		
JH	-0.67	-0.45	0.35	-0.03
KD	-1.44	-1.57	-1.89	-2.11
NB	-1.01	-1.21	-1.04	-1.35
NH	0.15	0.14	0.16	0.00
NW	-0.54	-0.68	-0.79	-0.72
SB	-0.63	-1.00	-1.14	-1.53
TH	-0.90	-1.35	-1.58	-1.65

7d) Subjects' oculomotor measurements

Response AC/A ratio (AC/A (r)), stimulus AC/A ratio (AC/A (s)), accommodative response gradient (AR grd), CA/C ratio (CA/C), 'phoria where S denotes an esophoric measurement and X denotes an exophoric measurement, tonic vergence disparity (TVD) where S denotes an esophoric measurement and X denotes an exophoric measurement, Steady-state open-loop accommodation (SOLA) measured in darkness (d) and when viewing a dim green light (gl).

EMMETROPES

	AC/A (r) Δ/D	AC/A (s) Δ/D	AR grd D/D	CA/C D/6Δ	'Phoria Δ	TVD Δ	SOLA (d) D	SOLA(gl) D
RD	1.79	4.38	0.54	1.56	2.95X	0.69X	-0.57	-0.41
SR	3.21	7.42	0.45	0.24	5.86S	7.19S	-0.68	-0.27
GJ	3.54	8.82	0.43	1.32	1.78S	2.77S	-1.13	-1.25
BS	3.42	6.04	0.60	2.64	0.62X	1.29S	-0.65	-0.70
HC	2.90	7.06	0.45	1.20	1.38X	3.17S	-0.13	0.27
HP	1.29	2.80	0.46	1.68	4.02X	1.18X	-0.65	-1.73
PP	1.75	4.24	0.40	0.00	1.35X	0.44S	-0.10	-0.62
GP	3.44	6.73	0.46	0.96	0.02X	2.44S	-0.62	-1.02
KP	2.74	5.55	0.46	3.12	0.55X	2.73S	-1.43	-1.81
JS	6.40	15.91	0.40	1.80	1.06X	2.22S	-1.07	-0.92
AS	2.61	4.75	0.54	1.44	1.02X	1.26S	-0.59	-0.94
JS	2.40	3.77	0.63	0.96	0.60X	1.20S	-0.65	-1.08
WI	2.37	5.44	0.41	0.60	0.69S	6.05S	-0.64	-0.85
JE	2.25	3.96	0.54	0.24	8.08S	1.18S	-0.81	-0.53
Mean	**2.86**	**6.20**	**0.48**	**1.06**	**0.20S**	**2.26S**	**0.65**	**0.85**
SEM	**0.09**	**0.23**	**0.00 1**	**0.26**	**0.23**	**0.16**	**0.03**	**0.04**

EARLY-ONSET MYOPES

	AC/A (r) Δ/D	AC/A (s) Δ/D	AR grd D/D	CA/C D/6Δ	'Phoria Δ	TVD Δ	SOLA (d) D	SOL(gl) D
KL	6.41	3.21	0.48	0.72	0.18S	8.92S	-0.83	-1.26
PH	6.95	5.01	0.52	1.80	3.95S	1.66S	-0.70	-0.76
WF	5.37	3.53	0.66	0.84	0.44S	3.31S	-0.83	-0.79
RM	7.99	5.23	0.66	0.96	1.91S	4.97S	-0.46	-0.80
AN	8.31	4.64	0.54	1.20	5.93X	0.86S	-0.73	-0.93
JG	6.35	4.31	0.66	0.84	1.46X	1.42S	-0.10	-0.42
AH	7.85	3.47	0.44	0.24	1.26X	0.24S	-0.45	-0.57
SS	7.38	3.04	0.40	0.60	2.26S	1.15S	-0.70	-1.54
JB	4.38	2.14	0.49	0.24	0.47S	5.55S	-1.25	-1.08
CW	11.19	5.67	0.48	0.36	2.69S	3.00S	-0.61	-0.24
GP	6.48	3.27	0.49	1.20	4.44S	2.86S	0.10	0.00
MD	5.27	2.61	0.48	0.24	3.33S	2.62S	0.06	0.00
NB	4.20	1.28	0.31	1.08	0.22X	2.71S	-1.15	-1.41
Mean	**3.65**	**6.78**	**0.51**	**0.78**	**0.83**	**3.02**	**0.59**	**0.75**
SEM	**0.10**	**0.14**	**0.001**	**0.14**	**0.21**	**0.18**	**0.03**	**0.04**

LATE-ONSET MYOPES

	AC/A (r) Δ/D	AC/A (s) Δ/D	AR grd D/D	CA/C D/6Δ	'Phoria Δ	TVD Δ	SOLA (d) D	SOL(gl) D
AW	6.65	1.88	0.28	0.48	0.72S	5.28S	-0.43	-0.24
NW	5.08	2.44	0.46	0.36	1.46S	1.89S	-0.71	-0.54
JH	4.70	2.64	0.57	1.20	5.64S	4.97S	-0.14	-0.67
SB	8.96	4.54	0.50	1.68	6.17S	11.72S	-0.83	-0.63
EF	9.64	4.25	0.36	0.60	3.77S	2.77S	-0.50	-0.28
KD	4.34	2.01	0.46	1.44	0.00S	2.20S	-1.16	-1.44
CW	8.09	3.47	0.42	1.80	0.49X	2.73S	-1.33	-1.18
NB	4.30	2.58	0.57	0.48	1.42X	0.47X	-0.30	-1.01
CH	6.74	4.06	0.59	0.12	0.69X	1.97S	-0.22	-0.26
NH	4.63	3.22	0.67	0.24	2.62S	0.31S	0.06	0.15
TH	8.68	4.40	0.51	1.44	0.67S	3.42S	-0.71	-0.90
CR	5.84	3.12	0.53	1.32	2.86S	4.86S	-0.07	-0.62
AW	2.06	0.94	0.46	1.44	5.22X	0.04X	-1.52	-0.86
Mean	**3.22**	**0.47**	**0.49**	**0.87**	**1.24**	**3.20**	**0.53**	**0.65**
SEM	**0.07**	**0.15**	**0.001**	**0.18**	**0.23**	**0.24**	**0.03**	**0.03**

APPENDIX 8

PRISM ADAPTATION IN EMMETROPIA AND MYOPIA

8a) Background data

Individuals' right eye data for mean sphere refractive error (Rx), keretometry ('K'), axial length (A.L.), anterior chamber depth (A.C.D.), lens thickness (L.T.), vitreous chamber depth (V.C.D) and age of subject.

EMMETROPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)
AD	0.12	7.78	23.40	3.73	3.48	16.19	20
BS	0.12	7.33	22.00	3.25	3.19	15.56	18
DH	0.37	8.15	24.65	3.91	3.14	17.60	19
FF	-0.12	7.83	23.33	3.78	3.62	15.93	22
GJ	-0.12						20
GR	0.25						24
HC	0.25	7.88	23.69	3.68	3.42	16.56	27
JE	0.37	7.48	22.16	3.86	3.68	14.62	21
JS	-0.12	7.45	23.93	3.89	3.85	16.19	18
JSm	-0.25	7.60	23.56	2.86	3.73	16.90	20
MH	0.50	7.63	22.63	3.61	3.38	15.24	20
NW	0.00	7.90	23.10	3.50	3.74	15.86	18
RD	0.25	7.83	23.91	3.30	3.71	16.90	25
RR	0.12						21
WI	0.00	8.43	23.99	3.31	4.00	16.67	18
Mean	**0.12**	**7.77**	**23.36**	**3.56**	**3.58**	**16.18**	**20.73**
SEM	**0.06**	**0.08**	**0.20**	**0.08**	**0.07**	**0.21**	**0.70**

EARLY-ONSET MYOPES

Subjects	Mean Rx (D)	Mean'K' (mm)	A.L. (mm)	A.C.D (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AD	-4.87	7.85	25.54	3.37	3.75	18.42	19	11
AH	-3.75	8.05	26.06	4.13	3.44	18.51	18	13
CG	-2.00	7.55	23.41	3.47	3.76	16.18	18	13
CW	-1.75	8.00	25.80	3.79	4.16	17.48	20	14
GD	-2.12						20	12
HH	-10.25						20	6
JG	-1.75	8.10	24.18	3.76	3.32	17.10	19	13
KL	-3.00	7.95	25.11	3.41	3.42	18.28	23	12
MD	-6.00	8.08	27.04	3.99	3.71	19.34	29	7
MP	-1.75	7.40	23.48	3.65	3.36	16.47	20	11
NB	-5.50						18	12
NE	-4.37	7.50	24.45	3.78	3.68	16.99	23	14
RH	-5.12	7.50	24.76	3.77	4.46	16.53	19	12
SL	-3.25	7.13	24.01	3.98	3.61	16.43	19	14
WF	-0.75	7.15	22.66	3.66	3.48	15.52	18	14
Mean	**-3.75**	**7.69**	**24.71**	**3.73**	**3.68**	**17.27**	**20.20**	**11.87**
SEM	**0.62**	**0.09**	**0.32**	**0.06**	**0.09**	**0.29**	**0.75**	**0.62**

LATE-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AW	-1.37	7.60	24.40	3.75	4.02	16.63	20	17
CH	-1.25						28	23
CR	-1.00	7.68	24.28	3.87	3.63	16.78	20	19
EF	-0.87	7.90	24.44	3.93	3.44	17.08	19	17
EW	-2.75	7.90	25.75	3.96	3.61	18.17	26	19
JH	-1.00	7.50	23.44	3.29	3.66	16.46	22	21
JP	-3.37	8.15	25.78	3.85	3.52	18.41	19	16
KD	-1.50	8.50	25.94	3.79	3.34	18.80	18	16
KJ	-0.75	7.53	24.09	3.68	3.63	16.78	20	18
NB	-1.50	7.93	25.08	3.85	3.61	17.62	30	25
NH	-1.50	7.50	24.24	3.86	3.63	16.76	23	19
NW	-0.87	7.45	23.78	3.89	3.36	16.52	28	24
RB	-1.25	7.33	23.19	3.89	3.38	15.92	19	18
SC	-0.75						20	17
TH	-1.87	7.98	24.57	3.79	3.66	16.89	20	17
Mean	**-1.44**	**7.76**	**24.54**	**3.80**	**3.58**	**17.19**	**22.13**	**19.07**
SEM	**0.19**	**0.08**	**0.23**	**0.04**	**0.05**	**0.23**	**1.01**	**0.75**

8b) Distance and near baseline heterophoria measurements
Average of three heterophoria measurements measured in Δ. 'S' denotesEsophoric measurements are suffixed by 'S', exophoric measurements are suffixed by 'X'.

	EMMETROPES			EOMs			LOMs	
	Distance	**Near**		**Distance**	**Near**		**Distance**	**Near**
BS	0.00	0.25S	GD	0.50X	2.00X	TH	1.00X	1.00S
DH	1.00S	2.00S	CW	0.50X	2.00S	CR	1.00S	1.00S
HC	0.50S	5.00X	CG	1.00S	1.00S	NW	2.00S	0.75S
JS	1.50S	0.50S	AH	1.50X	2.00X	RB	1.50X	3.50X
RR	2.00X	4.00X	WF	1.00X	3.00X	SC	0.00	1.00S
RD	1.00X	6.00X	RH	3.00X	5.00X	KJ	2.50X	8.00X
GR	0.50X	4.00X	JG	3.50X	7.00X	KD	1.75X	8.50X
FF	0.75X	4.00X	MP	1.00S	3.00S	AW	0.00	0.50X
GJ	1.00S	3.00S	AD	0.00	0.50X	CH	0.50X	1.00X
JS	0.50X	2.00X	KL	0.00	1.00X	JH	1.50S	1.00S
NW	1.50S	1.00S	HH	0.75S	2.00X	EW	1.50X	6.00X
WI	0.25S	2.00X	SL	0.50X	5.00X	NH	1.00X	3.00X
JE	1.50X	8.00X	NB	0.75X	5.00X	EF	1.00S	1.00S
MH	1.50X	5.00X	NE	1.00X	3.50X	JP	0.00	3.50X
AD	1.50X	4.00X	MD	1.50X	2.50X	NB	0.00	3.00X
Mean	**0.25X**	**2.48X**		**0.73X**	**2.17X**		**0.28X**	**2.08X**
SEM	**0.30**	**0.83**		**0.33**	**0.72**		**0.33**	**0.88.**

8c) Phoria measurements while adapting to induced prism

EMMETROPES

Distance 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
BS	6.50	5.50	4.50	3.50	3.00	2.00	2.00	1.75	1.50	1.50	0.25	1.00	1.25	1.50	1.25
DH	6.00	6.50	7.00	7.00	7.00	6.50	6.00	6.00	6.25	5.75	5.50	6.50	5.50	5.50	5.25
HC	6.50	5.50	5.50	5.00	5.00	5.00	5.50	6.00	5.75	5.50	5.00	5.00	5.00	4.50	4.50
JS	6.25	5.00	4.75	4.50	4.00	4.00	3.50	3.50	3.25	3.25	3.25	3.25	3.00	3.00	2.50
RR	7.00	4.75	4.50	4.00	3.50	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
RD	5.00	4.00	3.75	3.50	3.00	3.00	3.00	3.00	3.00	3.00	2.75	2.75	2.75	2.75	2.75
GR	5.50	5.50	6.00	5.50	4.50	4.50	4.50	4.00	4.50	4.50	4.50	4.50	4.50	4.00	3.50
FF	4.25	5.50	5.50	5.50	5.50	5.25	4.25	4.25	3.50	3.25	3.25	3.00	3.00	3.00	2.75
GJ	5.50	6.00	6.00	6.00	5.00	5.50	4.00	3.75	3.50	3.50	3.00	2.75	2.75	3.00	2.00
JS	5.50	4.50	4.50	3.50	3.50	3.00	3.00	3.00	2.50	2.00	2.50	2.00	2.00	2.00	2.00
NW	6.50	5.50	4.50	5.50	5.00	5.00	4.50	4.00	3.00	3.00	3.00	2.00	1.50	1.50	2.00
WI	4.25	4.25	4.25	4.25	3.75	3.75	4.25	4.25	4.25	4.50	4.75	4.25	4.25	4.25	4.25
JE	4.50	5.00	4.75	4.25	4.00	3.50	3.25	2.50	2.00	2.00	2.00	2.00	1.75	1.50	1.50
MH	6.00	4.50	4.50	4.00	4.00	3.25	3.25	3.00	2.75	2.50	2.00	2.00	2.50	2.00	2.00
AD	4.50	4.50	4.00	3.50	3.00	3.00	2.75	2.50	2.50	2.25	2.00	2.50	2.00	2.00	1.75

Distance 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
BS	6.00	6.00	4.50	4.00	4.75	3.50	2.50	2.00	3.00	2.75	1.75	2.50	2.00	2.00	1.50
DH	5.50	3.50	2.50	1.00	1.50	0.25	0.00	0.00	0.25	0.50	0.50	-0.50	-0.25	0.00	0.00
HC	6.25	4.75	4.75	5.75	4.75	3.75	4.25	3.25	3.75	3.75	3.25	3.25	3.25	3.75	3.75
JS	6.50	4.50	3.75	2.25	2.00	3.00	3.00	3.75	3.00	2.75	3.00	2.00	2.00	2.50	1.50
RR	6.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	2.50	2.50	2.50	2.50	3.00	2.00
RD	5.00	4.00	4.00	4.00	4.00	3.00	2.75	3.00	2.75	2.50	2.50	2.50	2.00	2.00	2.00
GR	4.00	3.00	3.00	2.00	2.50	2.50	2.00	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
FF	4.25	4.25	4.25	3.75	3.25	3.00	2.75	2.75	2.75	2.50	2.75	2.75	2.25	2.25	2.25
GJ	5.00	3.50	3.75	3.50	2.50	2.50	2.75	2.75	2.25	2.25	2.00	2.50	2.75	2.50	1.75
JS	5.50	3.50	3.00	2.50	3.50	3.00	2.00	1.00	1.50	1.00	1.00	0.50	1.00	1.00	1.00
NW	5.50	4.50	4.50	4.50	4.50	3.50	3.50	3.50	3.00	3.00	2.50	2.00	2.00	2.00	1.50
WI	4.75	5.25	5.25	4.25	4.25	4.25	3.25	3.75	3.75	3.25	2.75	1.50	1.25	1.50	1.75
JE	3.00	5.00	3.50	3.00	3.50	2.50	3.50	2.50	3.00	2.50	2.50	2.50	3.00	2.50	3.00
MH	6.25	4.00	2.50	3.00	2.50	3.00	2.50	1.50	2.00	2.50	2.50	1.00	2.50	1.50	2.00
AD	4.50	4.50	3.50	3.50	4.00	3.50	3.00	3.50	3.50	3.00	2.50	3.00	2.50	3.00	2.00

Near 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
BS	5.75	6.25	5.75	5.25	4.75	5.75	6.00	4.75	4.50	4.75	4.75	5.25	3.75	4.00	3.75
DH	6.00	2.00	2.00	4.00	0.00	1.00	1.00	1.00	0.00	1.00	1.25	-0.25	2.00	-0.5	0.00
HC	5.00	6.00	5.75	5.50	5.50	5.00	5.25	5.00	5.25	5.75	5.50	5.75	5.00	4.50	4.00
JS	6.75	6.25	4.75	5.25	3.75	3.25	3.75	4.75	4.75	4.75	3.25	4.25	3.75	3.25	3.00
RR	5.50	5.50	4.50	5.00	4.50	3.50	3.25	3.50	3.50	3.50	3.25	3.00	2.50	3.00	2.50
RD	5.50	4.50	3.50	3.50	4.50	3.50	2.50	2.50	2.50	2.50	2.50	3.50	2.50	2.50	2.50
GR	2.00	3.00	3.00	2.50	2.00	2.00	2.50	3.00	2.50	5.00	3.00	3.00	3.00	5.00	3.00
FF	2.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00
GJ	5.00	6.00	4.00	2.00	3.00	4.00	3.00	4.00	2.00	3.00	2.00	1.00	1.00	1.00	1.00
JS	5.00	4.50	4.00	4.00	3.00	3.00	3.50	3.00	1.00	1.00	1.00	1.50	1.00	1.00	1.00
NW	4.00	3.00	3.00	2.50	3.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00	2.00	2.00	2.00
WI	8.00	5.50	5.00	4.50	4.00	4.00	4.50	4.00	4.00	3.75	4.00	4.75	4.50	4.00	3.25
JE	4.00	4.00	2.00	3.50	3.25	2.50	2.50	3.00	2.00	2.25	3.00	2.25	2.00	2.25	2.75
MH	2.50	3.00	3.00	3.00	3.00	2.50	2.00	2.00	2.00	1.50	2.00	1.50	2.00	2.00	2.00
AD	4.00	3.00	3.50	4.00	4.00	4.00	3.50	3.50	3.00	2.00	3.50	2.00	2.50	2.00	2.50

Near 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
BS	6.25	5.75	5.75	5.50	6.00	4.75	4.50	4.75	4.75	4.75	3.75	3.25	3.00	2.75	2.50
DH	5.50	4.50	4.50	4.25	4.50	5.00	5.50	5.75	5.75	6.00	5.00	5.50	5.25	6.00	5.25
HC	7.00	4.50	4.00	3.50	2.50	2.50	3.50	4.00	4.00	3.50	5.00	4.00	3.00	4.50	4.50
JS	6.50	6.00	5.50	4.00	5.00	5.00	4.50	5.00	4.50	5.50	3.00	4.00	4.00	5.00	4.50
RR	3.50	3.50	2.50	3.00	3.00	2.25	2.75	2.75	2.75	2.00	3.50	2.00	2.25	2.00	2.00
RD	6.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	4.50	5.50	4.50
GR	6.00	5.00	5.00	5.00	5.00	5.00	4.00	3.00	3.00	5.00	3.00	3.00	3.00	2.00	3.00
FF	3.00	4.00	6.00	5.00	5.00	5.00	5.00	5.00	7.00	5.00	6.00	5.00	5.00	5.00	6.00
GJ	3.00	1.00	3.00	3.00	3.00	1.00	2.00	1.00	1.00	2.00	2.00	2.00	3.00	3.00	3.50
JS	5.00	6.00	5.00	6.00	5.00	5.00	6.50	5.00	6.00	5.00	5.50	5.75	6.00	5.50	5.00
NW	7.00	4.00	5.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	5.00	4.00
WI	4.00	3.00	3.00	2.50	2.50	3.00	2.50	3.00	3.50	3.50	3.00	3.00	3.00	2.50	3.00
JE	3.00	5.00	5.00	6.00	5.00	5.00	5.00	5.00	5.00	4.00	4.00	4.00	5.00	4.50	4.50
MH	5.00	4.00	5.00	5.00	5.00	5.00	6.00	5.00	5.00	6.00	6.00	5.00	5.00	5.00	6.00
AD	4.00	4.00	5.50	4.00	4.00	4.50	5.00	4.00	6.00	4.00	5.00	4.00	3.00	4.00	3.00

EARLY-ONSET MYOPES

Distance 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
GD	6.00	5.00	4.50	4.00	3.25	3.25	3.00	3.00	2.50	2.25	2.00	2.00	2.00	2.50	2.00
CW	6.00	5.50	5.00	3.50	3.50	3.00	3.25	2.25	2.50	2.00	2.00	2.00	1.75	2.00	2.00
CG	4.00	4.00	3.50	3.50	3.50	3.50	3.25	3.25	3.00	2.75	2.00	2.00	1.50	1.50	1.25
AH	6.00	4.50	5.50	3.00	2.50	2.00	1.75	1.50	1.50	2.00	2.00	1.50	1.50	1.00	1.50
WF	5.00	5.00	4.00	3.50	3.00	3.00	2.75	2.75	3.00	2.50	2.50	2.50	2.50	2.50	2.50
RH	4.00	2.00	2.00	3.00	2.00	2.00	2.00	1.00	1.00	2.00	1.00	1.00	0.00	0.00	0.00
JG	6.50	3.50	4.50	5.50	3.50	3.50	3.50	3.50	2.50	2.50	2.50	1.50	0.50	1.50	0.50
MP	7.00	5.00	5.00	5.00	5.00	4.50	5.00	4.00	4.00	4.00	3.50	3.50	3.50	3.00	3.00
AD	7.00	5.00	5.00	2.50	2.50	3.00	2.50	2.00	2.00	1.75	1.75	1.50	1.50	1.50	1.50
KL	5.00	5.00	5.00	5.00	4.00	4.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00	1.50
HH	4.75	3.50	2.50	2.00	2.25	1.25	1.50	1.25	0.75	0.75	0.25	0.00	0.50	0.75	0.75
SL	5.50	3.50	3.50	2.50	2.50	2.25	2.00	1.50	1.50	1.00	2.00	0.00	0.75	1.50	1.50
NB	6.50	5.00	3.75	4.25	3.75	4.50	2.75	2.50	2.50	3.00	2.75	2.75	2.50	2.25	2.50
NE	6.00	5.75	4.50	3.50	3.25	3.00	3.00	3.25	3.25	3.00	3.00	2.50	2.50	2.00	2.00
MD	6.50	6.50	5.00	4.00	4.00	4.00	3.00	3.50	3.50	3.50	3.50	3.00	3.00	2.50	2.50

Distance 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
GD	6.00	6.00	3.50	2.75	2.50	2.00	2.50	2.00	2.00	1.50	2.00	1.25	2.50	1.50	1.50
CW	3.00	2.50	2.75	2.75	2.75	2.50	2.50	2.50	0.75	1.00	1.25	1.25	1.50	0.75	0.75
CG	6.00	5.00	3.00	4.00	3.50	2.00	1.50	2.00	2.00	1.00	0.50	0.00	0.50	1.00	0.25
AH	6.00	4.00	3.00	3.00	3.00	2.00	2.50	2.00	2.00	2.00	1.50	2.00	1.50	1.50	2.00
WF	6.00	5.00	4.00	3.50	3.00	2.50	2.50	1.75	1.00	2.00	2.00	1.75	1.75	1.75	1.75
RH	4.00	4.00	4.00	3.00	4.00	3.00	3.00	4.00	3.00	3.00	4.00	3.00	3.00	2.00	2.00
JG	6.50	2.50	4.00	3.50	3.00	3.00	2.50	3.50	2.50	3.50	1.50	2.00	2.00	2.50	3.50
MP	6.00	2.50	1.50	2.00	2.00	3.00	2.50	3.00	1.00	1.50	1.50	1.50	2.50	1.00	1.00
AD	7.00	5.00	3.00	3.00	2.50	2.50	2.25	2.00	2.25	2.00	2.25	2.25	2.00	2.00	2.25
KL	5.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00	1.50	2.00
HH	5.25	3.75	3.25	2.75	3.75	3.75	5.75	3.75	2.75	3.25	2.75	2.75	2.75	2.75	2.25
SL	3.50	3.00	3.00	3.50	3.50	3.00	2.50	2.50	3.00	3.00	2.50	2.50	2.50	2.50	3.00
NB	7.25	5.75	5.25	6.25	4.25	4.25	4.25	4.00	3.75	3.25	3.25	3.25	3.00	3.00	4.00
NE	4.00	3.00	2.50	2.50	1.50	0.50	0.75	0.50	0.00	1.00	0.50	0.00	0.75	0.25	0.00
MD	6.50	4.50	3.50	3.50	3.50	2.50	3.00	3.00	2.50	2.50	2.50	2.50	2.50	3.00	2.00

Near 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
GD	6.00	5.00	4.00	3.00	4.00	3.00	2.00	3.50	2.50	2.50	3.00	3.00	3.50	2.50	2.50
CW	6.00	6.00	6.00	4.00	4.00	3.75	3.25	3.25	3.25	3.00	3.00	3.00	2.75	2.75	2.75
CG	5.00	5.00	4.50	3.75	4.00	3.00	2.50	3.00	3.00	3.25	2.00	2.00	2.00	2.00	2.00
AH	5.00	4.00	3.00	2.00	3.00	2.00	3.00	2.00	2.00	2.00	2.00	2.00	3.00	2.00	1.00
WF	5.00	3.00	2.75	3.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.25	1.25	1.00	1.00
RH	5.00	4.00	3.00	4.00	3.00	3.00	3.00	2.00	4.00	4.00	3.00	3.00	3.00	5.00	5.00
JG	6.00	4.00	4.00	4.00	3.00	4.00	3.00	2.00	3.00	2.00	3.00	2.00	2.50	3.00	3.00
MP	6.00	5.00	4.00	5.00	5.00	4.50	3.50	4.00	4.50	3.00	5.00	5.00	4.00	2.00	3.00
AD	4.50	4.00	1.75	1.75	1.75	1.75	1.50	2.50	2.00	1.50	1.00	2.50	1.50	1.50	2.00
KL	6.00	6.00	4.00	4.00	3.00	2.00	3.00	3.50	3.00	3.00	2.50	3.00	2.50	2.50	2.50
HH	7.00	5.50	6.50	5.00	4.50	3.00	2.50	2.00	2.50	2.50	3.00	2.00	2.00	1.00	0.00
SL	7.00	6.00	5.00	4.00	5.00	4.00	4.50	4.50	4.00	4.00	4.00	3.50	3.50	5.00	4.50
NB	5.50	4.50	4.00	4.50	4.00	3.00	3.50	3.50	2.00	2.00	3.50	2.00	3.00	2.50	3.00
NE	3.50	4.00	4.00	4.50	3.75	3.75	3.75	4.00	4.50	3.50	3.50	4.00	3.50	4.00	3.50
MD	5.50	4.50	4.50	4.50	3.50	3.50	3.50	3.00	2.50	4.50	2.50	3.50	2.50	2.00	2.50

Near 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
GD	6.00	4.50	4.50	4.50	4.00	4.00	5.00	4.50	4.00	3.00	5.00	4.50	3.50	3.00	3.00
CW	3.50	3.50	4.00	4.00	3.50	3.00	3.75	3.25	2.00	3.25	3.25	2.75	2.5	2.75	3.00
CG	5.00	6.00	4.00	4.00	5.00	4.00	5.00	4.00	4.00	3.50	3.50	4.00	2.75	2.50	2.50
AH	5.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	4.00	4.00
WF	6.00	4.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
RH	4.00	3.00	3.00	4.00	2.00	5.00	5.00	4.00	5.00	5.00	5.50	4.00	4.00	5.00	3.00
JG	5.00	5.00	5.00	5.00	4.00	4.00	4.00	3.00	4.00	4.00	3.00	2.00	4.00	4.00	4.00
MP	4.00	6.00	6.00	7.00	6.00	4.00	5.00	4.00	4.00	3.50	3.50	3.50	4.00	4.00	4.00
AD	7.50	5.50	4.50	3.00	3.00	2.50	3.00	3.75	2.50	2.25	3.00	2.75	2.50	3.00	3.50
KL	5.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	4.00	2.00	1.00	2.00	2.00
HH	6.00	4.00	3.50	3.00	2.50	3.00	4.50	2.50	2.50	3.50	3.00	2.50	4.00	3.50	2.00
SL	8.00	4.00	6.00	5.00	6.00	3.00	4.00	4.00	3.00	5.00	8.00	5.00	4.00	3.00	6.00
NB	6.00	6.00	6.75	3.00	4.50	4.50	6.00	6.00	4.75	5.00	5.25	4.75	3.75	5.00	4.50
NE	5.50	3.50	3.50	3.50	3.00	3.50	3.75	3.50	3.50	2.50	2.50	3.50	2.50	2.50	3.50
MD	4.50	3.50	2.50	2.50	2.50	2.50	2.00	1.50	1.50	2.50	2.50	1.50	3.50	2.50	2.50

LATE-ONSET MYOPES

Distance 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
TH	6.00	5.00	4.00	4.00	3.50	3.00	3.00	2.50	2.50	2.50	2.00	1.50	2.00	1.00	1.00
CR	6.75	5.50	4.50	4.50	4.00	5.00	5.00	4.00	4.50	4.00	4.00	4.00	5.00	5.00	6.00
NW	6.00	5.50	5.00	4.00	3.50	3.50	3.00	3.00	3.00	2.00	2.00	1.50	0.50	1.00	1.00
RB	5.50	5.50	5.00	5.50	4.50	4.50	4.00	3.00	2.50	2.00	2.00	1.50	2.00	1.00	0.50
SC	6.00	4.50	4.00	3.00	3.00	2.00	2.00	2.00	2.00	1.50	1.50	1.00	1.00	1.00	1.50
KJ	4.50	4.50	3.50	2.50	2.50	2.25	2.00	2.00	1.50	1.00	0.75	0.50	0.50	0.50	1.00
KD	6.75	5.75	5.25	4.25	3.75	3.75	3.50	3.25	3.25	3.00	2.75	2.50	2.75	2.75	2.25
AW	6.00	6.00	6.00	6.00	6.00	6.00	5.50	5.00	6.00	5.50	5.50	6.00	5.50	6.00	5.50
CH	6.50	6.50	5.50	4.50	4.00	4.00	4.00	3.50	3.50	3.25	3.00	2.50	2.25	2.00	2.00
JH	5.00	4.50	4.50	3.50	3.25	3.00	3.00	3.25	3.50	3.25	2.50	2.25	1.50	1.50	2.50
EW	4.50	3.50	3.50	2.50	4.50	4.00	3.00	2.00	2.00	1.75	1.50	3.00	1.50	2.75	2.50
NH	7.00	5.00	4.00	4.00	3.50	2.50	2.50	2.50	2.00	2.00	2.50	1.00	2.00	2.50	2.00
EF	5.00	4.50	2.50	2.00	1.00	1.50	0.75	0.75	0.50	0.50	0.50	0.25	0.50	0.50	0.00
JP	5.00	3.00	3.00	3.00	2.50	4.00	2.50	2.00	1.50	1.50	1.50	1.50	2.00	1.00	1.00
NB	4.00	5.00	5.00	4.00	4.00	3.50	3.50	3.50	3.00	3.00	3.00	2.75	2.00	2.00	2.00

Distance 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
TH	6.00	5.00	3.00	2.50	2.00	1.75	1.75	1.50	2.00	1.50	2.00	2.00	2.00	1.50	1.50
CR	6.00	3.50	3.00	3.00	2.75	2.50	1.25	1.25	1.50	1.25	1.25	2.00	1.25	2.00	2.25
NW	6.00	4.00	3.50	3.50	2.75	2.50	2.50	2.25	2.75	1.50	1.50	2.00	1.75	1.25	1.00
RB	5.50	5.00	4.50	4.00	4.50	3.50	3.50	3.25	3.50	4.50	4.50	3.00	2.50	2.00	1.50
SC	6.00	5.00	4.00	3.50	3.00	3.00	3.00	2.50	2.00	2.00	2.00	2.00	2.00	1.50	1.50
KJ	2.50	1.50	2.00	1.00	1.00	0.50	0.50	0.00	0.50	0.00	0.00	0.00	0.50	0.00	0.00
KD	2.75	4.25	4.25	4.25	4.25	4.25	3.75	3.25	3.25	3.00	2.75	2.75	3.00	2.75	2.75
AW	6.00	6.00	5.00	4.50	3.75	4.00	4.00	3.75	3.25	3.00	3.00	3.00	3.25	4.00	3.00
CH	5.50	4.50	3.50	3.00	2.50	2.25	1.75	1.50	1.50	3.50	1.50	1.50	1.50	2.00	1.50
JH	4.50	3.00	2.00	2.00	1.50	0.00	0.25	1.00	1.00	0.50	1.00	0.00	1.00	1.50	0.00
EW	4.00	3.50	2.50	2.00	1.50	0.75	0.25	0.25	1.50	0.25	0.00	0.50	0.50	0.50	0.25
NH	6.00	4.50	3.50	3.50	3.00	2.50	2.50	3.50	2.00	2.00	2.50	1.50	3.00	2.50	2.00
EF	2.50	3.50	2.75	3.00	3.00	2.50	2.00	2.00	2.25	1.75	2.00	2.00	1.50	1.75	1.75
JP	7.00	5.00	4.00	4.00	2.50	4.00	3.00	3.00	2.50	1.50	2.50	2.00	2.50	2.00	2.00
NB	4.50	5.00	5.00	5.00	5.00	4.50	4.00	3.75	4.00	4.00	4.00	4.00	3.50	3.00	3.00

Near 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
TH	6.00	5.00	5.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	4.00	3.50	3.00
CR	6.00	6.00	5.00	4.00	4.00	4.00	4.00	2.50	3.00	3.00	3.00	3.00	3.00	2.00	2.50
NW	6.25	6.25	5.75	5.75	5.25	6.25	5.25	5.25	4.75	4.25	4.75	4.25	5.75	4.75	4.25
RB	5.50	6.50	5.50	5.00	5.50	3.50	3.50	4.00	4.50	4.00	4.00	4.50	3.50	3.50	3.00
SC	4.00	4.00	4.00	3.00	3.00	2.00	2.00	1.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00
KJ	6.00	5.00	6.00	6.00	4.00	6.00	4.00	6.00	5.00	4.00	4.00	4.00	4.00	4.00	4.00
KD	4.50	3.50	4.50	4.50	5.00	4.50	3.50	2.50	2.50	2.50	2.50	2.50	2.50	3.50	3.50
AW	7.50	5.50	5.50	3.50	3.50	4.00	3.50	3.50	2.50	3.50	2.50	3.50	3.50	2.50	2.50
CH	3.00	3.00	3.00	2.00	3.00	4.00	3.00	1.00	3.00	2.00	3.00	3.00	3.00	1.50	2.50
JH	6.00	5.00	4.00	3.00	3.50	4.00	3.00	2.75	2.00	2.00	2.00	2.00	2.00	2.25	2.00
EW	6.00	4.00	2.50	2.00	3.00	2.00	2.00	4.00	4.50	2.00	4.00	4.50	2.00	3.00	3.50
NH	5.00	3.00	3.00	2.00	3.00	3.00	1.00	2.00	1.00	1.00	3.00	3.00	1.00	2.00	2.00
EF	4.00	3.50	4.00	4.00	3.00	4.00	3.00	3.00	3.00	3.50	3.00	3.00	3.00	3.00	3.00
JP	4.50	5.50	5.50	5.50	4.50	4.50	5.00	4.50	4.50	3.75	4.00	3.75	3.50	4.00	3.50
NB	3.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	4.00	4.00	4.00	4.00

Near 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
TH	6.00	4.00	3.00	2.50	2.00	1.50	1.50	2.00	1.50	1.25	1.25	1.00	1.00	2.00	1.00
CR	5.00	4.00	4.00	5.00	5.00	4.00	2.00	6.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00
NW	6.25	5.25	5.25	3.25	4.25	4.25	4.25	3.25	3.25	4.25	3.75	2.25	1.75	2.75	2.25
RB	5.50	4.50	3.50	3.50	3.50	2.50	3.00	3.50	3.00	2.00	1.50	2.00	3.50	2.50	1.50
SC	4.00	5.00	2.00	4.00	5.00	4.00	5.00	5.00	4.00	5.00	6.00	5.00	5.00	5.00	5.00
KJ	5.00	4.00	3.00	2.00	3.00	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00	2.00
KD	5.50	6.50	5.50	4.50	6.00	5.50	5.50	4.50	5.50	4.50	5.50	3.50	3.50	4.50	4.00
AW	6.50	5.50	5.50	5.50	6.50	5.50	5.50	5.50	4.50	4.50	4.50	5.50	4.50	4.50	4.50
CH	6.00	5.00	6.00	6.00	6.00	4.00	4.00	6.00	4.00	4.00	6.00	5.00	6.00	5.00	6.00
JH	6.00	5.00	4.00	4.00	4.00	4.00	4.00	3.25	3.25	3.50	3.75	3.75	3.75	3.75	400
EW	7.00	1.50	1.00	0.50	2.00	1.00	1.00	2.00	0.00	1.00	-0.5	-0.5	-1.0	0.00	2.00
NH	5.00	5.00	5.00	6.00	4.00	5.00	4.50	5.00	4.00	5.00	4.00	5.00	5.00	4.00	5.00
EF	4.00	4.25	4.00	4.00	4.00	3.50	4.00	4.00	4.50	4.00	3.00	3.00	3.50	4.00	3.00
JP	7.00	5.00	4.50	3.50	3.00	5.50	4.50	4.50	3.50	3.50	3.50	2.50	3.00	3.00	2.50
NB	4.00	4.00	3.00	3.00	4.00	2.00	3.00	2.00	3.00	3.00	2.00	2.00	1.00	2.00	1.00

8d) Phoria measurements while recovering from induced prism

EMMETROPES

Distance 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
BS	-4.50	-3.50	-1.00	-2.00	-1.50	-1.25	-1.50	-1.00	-1.00	0.00
DH	0.00	0.50	0.50	-0.50	-1.00	-1.00	0.00	-0.75	0.00	0.00
HC	-1.50	-0.50	-0.50	-0.25	-0.50	-0.25	-0.50	-0.25	0.25	0.00
JS	-4.00	-2.50	-2.50	-0.50	0.00	-0.25	-0.25	0.00	-0.25	-0.75
RR	-3.00	-1.00	-1.00	-1.00	0.00	-0.50	0.00	-0.50	0.00	0.00
RD	-3.25	-2.00	-1.50	-1.00	-0.75	-0.75	-0.50	-0.50	0.00	0.00
GR	-0.50	0.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
FF	-3.75	-1.75	-1.25	-1.25	-1.25	-0.25	-1.25	-0.75	-0.50	-0.25
GJ	-3.00	-2.50	-2.50	-2.25	-2.50	-1.00	-2.50	-1.50	-1.75	-2.00
JS	-4.50	-2.50	-2.50	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
NW	-5.50	-2.50	-1.50	-1.50	-1.50	-3.00	-2.00	-1.00	0.00	0.00
WI	-0.25	-0.25	-0.50	-0.50	-0.50	-0.25	-0.50	-0.25	0.00	-0.25
JE	-4.50	-1.50	-2.50	-2.25	-2.00	-1.75	-1.50	-2.00	-1.50	-1.50
MH	-5.00	-1.50	-2.50	-1.50	-1.50	-1.50	-0.50	-0.75	-0.5	-0.25
AD	-2.50	-1.25	-1.50	-0.50	-0.25	0.00	-0.50	0.00	0.00	0.25

Distance 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
BS	-4.50	-3.00	-1.50	-1.00	-1.50	-1.25	-0.50	-0.75	-0.50	-0.75
DH	-4.00	-3.00	-3.00	-1.50	-0.75	-1.00	-1.00	-0.75	-0.50	-.0.50
HC	-2.00	-1.00	-1.00	-0.50	0.00	0.50	0.50	-0.25	0.00	-0.50
JS	-4.00	-2.50	-1.00	-0.25	-0.75	-0.25	0.00	-.025	-0.50	-2.00
RR	-4.00	-2.50	-1.50	-2.00	-1.50	0.00	0.00	0.00	-0.50	0.00
RD	-4.50	-1.00	-1.00	-0.75	-0.75	-0.50	-0.50	0.00	0.00	0.00
GR	-4.50	-2.50	-1.50	-1.00	-1.00	-0.50	-1.00	-0.50	-0.50	-1.00
FF	-4.25	-3.50	-3.00	-2.75	-1.75	-1.25	-1.00	-0.75	-0.75	-0.75
GJ	-4.00	-2.50	-2.50	-1.75	-0.75	-0.50	-0.75	-1.00	-0.50	0.50
JS	-5.50	-3.00	-2.00	-2.00	-2.00	-1.00	-1.00	-1.00	-0.50	-0.50
NW	-3.50	-2.50	-1.00	-1.00	-1.50	0.00	0.00	0.00	0.00	0.00
WI	-1.75	-1.75	-2.25	-1.75	-1.75	-1.25	-1.00	-0.75	-1.00	-1.00
JE	-2.50	-1.50	-1.50	-1.50	-1.25	-1.00	-0.25	-0.50	-0.25	-0.25
MH	-4.50	-2.00	-1.50	-1.50	-0.50	-1.00	-1.00	-1.00	-0.50	-0.75
AD	-3.00	-2.50	-1.50	-1.50	-1.50	-0.75	-0.50	-0.50	-1.00	-1.25

Near 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
BS	-2.25	-2.00	-0.75	-0.25	-0.75	-0.25	-0.50	-0.50	-0.25	0.00
DH	-7.00	-4.00	-5.50	-3.00	-4.00	-4.00	-3.50	-2.00	-4.00	-4.00
HC	-2.00	-0.75	-0.75	0.25	-0.50	0.00	0.25	1.00	0.50	1.00
JS	-2.00	-2.00	-2.50	-1.00	-2.00	-3.00	-2.00	-1.00	-1.00	-1.00
RR	-3.50	-1.25	-0.50	-0.75	-0.50	0.00	0.00	0.00	-0.50	-0.50
RD	-3.50	-2.50	-3.50	-2.50	-2.50	-2.50	-2.50	-2.50	-2.50	-2.50
GR	-3.00	-2.00	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
FF	-1.00	0.00	-1.00	-1.00	0.00	-1.00	-2.00	-1.00	0.00	-2.00
GJ	-1.00	0.00	0.00	-1.00	-1.00	-1.00	-2.00	-1.00	-1.00	-1.00
JS	-5.00	-3.00	-3.00	-4.00	-2.00	-3.00	-2.50	-3.00	-2.50	-2.00
NW	-3.00	-1.00	-1.00	-2.00	-1.00	-1.00	-2.00	-2.00	-2.00	-1.50
WI	-0.75	-0.50	-1.25	-0.50	-1.00	-1.00	0.50	-0.75	0.00	0.00
JE	-3.00	-1.00	0.00	0.00	2.00	0.00	0.00	-0.50	-1.00	-0.50
MH	-3.00	-2.00	-3.00	-3.00	-3.00	-1.00	-2.00	-2.00	-2.50	-2.00
AD	-3.00	-1.50	-1.00	-1.00	-1.00	-2.00	-1.50	0.00	0.00	-1.00

Near 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
BS	-2.75	-2.75	-1.75	-1.50	-1.75	-1.25	-1.00	-0.75	-0.75	-0.25
DH	-2.00	1.00	1.00	1.00	2.00	2.00	2.50	2.50	1.00	0.50
HC	-2.50	-1.00	-1.00	-1.00	-2.00	-3.00	-1.00	-1.50	-1.25	-1.25
JS	-1.50	-0.50	-0.50	0.25	-0.50	-0.50	-0.25	0.00	0.50	0.00
RR	-3.50	-2.50	-2.75	-2.50	-2.00	-1.50	-2.50	-2.00	-1.50	-1.50
RD	-1.50	0.50	-0.50	0.25	1.50	1.50	1.50	1.50	0.50	0.00
GR	-3.00	-2.00	-2.00	-3.00	-2.50	-2.75	-1.75	-1.00	-1.00	-1.00
FF	0.00	1.00	2.00	2.00	1.00	1.00	4.00	3.00	2.00	2.00
GJ	0.00	0.00	-0.50	-0.50	-0.50	-0.50	0.00	0.00	0.00	0.00
JS	0.00	-2.00	-1.75	-1.75	-1.50	-2.25	-1.50	-0.50	-1.75	-1.00
NW	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	2.00	1.00
WI	-3.00	-2.50	-1.50	-2.00	-1.50	-1.00	-1.00	-1.00	0.00	-0.50
JE	-1.00	-1.50	-2.00	-1.50	-2.00	-1.75	-1.00	-0.50	0.00	-1.50
MH	-1.00	-0.50	-1.00	-0.50	-0.50	-1.00	-2.00	-0.50	-1.00	-1.00
AD	-2.50	-1.00	-2.00	-1.00	0.00	-1.00	0.00	-1.00	-0.50	0.00

EARLY-ONSET MYOPES

Distance 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
GD	-4.00	-2.00	-2.00	-1.75	-1.25	-1.00	-1.00	-0.75	-0.75	-0.50
CW	-3.50	-1.00	-1.00	-1.00	-0.50	-0.75	-0.50	-0.50	-0.75	-0.50
CG	-6.00	-3.50	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00	-0.50	-0.25
AH	-3.50	-1.50	-0.50	-1.00	-0.50	-1.00	-0.50	0.00	0.00	0.00
WF	-3.50	-2.00	-1.50	-0.75	-0.50	-0.50	0.00	-0.50	0.00	0.25
RH	-5.00	-4.00	-3.00	-2.00	-2.00	-1.00	0.00	0.00	0.00	-1.00
JG	-4.50	-3.50	-2.50	-2.50	-3.50	-2.50	-1.50	-1.50	-2.50	-1.00
MP	-3.00	-1.00	-1.50	-0.75	-1.00	-1.00	-0.50	-0.50	-0.50	0.25
AD	-5.00	-4.00	-3.00	-2.00	-3.00	-2.00	-1.75	-1.50	-1.50	-1.50
KL	-3.00	-1.00	-2.00	-1.50	-1.00	-1.50	-1.00	-1.00	-1.00	0.00
HH	-5.75	-4.25	-3.75	-3.75	-3.25	-2.50	-2.25	-3.00	-2.25	-2.50
SL	-2.50	-2.00	-2.50	-3.50	-3.50	-2.50	-2.50	-3.00	-2.00	-2.00
NB	-6.25	-3.25	-2.25	-2.25	-2.25	-1.75	-1.75	-1.00	-2.00	-1.75
NE	-4.50	-3.50	-2.00	-2.00	-2.00	-2.00	-1.75	-1.50	-2.00	-1.75
MD	-3.00	-2.50	-2.00	-1.50	-0.50	0.50	0.00	-0.50	0.00	0.00

Distance 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
GD	-5.00	-2.25	-2.00	-1.50	-0.50	-0.25	-1.00	-0.75	0.00	-0.25
CW	-5.00	-2.00	-2.00	-1.75	-1.50	-0.50	-0.50	-0.50	-0.50	-0.50
CG	-3.00	-3.00	-2.50	-1.00	-2.50	-1.50	-1.50	-0.50	-0.50	-1.00
AH	-5.50	-1.50	-1.50	-1.00	-1.00	-0.50	-1.00	-1.00	-1.00	-1.00
WF	-5.00	-1.00	-1.50	-1.50	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00
RH	-2.00	-1.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00
JG	-3.00	-5.00	-5.00	-5.00	0.00	-5.00	1.50	0.50	0.00	-0.50
MP	-5.00	-4.00	-4.00	-3.50	-2.75	-2.00	-2.00	-2.50	-2.00	-2.00
AD	-4.00	-1.75	-1.25	-1.00	-1.00	-0.75	-0.50	-0.75	-0.50	-1.25
KL	-5.00	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
HH	-4.25	-0.75	-1.25	-0.25	0.25	-0.25	0.50	0.50	0.50	0.25
SL	-3.50	-1.50	-0.25	-0.25	-0.25	-0.25	-0.25	1.50	2.00	-0.25
NB	-2.25	-2.25	-1.50	0.50	0.25	0.00	-0.50	0.50	-1.00	0.50
NE	-3.00	-1.00	-0.75	-0.25	0.00	-0.25	-0.25	0.25	0.25	0.25
MD	-4.50	-2.00	-1.00	-1.00	-1.50	-1.00	-1.00	-0.75	-0.75	-1.50

Near 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
GD	-1.00	-0.50	0.50	-0.50	-1.50	-0.50	-1.00	-1.00	1.00	0.00
CW	-2.00	-1.50	-1.50	-1.00	-1.00	-0.25	1.00	-0.50	0.00	-0.75
CG	-5.00	-2.00	-1.00	-1.00	-2.00	-1.00	-1.00	-1.50	-1.00	-1.50
AH	-2.00	-2.00	-2.00	-2.00	-1.00	0.00	1.00	0.00	0.00	0.00
WF	-3.00	-2.00	-1.25	-1.25	-1.00	-1.25	-1.25	0.00	0.00	0.00
RH	0.00	1.00	1.00	-2.00	-1.00	2.00	-2.00	-4.00	-1.00	-1.00
JG	-3.00	-1.00	0.00	0.00	-0.50	0.00	-1.00	0.00	-1.00	0.00
MP	-3.50	-3.50	-2.00	-2.00	-1.00	-1.00	-1.00	-0.50	-1.00	-1.00
AD	-3.50	-2.50	-3.50	-1.50	-1.00	-0.25	-0.75	-1.00	0.00	-0.50
KL	-2.00	-2.00	-2.00	-2.00	-2.00	-1.00	-1.00	-0.50	-1.50	-2.00
HH	-7.00	-6.00	-1.50	-1.75	-2.00	0.00	-1.00	-2.00	-0.50	-1.00
SL	-2.00	-2.00	0.00	-1.00	1.00	1.00	-2.00	0.00	-1.00	0.00
NB	-4.00	-1.00	-3.00	-1.00	-1.00	-0.50	-1.25	-1.50	-1.00	-1.25
NE	-2.50	-1.50	-1.50	-0.50	-0.50	-0.50	-1.00	-0.50	-1.00	-0.25
MD	-2.50	0.50	-0.50	1.00	2.50	0.50	0.50	0.50	0.50	1.50

Near 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
GD	-2.00	0.00	0.50	1.50	1.50	0.50	0.50	0.50	0.50	0.50
CW	-2.50	-2.25	-2.00	-1.75	-1.25	-1.25	-1.00	-1.25	-1.00	-1.00
CG	-3.00	-1.00	-1.00	-0.50	-0.25	0.00	0.00	0.25	0.00	1.00
AH	-1.00	0.00	-1.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
WF	-2.00	-1.00	0.00	0.50	0.00	1.00	1.00	1.00	1.00	1.00
RH	-2.00	1.00	-1.00	2.00	2.00	3.00	2.00	2.00	1.00	0.00
JG	-2.00	-.5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MP	-3.00	-2.00	-2.50	-2.00	-1.00	0.00	-0.50	-1.00	1.00	1.00
AD	-2.50	-1.50	-0.50	-1.25	-0.50	0.25	-1.00	-0.50	0.00	-0.50
KL	-4.00	-2.00	-1.50	-1.00	-2.00	-2.00	-2.00	-1.00	-1.00	-1.00
HH	-4.00	-2.00	-1.00	-0.75	-0.75	-0.75	-0.75	-1.00	-0.50	-1.00
SL	-1.00	-1.00	-2.00	0.00	-1.00	2.00	0.00	1.00	3.00	1.00
NB	-1.00	-0.50	0.50	0.50	1.25	2.00	1.25	1.00	2.00	0.75
NE	-3.50	-2.50	-2.50	-2.50	-1.50	-1.50	-0.50	-1.00	-1.00	-0.50
MD	-2.50	-2.50	-0.50	-0.50	-1.50	0.50	-0.50	-1.50	-0.50	-1.00

LATE-ONSET MYOPES

Distance 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
TH	-5.00	-4.00	-4.00	-3.00	-3.00	-2.00	-2.00	-1.00	-1.00	-1.00
CR	-2.00	-0.50	1.00	0.00	-1.00	-0.50	0.50	0.00	-0.50	1.00
NW	-2.75	-2.75	-1.75	-0.75	-0.75	-1.25	-1.25	-1.75	-1.25	-0.75
RB	-4.50	-3.50	-3.00	-2.50	-2.50	-2.00	-2.50	-1.50	-1.50	-1.50
SC	1.00	0.00	-1.00	0.00	0.00	0.00	0.00	-1.00	-2.00	-1.00
KJ	0.00	-1.00	-2.00	-2.00	-1.00	-2.00	-2.00	0.00	-1.00	0.00
KD	-1.50	-0.50	-0.50	0.50	0.50	0.50	0.00	1.50	0.50	1.50
AW	-2.50	-1.50	-2.50	-1.50	-0.50	0.00	0.00	0.50	0.00	-0.50
CH	-1.00	1.00	1.00	-1.00	0.00	1.00	1.00	1.00	-1.00	0.00
JH	-2.00	-1.00	-1.00	-1.00	-0.75	-0.25	-0.75	-0.75	0.00	0.00
EW	-4.00	-5.00	-3.00	-3.00	-2.50	-3.50	-3.00	-2.50	-2.00	-3.00
NH	-2.00	0.00	1.00	1.00	2.00	1.00	2.00	1.00	1.00	2.00
EF	0.00	0.50	-1.00	-1.50	0.00	0.00	-1.00	-1.00	-1.00	-1.00
JP	-3.50	-3.50	-2.75	-2.50	-2.25	-0.75	-2.50	-2.00	-2.00	-2.00
NB	-3.00	-1.00	-1.00	0.00	-2.00	-2.00	-1.00	-1.00	-1.00	0.00

Distance 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
TH	-5.00	-4.00	-2.75	-2.75	-1.50	-1.25	-1.25	-1.50	-1.00	-0.50
CR	-4.50	-3.00	-1.00	-1.00	-1.50	-0.75	-1.00	-0.50	-1.00	-2.00
NW	-4.00	-4.00	-3.00	-2.50	-1.00	-1.00	-1.00	-0.50	-0.50	-0.50
RB	-5.50	-3.50	-2.50	-1.50	-2.00	-2.00	-2.50	-2.50	-2.50	-2.00
SC	-5.00	-2.00	-0.50	-0.50	-0.50	-0.25	0.00	0.50	0.00	0.00
KJ	-4.50	-2.50	-1.50	-1.00	-1.00	-0.50	-0.50	-0.25	0.00	0.00
KD	-3.50	-2.25	-0.75	-0.75	-1.25	-1.25	-0.25	-0.25	0.00	0.00
AW	-4.00	-2.75	-2.50	-1.00	-1.50	-1.50	-1.00	-1.25	-1.25	-1.50
CH	-4.50	-2.50	-0.50	-1.00	-1.00	-1.00	-0.50	-0.25	0.50	0.50
JH	-3.50	-3.00	-3.25	-2.25	-1.50	-1.50	-1.25	-1.50	-2.00	-1.00
EW	-3.50	-3.00	-2.00	-3.50	-3.50	-3.00	-2.50	-2.75	-2.50	-2.50
NH	-6.00	-2.50	-2.00	-1.00	-1.50	-1.50	-1.00	-1.50	-0.50	-0.50
EF	-3.00	-1.00	-0.75	-0.50	-0.25	0.00	0.00	0.25	0.25	0.00
JP	-4.00	-1.00	-1.00	-1.00	-1.00	0.00	0.00	0.00	0.00	0.00
NB	-1.50	-1.00	-0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Near 6Δ base-in

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
TH	-3.00	-1.50	-1.00	-1.00	0.00	-1.00	-1.00	0.00	0.50	0.00
CR	-3.50	-2.00	-2.00	-1.50	-1.25	-1.75	-1.00	-1.00	-1.00	-1.00
NW	-1.25	-0.25	0.25	1.75	0.75	-0.25	0.75	2.75	1.75	2.75
RB	-3.50	-3.50	-2.50	-2.50	-0.50	-1.00	-1.50	-1.50	-0.50	0.50
SC	-3.00	-2.00	-2.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
KJ	1.00	0.00	0.00	-1.00	-1.00	0.00	1.00	0.00	0.00	1.00
KD	-1.50	-1.50	-2.50	-2.50	-0.50	-0.50	-1.50	-1.50	-2.50	-1.50
AW	-3.00	-1.50	-2.00	-1.50	-1.50	-1.50	-1.50	-2.50	-1.50	-2.50
CH	-3.00	-2.00	-2.00	-3.00	-2.00	-4.00	1.00	1.00	0.00	-2.00
JH	-2.00	-1.50	-1.00	-0.75	0.00	-0.50	-0.75	-0.75	-1.00	-1.00
EW	-2.00	0.00	0.00	0.50	1.00	2.00	1.50.	1.00	2.00	2.00
NH	-2.00	-3.00	-3.00	-2.00	-3.00	1.00	0.00	-1.00	-1.00	-2.00
EF	1.00	0.00	0.00	0.00	0.00	-0.50	0.00	0.00	1.00	-1.00
JP	-2.50	-1.50	-0.50	0.00	0.00	0.25	0.75	1.00	-0.50	0.00
NB	0.00	1.00	0.00	0.00	1.00	0.00	0.00	2.00	1.00	1.00

Near 6Δ base-out

S	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
TH	-5.00	-4.00	-4.00	-3.00	-3.00	-2.00	-2.00	-1.00	-1.00	-1.00
CR	-2.00	-0.50	1.00	0.00	-1.00	-0.50	0.50	0.00	-0.50	1.00
NW	-2.75	-2.75	-1.75	-0.75	-0.75	-1.25	-1.25	-1.75	-1.25	-0.75
RB	-4.50	-3.50	-3.00	-2.50	-2.50	-2.00	-2.50	-1.50	-1.50	-1.50
SC	1.00	0.00	-1.00	0.00	0.00	0.00	0.00	-1.00	-2.00	-1.00
KJ	0.00	-1.00	-2.00	-2.00	-1.00	-2.00	-2.00	0.00	-1.00	0.00
KD	-1.50	-0.50	-0.50	0.50	0.50	0.50	0.00	1.50	0.50	1.50
AW	-2.50	-1.50	-2.50	-1.50	-0.50	0.00	0.00	0.50	0.00	-0.50
CH	-1.00	1.00	1.00	-1.00	0.00	1.00	1.00	1.00	-1.00	0.00
JH	-2.00	-1.00	-1.00	-1.00	-0.75	-0.25	-0.75	-0.75	0.00	0.00
EW	-4.00	-5.00	-3.00	-3.00	-2.50	-3.50	-3.00	-2.50	-2.00	-3.00
NH	-2.00	0.00	1.00	1.00	2.00	1.00	2.00	1.00	1.00	2.00
EF	0.00	0.50	-1.00	-1.50	0.00	0.00	-1.00	-1.00	-1.00	-1.00
JP	-3.50	-3.50	-2.75	-2.50	-2.25	-0.75	-2.50	-2.00	-2.00	-2.00
NB	-3.00	-1.00	-1.00	0.00	-2.00	-2.00	-1.00	-1.00	-1.00	0.00

APPENDIX 9

STEADY-STATE OPEN-LOOP ACCOMMODATION IN EMMETROPIA AND MYOPIA

9a) Background data

Individuals' right eye data for mean sphere refractive error (Rx), keretometry ('K'), axial length (A.L.), anterior chamber depth (A.C.D.), lens thickness (L.T.), vitreous chamber depth (V.C.D) and age of subject. * indicates subjects who participated in parts 1 and 2 of the study, ** indicates subjects who participated in all three parts of the study

EMMETROPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)
AC	-0.12	8.05	24.02	3.65	3.61	16.76	19
AD**	0.12	7.78	23.40	3.73	3.48	16.19	20
AJ*	0.50	7.93	24.50	3.96	3.45	17.09	19
BS*	0.12	7.33	22.00	3.25	3.19	15.56	18
DH*	0.37	8.15	24.65	3.91	3.14	17.60	19
DJ	0.00						19
FF**	-0.12	7.83	23.33	3.78	3.62	15.93	22
FS	-0.12	7.78	23.41	3.49	3.49	16.43	20
GJ**	-0.12						20
GP*	-0.25	7.55	23.06	3.95	3.35	15.76	19
GR**	0.25						24
HC**	0.25	7.88	23.69	3.68	3.42	16.56	27
HO	0.25	7.65	24.03	3.73	4.30	16.00	30
HP*	0.25	7.58	22.45	3.30	3.70	15.45	18
IS*	-0.25						18
JE*	0.37	7.48	22.16	3.86	3.68	14.62	21
JL*	0.25	7.63	22.46	3.15	3.94	15.37	18
JS*	-0.12	7.45	23.93	3.89	3.85	16.19	18
KF*	0.25	7.70	23.28	3.46	3.48	16.34	20
KK*	0.00	7.68	23.20	3.68	3.71	15.81	19
KP*	0.00	8.98	25.77	3.26	3.58	18.93	18
LB*	0.00	8.20	24.30	3.44	3.36	17.50	18
LM**	0.00	7.83	23.62	3.84	3.75	16.55	23
LR	0.12	7.60	22.64	3.41	3.58	15.65	19
MH*	0.50	7.63	22.63	3.61	3.38	15.24	20
MH*	0.12	8.18	24.14	3.71	3.66	16.76	19
MR*	-0.25	7.93	23.96	3.78	3.20	16.98	21
MR*	0.25						19
NJ*	-0.12	7.73	23.23	3.45	3.28	16.50	25
NP**	-0.12						19
NW	0.00	7.90	23.10	3.50	3.74	15.86	18
PP*	0.50	7.55	22.65	3.65	3.41	15.59	19
PR*	0.00						20
RD**	0.25	7.83	23.91	3.30	3.71	16.90	25
RL*	0.25	7.83	22.79	3.31	3.87	15.61	18
RR*	0.12						21
RS*	-0.12	7.90	23.59	3.45	3.60	16.54	19
RS**	0.25	7.70	23.99	3.63	3.66	16.69	23
SD*	0.12	8.03	23.79	3.91	3.84	16.05	18
SP	0.75	7.83	22.21	3.66	3.61	14.94	20

SZ*	-0.25						19
WI*	0.00	8.43	23.99	3.31	4.00	16.67	18
ZJ*	-0.12	8.00	24.13	3.90	3.74	16.48	20
Mean	**0.10**	**7.84**	**23.47**	**3.61**	**3.60**	**16.27**	**20.16**
SEM	**0.04**	**0.05**	**0.14**	**0.04**	**0.04**	**0.14**	**0.40**

EARLY-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AB	-2.37	7.40	23.81	3.87	3.73	16.21	20	13
AH*	-3.75	8.05	26.06	4.13	3.44	18.51	18	13
AN*	-4.87	7.85	25.54	3.37	3.75	18.42	19	11
AN*	-6.12	7.50	25.64	3.90	3.69	18.05	18	7
AS*	-5.12	7.75	26.67	3.91	3.64	19.11	23	14
CG	-2.00	7.55	23.41	3.47	3.76	16.18	18	13
CW*	-1.75	8.00	25.80	3.79	4.16	17.48	20	14
EW	-2.00	8.15	24.15	3.47	3.40	17.23	18	12
GD*	-2.12						20	12
GP*	-8.50	7.60	26.48	3.45	3.47	19.56	21	5
HR*	-1.75	7.95	24.76	3.75	3.85	17.16	19	13
JG*	-1.75	8.10	24.18	3.76	3.32	17.10	19	13
JL*	-4.62	7.68	24.78	3.88	3.53	17.37	18	13
JM	-1.12	7.40	24.27	3.70	3.52	17.05	18	14
KL**	-3.00	7.95	25.11	3.41	3.42	18.28	23	12
MD*	-6.00	8.08	27.04	3.99	3.71	19.34	29	7
MP*	-1.75	7.40	23.48	3.65	3.36	16.47	20	11
NB*	-5.50						18	12
PH*	-2.50	7.98	25.27	3.84	3.92	17.57	33	12
PJ	-4.50	7.98	25.59	3.84	3.98	17.77	29	10
PP*	-4.75	7.73	24.97	3.87	3.65	17.45	19	14
RJ*	-2.87	7.65	24.35	3.35	3.51	17.49	18	14
RM*	-6.25	7.98	26.05	3.68	3.44	18.93	18	7
RS*	-1.50	7.65	23.57	3.72	3.53	16.32	18	8
SS*	-3.25	7.13	24.01	3.98	3.61	16.43	19	14
SS*	-3.37	7.60	24.51	3.71	3.57	17.23	19	10
SP*	-4.87	7.83	25.40	3.88	3.28	18.24	19	14
TB	-6.62	7.33	25.54	3.67	4.09	17.79	20	11
WF*	-0.75	7.15	22.66	3.66	3.48	15.52	18	14
WS	-3.00	7.50	24.68	3.95	3.56	17.18	21	12
ZR*	-4.25	7.75	25.88	3.94	3.38	18.56	20	14
Mean	**-3.63**	**7.71**	**24.95**	**3.74**	**3.61**	**17.59**	**20.32**	**11.71**
SEM	**0.34**	**0.05**	**0.20**	**0.04**	**0.04**	**0.19**	**0.65**	**0.45**

LATE-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AR	-1.25	7.98	24.26	3.68	3.71	16.87	20	19
AW*	-1.50	7.58	23.66	3.78	3.23	16.65	19	18
AW*	-1.37	7.60	24.40	3.75	4.02	16.63	20	17
BW	-3.00	8.10	24.96	3.16	4.06	17.78	34	23
CH**	-1.25						28	23
CP	-1.75	8.00	24.51	3.69	3.72	17.10	21	17
CR*	-1.00	7.68	24.28	3.87	3.63	16.78	20	19
CW*	-1.12	8.05	25.06	3.94	3.35	17.75	18	16
EF*	-0.87	7.90	24.44	3.93	3.44	17.08	19	17
EW*	-2.75	7.90	25.75	3.96	3.61	18.17	26	19

JH*	-0.75	7.73	23.92	3.26	3.39	17.28	20	17
JH*	-1.00	7.50	23.44	3.29	3.66	16.46	22	21
JL*	-0.87	7.50	22.71	3.95	3.45	15.32	18	17
JP*	-3.37	8.15	25.78	3.85	3.52	18.41	19	16
KD*	-1.50	8.50	25.94	3.79	3.34	18.80	18	16
KJ*	-0.75	7.53	24.09	3.68	3.63	16.78	20	18
LW*	-2.50	7.20	25.60	3.72	3.51	18.37	18	16
MC	-1.50	7.80	24.91	3.86	3.48	17.57	21	19
MV	-1.25	7.85	24.31	3.42	3.87	17.02	21	18
NB*	-1.50	7.93	25.08	3.85	3.61	17.62	30	25
NB	-2.50	8.15	27.05	3.77	3.46	19.82	19	17
NO*	-0.50	7.70	23.72	3.71	3.56	16.45	19	18
NW*	-0.87	7.45	23.78	3.89	3.36	16.52	28	24
PH*	-1.37						20	17
PK*	-2.50	7.63	24.23	3.39	3.46	17.38	23	18
PM	-1.12						21	17
RB*	-1.25	7.33	23.19	3.89	3.38	15.92	19	18
SB*	-1.75	8.08	24.49	3.50	3.94	17.05	20	19
SB*	-2.12	8.48	25.26	3.71	3.68	17.87	20	17
SC*	-0.75						20	17
SC*	-2.75	7.93	24.62	3.80	3.48	17.34	34	19
TH*	-1.87	7.98	24.57	3.79	3.66	16.89	20	17
Mean	**-1.57**	**7.83**	**24.57**	**3.71**	**3.56**	**17.27**	**21.72**	**18.41**
SEM	**0.13**	**0.06**	**0.17**	**0.04**	**0.04**	**0.17**	**0.78**	**0.42**

9b) Results from part 1 of study: Dark and pinhole SOLA

Mean SOLA levels in darkness (dark) and under pinhole (pin) conditions are given in mean sphere form for each subject.

	EMMs			EOMs			LOMs	
	DARK	**PIN**		**DARK**	**PIN**		**DARK**	**PIN**
RS	-0.53	-0.87	JL	-0.68	-0.25	PH	-0.28	-0.50
JS	-0.72	-3.78	WF	-0.58	-1.31	EW	-0.73	-0.40
JL	-0.08	-4.01	SS	-0.57	-0.53	NO	-0.37	-1.98
KP	-0.70	-1.15	CW	-0.98	-1.87	AW	-0.44	-1.84
RR	-2.10	-1.16	ZR	0.14	-0.95	LW	-0.21	-0.41
RS	-1.03	-1.48	KL	-0.56	-1.77	CR	-0.35	-1.04
SD	-0.33	-1.62	PP	-0.93	-2.51	JH	-0.21	-1.41
AD	-1.70	-2.14	PH	-0.42	-2.62	JH	-0.36	-1.02
GJ	-1.00	-1.85	AN	-1.40	-1.03	SB	-0.60	-0.43
HP	-1.54	-3.51	AN	-1.51	0.04	CW	-0.15	-0.83
WI	-0.17	-0.54	JG	-1.10	-0.93	MV	0.11	-0.64
PR	-0.54	-1.06	NB	-0.81	-1.77	NW	-0.04	-1.67
AJ	-0.32	-0.30	HR	-0.31	-1.29	SC	-0.12	-0.54
NJ	-0.35	-0.87	SS	-0.52	-0.61	PK	-0.21	0.06
SZ	-0.45	-1.57	AS	0.11	-0.23	KD	-0.66	-0.42
NP	-0.01	-0.68	GD	0.02	-0.61	RB	-0.15	-1.42
MH	0.13	-1.35	RS	0.17	-0.14	KJ	-0.51	-1.89
KK	-0.14	-2.16	SP	0.12	-4.39	AW	-0.24	-0.40
JE	-0.96	-1.62	AH	-0.09	-0.43	SB	0.22	-0.35
GR	-0.09	-0.91	GP	0.04	-0.30	NB	0.29	-0.96
HC	0.04	-1.16	RM	-0.16	-0.60	TH	0.10	-0.84
RL	-1.22	-2.29	MD	-0.41	-0.39	SC	-0.39	-0.59
KF	-0.78	-0.78	MP	-0.45	-0.78	CH	-0.06	-0.78
FF	-0.75	-0.86	RJ	-0.49	-0.52	EF	0.00	-0.68
MR	-0.03	-1.70	CG	-0.21	-3.25	CP	-0.03	-1.74
LB	0.19	-0.96	PJ	-0.34	-2.46	MC	-0.09	-1.20
RD	-0.38	-2.05	EW	0.24	-1.92	PM	0.36	-1.17

IS	-0.78	-1.45	TB	-0.83	-0.56	BW	-0.48	-1.13
GP	-0.20	-1.80	WS	0.50	-0.35	AR	-0.47	-0.91
LM	-0.30	-2.45	AB	-0.54	-3.44	NB	-0.48	-0.38
MH	-0.10	-0.96				JL	-0.23	-1.47
PP	-0.66	-1.17						
BS	-0.04	-1.83						
MR	-0.03	-0.87						
DH	-0.34	-0.30						
ZJ	-0.43	-0.92						
LR	-1.41	-1.62						
HO	-0.60	-2.99						
FS	-0.50	-4.03						
AC	-0.24	-1.80						
DJ	-0.17	-1.14						
NW	-0.07	-0.78						
SP	-0.16	-1.35						

9c) Results from part 2 of the study: The effect of concurrent mental effort on SOLA

Mean SOLA levels in darkness (dark) and under pinhole (pin) conditions both with (a) and without (b) concurrent mental effort are given in mean sphere form for each subject.

	EMMs					EOMs					LOMs			
	DARK		PIN			DARK		PIN			DARK		PIN	
	a	b	a	b		a	b	a	b		a	b	a	b
RS	-0.38	-4.34	-0.87	-1.29	JL	-0.36	-2.29	-0.25	0.14	PH	-0.78	-2.02	-0.50	-0.11
JS	-1.81	-2.69	-3.78	-4.69	WF	-0.96	-2.15	-1.31	-1.05	EW	-1.21	-1.25	-0.40	-0.67
JL	-0.61	-1.97	-4.01	-3.93	SS	-0.53	-1.54	-0.53	-0.71	NO	-0.47	-1.12	-1.98	-2.86
KP	-0.67	-1.69	-1.15	-0.98	CW	-0.75	-1.32	-1.87	-0.76	AW	-0.78	-0.84	-1.84	-1.38
RR	-21.53	-1.54	-1.16	-1.30	ZR	-1.19	-1.26	-0.95	-1.25	LW	-0.35	-0.70	-0.41	-0.99
RS	-1.15	-1.21	-1.48	-0.82	KL	-0.55	-1.22	-1.77	-1.71	CR	-0.67	-0.69	-1.04	-1.35
SD	-0.33	-1.14	-1.62	-0.94	PP	0.17	-1.17	-2.51	-0.76	JH	-0.09	-0.67	-1.41	-1.09
AD	-0.94	-1.12	-2.14	-2.09	PH	-0.42	-1.08	-2.62	-0.88	JH	-0.23	-0.67	-1.02	-0.43
GJ	-0.88	-1.11	-1.85	-2.00	AN	-1.57	-1.04	-1.03	-0.63	SB	-0.98	-0.65	-0.43	-0.13
HP	-0.64	-1.09	-3.51	-2.72	AN	-1.34	-0.98	0.04	0.19	CW	-0.41	-0.63	-0.83	-0.98
WI	-0.44	-1.04	-0.54	-1.07	JG	-0.47	-0.88	-0.93	-1.80	MV	-0.36	-0.55	-0.64	-0.74
PR	-0.72	-0.98	-1.06	-1.46	NB	-0.27	-0.71	-1.77	-0.80	NW	-0.31	-0.51	-1.67	-0.55
AJ	-0.86	-0.92	-0.30	-0.34	HR	-0.38	-0.64	-1.29	-1.75	SC	-0.31	-0.43	-0.54	-0.53
NJ	-0.50	-0.90	-0.87	-1.22	SS	-0.40	-0.58	-0.61	-0.71	PK	-0.20	-0.39	0.06	0.04
SZ	-0.45	-0.87	-1.57	-1.85	AS	0.29	-0.56	-0.23	-0.43	KD	-0.38	-0.37	-0.42	-0.99
NP	0.08	-0.84	-0.68	-1.00	GD	-0.02	-0.49	-0.61	-0.99	RB	-0.10	-0.34	-1.42	-0.39
MH	-0.01	-0.84	-1.35	-1.09	RS	-0.16	-0.33	-0.14	-1.57	KJ	-0.17	-0.31	-1.89	-3.37
KK	-0.55	-0.64	-2.16	-1.36	SP	-0.04	-0.21	-4.39	-2.00	AW	-0.16	-0.31	-0.40	-0.66
JE	-0.65	-0.62	-1.62	-1.05	AH	-0.10	-0.17	-0.43	-0.22	SB	-0.02	-0.26	-0.35	-0.58
GR	-0.36	-0.59	-0.91	-1.03	GP	-0.13	-0.11	-0.30	0.10	NB	0.22	-0.24	-0.96	-0.73
HC	-0.23	-0.59	-1.16	-1.11	RM	-0.07	-0.09	-0.60	-0.90	TH	0.07	-0.20	-0.84	-0.57
RL	-0.76	-0.58	-2.29	-1.61	MD	-0.18	-0.08	-0.39	-0.74	SC	-0.06	-0.16	-0.59	-0.60
KF	-0.37	-0.57	-0.78	-0.94	MP	-0.10	-0.07	-0.78	-0.89	CH	-0.21	-0.05	-0.78	-1.48
FF	-0.62	-0.56	-0.86	-1.08	RJ	-0.19	0.06	-0.52	-1.22	EF	0.65	0.07	-0.68	-1.15
MR	-0.40	-0.54	-1.70	-2.25										
LB	-0.18	-0.50	-0.96	-0.70										
RD	-0.49	-0.50	-2.05	-1.16										
IS	-0.28	-0.48	-1.45	-0.60										
GP	0.20	-0.40	-1.80	-1.59										
LM	-0.52	-0.39	-2.45	-3.09										
MH	0.05	-0.33	-0.96	-1.26										
PP	-0.27	-0.28	-1.17	-0.96										
BS	-0.04	-0.26	-1.83	-1.17										
MR	-0.27	-0.17	-0.87	-0.39										

DH-0.24 -0.11 -0.30 -1.41
ZJ -0.78 -0.84 -0.92 -1.23

8d) Results from part 3 of the study: Effect of target size on pinole SOLA levels

Mean SOLA levels under pinhole conditions for target sizes N8, N10, N15 and N20 both with (a) and without (b) concurrent mental effort are given in mean sphere form for each subject.

	SOLA N8		SOLA N10		SOLA N15		SOLA N20	
Subjects	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
NP-EMM	-1.98	-1.85	-1.40	-1.62	-1.28	-1.74	-1.11	-1.78
CH - LOM	-2.40	-1.68	-1.95	-1.72	-1.91	-1.72	-1.88	-1.58
LM - EMM	-4.12	-4.13	-3.42	-2.71	-2.28	-2.31	-3.82	-2.50
RD - EMM	-2.05	-1.16	-1.21	-0.96	-1.93	-1.80	-1.91	-1.55
KL - EOM	-1.11	-1.74	-1.93	-1.90	-1.47	-1.74	-1.90	-2.32
FF - EMM	-1.13	-1.35	-0.95	-1.11	-1.34	-1.93	-0.81	-1.64
RS - EMM	-1.48	-0.82	-1.63	-1.32	-1.69	-1.67	-1.82	-1.69
GR - EMM	-1.92	-1.64	-1.18	-1.14	-1.18	-1.42	-1.41	-1.60
HC - EMM	-0.91	-0.74	-1.48	-0.99	-1.24	-2.27	-2.44	-1.47
GJ - EMM	-2.16	-2.31	-4.28	-2.75	-3.47	-2.18	-5.28	-3.41
Mean	**1.93**	**1.74**	**1.94**	**1.62**	**1.68**	**1.89**	**2.23**	**1.95**
SEM	**0.29**	**0.30**	**0.34**	**0.21**	**0.14**	**0.09**	**0.42**	**0.19**

APPENDIX 10

THE EFFECT OF PROXIMITY ON ACCOMMODATION IN EMMETROPIA AND MYOPIA

10a) Background data

Presented here are individuals' right eye data for mean sphere refractive error (Rx), Keretometry ('K'), axial length (A.L.), anterior chamber depth (A.C.D.), lens thickness (L.T.), vitreous chamber depth (V.C.D.) and age of subject. For the early- and late-onset myopes the age of myopic onset has been included.

EMMETROPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)
AS	0.25	7.78	23.42	3.86	3.73	15.83	23
BS	0.12	7.33	22.00	3.25	3.19	15.56	18
GJ	-0.12						20
GP	-0.25	7.55	23.06	3.95	3.35	15.76	19
HC	0.25	7.88	23.69	3.68	3.42	16.56	27
HP	0.25	7.58	22.45	3.30	3.70	15.45	18
JS	-0.12	7.45	23.93	3.89	3.85	16.19	18
JS	-0.25	7.60	23.56	2.86	3.73	16.90	20
KP	0.00	8.98	25.77	3.26	3.58	18.93	18
PP	0.50	7.55	22.65	3.65	3.41	15.59	19
SR	0.12	7.63	23.62	3.45	3.62	16.55	22
WI	0.00	8.43	23.99	3.31	4.00	16.67	18
Mean	**0.06**	**7.80**	**23.47**	**3.50**	**3.60**	**16.36**	**20.00**
SEM	**0.07**	**0.15**	**0.30**	**0.10**	**0.07**	**0.30**	**0.80**

EARLY-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AH	-3.75	8.05	26.06	4.13	3.44	18.51	18	13
AN	-6.12	7.50	25.64	3.90	3.69	18.05	18	7
CW	-1.75	8.00	25.80	3.79	4.16	17.48	20	14
GP	-8.50	7.60	26.48	3.45	3.47	19.56	21	5
JB	-4.25	7.95	27.15	3.69	3.63	19.83	20	12
JG	-1.75	8.10	24.18	3.76	3.32	17.10	19	13
KL	-3.00	7.95	25.11	3.41	3.42	18.28	23	12
MD	-6.00	8.08	27.04	3.99	3.71	19.34	29	7
NB	-5.50						18	12
RM	-6.25	7.98	26.05	3.68	3.44	18.93	18	7
SS	-3.37	7.60	24.51	3.71	3.57	17.23	19	10
WF	-0.75	7.15	22.66	3.66	3.48	15.52	18	14
Mean	**-4.25**	**7.81**	**25.51**	**3.74**	**3.57**	**18.17**	**20.08**	**10.50**
SEM	**0.66**	**0.09**	**0.40**	**0.06**	**0.07**	**0.38**	**0.92**	**0.92**

LATE-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AW	-1.37	7.60	24.40	3.75	4.02	16.63	20	17
CH	-1.25						28	23
CR	-1.00	7.68	24.28	3.87	3.63	16.78	20	19
CW	-1.12	8.05	25.06	3.94	3.35	17.75	18	16
EF	-0.87	7.90	24.44	3.93	3.44	17.08	19	17
JH	-1.00	7.50	23.44	3.29	3.66	16.46	22	21
KD	-1.50	8.50	25.94	3.79	3.34	18.80	18	16
NB	-1.50	7.93	25.08	3.85	3.61	17.62	30	25
NH	-1.50	7.50	24.24	3.86	3.63	16.76	23	19
NW	-0.87	7.45	23.78	3.89	3.36	16.52	28	24
SB	-1.75	8.08	24.49	3.50	3.94	17.05	20	19
TH	-1.87	7.98	24.57	3.79	3.66	16.89	20	17
Mean	**-1.30**	**7.83**	**24.52**	**3.77**	**3.60**	**17.12**	**22.17**	**19.42**
SEM	**0.10**	**0.10**	**0.20**	**0.06**	**0.07**	**0.21**	**1.21**	**0.91**

10b) Accommodation regression (mean sphere) following sustained distance viewing through a plano lens (DNA)

The accommodative regression measures are preceded by accommodation measures taken during sustained viewing of the target. Time '0' represents the moment the room goes into complete darkness and the following accommodation measures are taken at 1 s intervals.

EMMETROPES

Time	SR	GJ	BS	HC	HP	PP	GP	KP	JS	AS	JS	WI
	0.00	0.62	0.18	0.12	0.68	0.12	0.56	1.62	0.56	0.43	0.50	0.18
	0.00	0.75	0.31	0.18	0.56	-0.12	0.62	1.62	0.80	0.43	0.80	-0.12
	0.00	0.62	0.18	0.06	0.62	-0.12	0.56	1.56	0.75	0.31	0.50	-0.12
	-0.37	0.62	0.12	-0.18	0.75	0.00	0.62	1.37	0.75	0.50	0.37	-0.12
	0.37	0.62	0.18	0.12	0.75	-0.06	0.56	1.43	0.87	0.37	0.81	-0.12
	0.25	0.75	0.37	0.12	0.50	0.00	0.50	1.75	0.80	0.25	0.93	0.00
	0.31	0.75	0.50	0.12	0.50	0.31	0.50	1.37	0.87	0.37	0.75	-0.18
	0.12	0.75	0.37	0.06	0.62	0.18	0.50	1.18	0.93	0.25	0.56	-0.12
	0.12	0.87	0.37	0.25	0.50	-0.06	0.50	1.30	1.12	0.31	0.80	-0.12
	0.00	0.62	0.00	0.25	0.62	0.06	0.43	1.43	0.93	0.50	0.68	-0.06
	0.19	0.75	0.18	0.00	0.56	-0.06	0.50	1.05	0.93	0.50	0.75	-0.25
	0.25	0.75	0.25	0.25	0.56	0.06	0.50	1.12	0.93	0.50	0.80	-0.18
	0.06	0.62	0.18	0.12	0.30	-0.06	0.43	0.80	0.68	0.37	0.75	0.12
	0.06	0.62	0.12	0.18	0.68	0.12	0.43	1.56	0.50	0.25	0.75	0.12
	-0.31	0.75	0.31	0.25	0.56	0.25	0.56	1.25	0.75	0.25	0.87	0.12
0												
1	0.56	0.68	0.25	0.18	1.06	0.00	0.56		0.43	0.68		
2	0.62	0.68	0.31	0.43	1.12	0.00	0.56		0.93	0.62	0.25	0.43
3		0.56	0.30	1.18	1.37	0.00	0.62		1.25	1.00		0.43
4	0.37	0.62	0.30	0.93	1.62	0.06	0.62	1.68	1.18	0.93		0.62
5		0.62	0.30	0.93	1.31	0.31	0.75	1.93	1.30	1.12	0.37	0.50
6	0.37	0.81	0.30	0.80	3.00	0.18	0.62	1.93	1.12	0.81	0.31	0.62
7	0.37	0.81	0.43	0.68	1.68	0.25	0.62	2.06	1.18	0.62	0.43	0.68
8	0.37	0.75	0.30	0.62	1.12	0.31	0.68		1.12	0.62	0.00	0.62
9	0.25	0.62	0.30	0.56	1.37	0.18	0.62	1.93	1.12	0.50	0.30	
10	0.12	0.68	0.43	0.87	1.25	0.12	0.62	2.00		0.75	0.25	0.43
11	-0.37	0.56	0.30	0.80	1.50	0.00	0.87	1.87	1.18	0.68	0.30	0.43
12	1.50	0.75	0.30	0.80	1.37	0.18	0.87		1.06		0.31	

13	0.37	0.75	0.25	0.68	1.12	0.31	0.68	1.80	1.12	0.62	0.43	0.37
14	0.37	0.62	0.30	1.00	1.30	0.25	0.62	1.87	1.00	0.62	0.37	
15	0.25	0.68	0.30	0.87	1.81	0.31	0.56	1.87		0.62	0.37	0.37
16	0.43	0.75	0.18	0.75	1.43	0.37	0.50	2.25	1.12	0.62	0.30	0.68
17	0.43	0.80	0.18	0.81	1.62	0.43	0.43	2.00	1.31	0.50		0.43
18	0.43	0.75	0.30	0.75	2.37	0.50	0.56		1.18	0.75		0.56
19		0.75	0.30	0.81	3.12		0.50	2.05	0.62		0.50	0.50
20	0.56	1.06		0.68	1.50	0.25	0.68	1.75	1.31	0.50	0.80	0.56
21		0.75	0.37	0.56	1.43	0.31	0.43	2.49	0.50		0.75	0.50
22	1.00	0.75	0.30	0.68	2.12	0.37	0.43		1.25	0.50	0.62	0.93
23	1.43	0.62	0.25	0.62	1.37	0.50	0.56	3.00		0.56	0.56	0.44
24	1.30	0.80	0.25	0.56	1.30	0.50	0.62	3.12	1.30	0.43	0.43	
25	1.25	0.75	0.25	0.62	1.37	0.62	0.68	3.18	1.25	0.43	0.43	
26	1.37	0.80	0.37	0.62	1.56	0.50	0.68	3.56	1.25	0.31	0.43	0.68
27	1.25	0.75	0.43	0.62	1.12	0.37		3.62	1.25	0.43		0.87
28	0.12	0.75		0.43	2.06	0.37	0.68	3.31	1.25	0.43	0.50	1.18
29	0.12	0.75	0.37	0.50		0.50	0.56	3.00	1.25	0.43	0.31	1.12
30	0.37	0.68	0.37	0.37	2.12	0.31	0.75		1.25	0.37	0.31	1.00
31	0.30	0.68	0.25	0.37	2.18	0.31	0.75		1.50	0.37	0.37	1.06
32	0.37	0.68	0.25	0.56	1.50	0.37	0.62	3.93		0.37	0.43	0.93
33	0.56	0.80	0.25	0.18	2.30	0.62	0.37	2.06	1.56	0.43		1.00
34	0.30	0.68	0.25	0.18	1.93	0.87	0.37	2.12		0.30		1.00
35	0.18	0.80	0.37	0.25	2.68	0.37	0.37		1.25	0.43	0.56	0.87
36	0.37	0.80	0.37	0.00	2.68		0.43		1.43	0.30	0.12	0.93
37	0.25	0.68	0.37	0.16	5.62	0.50	0.50	1.87	1.30	0.30	0.00	0.87
38	0.25	0.68	0.37	0.18	6.12	0.43	0.30	1.93	1.43	0.30	0.18	1.25
39	0.18	0.68	0.25	0.16	4.87	0.50	0.25	2.05	1.30	0.43	0.25	1.00
40	0.56	0.62	0.50	0.00	3.31	0.62	0.25		1.50	0.43	0.18	
41	0.87	0.75	0.37	0.06	4.50	0.31		1.68	1.75	0.56	0.56	1.50
42	1.68	0.68	0.25	0.00	5.62	0.68	0.37	1.43	1.75	0.43	0.37	1.12
43	1.80	1.06	0.25	0.06	6.18	0.50	0.37	1.62	1.87	0.30	0.50	1.00
44	1.62	0.68		0.12	6.18	0.62	0.50	1.50			0.50	1.12
45	1.25	0.68	0.25	0.12	6.43	0.80	0.50	1.31		0.43	0.43	0.87
46	1.62	0.68	0.30	0.12	6.25	0.68	0.50	1.37		0.37	0.31	
47	1.87	0.75	0.25	0.18	6.00	0.62	0.37	1.12	1.12	0.43	0.31	
48	2.87	0.68	0.12	0.06	4.25	0.62	0.43		1.30	0.43	0.50	1.18
49	2.75	1.00	0.12	0.06	4.37	-0.18	0.37		1.31	0.43	0.62	1.00
50	1.50	0.75	0.12	0.06	5.12	0.56	0.43	1.06	1.37	0.37	0.50	1.06
51	2.80	0.87	0.12	0.06	5.30	0.62	0.37		1.93	0.43	0.43	1.12
52	0.50	0.75	0.25	0.00	5.87	0.50	0.50	0.93	1.37	0.43	0.43	1.12
53	0.00	0.93	0.25	-0.12	6.62		0.43	0.81	1.56	0.37	0.56	
54	0.12	0.87	0.25	-0.06	6.68	0.37	0.43	0.75	1.50	0.43	0.43	1.00
55	0.25	0.81	0.25	-0.06	6.50	0.56	0.56	1.31		0.56	0.30	1.06
56	0.37	0.68	0.25	0.00	6.37	0.62	0.62	1.06	1.68	0.50	0.25	0.87
57	0.37	0.75	0.12	-0.06	6.50	0.68	0.56		1.25	0.56	0.43	0.80
58	0.62	0.56	0.25	0.00	6.56	0.68	0.62	1.06	1.06	0.43	0.50	1.12
59	0.87	0.68	0.37	0.00	6.68	0.62	0.62	0.31	1.18	0.43	0.43	1.37
60	0.68	0.87	0.25	0.00	6.30	0.68	0.50	0.81	1.18	0.43	0.31	1.37

EARLY-ONSET MYOPES

Time	KL	NB	WF	RM	AN	JF	AH	SS	JB	CW	GP	MD
	0.00	0.25	0.31	0.68	0.31	0.12	0.62	0.25	0.31	0.31	-0.18	0.25
	0.31	0.62	0.25	0.68	0.00	0.00	0.56	0.25	0.31	0.25	-0.25	0.12
	-0.06	0.43	0.50	0.56	0.37	0.43	0.50	0.56	0.56	0.43	-0.12	0.12
	0.43	0.37	0.62	0.56	0.50	0.62	0.56	0.62	0.37	0.00	-0.06	0.25
	0.50	0.50	0.43	0.43	0.12	1.25	0.56	0.18	0.25	0.37	-0.25	0.43
	0.43	0.43	0.62	0.50	0.37	0.12	0.56	0.25	0.25	0.06	0.56	0.62
	0.81	0.50	0.50	0.75	0.43	0.62	0.56	0.31	0.25	0.18	0.18	0.25
	0.56	0.50	0.43	0.43	0.37	0.06	0.50	0.37	0.18	0.31	0.00	0.30

	0.43	0.37	0.56	0.56	0.31	0.62	0.31	0.50	0.18	0.25	-0.06	0.25
	0.43	0.50	0.50	0.31	0.06	0.68	0.50	0.62	0.18	0.31	0.50	0.31
	0.80	0.37	0.56	0.50	-0.12	0.50	0.31	0.62	0.25	0.37	-0.12	-0.12
	0.56	0.37	0.56	0.43	-0.18	0.00	0.31	0.62	0.25	0.56	-0.12	0.00
	0.00	0.12	0.43	0.50	-0.12	0.81	0.31	0.37	0.37	0.06	0.06	0.31
	0.75	0.25	0.50	0.18	0.06	0.81	0.12	0.50	0.06	0.06	0.06	0.37
0												
1	0.31	0.12	0.62	0.31	0.00	0.62	0.37	0.87	0.31	0.56	-0.32	-0.12
2	0.56	0.18	0.50	0.31		0.43	0.37	0.56	0.68	0.56	-0.50	0.06
3	1.06	0.31	0.62	0.31	-0.25	0.56	0.37	0.62	0.80	0.62	-0.25	0.06
4	1.06	0.18	0.68	0.43	0.12	0.37	0.31	0.62	1.06	0.43	-0.18	0.18
5	1.06	0.18	0.62	0.43		0.43	0.31	0.50	1.37	0.25	-0.25	0.18
6	1.12	0.18	0.75	0.43	0.43	0.43	0.37	0.87	1.25	0.31	-0.31	0.43
7	0.68	0.25	0.93	0.43		0.43	0.37	0.43	1.00	0.25	-0.50	
8	0.93	0.31	0.75	0.37		0.31	0.37	0.56	1.30	0.25	-0.18	0.56
9	0.87	0.31	0.68	0.37	0.31	0.25		0.43	1.37	-0.18	-0.32	
10	1.00	0.43	0.68	0.37		0.12	0.43	0.50	1.37	0.06	-0.50	0.62
11	1.00	0.48	0.50	0.50	0.37	0.37	0.50	0.56	1.56		-0.44	
12		0.50	0.56	0.43			0.50	0.62			-0.44	0.68
13		0.62	0.68	0.43	1.00	0.12	0.43	0.75	2.18	-0.06	-0.50	0.25
14	1.18	0.37	0.80	0.56	0.00	0.12	0.56	0.25	2.00	-0.32	-0.56	0.06
15		0.50	0.87	0.56		0.06	0.50	0.75		0.00	-0.50	0.00
16	1.25	0.75	0.87	0.56	0.31	0.18	0.37	0.62		0.12		-0.12
17	1.12	0.75	0.87	0.62	1.12	0.31	0.37	0.75	2.18	0.12	-0.32	-0.25
18	0.93	0.93	0.87	0.68	1.43	0.43	0.37	0.81	2.62	0.12	-0.37	-0.25
19	0.87	0.93	0.75	0.68	2.81	0.25	0.37	0.75			-0.18	-0.31
20		1.00	0.87	0.56	2.30	0.25	0.50	0.75		1.31	-0.18	-0.25
21	0.87	0.87	1.12	0.56	1.18	0.18	0.25		1.50	0.56	-0.18	-0.37
22	0.75	1.06	1.00	0.50		0.25	0.43	0.87	1.87	1.00	-0.18	-0.37
23	0.87	1.18	0.93	0.56	1.81	0.37	0.56	0.87		1.00	0.06	
24	0.56	0.50	1.00	0.50	2.12	0.50	0.62	1.00		0.81	-0.12	-0.31
25	0.75	0.25	0.80	0.43	2.50	0.50	0.68	1.12	2.30	0.80	-0.18	-0.12
26	0.80	0.43	0.87	0.37	2.12	0.31	0.62	1.00	2.12	1.06	-0.37	-0.32
27	0.68	0.62	0.75	0.50	2.25		0.43		2.37	1.56	-0.37	-0.62
28	0.81	0.75	0.81	0.62		0.19	0.62		2.30	0.87	-0.12	-0.62
29	0.87	0.75	0.87	0.75		0.00	0.56			1.00	0.00	-0.68
30		0.81	0.93	0.80	1.43	-0.06	0.50		2.06	0.93	-0.50	-0.56
31	0.75	0.81	1.12	0.68	1.75	-0.12			2.00	1.00		-0.87
32	0.75	0.81	0.93	0.56		-0.32	0.56	0.75	2.25		-0.31	-0.37
33	0.50	0.81	0.93		0.37		0.56				0.00	-0.44
34	0.68	0.87	1.06		1.37		0.50	1.25			0.06	-0.31
35	0.68	1.00	1.12	0.75		0.43	0.62		2.25	-0.25	0.00	-0.62
36	0.50	0.93	1.12	0.56		0.80	0.50	1.37		-0.25	-0.44	-0.50
37	0.62		1.12	0.50	2.80	0.43	0.50	1.12			-0.18	-0.50
38	0.43	1.12	1.12		2.37	0.87	0.56	1.18		-0.06	-0.18	-0.43
39	0.56	1.18	1.12	0.56		0.12	0.37	0.62		0.00	-0.32	-0.25
40	0.68	1.18	1.06	0.56	2.30	0.43		1.37	1.87	0.25	-0.50	-0.43
41	0.68	1.06	1.25	0.43		0.43	0.37	0.68	1.31	0.18	-0.25	-0.50
42	0.62		1.18	0.50	0.75	0.31	0.25	1.30	1.62	0.18	-0.18	
43	0.68	1.00	1.25	0.37		0.37	0.31	1.25	1.68		-0.06	
44	0.80	1.12	1.12	0.43		0.50	0.37	0.75	1.62	0.31	-0.18	-0.43
45	0.56	0.87	1.12		0.43	0.25	0.50	0.81	1.37	0.12	-0.44	-0.31
46	0.87	1.06	1.06	0.43	1.00	0.31	0.37	0.75	1.50	0.12	0.06	-0.25
47	0.68	1.18	0.93	0.43	0.93	0.12	0.50	0.93	1.37	0.18		-0.56
48	0.87	1.30	1.00	0.50	1.56	0.18	0.37	0.81		0.18	0.00	
49	0.56	1.37	0.75	0.56	1.75	0.43	0.37	0.68	1.25	0.12	-0.32	-0.56
50		0.93	0.80	0.43		0.18	0.25	0.87		0.06	-0.12	-0.56
51	0.80	0.93	0.87	0.68	1.06		0.50	0.87		0.25	0.00	-0.43
52	0.81	0.93	0.87	0.75	1.93		0.50	0.87	1.18	0.25	-0.37	-0.32
53		0.80	0.68	0.75	1.93	0.75	0.37	0.75		0.37	-0.31	-0.50
54	0.68	1.00	0.62	0.81		1.12	0.37	0.31	1.18		-0.56	-0.50

55	0.43	1.00	0.62	0.87		0.81	0.37		1.06	0.62		-0.62
56	0.62	1.06	0.62	0.62		0.80	0.50		1.37	0.50	-0.25	-0.37
57	0.62	0.93	0.75	0.62	1.93	0.50		0.93		0.43	-0.44	-0.18
58	0.56	1.00	0.87	0.43		0.56	0.37	1.06	1.56		-0.50	0.12
59	0.50	0.93	0.87	0.62		0.75	0.37		1.25			0.12
60	0.62	1.06	0.75	0.62			0.25	1.00	1.25	1.00	-0.44	

LATE-ONSET MYOPES

Time	AW	NW	JH	SB	EF	KD	CW	NB	CH	NH	TH	CR
	0.18	0.31	0.00	-0.12	0.80	0.18	0.62	-0.25	0.31	-0.12	0.37	0.25
	-0.06	0.25	-0.12	-0.06	0.25	0.18	0.56	-0.06	0.43	-0.06	0.56	0.50
	0.25	0.50	0.12	-0.31	0.31	0.12	0.43	0.30	0.50	-0.31	0.43	0.25
	0.12	0.62	0.06	0.50	0.37	0.37	0.62	0.00	0.43	-0.12	0.43	0.18
	0.06	0.56	0.00	0.31	0.37	0.18	0.75	-0.06	0.37	-0.06	-0.06	0.18
	-0.18	-0.18	0.00	-0.25	0.12	0.18	0.68	-0.25	0.18	0.00	0.12	0.18
	0.18	0.68	0.06	0.25	0.06	0.25	0.62	-0.06	0.31	-0.25	0.06	0.18
	0.43	0.25	0.06	0.12	0.43	0.25	0.56	-0.50	0.25	-0.31	0.43	0.37
	0.50	0.43	0.18	0.12	-0.18	0.31	0.50	0.06	0.12	-0.25	0.68	0.50
	0.43	-0.06	0.06	0.43	0.00	0.37	0.37	-0.12	0.50	-0.25	1.00	0.50
	1.00	0.56	0.00	0.00	0.00	0.25	0.31	0.12	0.43	-0.32	0.37	0.18
	0.68	0.18	0.06	0.43	-0.12	0.31	0.37	-0.12	0.31	-0.12	0.06	0.25
	0.56	0.43	0.12	0.06	0.06	0.31	0.56	0.00	0.31	-0.18	0.30	0.25
	0.12	-0.06	-0.12	0.12	0.31	0.25	0.50	-0.12	0.31	-0.12	0.25	0.25
1		-0.06	-0.12	0.43	0.06	0.31	0.31		0.25	0.06	0.25	0.37
2		0.30	-0.06	0.50	0.43	0.25	0.68	0.25	0.25	0.06	0.43	0.37
3		0.62	0.06	0.62	0.50	0.80	1.06	0.06	0.18	0.25	0.06	0.37
4		0.30	0.00	0.75	0.56		1.68	0.18	0.18		0.30	0.43
5		0.50	0.06	0.56	0.56		1.75	0.25		0.37	0.62	0.31
6		0.50	0.06	0.62	0.75	0.80	1.37	0.37	0.25		0.25	0.37
7		0.62	0.00		0.50	0.75	1.62	0.31	0.25	0.62	2.68	0.31
8		0.50	-0.06		0.62	0.87	1.75	0.43	0.18	0.37	2.50	0.31
9	1.18	0.50	0.00	0.81	0.62		1.62	0.18	0.18	0.25	0.31	0.31
10	-0.44	0.50	0.06		0.75	1.00	1.80	0.18	0.25	0.06	0.25	0.50
11		0.50	0.00		0.50	1.00	1.31	0.30			-0.12	
12		0.50	0.00		0.56	0.93	1.00	0.30	0.31	-0.12	0.50	0.50
13	1.30	0.50	-0.06	1.25		1.06	1.56	0.37	0.40		0.44	0.56
14	1.06	0.50	-0.06	1.30	0.56	1.00		0.68	0.31	0.00		
15	1.62	0.50	-0.12	1.31	0.62	0.93	0.87	-0.06	0.31	0.06	0.31	0.68
16		0.50	0.00	1.43		1.18	1.18	0.62		-0.06	0.68	0.62
17			-0.06			1.43	1.18	0.68	0.06	-0.18		0.75
18		0.50	-0.25				1.18	0.80		-0.25	0.81	0.62
19	1.25	0.50	-0.12			1.06	1.30	0.75	0.25	0.06		
20	1.06		-0.12	1.12	0.37	0.75	1.37	1.12	0.06		0.87	
21	1.18	0.37	-0.12	1.30	0.50	1.12	1.30	1.37		-0.25		0.31
22	0.68	0.50	0.00		0.25	1.18	1.56	1.37	0.12		1.06	0.25
23	0.87		-0.19	0.80	0.62		1.25	1.12	0.06		0.81	0.12
24	0.87	0.62	-0.12			0.93	1.56	1.25	0.00	0.31		0.31
25		0.62	-0.06	0.56	0.62	1.37	2.18	1.37	0.12	0.50	0.93	-0.25
26		0.75	0.06	0.62	0.62		1.50	0.87	0.18	0.31	0.75	0.56
27	1.12	0.62	0.00		0.68	1.31	1.25	0.31	0.37			0.81
28	0.62	0.62	0.00	0.80	0.56	1.00	1.00	0.68	0.43	0.50	0.75	0.37
29	1.25	0.62	-0.06	0.68	0.43		1.00	0.62	0.25			0.50
30			-0.06	0.68	0.50	0.93	1.25	0.62	0.25	0.37	0.68	
31	1.37	0.68	-0.06	1.00	0.56		1.37		0.37			-0.25
32	1.00	0.62	-0.06	0.80	0.62	0.81	1.43	0.56		0.18	-1.00	0.18
33	1.25	0.62	-0.06			0.56	1.25	1.00	0.37		-1.50	
34	1.18	0.62	-0.12	0.87	0.50	0.87	1.25	1.12	0.43		0.31	0.37
35	1.25	0.62	0.00	1.00	0.37	0.96	1.18	0.43				0.31

36	1.18	0.75	0.12	1.25	0.43	0.62	1.43	0.62	0.12	0.06	0.50	0.06
37	1.06	0.75	0.00	1.18	0.50	0.31	1.25	0.68	0.12	0.18		-0.06
38	1.00	0.75	0.06	1.25	0.37	0.75	1.18	0.75	0.12		0.31	-0.12
39	0.80	0.75	0.12	0.87	0.43		1.06	1.31	0.18		1.06	-0.12
40	0.68	0.75	0.06		0.43	0.81	1.06	0.56			0.25	-0.12
41		0.75	0.06	1.30	0.31	0.62	0.93	0.56		0.50		-0.12
42	0.87	0.62	0.12		0.37	0.75	1.00			0.56	-0.06	0.06
43	0.62		0.18	1.43	0.43	0.75	1.06		0.12			0.06
44	0.87	0.75	0.12	1.12	0.43	1.56	1.06			0.44		0.62
45	1.50		0.18	1.68	0.43		1.18	0.56	0.00	0.43		-0.25
46	1.37	0.62	0.18				1.18	0.81		0.56	0.30	
47	1.00	0.43	0.31	1.80	0.43	2.00	1.25	1.06	0.18	0.18	0.06	0.06
48	1.06	0.56	0.18	1.18	0.43	2.37	1.25	1.06	0.18		0.87	0.06
49	0.75		0.18	0.81			1.00	0.62	0.06	0.50	0.00	0.25
50	0.81	0.62	0.18	0.75	0.50	2.75	1.31	0.75	0.18		0.81	-0.18
51	1.12	0.62	0.18	0.93	0.56		1.25			0.18	0.06	
52	0.93	0.50	0.18			0.87	1.25	0.62	0.18		0.18	
53	1.18	0.50	0.06		0.50	1.06	1.25	0.75	0.12	0.00	0.80	
54			0.25	0.68	0.62	1.12			0.06	0.06	0.87	0.06
55	1.50	0.50	0.12	0.56	0.56	1.18	1.37		0.00	-0.06	0.50	
56	1.18	0.50	0.12	0.62	0.00	1.25	1.68			0.00	-0.06	0.25
57	0.93	0.62	0.12	0.56	0.43	1.68	1.75	0.80	0.06	0.06		-0.18
58	0.87		0.06	0.56	0.62	1.56	1.25		0.06		0.68	-0.06
59	1.00	0.62	0.06	0.56	0.68	1.00	1.50			0.12	0.12	-0.18
60	0.56	0.62	0.18		0.75	1.25	1.43		0.06	-0.18	0.87	

10c) Accommodation regression (mean sphere) following sustained distance viewing through a minus lens (DWA)

EMMETROPES

Time	SR	GJ	BS	HC	HP	PP	GP	KP	JS	AS	JS	WI
	2.87	2.18	2.56	2.00	3.62	2.37	2.30	3.50	2.80	3.31	2.93	2.87
	2.68	2.75	2.56	2.50	3.25	3.12	2.43	3.55	3.25	2.93	3.43	2.12
	2.62	2.62	2.37	2.62	2.93	2.75	2.43	3.30	2.68	2.93	3.06	1.93
	2.80	2.62	2.25	2.06	3.18	2.62	2.43	3.18	2.87	2.62	3.43	2.68
	3.12	2.68	2.50	2.56	2.81	2.68	2.56	3.87	3.12	2.87	3.12	1.93
	2.93	2.56	2.50	2.30	3.12	2.75	2.25	3.25	2.56	2.75	3.25	2.18
	3.00	3.06	2.18	2.62	3.37	2.75	2.30	3.18	2.50	2.62	2.68	2.12
	2.62	3.00	2.56	2.75	2.93	2.75	1.93	3.18	3.18	2.80	3.50	1.87
	2.62	2.87	2.68	2.62	3.18	2.75	2.50	3.12	2.62	2.75	3.75	1.75
	2.50	2.87	2.62	2.56	3.00	2.37	2.18	3.31	2.81	2.87	3.25	2.25
	2.93	2.75	2.62	2.62	2.75	2.75	2.43	3.05	2.75	2.81	3.37	1.87
	3.50	2.81	2.75	2.56	2.80	2.93	2.30	3.25	2.68	3.06	3.18	2.43
	2.25	2.81	2.43	2.43	3.00	3.00	2.30	3.43	3.00	2.87	3.18	2.31
	2.62	3.06	2.50	2.68	2.93	2.81	2.12	4.05	2.75	3.12	3.18	2.62
	2.68	2.62	2.37	2.68	2.93	2.56	2.30	3.00	2.93	2.68	2.93	2.31
0												
1		2.56	2.75	2.05	2.37	1.50			2.12	3.12		
2		1.68	2.12	2.05	3.05	0.62	1.56		2.31	3.37	1.00	2.30
3		1.50	1.93	1.56	2.80	0.68	1.50	2.62	2.43		1.37	1.75
4	0.68	1.50	1.12	1.56	2.06		1.30		2.30	2.06	1.43	
5	0.31	1.31	0.80	0.93	2.00	0.75	1.12	2.56	1.75	1.05	1.43	0.80
6	0.56		1.06	0.75	2.00	0.62	1.06	3.00			1.25	0.68
7	0.68	1.75	0.80	0.93	2.12	0.75	0.87	3.31		0.87	1.62	0.87
8	0.50	1.37	0.87	0.93	1.68	0.80	0.80	3.25		1.12	1.56	
9		1.31	0.87	0.87	1.62	0.87	1.56	3.31			1.43	0.68
10	0.62	1.18	0.75	0.75	1.50	0.75	1.00	2.75	1.68	0.81	1.37	0.75
11	0.68	1.31	0.68	0.56	1.50	0.68	0.93		1.93	0.75	1.31	0.68
12	0.56	1.18	0.81	0.56	1.68	0.68	1.00	2.81	2.00	0.81		0.68

13	0.68	1.25	0.62	0.62	1.62	0.56	0.93			0.81	1.18	0.68
14	0.93	1.05	0.87	0.68	1.75	0.62	0.87		2.06	0.87	1.18	0.81
15	1.12	1.25	0.75	0.75	1.56		0.93	2.43		0.87	0.81	1.12
16	0.80	1.18	0.68	0.62	1.25	0.56	1.00	2.75	2.00	0.75	0.75	0.80
17	0.87	1.43	0.56	0.43	1.18	0.62	0.87			0.87	0.87	0.62
18	1.06	1.37	0.50	0.06	1.18	0.56	0.62	2.87		0.87	0.80	0.75
19	1.43	1.18	0.62	0.06	1.25	0.62	0.68	2.68		0.81	0.87	0.75
20	1.06	1.06	0.56	0.18	1.87		1.06	3.12		0.81	0.68	0.62
21	0.87	1.06	0.75	0.00	1.37	0.68	1.18	3.80	2.43	0.75	0.80	0.81
22	0.87	1.12	0.80	0.00	1.68	0.62	1.30	4.05	2.80	0.93	0.75	0.93
23	0.75	1.25	1.06	0.12	1.37	0.50	1.12	4.30	2.75	0.87	0.81	0.81
24	0.81	1.25	1.00	0.12	1.31	0.30	1.18	3.06	2.62	0.75	0.93	0.81
25	0.75	1.25	1.00	0.25	1.06	0.50	1.06	3.00	2.81	0.80		0.62
26	0.62	1.12	0.93	0.18	1.43	0.50	0.93	3.06	2.87	0.56	0.80	0.93
27	0.56	1.18	1.00	0.37	1.31	0.30	1.06		2.93	0.56	0.75	0.75
28	0.56	1.12	0.81	0.37	1.43	0.50	1.06	2.87	2.62	0.43	0.87	0.62
29	0.56	1.12	1.00	0.31	1.25	0.56	1.00	2.75	2.56		0.87	0.62
30	1.00	1.18	1.18	0.31	1.68	0.56	1.18	2.81	2.37	0.56	1.06	0.56
31	1.00	1.31	0.80	0.37	1.56	0.62			2.30	0.68	1.18	0.43
32	1.25	1.06	0.87	0.06	1.81	0.50	1.12	2.75	2.06	0.50	1.00	0.37
33	1.18	1.31	1.06	0.00	1.56	0.68	1.06	2.75		0.62	0.93	0.56
34	1.62	1.37	0.93	0.25	1.50	0.56	0.87	2.12		0.62	1.06	0.87
35	1.37	1.50	0.80	0.18	1.50	0.56	1.06	2.87		0.50	1.00	0.93
36	1.25	1.05	0.80	0.18	1.31	0.68	0.93	2.75		0.50	1.00	0.62
37	0.87	1.56	1.12	0.06	1.06	0.56		2.62		0.62		0.81
38	0.68	1.25	1.25	0.12	1.30	0.56	0.87	2.56	1.81	0.62	1.00	0.62
39	0.75	1.18	1.12	-0.18	1.25	0.56	0.87	2.62	1.87	0.62	0.87	
40	0.62	1.12	1.18	-0.18	1.18	0.50	0.87	2.93	2.12	0.50	1.06	
41	0.50		1.06	-0.18	1.18	0.56	1.00	3.18		0.50	0.93	1.50
42	0.87	1.06	1.30	0.12	1.00					0.50		1.12
43	0.75	1.18	1.18	0.06	1.37	0.62	0.93	2.75		0.50	0.80	1.12
44	0.62	1.25	1.37		1.12	0.62	0.93	2.43			0.75	1.00
45	0.56	1.25	1.43	0.18	1.25	0.62	0.93		1.56	0.50	0.62	1.06
46	0.75	1.25	1.50	0.56		0.62	1.06	2.50	1.50	0.50	0.62	0.93
47	0.81	1.06	0.62	0.31	1.56	0.62	1.06	2.43	1.62	0.62	1.25	
48	0.87	1.18	0.50	0.31	1.68	0.62		2.31	1.68	0.62	1.12	0.75
49	0.93	1.18	0.62	0.25	2.87	0.37	0.81	2.50	1.50	0.50	0.87	0.62
50	0.68	1.06	0.50	0.00	1.93	0.50	0.75	2.62	1.31	0.50	0.81	0.68
51	0.68	1.18	0.62	0.06	1.93	0.50	0.81	3.00	1.43	0.50	0.87	0.56
52	0.75	1.18	0.62	0.06	1.75	0.62	0.81	3.06	1.43	0.68	0.87	0.62
53	0.62	1.12	0.62	0.00	1.56	0.62	0.93	2.80	1.56	0.68	0.80	0.62
54	0.75	1.18	0.68	0.06	1.50	0.62	0.87	2.62	1.75	0.80	0.87	0.43
55	0.75	1.30	0.75	0.06	1.43	0.56	0.87	2.56		0.87	0.56	0.68
56	0.56	1.25	0.68	0.18	1.37	0.50	0.81	3.43	1.25	0.75	0.80	1.12
57	0.62	1.37	0.75	0.43	1.37	0.62	0.93	3.25		0.68	0.75	1.37
58	0.62	1.06	0.75	0.25	1.30	0.62	1.00	3.37	1.18	0.68	0.75	1.62
59	0.37	1.25	0.80	-0.25	0.87	0.56	0.87	3.06	1.37	0.93	0.75	2.18
60	0.50	1.25	0.93	0.12	1.30	0.50	0.68	3.37	1.25	0.75	0.75	

EARLY-ONSET MYOPES

Time	KL	NB	WF	RM	AN	JF	AH	SS	JB	CW	GP	MD
	3.00	2.62	2.93	2.43	2.06	3.00	2.81	2.75	3.25	2.62	2.62	2.56
	2.81	2.87	2.87	2.43	2.50	2.93	2.43	2.87	2.18	2.37	3.37	2.81
	2.75	2.68	2.43	2.50	2.12	2.87	2.93	2.62	2.31	2.75	2.75	2.68
	3.25	2.30	2.56	2.87	2.43	2.87	2.68	2.25	2.56	2.87	2.43	2.68
	2.68	2.56	2.50	2.93	2.68	2.93	2.56	2.87	3.62	2.75	1.93	2.75
	2.81	2.81	2.56	3.00	2.68	2.68	2.75	2.25	2.68	2.62	2.37	3.06
	3.68	2.93	2.87	2.87	2.37	3.31	2.93	2.93	2.62	2.80	2.43	2.62
	2.75	2.80	3.18	2.81	2.43	2.50	2.62	2.68	2.75	2.87	2.80	3.06

	2.75	3.06	3.18	3.18	2.12	2.62	2.50	2.56	2.56	2.37	2.12	2.93
	2.56	2.62	2.93	2.81	1.80	2.43	2.68	2.50	2.30	2.43	2.25	2.43
	2.87	2.62	2.68	3.12	1.80	2.43	2.75	2.37	2.31	2.81	2.65	3.50
	3.25	2.87	2.93	3.06	2.12	2.37	2.68	2.68	2.75	2.50	1.81	2.43
	3.56	3.30	2.81	3.05	2.06	2.68	2.37	3.00	3.37	2.56	1.93	3.31
	2.93	2.62	2.93	2.87	2.00	2.68	2.68	2.30	2.37	2.75	2.37	2.43
0												
1	3.06	2.56	2.93	2.87	2.06	3.25	2.75	3.06	2.68	2.56	2.87	3.56
2	2.37	2.37	2.30	2.37	2.18	1.93	2.43	2.06	2.12	3.56	1.50	
3	2.31	1.12		1.25	2.43	1.75	1.75	1.25	2.87	2.75		0.93
4	2.81	0.80	1.18	1.12	2.87	0.93	1.43	1.68	2.12	1.50		0.18
5	2.68	0.87	1.37	1.18	2.06	1.18	1.18	1.56	2.87	1.30	1.37	0.31
6	2.62	0.50	1.43	1.30	3.25	1.25	1.06	1.43	2.25	1.06	0.96	0.56
7	2.68		1.37	1.50	1.68	1.43	1.18	1.31	2.37	1.43		0.50
8	2.50	0.62	1.50	1.50	2.06	1.18	0.80	1.43	2.18	1.43	0.50	0.87
9	2.75	0.62	1.31	1.50	1.81	1.06	0.75	1.68	2.30		0.31	0.68
10	2.87	0.68	1.37	1.37	2.12	1.12	0.87	1.75	2.43	1.25	0.62	
11	2.80	0.68	0.87	1.62	2.18	0.87	0.80	1.75	2.56	0.93	0.62	0.87
12	2.93	0.75	0.93	1.68	2.18	1.06	0.93	0.87	2.31	0.56		0.80
13	3.06		1.62	1.62	2.50	1.18	0.93		2.62	0.87		0.80
14	3.06	0.75	1.00	1.50	3.18	1.00	0.87	1.50	2.56			0.93
15	2.93	0.93	1.00	1.50	3.68		0.62	1.62	3.00	0.87		0.75
16	2.75	1.00	0.87	1.50	3.30	1.12	0.80	1.68	2.50	0.87		0.43
17		1.18	0.87	1.25	4.68	1.43	0.87	1.75	2.37	0.62		0.37
18	2.87	1.30	0.93	1.37	4.50	1.18	0.87	1.56	2.18	0.81		0.25
19	2.68	1.37	1.00	1.50	3.75	1.12	0.75	1.93	1.75	0.93	0.93	0.06
20	2.56	1.37	0.75	1.25	3.62	1.05	0.87	1.87	2.00			-0.12
21	2.37	1.37	0.75	1.37		1.25	0.87	1.25	2.56	1.87		-0.06
22	2.50	1.18	0.81	1.25	3.50	1.12	0.87	1.75	2.25	0.43	0.75	
23	2.75	1.62	0.62	1.25	3.43	1.05	0.75	1.87	2.50	1.18		-0.18
24	2.50	1.62	0.68	1.12	4.31	0.81	1.00	1.56		1.06		-0.12
25	3.06	1.62	0.81	1.06	3.50	0.87	1.00	1.37		1.00		
26	2.18	1.37	0.87	1.18	5.12	0.50	0.87	1.43		1.00		-0.43
27	2.18		0.87	1.30	3.93	0.37		1.68	3.12	0.87	0.56	-0.37
28	2.06	1.18	0.80	1.30		0.43		1.50		0.93	0.87	-0.37
29	2.06		0.75	1.25		0.37		1.68		0.68	0.43	-0.06
30	1.93	1.00	0.75	1.06	3.75		0.62	1.81			0.43	0.37
31	1.80	1.12	0.93	1.25			0.93	1.81	2.18	0.56	0.43	
32	2.56	1.37	0.62	1.00			0.80	1.87	2.25	0.37		0.06
33	2.25		0.81	0.62	4.37		0.81	2.06		0.87		
34	2.31		0.68	1.18	3.75		0.81	2.18				0.12
35	2.56	1.25	0.81	1.12			0.75	2.00	1.87	1.50		
36	2.12	1.50	0.81	0.68	3.43		0.87	2.18		1.31		0.43
37		1.37	0.81	0.87	4.18	0.31	0.87	2.00	1.30	0.80		0.56
38		1.62	1.06	0.68	4.18	0.25	0.80	2.43	1.75	1.62	0.00	
39		1.68	0.87	0.68	3.43	0.75	0.56		1.87	1.56	-0.06	
40	2.68	1.87	0.93	0.68		0.25	0.62	2.30	1.93	1.43	-0.25	
41		1.62	0.68	0.87		0.62	0.68	2.93	1.80	1.18		0.62
42		1.87	0.81	1.37			0.56	2.30	1.80	0.50		0.31
43	2.56	1.93	0.87	0.80	3.12	1.00	0.62	2.12	1.87	0.81		0.00
44	2.81	1.56	0.87	1.25	3.00	0.93	0.56	2.18	1.80	0.68	-0.25	-0.12
45		1.81	0.87	0.81	2.00		0.56	1.75		1.50		
46		2.12	0.81	1.06	2.87	1.50	0.56		1.87	1.06		
47	2.56	1.68	0.62	0.87		1.68	0.43	2.37	1.80	1.56	0.00	
48	2.12	1.50	0.62	1.06		1.37	0.37	2.00			-0.12	
49	2.31	0.93	0.62	0.87			0.56	2.37		1.80	0.12	
50			0.75	1.06			0.43	2.12		1.25	0.00	0.56
51		0.75	0.68	1.06	2.50		0.25	2.25	1.12	1.56	0.37	0.80
52	1.62	1.43	0.87	1.06	2.30		0.56	2.00	1.50	1.50		0.93
53	1.68			0.93	2.56		0.50		1.30	1.18	-0.06	0.75
54	1.50	1.18	0.68	0.93	2.37		0.56			1.80	-0.12	0.43

55	1.25	1.37	0.87		2.12			1.87	1.68	1.12	-0.37	0.18
56		1.56	0.93	1.00	2.18	0.81	0.56	1.62	1.18	1.25		0.18
57		1.68	0.68	1.06	1.87	0.68	0.43	1.50				-0.37
58		1.68	0.75	1.00	1.68	0.25	0.43	2.00	1.12			-0.50
59	1.18	1.75	0.81	1.06			0.68	1.75	1.18	1.87		-0.50
60	1.30	2.25	1.18	0.93	1.93		0.56	1.81	1.00	0.50		-0.62

LATE-ONSET MYOPES

Time	AW	NW	JH	SB	EF	KD	CW	NB	CH	NH	TH	CR
	2.25	2.62	2.75	2.93	2.56	2.87	1.81	2.62	2.87	2.50	3.12	2.30
	2.56	2.68	2.37	2.68	2.62	2.56	2.80	2.80	2.68	2.37	3.06	2.43
	2.87	3.00	3.25	2.56	2.75	2.43	2.75	2.43	2.80	2.68	3.06	2.18
	1.87	2.68	2.75	2.62	3.06	2.80	3.00	2.50	2.75	2.56	3.00	2.68
	2.00	2.75	2.75	2.56	2.87	2.50	3.18	2.43	2.75	2.30	3.62	2.30
	2.43	2.87	2.37	2.93	2.50	2.62	2.93	2.87	2.68	2.37	2.68	2.25
	2.37	2.68	2.68	2.37	2.50	3.06	3.06	2.00	2.68	2.30	3.00	2.25
	2.43	2.75	2.30	2.87	2.50	2.62	2.93	2.50	2.68	2.31	3.12	3.37
	3.06	3.06	2.87	3.06	2.68	2.56	2.80	2.00	2.75	2.43	2.68	2.25
	2.87	2.25	2.75	2.50	2.43	3.12	3.18	2.81	2.43	2.75	3.00	2.43
	3.18	2.87	2.62	2.75	2.30	2.50	3.00	3.00	2.56	2.18	2.50	2.25
	3.18	2.80	2.75	2.68	2.43	2.75	2.68	2.43	2.18	2.62	3.31	2.18
	2.37	2.75	2.62	2.56	2.25	2.75	2.80	2.56	2.68	2.25	3.37	2.18
	2.50	2.37	2.62	2.31	2.37	2.43	2.81	2.50	2.68	2.50	3.12	2.18
0												
1	2.56	2.06	2.00	2.50	1.93	2.93	2.50	2.12	2.00	1.18	3.00	2.00
2			1.06	2.30	1.62	4.43	2.50	1.75	1.18	1.06	1.62	2.00
3	2.25	1.62	0.43	2.37	0.68	3.00		1.62	0.93	0.75	1.75	1.18
4	1.93	1.56	0.25	2.56		2.55	2.81	1.87	0.80	0.81	1.62	0.75
5	2.12	1.37	0.25		0.75	2.30	2.50	2.25	0.93	0.93	1.62	0.68
6	2.43		0.25	1.87	0.81	1.68	2.56	2.25	0.87		1.75	0.75
7	2.55	1.12	0.12	2.37	1.00	1.62	1.81	2.37	0.75		1.68	0.50
8	2.62	1.18	0.12	2.18	0.68		2.18	3.06	0.50		1.56	0.75
9	2.69		0.12	1.81	0.87	2.00	1.87	2.75		1.18	2.06	0.56
10	2.00	0.93	0.12	2.12	0.93	2.37	1.80	3.75	0.56		1.30	0.68
11			0.25	2.37	0.87	2.06	1.62	3.75	0.75	1.93	0.31	0.43
12	2.31	0.56	0.43	2.30	0.75	2.06	1.56	3.80			-0.62	0.25
13	2.37	0.56	0.43		0.68	2.18	1.50	4.00			0.93	0.25
14	2.56	0.43	0.31	2.43	0.50	2.06	1.56	4.00	0.62	1.00		0.25
15		0.43		2.37		1.80	1.56	4.25	0.50	1.06	1.37	0.31
16	2.62	0.43	0.06	2.12	0.50	2.00	1.43	4.62		0.81	1.06	0.31
17		0.50	-0.06	2.18	0.56	1.62	1.43	5.18		0.43	1.30	0.37
18	2.81	0.43	-0.06	2.25	0.62	2.00	1.50	5.18	0.37	0.87	1.68	0.37
19	2.81	0.50	0.00	2.43	0.62	2.31	1.68	5.30		1.25	1.06	0.31
20		0.43	0.06		0.50	2.12	1.37	5.06			1.06	0.43
21	2.62	0.50	0.12	1.80	0.37	1.93	1.18	4.00		1.06	1.18	0.80
22		0.37	0.12	3.06	0.50	2.43	1.06	3.87	0.50	0.37	1.50	0.31
23	2.81	0.37	0.18	2.62	0.50	2.25	1.12	4.56			1.18	
24	2.80	0.43	0.06	2.25	0.62	2.12	1.06	2.87			1.25	0.31
25	2.56	0.25	0.12	2.12	0.62	2.00	0.81	3.06			1.25	0.43
26		0.43	0.25	2.37	0.62	1.93	0.68	3.50	0.31		1.80	0.37
27	3.18	0.62	0.25	2.06	0.50		0.87	3.37	0.62	0.50	0.93	0.50
28	3.37	0.50	0.00	2.37		1.56	0.93	3.37	0.68	0.37	0.93	0.43
29	3.43		0.25	2.12	0.68	0.87	0.81	3.25	0.50		1.00	
30			0.25		0.68		0.62	3.62	0.44	0.93		0.37
31		0.75	0.25		0.75	1.18	0.87	3.87	0.06	0.75	1.06	0.37
32	2.93	0.81	0.12	1.93	0.68	0.93	1.00	4.25			1.06	
33	3.49	0.93	0.50		0.68	1.12		4.00		0.93	1.00	0.37
34		1.00	0.18	1.75		1.25	1.18		0.37	0.43	1.00	0.43
35		1.12	0.31	1.37	0.68	1.30	1.18	3.43	0.43	1.06	1.06	

36		0.75			0.50	1.43	0.87	2.75	0.31	0.93	0.81	0.31
37	3.25	1.12		1.75	0.56	1.56	0.80	3.37	0.37			0.31
38			0.18	1.62	0.56	1.68	0.87	3.12	0.31	1.25		0.25
39	3.06	0.80	0.43	2.00	0.75	1.80		2.93			1.18	0.31
40	2.81	0.62		2.00	0.75	2.12	0.80	2.62	0.37	1.18	1.12	0.25
41	2.62	0.75			0.68	1.87	0.68	1.80	0.31	1.00	0.93	0.18
42	2.87	0.50	0.43	1.75	0.68	1.93	0.62	1.56	0.50		0.93	0.25
43	2.37	0.75	0.06	1.87	0.56		0.68	1.37	0.25	0.80	1.00	0.31
44				1.93	0.56	1.87	0.68		0.25		1.00	0.43
45	2.56	0.62	0.43		0.62	1.93	0.56			0.31	1.18	0.25
46		0.62	0.19	2.18	0.75	2.06	0.56					0.50
47	2.25	0.75	0.25	2.50	0.62	3.93	0.37	0.18	0.56		1.12	0.43
48	2.06	0.43	0.25	2.25	0.75	4.68	0.25		0.37	0.75	1.18	0.43
49	2.31	0.30	0.18	2.30	0.68	4.18	0.25	-0.12	0.43		0.93	0.50
50	2.31	0.30	-0.12	2.00	0.75	4.68	-0.12	0.12	-0.37		0.93	0.50
51	1.93	0.37	0.00		0.87	2.25	0.25	0.30	0.68	0.43	0.93	0.31
52	1.87	0.30	0.00	2.00	0.87	2.62	0.37		0.81	0.56	0.87	0.12
53	2.37	0.30		1.62	0.62	3.00	0.31		0.56		1.12	0.31
54	2.50	0.43	-0.06		0.62	3.37	0.37	0.62	0.62	0.62	1.00	0.25
55	2.50	0.43	0.43	1.18		3.25	0.75		0.68	0.93	1.00	0.37
56		0.37	0.37	1.62	0.56		0.80	0.93	0.43	0.81	1.18	0.31
57		0.37	0.37	1.50	0.68	1.93	1.00	0.56			1.00	0.18
58	3.00	0.31			0.68	1.56	0.87	0.75	0.75	0.50	0.75	0.31
59		0.50		1.62	0.75	1.50	0.87	0.75	0.56	0.43	0.50	0.25
60	2.75	0.37	0.12	1.75	0.75	1.56	0.81		0.62	0.31	0.50	0.06

10d) Accommodation regression (mean sphere) following sustained near viewing through a plano lens (NWA)

EMMETROPES

Time	SR	GJ	BS	HC	HP	PP	GP	KP	JS	AS	JS	WI
	2.56	2.62	2.62	2.18	2.75	1.81	2.87	3.00	2.30	2.56	3.25	2.43
	2.30	2.62	2.31	2.25	2.75	2.43	2.30	3.00	2.62	2.31	2.87	2.37
	2.43	2.62	2.43	2.25	2.75	2.37	2.25	3.31	2.62	2.25	2.62	2.12
	2.87	2.62	2.37	1.81	2.30	2.12	2.50	3.06	2.93	2.50	3.25	2.87
	2.93	2.75	2.25	2.43	2.50	2.06	2.31	3.18	2.56	2.56	2.87	2.25
	2.56	2.62	2.31	2.56	2.68	2.43	2.00	3.12	2.50	2.43	3.06	2.18
	3.00	2.37	2.37	2.18	2.56	2.31	2.37	3.00	2.25	2.75	2.62	2.43
	2.50	2.43	2.30	2.30	2.93	2.37	2.25	3.12	1.93	2.62	2.68	2.37
	2.56	2.62	2.87	2.12	3.06	2.25	2.43	3.12	2.12	2.75	2.87	2.62
	2.25	2.43	2.75	2.12	2.31	2.25	2.12	2.87	2.37	2.50	3.00	2.75
	2.68	2.06	2.87	2.18	2.25	2.75	2.30	2.81	2.25	2.25	2.68	2.62
	2.50	2.75	2.12	2.31	3.06	2.12	2.50	2.93	2.68	2.37	2.87	2.25
	2.50	2.31	2.56	2.18	2.43	2.12	2.30	3.00	2.00	2.62	2.56	2.56
	2.56	2.68	3.00	2.30	2.68	1.87	2.30	2.93	2.62	2.62	2.68	2.18
	2.50	2.30	2.87	2.25	2.87	2.62	2.06	3.00	2.50	2.50	3.00	2.50
0												
1	3.12	2.43	2.18	1.68	2.56	1.93	2.06	2.93	1.68	2.43	2.06	
2		2.00	1.62	1.56	2.93	0.93	2.06	3.06	1.25	2.56		2.25
3	1.30	1.87	1.43	1.25	3.12	0.68	2.25	2.93		2.43		2.18
4		1.81	0.87	0.68	2.68	0.50	2.12	3.18		1.93		1.93
5	1.06	2.00	1.30	0.87	2.25	0.56	1.80			0.80		2.06
6	1.12	2.00		0.87	2.25	0.56	1.62	3.25	2.18	0.80		1.81
7	0.75	1.81	1.18	0.50	3.18		1.68	2.93	2.25	1.12	1.25	1.37
8	0.56	1.56	1.06	0.37	2.93	0.50	1.68	2.80		0.93	1.25	1.25
9	0.50	1.43	0.81	0.18	3.25	0.56	1.80	2.87	2.06	1.12		1.12
10	0.37	1.50	0.81	0.43	2.87	0.62	1.43	2.75	2.37	1.06	1.43	1.50
11	0.37	1.43	0.56	0.62	1.25	0.50	1.62	2.75	2.37	1.75	1.62	1.37
12	0.62	1.50	0.50	0.62	1.56	0.62	1.30	2.50	2.00	1.00	1.30	1.43

13	0.50	1.37	0.62	0.56	1.93	0.62	1.30	2.75	2.18	0.93	1.68	0.93
14	0.37	1.50	0.50	0.43	2.00	0.56	1.25	2.62	2.18	0.87	1.12	0.75
15	0.37	1.43	0.50	0.31		0.43		2.56	2.12	0.75	1.30	0.75
16	0.37	1.43	0.68	0.62		0.50	1.75	2.30	2.12		1.00	0.50
17	0.37	1.30	0.62	0.93	2.00	-0.06	1.30	2.12	1.81	0.87	0.75	0.56
18	0.12		0.56	0.75	1.93	0.37	1.18	2.12	1.75	0.75	0.87	0.56
19	0.37	1.43	0.68	0.37	1.87	0.37	1.50	2.75	1.68	0.93	0.50	0.56
20	0.37	1.25	0.62	0.50	1.93	0.30	1.30		1.06	0.75	0.81	0.68
21	0.37	1.50	0.87		2.05	0.50	1.06	2.12		0.80	0.68	
22	0.37	1.43	0.68	0.43	2.06	0.37	1.06	2.00	1.81	0.62	0.68	0.50
23	0.25	1.25	0.50	0.31	2.18	0.31	1.12	2.68	1.62	0.56	0.81	0.62
24	0.37	1.25	0.37	0.18	2.25	0.31	1.00	2.75	1.56	0.56	0.62	0.56
25	0.37	1.43	0.50	0.31	2.18	0.25	1.18	2.62	1.81	0.56		0.56
26	0.37	1.30	0.68	0.25	2.25	0.31	1.00	2.50	1.87	0.62	0.75	0.62
27	0.25	1.37		0.12	2.12	0.31	1.00		1.62		0.68	0.68
28	0.12	1.37	0.62	0.06	2.12		1.18		1.62	0.62	0.62	0.62
29	0.25	1.18	0.25	0.06		0.18	1.18	2.75	1.80	0.56	0.68	0.80
30		1.25	0.25	0.00	2.37	0.18	1.06	1.50	1.75	0.68	0.93	1.00
31	0.25	1.18	0.25	0.00	3.12	0.18	1.00	1.68	1.56	0.56	0.37	1.56
32	0.62	1.12	0.25	0.00	2.75	0.31	0.75	1.68	1.50	0.56	0.75	1.62
33	0.25	1.37	0.25	0.00	2.50	0.31	0.87	1.43		0.56	0.93	1.80
34	0.30	1.25	0.50	0.06	2.31	0.25	0.87	1.25	1.43	0.50	0.93	
35	0.37	1.37	0.50	0.25	1.30	0.37		1.68	1.37	0.50	0.75	1.62
36	0.50	1.30	0.50	0.18	1.37	0.43	0.87	1.25	1.43	0.50	0.50	1.43
37	0.37	1.25	0.50	0.18	1.18	0.37	0.93	1.30	1.37	0.56		
38	0.43	1.18	0.62	0.00	1.25	0.62	1.06		1.80	0.37	0.68	1.37
39	0.37	1.37	0.37	0.00	1.00	0.62	1.25	1.30	1.56	0.50	0.56	
40		1.37	0.25	0.00	1.37	0.37	0.93	1.12	1.87	0.62	0.50	1.12
41	1.50	1.06	0.37	-0.06	1.37		0.87	1.43	1.93	0.50	0.50	0.80
42	0.87	1.18	0.50	-0.25	1.56	0.06	0.87	1.87	1.93	0.62		1.00
43	0.87	1.25	0.75	-0.12	1.62	0.31	0.62	2.06	1.68	0.50	0.62	
44	0.81	1.30	0.62	-0.12	1.87		0.62	2.25	1.25	0.62	0.87	0.87
45	0.75	1.06	0.37	-0.12	2.00		0.62		1.25	0.50	0.62	0.75
46	0.56	1.12	1.37	-0.06	2.30	0.18	0.81	1.75	1.43	0.56	1.00	0.68
47	0.56	1.12	1.00	-0.06	1.87	0.37	0.93	1.62	1.43	0.50		0.56
48	0.50	1.30	0.37	0.00	1.56	0.37	0.87		1.43	0.18	0.87	0.62
49	0.37	1.00	0.25	0.00	1.25	0.80	0.87			0.50	0.75	0.68
50	0.62	1.00	0.62	0.00	1.06	0.56	0.93	.1.62	1.93	0.50	0.93	0.93
51	0.75	0.93	0.93	0.12	1.06	0.00	0.93	1.62	1.31	0.50	0.62	0.80
52	0.62	1.12		0.37	1.18	0.00	0.80		1.18	0.50	0.62	0.80
53	0.50	1.12	0.62	0.37	1.25	0.56	0.80		1.25	0.56		0.68
54	0.37	1.06	0.37	0.37	1.25	0.75		1.62	1.31	0.43	0.75	0.68
55	0.37	1.12	0.25	0.31	1.25	0.62	0.68	1.50	1.25	0.62	0.56	0.75
56	0.37		0.37	0.25	1.56	0.43	0.68	1.30	1.50	0.43	0.43	0.62
57	0.37	0.81	0.37	0.25	1.75	0.25		1.31	1.30	0.50		0.43
58	0.37	0.87	0.43	0.31	1.37	0.31	0.81	1.18	1.50	0.43	0.62	1.00
59	0.37	0.75	0.25	0.25	1.37	0.12	1.06		1.37	0.43	0.62	1.80
60	0.12	0.80	0.25	0.31	1.37	0.25	1.25	1.18	1.50	0.43	0.68	0.80

EARLY-ONSET MYOPES

Time	KL	NB	WF	RM	AN	JF	AH	SS	JB	CW	GP	MD
	2.62	2.06	2.56	2.62	2.50	2.68	2.75	2.75	2.50	2.75	2.30	3.25
	2.81	2.87	2.43	2.18	2.12	3.25	2.56	2.43	2.80	2.25	2.50	2.62
	3.62	2.80	2.50	2.18	2.25	2.81	2.56	2.37	2.30	2.37	2.50	2.56
	3.30	2.56	2.68	2.18	2.18	2.75	2.81	2.18	2.43	2.87	2.50	2.56
	3.00	2.37	2.87	2.43	2.18	3.00	2.68	2.30	2.43	2.50	3.05	2.43
	2.75	2.62	2.62	2.50	2.30	3.18	2.87	1.43	2.18	2.50	2.50	2.06
	2.68	2.62	2.80	2.43	2.00	2.75	3.06	2.81	2.37	2.43	2.56	2.62
	2.93	2.87	2.93	2.50	2.12	2.87	2.68	2.37	2.75	2.37	2.62	2.68

	3.06	2.68	3.00	2.50	1.87	2.56	2.93	2.18	2.43	2.37	2.18	2.25
	2.56	2.68	2.75	2.75	1.93	3.37	2.81	2.37	2.50	2.37	2.37	2.80
	2.81	2.50	2.81	2.18	2.12	3.06	2.87	2.56	2.56	2.68	3.12	3.75
	3.37	2.43	2.75	2.56	1.93	3.12	2.62	2.43	2.50	2.37	2.87	2.75
	2.50	2.31	2.43	2.56	1.87	2.93	2.68	2.43	2.56	3.00	3.00	2.62
	2.87	2.68	3.00	2.18	1.62	2.43	2.93	2.50	2.25	2.80	2.87	2.50
0												
1	2.75	2.93	2.37	2.80	1.93	2.68	3.00	2.18	2.12	2.62	2.62	3.12
2	2.25	2.37	2.62	1.62	1.80	1.62	2.06	1.62	1.93	1.93	2.37	
3	2.25	1.37	1.37	0.87		1.50	1.68	1.50	2.80	0.37	1.06	0.43
4	2.37		1.56	0.87	3.06	1.18	1.62	0.06	3.30	0.25	0.68	0.37
5	1.68	1.80	1.56	0.75	3.00	1.75	1.12	1.00	3.75	0.25	0.50	0.12
6	1.87	1.62	1.31	0.81	2.80		1.12	1.06	3.68	0.12	0.80	0.93
7	2.12	1.80	1.06	0.93	2.87	1.68	1.25	1.00		0.50	0.68	
8	2.25	1.93	1.09	0.93	3.00	1.75	1.43	0.37	3.80	0.25	0.37	-0.18
9	1.50	2.06	1.25	1.00	3.30		1.37		3.56	0.37	0.68	-0.06
10	1.75	2.31	1.31	0.68	3.62		1.56	0.12	3.37	0.37		0.06
11	2.31	2.25	0.25	0.68	3.75		1.37	0.68	3.25		0.56	-0.06
12		2.37	1.25	0.75	3.43		1.37	1.06	3.31	0.25	0.56	0.25
13	1.56	2.80	1.06	0.75	3.50			0.80	3.68	1.12		0.37
14	2.06	2.75	1.12	0.75	3.37		1.56		4.18	1.00	0.56	0.37
15	1.75	2.56	0.81	0.62	3.43	1.30	1.31	0.75	3.80	0.93	0.43	0.56
16	1.43	2.87	1.56	0.75	3.50	1.31	1.12	1.30	3.68	0.68		0.56
17	1.06	2.50		0.68	3.25	0.62	1.00	1.37	4.25	0.87	0.31	0.56
18	1.18	2.50	0.87	0.68	3.62		1.00	1.30	3.18	0.30		0.93
19	0.44	2.81		0.80		1.80	1.00	1.50	3.25			1.43
20		2.56		1.00		1.30	1.00	1.56	3.68	0.87	0.31	1.62
21		1.75	0.81	1.12	3.06	1.80		1.56	3.43	1.12	0.56	
22		1.37	0.80	1.12	3.75	1.75	1.43	1.81	3.12	1.75		1.50
23	-0.31		0.68	1.12		1.30	1.37	1.37	3.62	0.37		1.43
24		2.00	0.80	1.25			1.25	1.31	3.75	0.37	0.68	0.18
25	0.68	2.25	0.93	1.62		1.25	1.18	1.37	3.75	0.50		0.12
26		2.25	0.68	1.50	3.12	1.05	0.93	0.62		1.37	0.50	-0.12
27		2.00	0.93	1.25	2.87	1.05	0.87	1.75	3.12	1.43	0.50	-0.25
28		2.25	1.00	1.12	2.68	1.31	1.00	1.37	3.75		0.37	-0.44
29	1.37	2.25	0.87			1.18	1.18	1.62	3.93	0.75		-0.37
30	1.06	2.25	1.00	0.93	1.93	1.18	1.18	2.25		0.75		-0.37
31	1.18	2.56	0.93	1.37		1.25	1.25	1.81				-0.62
32	0.75	3.00		1.25	2.50	1.12	1.12	1.87	3.50		0.31	-0.62
33	0.93	2.50		1.12	3.18	1.93	1.12	1.68	2.80		0.25	-0.62
34	1.50	2.62	1.56	0.87		1.06	1.12	1.62	3.43	1.80		-0.50
35	1.31	2.75	1.12	0.87	2.93	1.25	1.00	1.50	3.62	1.62	0.43	
36	0.87	2.25	1.00	0.81	2.62	1.18	1.06	1.37	4.31	1.87	0.31	0.18
37	0.87	1.87	1.06	0.93	2.31	0.43	1.12	1.50	3.50	1.62	0.44	0.00
38	1.06	2.37	0.87	1.00	1.68	1.06		1.56	3.37	1.43	0.31	
39	0.93	2.56	0.93	1.18	2.62		1.12	1.50	3.00	1.62	0.18	-0.18
40	1.00	1.93	0.75	1.37	3.12	1.25	1.18	1.30	2.81	1.31	0.18	0.12
41	0.62	2.18	1.06	1.25	3.00	0.93	0.93		2.75	1.30	0.25	0.00
42	0.50	1.56	0.87	1.06	2.93	1.18	0.75	1.18	2.43	1.31	0.25	0.00
43	0.12		0.75	0.62	2.87	1.18	0.87	1.37	2.43	0.93	0.06	0.00
44	0.30	1.80	0.87	0.75	2.56	0.87	0.87	1.25	2.18	1.18	0.31	
45	-0.31	2.06	0.93	0.68	2.68	1.06	0.62	0.62	2.00			-0.12
46	-0.56	1.87	0.81	0.80	2.75	1.12	0.50	0.37	1.81	0.93		0.12
47	-1.00	2.93	0.68	0.75		1.00	0.37	1.12		0.75	0.00	-0.31
48	-0.18	2.43	0.68	0.81	3.56	0.62	0.37	1.00	2.12		-0.06	-0.56
49	-0.37	2.37	0.75	0.75	3.30	0.93	0.62	0.80	1.75	1.06		
50		2.43	0.75	0.68		0.75	0.56	0.93	1.62	0.75		-0.56
51	0.56		0.80	0.87		1.06	0.62	0.81	1.75			-0.31
52	0.18	1.93	0.93	0.81	3.43	1.12	0.62	1.06	2.18	2.00		-0.31
53	0.25	2.31	1.12	0.81	3.68	1.18	0.50	1.31	2.12	0.50		-0.50
54	0.37	2.43	0.81	0.68	3.56	1.25	0.62	1.12	2.12	1.06		-0.44

55	0.81	3.00	0.80	0.81		1.80	0.43	1.18			-0.12	-0.68
56	1.06	3.00	0.87	0.81	2.56	1.18	0.43	1.25	2.43	0.50		-0.50
57	0.68	3.00	0.87	0.93		1.50	0.43	1.18	2.87	1.75		-0.56
58	0.18	2.00	0.80	0.93	1.30		0.37	1.25		0.75	0.43	-0.50
59	0.31	1.62	0.87	0.93	0.87		0.50	1.12	2.30	1.93		-0.43
60	0.00		0.81	0.87	0.75		0.50	0.93	2.12	1.37		-0.62

LATE-ONSET MYOPES

Time	AW	NW	JH	SB	EF	KD	CW	NB	CH	NH	TH	CR
	0.81	3.43	2.56	2.87	1.93	2.18	2.68	3.18	2.75	3.06	2.30	2.06
	0.87	3.25	2.62	2.81	2.12	2.43	2.43	2.80	2.31	3.00	2.30	1.87
	0.93	2.25	2.81	2.68	2.25	2.75	2.75	2.50	2.75	2.56	2.12	2.00
	0.68	1.93	2.37	2.81	2.56	2.18	2.81	2.75	2.56	2.50	2.43	1.87
	0.37	2.62	2.37	2.81	2.43	2.62	2.43	2.68	2.87	2.50	2.56	2.50
	0.80	2.18	2.25	2.56	2.87	2.50	2.80	2.75	3.18	3.25	3.12	2.12
	0.87	2.12	2.43	2.37	2.56	2.87	2.50	2.93	2.87	3.00	2.93	2.43
	0.75	2.81	2.49	2.50	2.30	2.93	3.18	3.37	2.93	2.62	2.93	2.87
	0.68	2.12	2.37	2.75	2.56	2.80	2.80	2.87	2.93	2.30	2.93	2.25
	0.50	2.43	2.25	2.56	2.37	2.56	2.75	2.56	3.00	2.62	3.06	2.50
	0.87	2.87	2.50	2.62	2.75	2.62	2.75	3.50	2.62	3.00	3.06	2.56
	0.18	2.50	1.75	3.18	2.25	2.75	2.75	2.81	2.37	2.68	3.37	2.25
	0.00	2.00	2.87	2.80	2.00	2.75	2.50	2.75	2.80	2.80	2.75	2.56
	0.43	2.50	2.25	2.37	2.18	2.81	2.37	2.68	2.25	2.62	3.25	2.37
0												
1	1.25		1.87	2.18	1.43	2.75	2.50	1.93	2.18			
2	1.55	1.93	0.68	2.62	0.80	3.25	2.80	1.06		1.37	1.50	1.81
3	1.62	1.25	0.50		1.31	1.62	2.68		0.31	0.75	1.87	1.62
4	1.50		0.25	3.06	1.37	1.56		0.62		0.37	1.43	1.37
5	1.62	1.50	0.25	2.75		1.37	2.18		0.62	0.80		1.25
6		1.00	0.25	3.00	1.06	1.18	2.50	0.30	0.68	1.00	1.93	1.25
7	1.62	1.18	0.31	2.37	1.25	1.68	2.56		0.68		1.93	1.00
8		1.00	0.31	3.43	1.12	1.37	2.87	0.25	0.37	1.18	1.87	1.06
9		1.18	0.37	3.31	0.87	1.12	2.56	0.30	0.37	1.31	1.43	0.87
10		0.87	0.31	3.25	0.93	0.87	2.62	0.30	0.50	0.87	1.75	0.81
11			0.18	2.18	1.12	0.80		0.37	0.50	1.18	1.81	0.56
12	2.06	0.93	0.31	2.50		0.75	2.43	0.18	0.43	0.80	1.93	0.43
13		1.06	0.37	2.37	0.56	0.93	2.06	0.06	0.62	0.93	1.81	0.50
14	1.87	1.06	0.37	2.18	0.62	0.75	1.75		0.43	0.81	1.81	
15	1.93	1.00	0.37	2.06	0.37	0.68	1.56	0.00	0.43	0.62	1.80	1.00
16	2.18	1.00	0.31		0.18	0.75	1.68	0.00		0.81	1.50	1.06
17	2.00	1.30	0.25	1.93	0.37	0.81	1.62	0.06	0.37		1.31	0.93
18		1.18	0.43		0.25	0.56	1.75	-0.06		0.75	1.18	1.00
19	1.12	1.31	0.18	2.12		0.62		0.00	0.31	0.81	0.93	1.00
20	1.12	1.37	0.18	2.12	0.18	0.75	1.25		0.37			1.12
21	1.06	1.12	0.18	2.00	0.37	1.06	1.50	0.06		1.12	1.12	1.06
22		1.68	0.06	2.37	0.18	0.93	1.37	0.12	0.37	0.87	0.68	1.06
23	1.00		0.31			1.00			0.31	0.75	1.31	0.37
24	1.18	1.37	0.18	1.87	0.56	1.12	1.50	0.12		1.00	2.25	0.62
25	1.25	1.25	0.12	2.25	0.43	0.93	1.68	-0.06	0.50	1.06	0.62	0.68
26	0.62	1.30	0.00	1.50		0.93		0.00		1.37	0.18	0.43
27	0.87	1.43	0.00	1.62		1.00			0.56	1.18	0.62	0.80
28	0.93	1.37	0.00	2.12	0.56	1.00	1.56	0.25	0.62	0.81		0.87
29			0.12	2.18		1.12	1.68			0.81		
30	0.62	1.18	0.12		0.68		1.62		0.56	0.62	0.50	0.68
31	0.56	1.31	0.12	1.37	0.43		1.56			0.56	0.37	0.62
32	1.00	1.18	0.12		0.43	0.87	1.30		0.43			0.56
33	0.75	0.68	0.25		0.43	0.93	1.06	-0.18	0.43	0.12		0.37
34			0.18		0.56	1.06	1.37	0.31	0.31		1.30	0.62
35	0.87	1.18	0.18	1.75		0.93	1.50	0.00		0.62	1.12	0.68

36	0.93	1.81	0.00	1.43	0.12	0.93	1.25	0.12	0.37	0.12		
37		1.18	0.18	1.37	0.18		1.00	0.18	0.43	0.12		0.75
38	0.81		0.31			1.06	1.43			0.18		
39	0.81		0.18		0.68	1.06	1.25	0.37	0.62			0.62
40	0.93	1.43	0.31	1.00	0.68	1.25	1.18			0.25		0.75
41	1.00	1.18	0.18	1.37	0.93	1.12	1.43			0.31	0.06	0.56
42		1.18	0.31		1.00	1.06	1.18	0.31	0.56	0.31		0.75
43		1.25	0.18		1.00	1.18	1.18		0.68	0.12	0.87	0.87
44		1.25	0.18	1.06	1.00	1.18	1.12	0.25		0.18		0.62
45		1.37	0.18	1.43	1.12	1.18	1.43	0.12	0.50	0.25	1.12	
46		1.37	0.06	1.25	1.18	1.43	1.50	0.06	0.50		1.25	0.68
47	0.62	1.31	0.25	1.56	1.06	1.50	1.12	0.00	0.56			0.75
48	0.87	1.18	0.18	1.68	1.12	1.43	1.00	0.12	0.75	0.37	1.25	
49	0.68	1.30	0.25	1.62	2.25		1.05		0.62	0.31	1.06	1.18
50		1.12	0.12	1.62	1.31	1.56	1.05	0.12	0.56	0.43		1.00
51	0.87	1.25	0.18		1.12	1.37	1.18	0.12		0.50	1.00	1.18
52		1.06	0.00	1.75	1.43	1.50	0.68	0.43	0.43	0.56	1.37	1.06
53	0.75		-0.06	1.62	1.25	1.37	1.12			0.37	1.50	
54	0.62	0.93	0.00	1.68	1.25		1.25	0.31		0.37	0.81	1.00
55	0.75	0.75	-0.12	1.81	1.18	0.81	1.18	0.12	0.68	0.56	1.37	0.75
56	0.87	1.00	0.12	1.50	1.06	1.68	1.06		0.43	0.12	1.75	0.75
57	1.00	0.56	0.18	1.80	1.12	1.43	1.12		0.68	0.18	1.31	
58	1.55		0.12		1.12	1.62	1.06		0.87	0.37	0.62	1.06
59	1.50	0.75	0.06	1.68	1.18	1.56	1.25	0.00		0.25	0.87	0.68
60			0.18	1.75		1.62	1.37	0.06	0.68	0.12	0.62	0.87

10e) Accommodation regression (mean sphere) following sustained near viewing through a positive lens (NNA)

EMMETROPES

Time	SR	GJ	BS	HC	HP	PP	GP	KP	JS	AS	JS	WI
	-0.25	0.75	0.25	0.06	0.37	-0.06	0.75	1.30	0.25	0.31	0.31	0.12
	-0.44	0.62	0.31	-0.06	0.43	0.68	0.56	1.68	0.18	0.62	0.56	0.56
	0.06	0.68	0.25	-0.06	0.56	0.25	0.68	1.50	0.06	0.56	0.62	0.12
	-0.06	0.62	0.18	-0.32	0.56	0.12	0.68	1.30	0.62	0.06	0.37	0.50
	-0.25	0.68	0.18	-0.06	0.75	0.31	0.68	1.18	0.75	0.31	0.68	0.25
	-0.18	0.56	0.25	-0.25	0.50	0.12	0.56	1.18	0.30	0.25	0.62	0.30
	-0.50	0.31	0.12	-0.25	0.56	0.25	0.56	1.50	0.50	0.06	0.62	-0.06
	-0.37	0.56	0.18	-0.06	0.75	0.06	0.50	1.25	0.31	0.50	0.56	0.06
	-0.50	0.50	0.50	0.12	0.80	0.12	0.50	1.43	0.68	0.37	0.68	0.18
	-0.25	0.50	0.56	0.37	0.68	0.25	0.62	1.43	0.50	0.30	0.25	-0.18
	0.06	0.56	0.50	0.18	0.62	-0.18	0.75	1.50	0.50	0.62	0.56	0.06
	-0.12	0.62	0.56	0.50	0.62	-0.12	0.62	1.37	0.12	0.56	0.43	0.06
	-0.56	0.56	0.31	0.25	0.50	-0.18	0.62	1.62	0.81	0.87	0.43	-0.06
	-0.06	0.62	0.12	0.37	0.75	0.12	0.56	1.62	0.68	0.75	0.43	0.18
	0.00	0.62	0.12	0.25	0.87	0.25	0.43	1.50	0.37	0.50	0.43	0.25
0												
1	-0.12	0.56	0.56	0.50	0.93	0.00	0.37	1.75	0.93	0.37	0.18	1.18
2	-0.18	0.68	0.62	0.37	1.18	0.06	0.56	1.81	0.87	0.50	0.31	1.37
3	0.12	0.62	0.75	0.37	1.12	0.06	0.56	1.93	1.06	0.56	0.31	1.25
4	0.06	0.68	0.62	0.75	1.12	0.37	0.68	1.62	1.00	0.43	0.31	1.31
5		0.62	0.43	0.87	1.00	0.18	0.62	1.87	1.12		0.31	0.93
6	-0.32	0.62	0.43	0.56	1.50	0.25	0.56	2.12	1.06	0.50	0.25	1.00
7	-0.12	0.62	0.56	0.56	1.50		0.56	2.37	1.12	0.56	0.31	1.06
8		0.68	0.50	0.81	1.06	0.25	0.56	2.18	1.12	0.50	0.25	1.00
9		0.68	0.68	0.56	0.93	0.43	0.56	2.43	1.12	0.43	0.37	1.00
10		0.75	0.56	0.73	1.00	0.43	0.50	2.43	1.18	0.50	0.31	
11		0.68	0.75	0.31	1.12	0.31	0.50	2.50		0.56	0.43	
12	0.06	0.75	0.68	0.18	1.18	0.18	0.56	2.18	1.06	0.56	0.37	1.87

13	-0.18	0.68	0.62	0.18	1.12	0.25	0.50	2.43	1.25	0.43	0.62	1.50
14	-0.37	0.62	0.80	0.06	1.31	0.25	0.43	2.62	1.12	0.68	0.31	
15	-0.25	0.68	1.06	0.06	1.43	0.06	0.37	3.68	1.06	0.31	0.50	
16	-0.25	0.68	0.75	0.06	1.68	0.25	0.37	3.68	1.12	0.50	0.50	
17	0.00	0.80	0.75	0.06	1.37	0.25	0.00	3.62	1.12	0.25	0.62	
18	0.12	0.80	0.37	0.06	1.62	0.18	0.37	3.37	0.87	0.43	0.43	1.68
19	-0.12	0.80	0.37	0.00	1.25	0.00	0.43	2.56	0.80	0.56	0.43	1.56
20	0.00	0.80	0.31	0.00		0.00	0.37		0.80	0.56	0.43	1.56
21	-0.12	0.80	0.37	-0.06	1.43	-0.18	0.43	2.30	0.75		0.43	1.31
22	-0.06	0.80	0.37	0.12	1.43	-0.25	0.50	2.06	1.06	0.62	0.56	1.25
23	-0.12	0.87	0.37	0.12	2.50	-0.12	0.56	1.93	1.18	0.56	0.68	1.25
24	0.06	0.75	0.50	0.06	1.75	-0.18	0.50	1.87	1.37	0.50	0.68	1.43
25	-0.06	0.75	0.56	0.25	1.30		0.50	2.00	1.18	0.50	0.25	1.50
26	-0.12	0.93	0.62	0.31	1.12	-0.12	0.37		1.25	0.56	0.25	1.31
27	0.00	0.80	0.62	0.37	0.93	0.00	0.50	1.93	1.18	0.43	0.30	2.25
28	0.18	0.80	0.43	0.37	0.93	0.06	0.37	1.75		0.37	0.56	2.25
29	-0.12	0.81	0.75	0.43	1.12	0.00	0.43		1.31	0.43		2.12
30		0.93	0.75	0.37	1.12	-0.06	0.56	2.37	1.31	0.43	0.50	2.00
31	-0.06	1.12	0.50	0.37	0.75	-0.25	0.50		1.18	0.43	0.43	2.00
32	0.12	1.00	0.56	0.56	1.18	-0.25	0.43	1.75	1.18	0.30	0.37	1.93
33	0.00	0.81	0.68	0.37	1.37	-0.37	0.50		1.18		0.43	1.87
34	-0.12	0.75	0.75	0.56	1.37	-0.37	0.50	1.80	1.06	0.37	0.50	1.93
35	-0.12	0.75	0.81	0.37	1.25	-0.25	0.56	1.93	0.87	0.62	0.56	1.75
36	0.25	0.75	0.75	0.37	1.31	-0.37	0.50	1.93	0.80	0.75	0.56	
37	0.00	0.75	0.68	0.43	1.25	-0.25			0.93		0.43	1.62
38	0.00	0.93	0.68	0.25	1.31	-0.37	0.37		0.62	0.50	0.43	1.87
39	-0.25	1.00	0.68	0.25	0.93	-0.37	0.50	1.75	0.80	0.56	0.62	1.93
40	0.00	0.87	0.62	0.25	0.87	-0.25	0.56	1.62		0.43	0.50	
41	0.12	0.75		0.25	0.62	-0.37	0.56	1.50	0.93	0.37	0.62	2.06
42	0.12	0.87	0.62	0.18	0.37	-0.32	0.50	1.37		0.62	0.62	2.06
43		0.80	0.50	0.37	0.50	-0.37	0.50	1.31	0.93	0.56	0.56	
44	-0.12	1.00	0.75	0.25	0.56	-0.50	0.50	1.56	0.87	0.50	0.62	1.87
45	-0.12	0.87	0.75	0.18	0.68	-0.37	0.50	2.06	0.93	0.30	0.62	
46	0.00	0.87	0.50	0.31	0.80	-0.37	0.56		1.00	0.37	0.87	
47	0.00	1.12	0.62	0.25	0.75	-0.37	0.56	1.80	0.93	0.56	0.80	
48	0.00	1.18	0.68	0.12	0.75	-0.56		1.68	0.87	0.62	1.00	
49	-0.06	1.30	0.50	0.12	0.62	-0.50	0.43	1.68	0.80	0.56	0.62	1.75
50	-0.06	1.25	0.68	0.12	0.87	-0.50	0.50	1.68	0.75	0.43	0.50	1.93
51	-0.12	0.75	0.56	0.06	0.75	-0.25	0.50	1.37	0.93		0.68	1.56
52	-0.12	0.75	0.56	0.12	1.00	-0.32	0.50		1.25	0.50	0.68	
53	-0.12	0.87	0.68	0.12	0.81	-0.18	0.50	1.56	1.25	0.62	0.75	1.37
54	-0.18	1.12	0.68	0.06	1.00	-0.19	0.62		1.50	0.37	0.87	1.18
55	-0.12	1.18	0.62	0.06	1.06	-0.06	0.50		1.50	0.56	0.80	1.18
56	-0.06	1.37	0.68	-0.06	0.93	-0.06	0.62		1.18		0.93	1.31
57	-0.06	1.37	0.68	-0.18	0.81	-0.43	0.56		1.37	0.56	0.87	1.50
58	0.12	1.12	0.62	-0.06	0.93	-0.32	0.56	1.68	1.56	0.81	0.68	1.87
59		1.18	0.56	-0.12	0.87	-0.32	0.68	1.62	1.43	0.68	0.43	1.18
60		1.00	0.56	-0.06	1.62	-0.62	0.68		1.18	0.43	0.43	1.25

EARLY-ONSET MYOPES

Time	KL	NB	WF	RM	AN	JF	AH	SS	JB	CW	GP	MD
	0.56	0.18	0.87	-0.06	-0.18	0.31	0.43	0.06	-0.32	-0.12	0.18	-0.44
	0.56	0.43	1.18	-0.06	0.00	-0.18	0.43	0.06	-0.18	-0.25	0.06	-0.18
	0.68	0.18	0.93	0.43	0.31	0.18	0.37	0.50	-0.12	-0.32	0.44	-0.06
	0.93	0.80	0.93	0.43	0.12	0.62	0.50	0.25	-0.18	-0.31	0.06	-0.56
	0.81	0.56	0.81	0.06	0.18	0.18	0.50	0.06	-0.25	-0.25	0.80	-0.12
	0.68	0.37	0.62	0.50	0.25	0.18	0.50	0.50	-0.06	-0.43	0.18	-0.06
	0.43	0.50	0.93	0.25	0.06	0.31	0.50	0.18	-0.06	-0.37	0.56	-0.31
	0.87	0.37	0.56	0.25	0.06	0.43	0.68	0.00	0.06	-0.18	0.00	0.00

	0.81	0.12	0.75	0.37	0.06	0.31	0.68	0.62	0.12	-0.25	0.12	0.12
	0.75	0.18	0.81	0.75	-0.18	0.25	0.75	0.50	-0.32	0.00	-0.31	0.12
	0.87	0.43	0.68	0.62	0.00	0.12	0.31	-0.06	-0.12	-0.43	0.00	-0.06
	0.93	0.68	0.93	0.37	0.00	0.43	0.50	0.18	-0.37	-0.32	-0.31	0.06
	0.31	0.31	0.43	0.37	-0.37	0.18	0.37	0.12	-0.18	-0.32	-0.06	-0.18
	0.62	0.62	1.06	0.43	-0.12	0.62	0.37	0.18	-0.12	-0.31	0.37	0.18
0												
1		0.81	1.18	0.25	-0.12	0.12	0.50	-0.06		-0.18	0.68	-0.31
2	1.12	0.18	0.81	0.31	-0.69	0.50		0.68		-0.06	0.06	-0.25
3		0.31	1.06	0.37	1.25	0.50	0.56	0.25	0.56	0.00		-0.31
4	0.87	0.25	1.30	0.37		0.43	0.75	-0.06	1.18	0.00	0.18	-0.25
5		0.12	1.25	0.37	-0.12	0.50	0.50	0.56	0.80	-0.12	0.06	-0.18
6	1.50	0.31	1.68		-0.50	0.68	0.50	0.37	0.62	-0.12	0.00	-0.50
7	1.43		1.31	0.50	-0.62	0.56	0.62	0.62	0.62	-0.12	0.18	
8	1.25	0.50	1.12	0.50		0.50	0.62	0.75	0.50	0.00	0.18	-0.44
9	1.18	0.06	1.12	0.62	0.25	0.56	0.62	0.31	0.37	-0.12		
10	1.00	0.31		0.56		0.50	0.87	0.68	0.43	-0.18		
11	1.12	0.31	1.12	0.68	0.18	0.62				0.00		-0.50
12	0.87	1.37	1.12	0.75		0.56	0.75	0.62	0.62	-0.12		
13	0.68	-0.06	0.68	0.75		0.37	0.93	1.93		-0.25		-0.18
14	0.68	-0.18	1.00	0.50	0.43	0.25	1.00	0.81		-0.12	0.37	-0.12
15	0.68	0.12	0.87	0.25		0.25	1.50	0.31		0.00	0.37	0.12
16	0.62	0.93	1.06	0.25	0.12	0.31	1.00	0.62	0.68		0.31	
17			0.75	0.25	0.25	0.50		0.62	0.62	0.80		-0.43
18		0.43	1.12	0.31	0.50	0.37	1.43	0.75	0.56	0.37	-0.12	0.12
19	1.18	0.56	0.87	0.31		0.12	0.87	0.75	0.81	1.00	-0.12	-0.18
20	0.93	0.87	0.81	0.18	0.31	0.56	0.75	1.00	0.56	0.62	-0.18	
21	0.87	0.18	0.93	0.31		0.25	1.00	1.00				-0.25
22	0.62	1.06	0.93	0.18	-0.18	0.25	0.87	0.93		1.31		-0.31
23	0.50	0.87	0.75	0.25	0.31	0.18	0.87	0.93	0.37			0.12
24	0.43		0.81	0.25	0.50	-0.12		1.00		0.81		0.18
25	0.25	0.68	0.81	0.25		-0.18		1.06		0.50		0.31
26		0.56	0.93	0.31			0.80					-0.06
27		0.62	0.87	0.31	0.50	-0.12	0.80	0.80		0.62		
28	0.43	0.56	1.12	0.25	0.68	-0.12	0.68	0.87		-0.06		
29		0.62	1.43	0.25		-0.06	0.93	1.12	0.62		0.37	0.12
30		0.93	0.81	0.25	0.75	-0.06	1.12	0.87	0.75	-0.25	0.43	0.06
31		0.62	0.87	0.50		-0.12	0.50	0.80	0.56		0.43	0.06
32		0.75	0.75	0.37	0.50	-0.25	0.31	0.87	0.56	0.06	0.18	0.00
33		1.50	1.18	0.37		-0.25	0.50	0.87	0.75	0.00	0.25	0.06
34		1.12	0.75	0.50	1.00	-0.25	0.50	1.06	0.50	0.00	0.06	0.18
35			0.93	0.50		-0.50	0.75	1.00		0.00	0.18	-0.37
36		0.56	0.93	0.43			0.68			0.68	0.12	-0.56
37		0.50	1.00	0.43	0.75	-0.18		0.81	0.81	0.93	0.12	-0.31
38		1.37	1.00	0.37	1.12	0.00	0.56	1.00	0.18	1.00		0.06
39		1.43	0.87	0.31	1.68	0.06	0.75	1.06		1.25	0.12	-0.75
40		1.56	0.93	0.37	1.87	0.12	0.43	1.12	-0.18	1.00	0.12	-0.44
41	0.31	1.75	0.75	0.37		-0.32	0.75	1.00		1.18	0.00	-0.31
42	0.50	1.06	1.31	0.31	1.06	0.12	0.87	0.81		1.00	-0.06	-0.25
43	0.37	1.12	1.25	0.37	1.43	0.00	0.93	1.37	0.12	1.06	-0.18	
44	1.00	1.30	1.31	0.68	1.62	-0.06	1.06	1.18	0.06	0.75		-0.31
45	0.50	1.25	1.18	0.75		-0.18	0.75	0.80	0.18	0.75		-0.62
46	0.37	1.50	1.12	0.62		0.56	0.87	0.87	0.31	0.50		-0.32
47	0.87	1.50	0.87	0.68	0.56		0.75			1.43	0.37	0.00
48	0.68	1.81	1.00	0.56	0.80	-0.25	1.00			1.25		-0.18
49		1.81	0.81	0.56		0.37	0.93	0.75	0.56	1.00	-0.06	-0.12
50	0.43	1.56	0.80	0.56		-0.06	0.75	1.00	1.00	1.12	-0.31	-0.44
51	0.37	1.50	0.93	0.37		0.06	0.87	1.00	1.18	1.25	-0.12	
52		1.50	0.56	0.31		0.25	0.80	1.12	1.25	1.18		-0.37
53	0.56	1.75	0.87	0.31		-0.06	0.87	1.25	0.80	0.93	0.43	-0.62
54	0.12	1.25	0.93	0.43		-0.06	0.75	1.06	0.62	0.93	0.31	-0.43

55		1.25	1.00	0.43		-0.12	0.80	0.87	0.62		0.25	-0.50
56		1.56	0.80	0.50		-0.18	0.80		0.68	0.68	0.18	0.44
57		1.12	0.93	0.56		-0.18	0.62		0.25	1.00		-0.62
58	0.62	1.43	0.93	0.37	0.87		0.62		0.68	1.18	0.18	-0.56
59	0.43	1.37	0.87	0.43	0.80	0.06	0.62	0.93	0.68	1.37	0.31	-1.25
60	0.43	1.25	0.93	0.37	1.00	-0.06	0.37	1.06	0.81	0.68	0.50	-0.56

LATE-ONSET MYOPES

Time	AW	NW	JH	SB	EF	KD	CW	NB	CH	NH	TH	CR
	0.43	0.25	-0.25	0.06	0.31	0.25	0.68	0.30	0.56	0.12	0.37	0.31
	0.62	0.56	0.31	0.00	0.06	0.18	0.50	0.12	0.68	0.12	0.06	0.06
	0.62	0.50	-0.25	0.00	0.18	0.18	0.62	0.31	0.43	0.12	-0.12	-0.06
	0.30	0.31	0.18	0.25	0.12	0.25	0.80	1.12	0.25	0.06	0.00	0.25
	0.56	0.50	0.12	0.37	0.12	0.37	0.80	0.25	0.12	-0.06	0.12	0.25
	0.00	0.25	0.25	0.25	-0.32	0.31	0.68	0.80	0.06	0.00	0.12	0.31
	0.75	0.62	0.43	0.31	-0.18	0.25	0.80	0.18	0.68	0.00	0.31	0.18
	0.56	0.25	0.00	-0.12	-0.32	0.37	0.87	0.43	0.12	0.00	0.37	0.56
	0.37	0.31	0.18	0.31	0.06	0.06	0.87	0.43	0.06	0.18	0.06	0.43
	0.75	0.37	0.25	0.31	0.25	0.25	0.80	0.31	-0.12	-0.18	0.31	0.62
	0.43	0.56	0.37	0.25	-0.18	0.25	0.68	0.37	0.25	-0.12	0.00	0.43
	0.25	0.56	-0.12	0.30	0.37	0.12	0.56	0.50	-0.12	-0.25	0.18	0.43
	0.25	0.37	0.12	0.00	0.06	0.18	0.37	0.37	-0.06	-0.12	0.18	0.31
	0.50	0.68	0.06	-0.06	0.06	0.37	0.56	0.31	0.12	-0.18	0.25	0.68
1	0.87	0.18	0.19	0.18	-0.32	0.68	1.12	0.12	-0.12	-0.37	0.62	0.18
2	0.12	0.43	0.06	0.62	0.43	0.80	1.56	0.30	0.12		0.75	0.25
3	0.18	0.25	0.18		0.43	0.62	1.75	0.56	0.18	0.00		0.18
4	0.00	0.62	0.18	0.75	0.31	0.93		0.80	0.43	-0.06	0.75	0.37
5	0.00	0.50	0.25	0.93	0.50	0.93	1.56	0.75	0.06	-0.06	0.80	0.37
6	0.25	0.37	0.18	0.93	0.56		1.68	0.50	0.25	-0.25	0.68	0.62
7	0.75	0.50	0.37	1.25	0.25	0.81		0.68	0.25	0.06	0.37	0.37
8	0.62		0.18	0.62	0.43	0.50	1.68	0.43		-0.18	0.18	0.18
9	0.00	0.37	0.37	1.00	0.43	0.81	1.75	0.62	0.25	-0.25	0.62	1.25
10	0.18	0.37	0.56	0.87	0.43	0.62	1.62	0.43		0.00	0.30	0.93
11	0.25	0.37	-0.06	0.93	1.18	0.75	1.30			0.12		0.43
12	0.30	0.37	0.31		0.50	0.68	1.37	0.62	0.06	0.00	0.81	0.18
13	0.00	0.37	0.12	1.00		0.43	1.37	0.56		0.00	0.68	-0.31
14	0.18	0.50	0.18	1.25	0.56	0.43	1.56	1.62	0.12	0.00	0.75	0.18
15	0.50	0.37	1.18		0.37	1.75	2.25	0.25	0.00	0.80		
16	0.00	0.50	0.50	0.18	0.12	0.31	1.62	2.43				0.25
17	0.75	1.00	0.31	1.30	0.31	0.43	1.80	2.12	0.50	-0.12	0.93	0.18
18		0.80	0.44		0.37	0.50	1.93	1.75	0.18	-0.06	0.75	0.00
19	0.00		0.31	0.93	0.37	0.37	1.62	2.37		0.06	0.80	
20	0.87		0.18		0.31	0.50	1.56	1.93			0.56	0.06
21	0.81		0.37	1.06	0.43	0.56	1.56		0.00			0.06
22	0.18	1.00	0.31	1.00	0.43	0.50	1.68	1.56		-0.37	0.68	0.43
23	0.18	0.18	0.43	1.00	0.50	0.56	1.50			-0.12	0.37	-0.12
24	0.50	0.31	0.43	1.00	0.43	0.50	1.62	1.12	0.12	-0.06	0.62	-0.12
25	0.12	-0.19	0.18		0.43	0.31	1.43	1.12		0.00	0.62	0.18
26	0.00	0.87	0.43	0.68	0.31	0.50	1.68	0.00		-0.18	0.50	0.00
27		0.62	0.25		0.56	0.75	2.06	0.18	0.37	0.12	0.68	0.00
28	0.12	0.68	0.06	0.06	0.43	0.62	2.00	0.25	0.12			0.31
29	0.12		0.25		0.50	1.37	1.50	0.43		0.12	0.50	0.31
30	0.93	0.31	0.00		0.62	1.00	1.43	0.18		0.12	0.56	0.31
31	0.25	0.50	0.00	1.06	0.12	0.62	1.56	0.25	0.31	0.25	0.37	0.12
32	0.00	0.87	0.06	0.87	0.43	0.75	1.37	0.31		0.06	0.75	
33		1.00	0.00			0.87	1.12	0.43	0.31	0.12	0.68	
34	0.30	1.00	0.06	0.62		1.25	1.06				0.75	0.50
35	0.68	0.87	0.00		0.50	1.12	1.06		0.56	0.12	0.68	-0.31

36	0.50	1.00		0.37	0.37		0.93	0.56		0.06	0.56	-0.12
37		0.81			0.56	0.75	1.06		0.31	-0.06	0.62	0.25
38	0.43	0.81		0.25	0.25	0.87	1.18			0.00	0.43	0.12
39	0.31	0.68	-0.06	0.62	0.50	1.25	1.25	0.93		0.12	0.43	0.37
40		1.00	0.06	0.68	0.06	1.43	1.37	0.75	0.06	0.25	1.00	-0.25
41	0.00	0.87	0.00	0.62	0.43	1.12	1.12	0.43	0.06	-1.00		
42	0.25	0.68	0.12		0.43	1.18	1.12				0.56	0.62
43	0.75	0.56	0.12	0.56		1.43	1.25	0.87			0.43	0.56
44	0.12	0.50	0.06		0.50	1.06	1.30				0.68	0.62
45	0.00	0.75	0.37	-0.12	0.56		1.12			-0.50	0.75	0.18
46	0.56	0.62	0.25		0.50	1.50	1.25	0.37		0.12	0.25	
47	0.75	0.50	0.37	1.00	0.50		1.30					
48	0.62	0.68	0.12		0.56	0.87	1.30		0.25			
49	0.62	0.50	0.12	1.00		0.75	1.50	-0.25	0.37		0.50	0.56
50	0.06	0.75	0.25		0.50	0.87	1.18	0.43	0.06	-0.60	0.43	0.68
51	0.62	0.50	0.06	0.06	0.56	0.50	1.56	0.43	0.00		0.50	
52	0.81	0.43	0.12	0.18		0.81	1.93	0.62	0.00			0.62
53	0.18	0.56		-0.06		1.06	1.75	0.80	0.12	-0.12		0.75
54	0.06	0.43		0.00	0.56	1.06	1.12	0.68		-0.06	0.43	
55	0.12	0.43	0.18			1.56	1.00	0.87	0.31	0.00	0.56	0.68
56	0.12	0.56	0.25	0.00	0.44	1.68	1.00	0.56	0.56	0.25	0.56	0.18
57	0.00	0.37	0.25	0.06	0.68	1.56	1.18	0.31			0.56	
58	0.25	0.56	0.25		0.56	1.31	1.12	0.50	0.31		0.50	0.37
59		0.50	0.18		0.50	1.30	1.06	-0.06	0.43	0.12	0.50	0.25
60			0.25	0.18	0.62	1.56	1.00	0.06		0.18	0.75	0.31

APPENDIX 11

THE EFFECT OF TOPICAL β - ADRENOCEPTOR ANTAGONISTS ON ACCOMMODATION IN EMMETROPIA AND MYOPIA

11a) Background data

Presented here are individuals' right eye data for mean sphere refractive error (Rx), Keretometry ('K'), axial length (A.L.), anterior chamber depth (A.C.D.), lens thickness (L.T.), vitreous chamber depth (V.C.D.) and age of subject. For the early- and late-onset myopes the age of myopic onset has been included. * denotes subjects who participated in both prts of the study.

EMMETROPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)
AS	0.25	7.78	23.42	3.86	3.73	15.83	23
CH	0.25						29
DH	0.37	8.15	24.65	3.91	3.14	17.60	19
FF*	-0.12	7.83	23.33	3.78	3.62	15.93	22
HC*	0.25	7.88	23.69	3.68	3.42	16.56	27
JE*	0.37	7.48	22.16	3.86	3.68	14.62	21
JL	0.25	7.63	22.46	3.15	3.94	15.37	18
KF	0.25	7.70	23.28	3.46	3.48	16.34	20
KP*	0.00	8.98	25.77	3.26	3.58	18.93	18
OW*	0.25	7.83	23.46	3.98	3.55	15.93	22
RD*	0.25	7.83	23.91	3.30	3.71	16.90	25
TW	-0.25	7.88	23.47	3.83	3.72	15.92	21
Mean	**0.18**	**7.91**	**23.60**	**3.64**	**3.60**	**16.36**	**22.08**
SEM	**0.06**	**0.12**	**0.29**	**0.09**	**0.06**	**0.35**	**1.00**

EARLY-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AB*	-2.37	7.40	23.81	3.87	3.73	16.21	20	13
AE	-3.00						29	12
GD	-2.12						20	12
JB*	-2.75	7.90	26.34	3.20	3.91	19.22	22	14
JB*	-4.25	7.95	27.15	3.69	3.63	19.83	20	12
JG*	-1.75	8.10	24.18	3.76	3.32	17.10	19	13
MD*	-6.00	8.08	27.04	3.99	3.71	19.34	29	7
RM	-6.25	7.98	26.05	3.68	3.44	18.93	18	7
SL	-3.25	7.13	24.01	3.98	3.61	16.43	19	14
WF	-0.75	7.15	22.66	3.66	3.48	15.52	18	14
Mean	**3.25**	**7.71**	**25.15**	**3.73**	**3.60**	**17.82**	**21.40**	**11.80**
SEM	**0.56**	**0.15**	**0.60**	**0.09**	**0.07**	**0.60**	**1.32**	**0.84**

LATE-ONSET MYOPES

Subjects	Mean Rx (D)	Mean 'K' (mm)	A.L. (mm)	A.C.D. (mm)	L.T. (mm)	V.C.D. (mm)	Age (years)	Age of onset
AW	-1.37	7.60	24.40	3.75	4.02	16.63	20	17
CH*	-1.25						28	23
CW*	-1.12	8.05	25.06	3.94	3.35	17.75	18	16
EW*	-2.75	7.90	25.75	3.96	3.61	18.17	26	19
JL*	-0.87	7.50	22.71	3.95	3.45	15.32	18	17
LW	-2.50	7.20	25.60	3.72	3.51	18.37	18	16
SB*	-1.75	8.08	24.49	3.50	3.94	17.05	20	19
TH	-1.87	7.98	24.57	3.79	3.66	16.89	20	17
Mean	**1.68**	**7.76**	**24.65**	**3.80**	**3.65**	**17.17**	**21.00**	**18.00**
SEM	**0.23**	**0.12**	**0.38**	**0.06**	**0.09**	**0.39**	**1.45**	**0.82**

11b) Results from the initial SOLA study

The mean value of the mean sphere refractions measured under open-loop conditions - complete darkness and viewing a laser speckle pattern in an otherwise darkened room before and 40 minutes after the instillation of timolol and betaxolol.

EMMETROPES

	TIMOLOL				BETAXOLOL			
	DARK		LASER		DARK		LASER	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
AS	-0.72	-0.56	-0.56	-0.37	-0.42	-0.40	-0.41	-0.42
FF	-1.61	-0.97	-0.91	-0.93	-1.84	-1.30	-0.84	-1.08
KF	-0.12	0.01	-0.16	-0.04	0.15	0.08	-0.09	0.21
HC	-0.12	-0.22	0.08	-0.20	0.09	0.38	0.12	-0.89
OW	-1.16	-1.04	-0.76	-1.12	-1.05	-1.00	-0.88	-0.74
CH	-1.30	-1.19	-0.93	-0.86	-1.48	-1.19	-1.04	-0.96
RD	-2.10	-3.73	-1.78	-2.62	-0.77	-0.62	-1.82	-1.68
JE	-1.07	-1.60	-1.14	-1.82	-1.05	-1.04	-2.22	-1.54
TW	-0.24	0.06	-0.24	-0.23	-0.06	-0.09	-0.45	-0.26
JL	-0.19	-0.09	-0.43	-0.38	-0.22	-0.20	-1.06	-1.19
DH	-0.48	-0.58	-1.27	-1.29	-0.18	-0.78	-0.56	-0.85
KP	-2.24	-1.56	-2.55	-1.78	-1.00	-1.14	-1.35	-1.96

EARLY-ONSET MYOPES

	TIMOLOL				BETAXOLOL			
	DARK		LASER		DARK		LASER	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
RM	-0.66	-0.89	-0.83	-0.64	-0.07	-0.23	-0.06	-0.16
JG	-0.04	-0.06	-1.59	-1.86	-0.15	-0.06	-1.03	-1.13
MD	-0.33	-0.53	-0.17	-0.62	-0.96	-0.27	-0.21	0.00
JB	-1.05	-2.45	-1.03	-1.87	-1.87	-2.13	-1.50	-1.02
SL	-1.13	-0.93	-0.87	-0.59	-0.64	-0.51	0.07	-0.08
JB	-0.96	-1.17	-0.79	-0.90	-1.34	-1.00	-1.54	-1.01
AB	0.18	-0.43	-0.56	-2.02	-0.56	-0.40	-0.40	-0.77
GD	-0.24	-0.78	0.34	0.04	-0.54	-0.91	0.00	0.03
WF	-0.29	-0.34	-0.30	-0.44	-0.90	-0.42	-0.50	-0.47
AE	-1.20	-1.33	-0.10	-1.16	-1.13	-1.46	-0.67	-1.92

LATE-ONSET MYOPES

	TIMOLOL				BETAXOLOL			
	DARK		LASER		DARK		LASER	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
CH	-0.40	-0.64	-1.40	-0.67	-0.45	-0.44	-0.43	-0.43
CW	-1.21	-0.98	-1.95	-1.81	-0.94	-1.00	-1.13	-0.99
LW	-0.52	-0.77	-0.69	-0.91	-0.47	-0.45	-0.46	-0.54
TH	-0.55	-0.20	-0.73	-0.31	-0.46	-0.60	-0.68	-0.55
EW	-1.04	-0.34	-0.12	-0.19	-1.23	-0.71	0.00	0.02
JL	-0.14	-0.43	0.01	-0.09	-0.61	-0.17	-0.13	0.04
SB	-1.63	-0.46	-1.06	-0.40	-0.36	-0.49	-0.61	-0.22
AW	-0.33	-0.16	-0.28	-0.36	-0.27	-0.43	-0.21	-0.41

11c) Pre timolol accommodative regression (mean sphere) following distance (D) and near (N) sustained viewing.

EMMETROPES

Time	FF		HC		JE		RD		KP		OW	
	D	N	D	N	D	N	D	N	D	N	D	N
	0.37	3.87	-0.12	3.00	0.00	4.18	0.18	4.12	0.56	4.68	0.43	0.68
	0.68	3.80	0.00	3.68	0.12	4.87	0.31	4.06	0.56	4.75	0.31	3.75
	0.50	4.62	0.00	3.56	0.25	4.37	0.18	3.87	0.50	4.43	0.25	3.93
	0.62	4.25	0.12	3.50	0.12	3.80	0.18	5.25	0.37	4.25	0.25	3.12
	0.62	4.62	0.00	3.50	0.37	5.12	0.00	4.75	0.50	4.30	0.31	3.93
	0.87	5.00	0.06	3.43	0.18	4.37	0.18	3.81	0.50	4.30	0.25	3.68
	0.68	4.43	0.12	3.43	0.06	3.93	0.18	3.87	0.56	4.30	0.37	3.68
	0.93	4.18	0.12	3.56	0.30	4.50	0.00	4.12	0.56	4.18	0.31	3.87
	0.56	3.00	0.00	3.37	0.18	4.43	0.06	4.18	0.50	4.50	0.25	3.81
	0.68	4.06	0.12	3.81	0.18	4.68	0.12	4.18	0.50	4.30	0.37	3.75
0.0												
1.5	0.62	3.50	0.18	2.50	0.00	3.50	0.12	4.00	0.56	4.18	0.25	2.00
3.0	1.12	4.00	0.18	1.62		0.80	0.31	2.37	0.68	4.00	0.25	1.75
4.5	1.43	3.12	0.25	2.37	0.37	1.00	0.43	2.80	0.75	4.43	0.25	1.62
6.0	1.80	2.62	0.00	2.37	0.30	0.75	0.43	3.93		3.43	0.25	0.87
7.5	1.80	2.62	0.25	1.68	0.25	0.93	0.56		1.00		0.25	0.93
9.0	1.81	2.56	-0.12	1.37	0.62		0.68	1.43	1.75	2.75	0.12	0.50
10.5	1.56	2.37		1.30	0.56	1.50	0.68	1.93	1.62	2.50	0.25	0.62
12.0		1.75	0.06	1.12	0.75	1.50	0.81	2.12	1.68	3.12	0.12	0.62
13.5	1.25	1.87	0.25	0.80	0.68	1.43	0.81	1.75	1.62		0.18	0.68
15.0		2.06	0.06	0.87	0.93	1.37	0.87	1.75	1.50		0.25	0.62
16.5	0.87	2.12	0.06	1.56	0.62	1.18	1.00	2.18		2.12	0.18	0.75
18.0	1.50	1.75	0.18	0.87	0.43	1.12	0.68	1.06	2.81	2.18	0.12	0.93
19.5	1.37	0.56	-0.06	0.43	0.31	2.00	0.87	1.12		2.05	0.12	0.68
21.0	1.75	0.50	-0.12	0.87	0.31	1.30	0.87	0.80	1.81	1.87		0.93
22.5		0.56	0.18	0.68	0.62	0.87	1.06	1.25	1.68		0.31	0.87
24.0			0.00	0.62	0.25	1.25	1.18	1.12	1.50		0.25	0.87
25.5	1.50	0.37	-0.06	0.56	0.43	1.37	1.62	0.75	1.18		0.25	0.56
27.0	1.75	0.12	-0.06	0.87	0.43	1.00		0.62		1.43	0.18	0.43
28.5	1.62	0.12	0.18	0.75	0.62	0.75	0.56	0.62		1.56	0.31	0.50
30.0	1.50	0.25	0.37	1.37	0.62	0.93	0.68	0.68	2.00			
31.5	1.62	0.25	0.37	0.80	0.87	0.75	0.87	0.68	1.87	1.50		0.68
33.0			0.37	0.68	0.75	0.87	1.00	0.75		1.56		0.62
34.5	1.62	0.43	0.18	0.62	0.50	0.68	1.06	1.18	1.68		0.25	0.37
36.0		0.12	0.12	0.43	0.62	0.87	1.06	0.68	1.68	1.43	0.37	0.31
37.5	1.30	0.25	-0.12	0.62	0.87		1.00	0.68		1.62	0.37	0.37
39.0	1.50	0.12	-0.06	0.62	0.50	0.43	0.87	0.56		1.56	0.30	0.30
40.5	1.50	0.12	0.56	0.56	0.56	0.62	0.62	0.50	1.75	1.43	0.30	0.50
42.0	1.12	0.12	0.62	0.62	0.68	0.56	0.62	0.68	1.87	1.80	0.30	
43.5	1.50	0.25	0.75	0.68	0.50	0.87	0.87	0.68	1.81	1.75		0.37
45.0	1.12	0.12	0.87	0.50	0.68	1.12	1.31	0.68	2.25	2.12	0.25	
46.5	1.00		0.75	0.56	0.81	1.37	1.56	0.68			0.31	0.43
48.0	1.12	0.25	0.56	0.56	0.75	0.93	1.50	0.62			0.31	0.50
49.5	0.93		0.18	0.68	0.93	1.50	1.62	0.75	2.30	1.12	0.12	0.37
51.0	0.62	0.25	0.43		0.37	1.68	0.75	0.43	2.18		0.50	0.37
52.5		0.18	0.18	0.87	0.62	1.50	0.93	-0.31	2.18	0.93	0.12	0.50
54.0	0.50	0.25	0.00	0.75	1.06	1.62	0.93	0.37	2.06		0.06	0.43
55.5	0.37	0.18	0.12	0.56	0.93	0.43	0.87	0.62	2.06	0.87	0.18	0.43
57.0	0.12	0.37	0.18	0.81	0.68	0.50	1.00	0.75	2.31	1.50	0.31	0.25
58.5	0.12		0.12	0.81	0.62		1.31	0.75	2.37	1.30	0.25	0.43
60.0	0.31	1.87	-0.06	0.80	0.18	0.75	1.56	0.75	2.43	1.25	0.31	0.43

EARLY-ONSET MYOPES

Time	AB		JB		JB		JG		MD	
	D	N	D	N	D	N	D	N	D	N.
	-0.18	3.50	0.31	4.50	0.12	5.12	0.06	3.30	-0.18	3.37
	-0.12	3.43	0.18	4.06	0.06	5.00	0.00	3.06	0.31	3.80
	-0.12	3.37	0.25	4.30	-0.18	4.75	0.06	3.68	0.31	3.37
	0.00	3.43	0.25	4.00	-0.12	5.06	-0.06	2.93	0.12	2.93
	-0.18	3.43	0.31	4.00	0.12	5.12	-0.12	2.75	0.00	3.00
	-0.12	3.30	0.37	4.06	0.06	5.06	-0.18	2.62	0.12	3.12
	-0.12	3.62	0.37	4.06	0.00	4.87	-0.06	3.00	0.31	3.00
	-0.12	3.75	0.37	4.30	0.06	6.18	-0.12	3.55	0.00	3.18
	-0.12	3.62	0.37	4.12	0.06	4.93	0.06	3.00	0.18	3.62
	0.06	3.37	0.37	4.18	0.12	5.31	-0.12	2.75	0.31	3.12
0.0										
1.5	-0.37	2.93	0.37	3.75	0.06	4.00	-0.56	1.43	-0.31	3.00
3.0	-0.37	0.18	0.43	1.75	0.37	4.93	-0.31	0.43		0.37
4.5	-0.25	0.12	0.25	1.75	0.50	4.80	-0.43	0.00	-0.06	0.50
6.0	-0.37	-0.37	0.31	1.62	0.50	4.00	-0.43	-0.06		0.12
7.5	-0.37	0.30	0.25	2.00	0.43	3.68	-0.43	-0.18	-0.06	0.12
9.0		-0.18	0.25	1.62	0.43	3.43	-0.37	-0.12	0.00	-0.12
10.5	-0.43		0.18	1.25	0.50	3.68	-0.43	0.00	0.00	
12.0		0.25	0.18	1.25	0.68	3.06	-0.25	-0.12		0.06
13.5	-0.37	0.18	0.30	1.25	0.62	2.68	-0.56	0.00	0.00	
15.0	-0.32	0.18	0.18	1.43	0.75	2.37	-0.32	0.00	-0.25	
16.5	-0.18	0.12	0.37	1.18	0.87	2.18	-0.37	0.25	-0.18	
18.0	-0.18		0.30	1.18	0.93	1.68	-0.50	-0.12		
19.5	-0.18	0.30	0.30	1.00	1.18	1.62	-0.50	0.06	-0.12	
21.0	-0.12	0.50	0.37	0.87	1.25	0.68	-0.43		-0.12	0.37
22.5	-0.18	0.37	0.43		1.06	0.50		0.06	-0.31	0.56
24.0	-0.18	0.30	0.37	0.80	1.50		-0.18	0.06	-0.12	
25.5	-0.37	-0.25	0.37	0.87	1.37	0.80	-0.12	0.12	0.00	0.62
27.0	-0.43	0.50	0.37	0.75	1.80	1.31	-0.12	-0.12	0.06	0.62
28.5	-0.32	0.62	0.25	1.00	1.62		-0.06	0.25	-0.25	0.87
30.0	-0.18	0.18	0.37	0.93	0.62	1.00	-0.12	0.43	-0.12	1.12
31.5	-0.32		0.37	0.80	0.25	1.25	-0.25	0.56	0.00	0.93
33.0	-0.37		0.37		0.37	0.56	-0.25	0.56	0.06	
34.5	-0.37	0.12	0.37	0.62		0.50	-0.18			0.93
36.0	-0.56	0.18	0.12	0.87	0.68	0.43	-0.31	0.31	-0.31	0.31
37.5	-0.62	0.25	0.25	0.56	0.68	0.43	-0.12	0.37	0.18	0.18
39.0	-0.50	0.25	0.31	0.62	0.75	0.37	-0.18	0.25	0.00	-0.12
40.5	-0.56	0.25	0.37	0.68	1.31	0.62	-0.12	0.37	0.18	-0.43
42.0	-0.50	-0.06	0.18	0.62	1.18	0.37	-0.43	0.31	-0.25	-0.06
43.5	-0.56	-0.06	0.12	0.75	1.12	0.37	-0.25	0.25	-0.31	0.18
45.0	-0.31	0.12	0.37	1.00	1.37	0.37	-0.25	0.18	0.00	
46.5	-0.31	0.18	0.25		1.18	0.18	-0.25	0.06		-0.06
48.0	-0.62		0.25	1.00	0.87		-0.25	0.18	-0.18	0.50
49.5	-0.50	0.25	0.25	0.75	1.25	2.25	0.00	0.06		0.37
51.0	-0.32	0.31	0.25	0.62	1.75	2.06	-0.06	0.12	-0.37	0.06
52.5	-0.25	0.25	0.18	0.75	2.00	2.37	-0.25	0.06	-0.25	0.50
54.0	0.12	0.00	0.18	0.62	2.56	2.12	-0.43	-0.06		
55.5	0.18	0.00	0.18	0.56	2.18	1.56	-0.37	-0.12	-0.43	0.12
57.0	-0.12	0.06	0.18	0.62	2.12	2.12		-0.06	-0.50	-0.12
58.5	-0.37	-0.06	0.18	0.62	1.37	2.25	-0.25	-0.12	-0.37	-0.37
60.0										

LATE-ONSET MYOPES

Time	CH		CW		EW		JL		SB	
	D	N	D	N	D	N	D	N	D	N.
	0.18	3.56	-0.12	2.62	0.18	4.00	0.12	4.06	0.37	3.93
	0.18	3.56	0.06	2.68	0.18	4.62	0.25	3.87	0.37	4.25
	0.06	3.12	0.12	2.87	0.18	4.25	0.37	3.75	0.37	4.30
	0.12	3.31	0.00	3.00	0.18	4.50	0.30	3.68	0.43	4.12
	0.00	3.25	0.12	3.12	0.25	4.37	0.30	3.75	0.37	3.75
	0.06	2.87	0.00	3.00	0.12	4.00	0.18	3.68	0.31	4.00
	-0.12	3.25	0.00	2.87	0.31	4.25	0.30	3.81	0.18	4.00
	-0.06	3.18	0.06	3.12	0.18	4.37	0.25	3.75	0.18	3.75
	-0.12	3.56	0.00	3.37	0.18	4.25	0.06	3.75	0.37	3.50
	-0.12	3.25	0.18	2.75	0.18	4.37	0.06	3.68	0.00	3.87
0.0										
1.5	0.31	2.87	0.06		0.25	3.87	0.62	3.30	0.31	3.37
3.0	0.18	1.50	0.12		0.12	1.68	0.62	3.18	0.31	2.50
4.5	0.00	0.37	0.25	0.50	0.00	1.37	0.56	3.06	0.37	2.50
6.0	-0.12	0.25	0.62	0.80	0.00	1.00	0.62	2.12	0.50	2.12
7.5	-0.06	0.00	0.62		0.00	0.87	0.62	2.12	0.50	2.37
9.0	-0.12	0.06	0.37		0.12	0.81	0.56	2.06	0.37	2.37
10.5	-0.18	-0.32	0.25		0.06	0.93	0.68	2.25	0.50	1.75
12.0	-0.25		0.18		0.12	0.81	-0.75	2.30	0.50	
13.5	-0.25	0.06	-0.12		0.12	0.81	-0.75	2.18	0.62	1.43
15.0	-0.12	0.56	0.00	1.00	0.31	1.00		2.25		1.37
16.5	-0.12	0.06	0.25	0.75	0.37	1.31	0.06	1.50	0.56	1.25
18.0	-0.12	0.68	0.37	0.50	0.62	1.12	-0.62	1.68	0.50	0.68
19.5	0.06	0.62	0.68	0.50	0.62	1.12	-0.25	1.75	0.43	0.37
21.0	-0.12	0.37	0.12	0.37		1.30	-0.12	1.43	0.62	0.43
22.5	-0.25		0.50	-0.12	0.43	1.06	-0.06	1.25	0.56	0.37
24.0	-0.12	0.37	0.12	0.37	0.50	0.93	-0.50	1.06	0.62	0.18
25.5	-0.32		0.18	0.18	0.56	0.75	-0.37	1.06	0.43	0.12
27.0				0.31	0.87	0.75	-0.37	1.06	0.25	0.18
28.5	0.00		0.12	0.31	0.68	0.62	-0.25	1.00	0.37	0.30
30.0		0.80	-0.12	0.18	0.93	0.62	0.00	1.06	0.18	0.25
31.5	0.00	0.68	0.12	0.06	1.06	0.62	-0.50	1.06	0.18	
33.0	0.06		0.00		1.12	0.75	-0.56	1.00	0.06	0.37
34.5	0.06	0.50	-0.06	-0.25	0.75	0.68	-0.18	0.75	0.00	0.25
36.0	0.06	0.50	-0.18	-0.25	0.93		-0.12	0.75	0.00	0.43
37.5	0.43		0.18	-0.18	1.00	0.68	-0.56	0.81	0.06	0.56
39.0	0.12		0.25	-0.43	0.93	0.68	-0.50	0.68	0.06	0.62
40.5	0.06		0.12	-0.50	1.18	0.87	-0.19	0.68	0.06	
42.0	0.06	0.37	0.00	0.12		0.81	-0.56	0.75	0.18	0.68
43.5	0.06	0.37	0.12	0.00	1.25		-0.56	0.81	0.00	0.62
45.0	0.12	0.87	0.31	-0.06	1.00	0.81	-0.32	0.87	0.12	0.62
46.5	-0.06		0.31	-0.18	1.37	0.93	-0.12	0.80	-0.06	0.50
48.0	0.06	0.37	0.12	0.06	0.87	0.93		0.75	0.12	0.56
49.5	0.18	0.43	0.30	-0.37	0.80	0.93		0.62		0.50
51.0	0.12		0.12	-0.37	1.25	0.87		0.93	0.12	0.62
52.5	0.18	0.50	0.31	-0.12	1.12	0.93	-0.62	0.93	0.25	0.62
54.0	0.25	0.43	-0.12	-0.25	1.12	1.31	0.25	0.93	0.18	0.68
55.5	0.30		0.00	-0.50		1.31		0.87	0.31	0.80
57.0		0.50		-0.37	0.43	1.18	-0.43	1.12		1.00
58.5	0.43	0.31	0.06	-0.37	0.87	1.12	-0.50		0.50	0.68
60.0	0.25		-0.25	-0.37	0.62	0.68	-1.37	1.56	0.50	0.62

11d) Post-timolol accommodative regression (mean sphere) following distance (D) and near (N) sustained viewing.

EMMETROPES

Time	FF		HC		JE		RD		KP		OW	
	D	N	D	N	D	N	D	N	D	N	D	N
	0.37	4.50	-0.12	3.68	0.12	5.00	0.31	4.06	0.50	4.37	0.31	4.18
	0.50	4.50	0.06	3.31	0.12	4.50	0.37	4.18	0.50	3.68	0.25	4.37
	0.37	5.06	0.00	3.50	0.25	4.75	0.31	4.12	0.56	4.00	0.25	4.25
	0.30	4.37	0.00	3.80	0.25	4.50	0.37	4.37	0.50	4.18	0.18	5.12
	0.43	3.87	0.00	3.56	0.12	4.50	0.25	4.06	0.50	4.12	0.06	3.87
	0.37	4.12	0.00	3.56	0.00	4.62	0.12	4.12	0.50	4.30	0.31	4.25
	0.37	4.30	0.00	3.43	0.06	4.43	0.18	4.12	0.56	3.87	0.31	3.93
	0.30	4.18	0.12	3.43	0.18	4.50	0.25	3.93	0.43	3.87	0.25	4.18
	0.37	4.50	0.00	3.43	0.12	4.62	0.18	3.93	0.37	4.37	0.25	3.87
	0.25	4.50	0.00	3.43	0.12	4.18	0.18	3.93	0.50	4.12	0.25	4.18
0.0												
1.5	0.62	2.37	0.00	2.56	0.12	4.25	0.25	2.87	0.43	3.56	0.31	3.68
3.0			-0.18	1.25	0.12	0.93	0.12	1.31	0.43	3.06	0.31	2.18
4.5	0.87	1.25	-0.12	0.87	0.12	0.75	0.18	0.93	0.43	2.68	0.37	1.43
6.0	0.68	0.37	0.12	0.31	0.31	0.80	0.25	0.81		2.56	0.37	1.00
7.5	0.43	0.12	0.12	0.25	0.25	0.43	0.25	0.75	1.06	2.93	0.31	0.80
9.0	0.50	0.12	-0.06	0.25	0.37	0.56	0.31	0.81	1.30	2.81	0.37	0.87
10.5	0.62	0.12	0.00	0.18	0.50	0.43	0.25	0.81	1.12	2.31	0.30	0.68
12.0		0.18	0.12	0.12	0.43	0.43		0.62	1.00	1.81	0.18	0.68
13.5	0.62	0.00	-0.25	0.12	0.50	0.56	0.31	0.75	1.00	1.68	0.25	0.75
15.0	0.56		-0.12	-0.18	0.56	0.81	0.25		1.00	2.25	0.25	0.37
16.5		0.25	-0.25	-0.06	0.06	1.00	0.37	0.62	1.12	2.68	0.30	0.62
18.0	0.50	0.18	-0.25	-0.06		1.25	0.50	0.81		1.81	0.18	0.75
19.5	0.37	0.25	0.00	-0.18	0.37	1.06	0.37	0.87	1.12	1.75	0.25	
21.0	0.75		0.00	-0.12	0.87	1.12	0.50	0.68	0.93	1.56	0.30	
22.5	0.37	0.18	-0.37	-0.06	0.18	1.12	0.50	0.50		1.75	0.30	0.50
24.0			-0.25	-0.18	0.25	1.00	0.68	0.62		1.68	0.30	0.50
25.5	0.25	0.12	-0.37	-0.31	0.00	0.87	0.62			1.68	0.18	0.68
27.0	0.25	0.62	-0.12	-0.31	0.56	0.62	0.80	0.37	1.06	1.80	0.30	0.43
28.5	0.25	1.00	-0.25	-0.12	0.56	0.62	0.37	0.56	0.93	1.56	0.30	0.50
30.0		1.12	-0.37	-0.18	0.68	0.50	0.37	0.62	1.25	1.06	0.30	0.56
31.5	0.25	1.68	-0.50	-0.18	1.25	0.56	0.43	0.68	1.87	1.12	0.25	0.62
33.0	0.12		-0.50	0.06	0.62	0.68	0.68	0.75	1.30	0.87	0.18	0.50
34.5	0.25	0.43	-0.50	0.06	0.18	0.50	0.62	0.75		0.87	0.30	0.50
36.0	0.25	-0.18	-0.50	0.00	0.68	0.43	0.87	0.43	1.06	0.93	0.18	0.50
37.5	0.12		0.31	-0.12	0.43	0.43	1.12	0.56	1.06	0.93	0.12	0.62
39.0	0.12		0.12	-0.25	0.37	0.50	0.75	0.68	0.87	0.81	0.25	0.50
40.5	0.12		-0.06	-0.18	0.37	0.50	0.81	0.68		0.75	0.25	0.43
42.0	0.12	0.12	-0.06	-0.31	0.50	0.37	0.80	0.87	1.31		0.25	0.56
43.5	0.12	0.62	-0.18	-0.37	0.62	0.43	0.62	0.68		1.00	0.25	0.50
45.0	0.25		-0.32	-0.31	0.37	0.18	0.75	0.75	1.56	0.93	0.12	0.50
46.5	0.12	1.00	-0.43	-0.18	0.50	0.12	0.62		1.06	1.00	0.25	0.50
48.0			-0.37	-0.25	0.37	0.00	0.87	0.75	1.31	0.81	0.25	0.68
49.5	0.25	1.12	-0.56	-0.25	0.31	0.25	0.87	0.81	1.56	0.93	0.25	0.50
51.0	0.12	0.81	-0.37	-0.31	0.43	0.12	1.00	0.75		1.06	0.25	0.30
52.5	0.25	0.87	-0.37	-0.18	0.31	0.06	1.25	0.87	1.93	1.12	0.25	0.30
54.0	0.30	1.06	-0.25	-0.06	0.18	0.25		0.50	1.50	1.06	0.37	0.68
55.5	0.12	1.37	-0.37	-0.12	0.12	0.06	0.87	0.56		1.12	0.25	0.62
57.0	0.30	1.25	-0.43	-0.25	0.31	-0.12	1.12	0.62	1.18	1.12	0.25	0.43
58.5		1.12	-0.43	-0.12	0.37	0.25	1.00	0.68	1.37		0.30	1.25
60.0		1.56	-0.43	-0.18	0.25	0.31	1.37			1.25	0.18	0.43

EARLY-ONSET MYOPES

Time	AB		JB		JB		JG		MD	
	D	N	D	N	D	N	D	N	D	N.
	-0.25	3.06	0.18	4.50	0.18	4.30	-0.37	3.18	0.25	2.87
	-0.12	3.68	0.18	4.37	0.06	4.12	-0.12	3.43	0.25	2.80
	-0.25	3.43	0.18	4.30	0.00	4.37	-0.18	3.37	0.25	2.68
	-0.25	3.43	0.31	4.50	0.06	4.31	-0.06	3.12	0.12	2.93
	-0.12	3.25	0.18	4.25	0.00	4.43	0.06	3.12	0.31	3.31
	-0.12	3.25	0.18	4.43	0.00	4.12	-0.06	3.62	0.06	3.56
	-0.12	3.30	0.25	4.37	0.18	4.06	0.00	3.30	0.18	4.43
	-0.12	3.37	0.18	4.25	0.25	4.18	0.00	3.43	0.06	3.80
	0.00	3.18	0.25	4.62	0.18	4.25	-0.06	3.87	0.06	3.93
	-0.12	3.37	0.25	4.25	0.18	4.25	-0.06	4.06	0.25	4.00
0.0										
1.5	0.00	3.25	0.50	4.12	0.18	4.30	-0.25	2.81		0.62
3.0	-0.12	1.00	0.31	2.37	0.31	3.56	0.00			0.12
4.5	0.00	0.80	0.25	1.87	0.31	2.75	-0.06		-0.06	0.12
6.0	-0.32	0.75	0.37	1.80	0.31	2.31	-0.12	0.56	-0.37	0.00
7.5		0.80	0.43	1.62	0.62	2.30	-0.37	0.56	-0.31	-0.37
9.0	0.12	0.56	0.43	1.12	1.06	2.30	-0.50	0.80	-0.43	-0.06
10.5	0.12	0.56	0.30	1.12	0.56	2.50	-0.37	0.80	-0.25	-0.06
12.0	-0.25	0.37	0.43	0.87	0.80	2.06	-0.50	0.56	-0.37	0.00
13.5	-0.18	0.31	0.43		1.18	2.30	-0.25	0.50	-0.50	0.06
15.0	-0.25	0.12	0.43	1.25	1.30	2.81	-0.18	0.80	-0.06	-0.25
16.5	-0.12	0.00	0.43	1.30	1.00		-0.25	0.62	-0.37	-0.25
18.0	-0.43	0.12	0.50	1.12	0.93	2.30	-0.12	0.50	-0.25	-0.37
19.5	-0.32	0.18	0.56	1.00	0.80	1.62	-0.12	0.31	-0.37	-0.43
21.0	-0.37	0.25	0.62	1.06	1.00	1.37	0.06	0.18	-0.43	-0.31
22.5	-0.25	0.12	0.62	1.00	1.25	1.87	0.06	0.18	-0.50	-0.31
24.0	-0.18	0.18	0.62	0.87	1.12	2.12	0.00		-0.37	-0.25
25.5	-0.37	0.06	0.62	0.31	1.37	2.37	-0.06	0.00	-0.31	-0.31
27.0	-0.25	0.25	0.50	0.37	1.25	2.43	-0.18	0.25	-0.37	-0.31
28.5		0.00	0.37	0.43	1.25	2.68	-0.32	0.37	-0.31	-0.31
30.0	-0.37	0.12	0.37	0.68	1.50	1.12	-0.25	0.25	-0.31	-0.18
31.5	-0.32	0.12	0.31	0.68	1.75	1.31	-0.18	0.25	-0.31	-0.12
33.0	-0.06	0.18	0.12	0.68	1.31	1.06	-0.37	0.43	-0.43	
34.5	-0.37	0.18	0.18	0.68	1.06	1.43	-0.37	0.37	-0.31	-0.31
36.0		0.18	0.18	0.80	1.00	1.81	-0.43	0.25		-0.18
37.5	-0.06	0.00	0.56	0.75	1.37	2.18	-0.25	0.12	-0.31	-0.43
39.0	-0.12		0.43	0.80	0.62		-0.18	0.37	-0.37	
40.5		0.12	0.62	1.06	0.56	2.00	-0.12	0.62	-0.31	-0.50
42.0	0.18	0.18	0.62	1.12	0.18	2.18	-0.06	0.62		-0.37
43.5	-0.37	0.06	0.43	1.06	0.31	2.00		0.75	-0.31	-0.43
45.0	-0.32	0.00	0.43	0.75	0.50	2.25		0.56	-0.25	-0.31
46.5	-0.12	-0.25	0.50	0.62	0.25	2.25	-0.31	0.62	-0.43	-0.43
48.0	0.00	-0.06	0.50	0.50	0.12	2.62	-0.12	0.50	-0.50	
49.5	-0.06	-0.18	0.87	0.62	0.18	2.50	-0.18	0.18	-0.43	-0.18
51.0	0.31	-0.18	0.62	0.37	0.06	2.12	-0.31	0.00	-0.31	-0.43
52.5	0.31	-0.25	0.62	0.30	0.06	2.50	-0.50	-0.12	-0.18	
54.0			0.50	0.30	0.25	2.62	-0.06		-0.43	-0.18
55.5	0.31	-0.25	0.50	0.37	0.12	3.25	-0.31		-0.31	-0.37
57.0	0.00	-0.43	0.50	0.50	-0.12	3.12		0.00	-0.50	-0.43
58.5	-0.12	-0.50	0.75	0.62	0.12		-1.06		-0.50	-0.43
60.0										

LATE-ONSET MYOPES

Time	CH		CW		EW		JL		SB	
	D	N	D	N	D	N	D	N	D	N.
	-0.12	3.30	0.31	4.18	0.18	4.25	0.06	3.75	0.43	3.50
	-0.06	3.37	0.25	2.37	0.18	4.31	0.06	3.80	0.37	3.25
	0.00	3.12	0.18	3.75	0.18	4.50	0.00	4.06	0.18	3.87
	0.12	3.43	0.18	4.12	0.31	4.06	0.00	3.87	0.37	3.31
	0.12	3.25	0.25	3.87	0.25	4.00	0.00	3.80	0.25	3.81
	0.00	3.30	0.18	3.50	0.25	4.18	-0.06	3.75	0.25	3.93
	0.12	3.06	0.18	3.62	0.18	4.30	-0.06	3.75	0.25	3.75
	0.06	3.12	0.00	3.87	0.31	4.18	-0.06	3.87	0.25	3.62
	0.00	3.06	0.12	3.80	0.31	4.18	0.00	3.68	0.43	3.62
	0.25	3.50	0.18	4.00	0.25	4.31	0.00	3.62	0.25	3.62
0.0										
1.5	-0.06	3.18	0.25	3.87	0.25	3.43	-0.25	3.87		
3.0	0.00	0.56	0.56	2.50	0.31	1.18	0.06	3.18	0.43	2.75
4.5	0.00	0.37	1.25	1.43	0.18	0.93	0.06	3.00		2.81
6.0	0.00	0.00	0.18	1.00	0.31	0.93	0.06	0.62	0.25	2.50
7.5	0.00	0.25	0.50	1.37	0.31	0.80	0.06	0.87	0.50	2.50
9.0	0.06	0.25	0.68	0.62	0.25	0.68	-0.12	0.50	0.50	2.50
10.5	0.06	0.12	0.50	0.50	0.31	0.68	-0.18	0.62	0.50	2.56
12.0	0.18	0.31	0.50	0.80	0.25	0.56	-0.12	0.62	0.50	1.68
13.5	0.18	0.18	0.25	0.50	0.31	0.80	-0.06	0.37		1.31
15.0	0.00	0.25	0.75	0.37	0.43	0.87	0.00	0.62	0.50	1.18
16.5		0.18	0.75	0.12	0.37	0.81	-0.06	0.56	0.43	1.25
18.0		0.06	0.50	0.12	0.43	0.93	0.00	0.68	0.37	0.93
19.5		0.18	0.62	0.25	0.56	0.93	0.12	0.68	0.50	0.87
21.0	-0.18	0.25		0.31	0.43	0.75	0.18	0.56	0.68	0.93
22.5	0.12	0.37	0.25	0.25	0.62	0.75	0.06	0.43	0.56	1.25
24.0		0.00	0.62	0.56	0.75	0.68	0.06	0.50	0.50	1.50
25.5		0.06	0.62	0.56	0.93	0.56	0.12	0.50	0.62	1.43
27.0	-0.12	-0.06	0.62	0.43	0.68	0.62	-0.12	0.50		1.37
28.5	0.12	0.06	0.50	0.43	0.75	0.62	-0.06	0.50	0.62	1.12
30.0	0.00	0.00	0.12	0.12	0.81	0.81	0.12	0.56	0.62	1.00
31.5		0.12	0.25	-0.68	0.68	0.75	0.18	0.75	0.68	1.06
33.0		0.06	0.56	-0.06	0.75	0.62	0.06	0.80	0.62	1.37
34.5	0.06	-0.06	0.62	-0.06	0.68	0.62	0.06	0.62	0.25	1.68
36.0	0.12	0.12	0.80	0.06	0.62	0.50	0.00	0.43	0.30	1.50
37.5	0.12	0.06	0.62	-0.12	0.80	0.43		0.37		1.62
39.0	0.00	-0.12	0.50	-0.12	0.80	0.50	0.12	0.43	0.25	1.62
40.5	-0.25	0.12	0.50	-0.12	1.18	0.50	0.06	0.50	0.31	1.31
42.0	-0.06	0.06	0.37	-0.31	0.87		0.12	0.81		1.06
43.5	0.00	0.00	0.50	-0.18	0.56	0.43	-0.18	0.81	0.31	1.12
45.0	-0.06	-0.18	0.37	-0.12	0.68	0.50	0.12	0.68		1.25
46.5	0.06	0.00	0.25		0.56	0.37	0.25	0.62	0.50	1.31
48.0	-0.25	0.06	0.06	-0.18	0.81	0.56	0.06	0.62	0.56	1.43
49.5				-0.12		0.68	0.12	0.68	0.56	1.43
51.0	0.00		-0.12	0.06	0.75	0.68	0.18	0.81		1.81
52.5	-0.32	-0.06	0.06	0.00	0.68	0.62	0.25	0.68	0.62	1.93
54.0	0.06	0.12	0.37	-0.06	0.56	0.75	0.43	1.00	0.68	
55.5	0.06	-0.12	-0.12	0.12	0.62	0.62	0.25	1.00	0.68	1.31
57.0	0.00	0.00	-0.31	0.31	0.80	0.75	0.25	0.87	0.68	
58.5	0.12	0.00	-0.43	0.31	0.87	0.75	0.18	0.68	0.68	1.31
60.0	-0.32	-0.06	-0.50	0.50	0.81	0.87	0.12	0.80		1.25

11e)Pre-betaxolol accommodative regression (mean spherer) following distance (D) and near (N) sustained viewing.

EMMETROPES

Time	FF		HC		JE		RD		KP		OW	
	D	N	D	N	D	N	D	N	D	N	D	N
	0.18	4.56	-0.18	3.50	-0.12	4.37	-0.06	3.62	0.62	4.37	0.18	3.18
	0.25	5.00	-0.12	3.62	-0.12	4.56	-0.31	4.12	0.31	3.25	0.30	3.12
	0.37	4.31	0.06	2.87	0.00	5.00	-0.31	4.50	0.25	4.68	0.37	4.00
	0.37	4.68	0.06	3.06	-0.06	4.25	-0.31	4.31	0.25	4.43	0.25	3.43
	0.43	3.87	0.12	3.18	0.00	4.75	-0.31	4.31	0.25	4.87	0.25	3.68
	0.37	4.43	0.06	3.18	0.06	5.30	-0.06	4.25	0.25	4.37	0.25	3.50
	0.37	4.06	-0.06	3.31	0.00	4.56	-0.18	3.93	0.25	5.00	0.18	3.50
	0.37	3.75	0.18	3.25	0.06	5.00	-0.31	2.81	0.37	4.93	0.18	3.12
	0.37	4.56	0.06	3.06	-0.12	4.62	-0.31	3.37	0.31	4.18	0.25	3.75
	0.12	4.56	0.06	2.75	0.00	4.81	-0.31	3.87	0.25	4.50	0.12	3.43
0.0												
1.5	0.56	3.50	0.25	2.75		3.75	0.25	3.50	0.37	3.93	0.25	
3.0	1.25	4.00	0.31	1.62	0.37	1.25	0.43	1.93	0.50	3.12	0.18	2.87
4.5	1.37	3.12	0.25	1.25	0.18	1.37	0.56	0.87	0.80	3.25	0.25	
6.0	1.75	2.62	0.18	1.87	0.06	1.12	0.62	0.75	1.18	2.56	0.25	2.06
7.5	1.75	2.62	0.37	1.75	0.12	1.12	1.43	1.75	1.12		0.37	1.81
9.0	1.75	2.56	1.06	1.06	0.30	1.06	1.00	1.12	1.12	2.18	0.37	2.25
10.5	1.80	2.37	0.93	1.12	0.06	1.18	1.00	0.81	1.12	2.37	0.37	1.50
12.0	2.12	1.75	0.93	0.68	0.06	1.12	1.12	1.00	1.12	2.31	0.31	0.87
13.5	2.06	1.87	0.56	1.12	0.18	1.25	0.50	0.62	1.25	2.75	0.37	1.18
15.0	2.12	2.06	0.50	0.68	0.43	1.18	0.81	0.80	1.68	2.50	0.43	1.43
16.5	2.00	2.12	0.50	0.43	0.87	0.80	0.87	1.50	1.43	2.37	1.00	1.43
18.0	1.75	1.75	0.00	0.62	0.62	1.06	0.75	2.06	1.43	2.25	0.81	0.93
19.5	1.75	0.56	-0.12	0.25	0.50	0.80		1.12	1.18	1.93	0.75	0.93
21.0	1.80	0.50	0.06	0.37	0.50	0.62	1.06	1.37	1.12	1.87	0.30	0.93
22.5	1.18	0.56	0.43	-0.06	0.31	0.50		2.25				1.12
24.0	1.12		0.12	-0.25	0.50	0.50	2.12	2.25	1.87		0.56	1.50
25.5	0.68	0.37	0.06	-0.12	0.56	0.37	1.06	0.80	1.25	1.87	0.37	0.87
27.0	0.75	0.12	0.68	0.06	0.43	0.37	1.06		1.30	1.80	0.68	0.62
28.5	0.80	0.12	0.68	-0.06	0.50	0.43	0.75	1.00		1.56	0.62	0.80
30.0	0.50	0.25	0.43		0.37	0.18	1.25	1.31	1.18	1.68	0.56	0.80
31.5	1.06	0.25	0.87	0.18	0.56	0.50	0.81	5.37	1.87	1.30	0.80	0.93
33.0	0.80		0.75		0.62	0.43	0.75	5.25		1.18	0.80	1.12
34.5	0.62	0.43	0.18		0.68	0.50	1.12	0.87	2.06	1.31	0.87	0.75
36.0	0.50	0.12	0.31	0.25	0.75	0.87		1.00	1.80	1.18	0.87	0.81
37.5	0.56	0.25	0.37	0.37	0.62		0.93		1.75	1.25	1.12	0.68
39.0	0.62	0.12	0.25	0.50	0.62	1.00	1.06	1.06	1.80	1.12	0.50	0.50
40.5	0.68	0.12	0.50	0.25	0.56	0.62	0.80	1.75	2.12		0.87	0.62
42.0	0.62	0.12	0.62	0.31	0.30	0.50	0.81	2.68	1.75	1.50	0.87	0.43
43.5	0.80	0.25	0.12	0.31	0.50	0.06		1.00	1.56	1.18	0.56	0.43
45.0	1.43	0.12	0.00	0.25	0.12		0.75	0.87	1.56	1.12	0.62	0.43
46.5	1.37		0.12	0.62		-0.06	1.06	1.50	1.56		0.87	0.56
48.0	1.56	0.25	0.06	0.43	0.12	0.00	1.43	0.75	1.68	1.06	1.06	0.75
49.5	1.62		0.06	-0.06	0.50	-0.12	0.87	1.25	1.93	1.18	0.80	0.81
51.0	1.75	0.25	0.12	-0.12	0.62	-0.25		0.93		0.93	0.30	0.50
52.5	1.00	0.18	0.06	-0.37	0.43	-0.25	0.75	0.93	2.18	1.18	0.43	
54.0	1.50	0.25	0.06	-0.37	0.50		1.06	0.68	2.50	1.00	0.43	0.43
55.5	1.56	0.18	-0.06	-0.37	0.62	0.30	1.75		2.06	0.87	0.06	0.37
57.0	1.75	0.37	-0.18	-0.37	0.56	0.25	2.18	0.56		0.62	0.25	0.50
58.5	1.93	-0.25	-0.37	0.37	0.50	14.93		0.62	1.68	0.68	0.25	0.80
60.0	1.75	1.87	-0.18	-0.43	0.43	0.43	4.68	0.12	1.75		0.50	0.68

EARLY-ONSET MYOPES

Time	AB		JB		JB		JG		MD	
	D	N	D	N	D	N	D	N	D	N.
	-0.32	3.30	0.56	4.25	0.12	5.12	-0.50	3.00	0.06	3.25
	-0.12	3.30	0.37	4.50	0.06	5.00	-0.25	3.18	0.37	3.50
	-0.06	3.43	0.50	4.18	-0.18	4.75	-0.18	2.75	0.18	3.43
	-0.18	3.50	0.43	4.50	-0.12	5.06	0.06	3.00	0.00	3.37
	-0.06	3.00	0.43	4.25	0.12	5.12	-0.18	3.18	0.25	2.93
	-0.06	3.12	0.43	4.30	0.06	5.06	0.37	3.06	0.31	2.93
	-0.06	3.30	0.43	4.50	0.00	4.87	0.00	3.31	0.12	2.80
	0.00	3.06	0.50	4.37	0.06	6.18	0.32	3.00	0.06	2.93
	0.00	3.43	0.37	4.30	0.06	4.93	0.87	3.06	0.12	2.62
	0.12	3.06	0.50	4.25	0.12	5.31	0.00	3.18	0.12	3.00
0.0										
1.5	-0.37	2.30	0.37	3.75	0.06	4.00	-0.43	1.43	-0.12	3.37
3.0	-0.37		0.37	3.18	0.37	4.93	-0.25	0.25	-0.25	
4.5	-0.37		0.31	3.18	0.50	4.80	-0.37	0.00	-0.18	0.87
6.0	-0.37	0.75	0.37	2.62	0.50	4.00	-0.37	-0.06	-0.37	-0.06
7.5	-0.50			2.12	0.43	3.68	-0.50	0.00	-0.25	-0.12
9.0	-0.37	0.43	0.50	1.68	0.43	3.43	-0.56	0.18	-0.18	-0.32
10.5	-0.62		0.56	1.31	0.50	3.68	-0.56	0.43	0.06	-0.32
12.0	-0.50	0.25	0.68	1.18	0.68	3.06	-0.25	0.31	-0.62	-0.25
13.5	-0.37	0.12	0.43	0.87	0.62	2.68	-0.56	0.37	-0.25	-0.12
15.0	-0.50	0.12	0.43	0.75	0.75	2.37	-0.68	0.37	-0.37	-0.06
16.5	-0.25		0.43	1.00	0.87	2.18	-0.68	0.25	-0.06	
18.0	-0.37	0.12	0.43	1.12	0.93	1.68	-0.37	-0.06	-0.31	
19.5	-0.43	-0.25	0.37	1.18	1.18	1.62	-0.31	0.12	-0.25	-0.12
21.0	-0.50	-0.25	0.68	1.30	1.25	0.68	-0.18	0.00		0.06
22.5	-0.37	-0.25	0.56	1.25	1.06	0.50	-0.25	0.18	-0.25	-0.06
24.0		-0.50	0.62	1.37	1.50		-0.12		-0.56	-0.12
25.5	-0.50	-0.50	0.43	1.37	1.37	0.80		0.31	-0.31	-0.06
27.0	-0.50	-0.37	0.62	1.37	1.80	1.31		0.31	-0.18	-0.18
28.5	-0.75		0.56	1.18	1.62		0.06	0.75	0.06	-0.37
30.0	-0.50		0.43	1.12	0.62	1.00	-0.25	0.56	-0.31	
31.5	-0.62	-0.43		1.37	0.25	1.25	-0.12	0.62	-0.31	-0.18
33.0		-0.50	0.62	1.25	0.37	0.56	0.00		-0.43	-0.32
34.5	-0.62	-0.37	0.68	1.37		0.50	-0.31	0.68	-0.31	-0.32
36.0	-0.50	-0.50	0.62	1.18	0.68	0.43	-0.12		-0.25	-0.18
37.5		-0.37	0.68	1.31	0.68	0.43	-0.12		-0.37	-0.25
39.0	-0.37	-0.50	0.81	1.18	0.75	0.37	-0.43		-0.43	-0.18
40.5	-0.37	-0.62	0.81	1.31	1.31	0.62	0.12	0.31	-0.31	-0.56
42.0	-0.50	-0.56	0.81	1.06	1.18	0.37		0.12	-0.56	-0.37
43.5	-0.37	-0.62	0.87	1.43	1.12	0.37		0.06	-0.62	
45.0	-0.37	-0.50	0.81	1.68	1.37	0.37		-0.12	-0.37	
46.5	-0.12	-0.56	0.75	1.75	1.18	0.18		-0.12	-0.43	-0.12
48.0	-0.25	-0.56	1.00	1.75	0.87			-0.06	-0.50	
49.5	-0.25	-0.56	0.62	1.68	1.25	2.25	0.00	-0.06	-0.32	0.00
51.0		-0.50	0.75	1.43	1.75	2.06	-0.12	0.12		
52.5	-0.25	-0.50	0.87	1.50	2.00	2.37	-0.25	0.00	0.25	0.00
54.0	-0.50		0.93	1.31	2.56	2.12	-0.18	0.00	-0.25	0.25
55.5	-0.37	-0.25	0.87	1.12	2.18	1.56	-0.25	0.00		
57.0	-0.37	-0.32	0.87	1.87	2.12	2.12	-0.32	-0.06	-0.37	0.00
58.5	-0.18		0.75	1.56	1.37	2.25	-0.25	-0.12	-0.31	0.25
60.0										

LATE-ONSET MYOPES

Time	CH		CW		EW		JL		SB	
	D	N	D	N	D	N	D	N	D	N.
	-0.12	3.30	0.31	4.18	0.18	4.25	0.06	3.75	0.43	3.50
	-0.06	3.37	0.25	2.37	0.18	4.31	0.06	3.80	0.37	3.25
	0.00	3.12	0.18	3.75	0.18	4.50	0.00	4.06	0.18	3.87
	0.12	3.43	0.18	4.12	0.31	4.06	0.00	3.87	0.37	3.31
	0.12	3.25	0.25	3.87	0.25	4.00	0.00	3.80	0.25	3.81
	0.00	3.30	0.18	3.50	0.25	4.18	-0.06	3.75	0.25	3.93
	0.12	3.06	0.18	3.62	0.18	4.30	-0.06	3.75	0.25	3.75
	0.06	3.12	0.00	3.87	0.31	4.18	-0.06	3.87	0.25	3.62
	0.00	3.06	0.12	3.80	0.31	4.18	0.00	3.68	0.43	3.62
	0.25	3.50	0.18	4.00	0.25	4.31	0.00	3.62	0.25	3.62
0.0										
1.5	-0.06	3.18	0.25	3.87	0.25	3.43	-0.25	3.87		
3.0	0.00	0.56	0.56	2.50	0.31	1.18	0.06	3.18	0.43	2.75
4.5	0.00	0.37	1.25	1.43	0.18	0.93	0.06	3.00		2.81
6.0	0.00	0.00	0.18	1.00	0.31	0.93	0.06	0.62	0.25	2.50
7.5	0.00	0.25	0.50	1.37	0.31	0.80	0.06	0.87	0.50	2.50
9.0	0.06	0.25	0.68	0.62	0.25	0.68	-0.12	0.50	0.50	2.50
10.5	0.06	0.12	0.50	0.50	0.31	0.68	-0.18	0.62	0.50	2.56
12.0	0.18	0.31	0.50	0.80	0.25	0.56	-0.12	0.62	0.50	1.68
13.5	0.18	0.18	0.25	0.50	0.31	0.80	-0.06	0.37		1.31
15.0	0.00	0.25	0.75	0.37	0.43	0.87	0.00	0.62	0.50	1.18
16.5		0.18	0.75	0.12	0.37	0.81	-0.06	0.56	0.43	1.25
18.0		0.06	0.50	0.12	0.43	0.93	0.00	0.68	0.37	0.93
19.5		0.18	0.62	0.25	0.56	0.93	0.12	0.68	0.50	0.87
21.0	-0.18	0.25		0.31	0.43	0.75	0.18	0.56	0.68	0.93
22.5	0.12	0.37	0.25	0.25	0.62	0.75	0.06	0.43	0.56	1.25
24.0		0.00	0.62	0.56	0.75	0.68	0.06	0.50	0.50	1.50
25.5		0.06	0.62	0.56	0.93	0.56	0.12	0.50	0.62	1.43
27.0	-0.12	-0.06	0.62	0.43	0.68	0.62	-0.12	0.50		1.37
28.5	0.12	0.06	0.50	0.43	0.75	0.62	-0.06	0.50	0.62	1.12
30.0	0.00	0.00	0.12	0.12	0.81	0.81	0.12	0.56	0.62	1.00
31.5		0.12	0.25	-0.68	0.68	0.75	0.18	0.75	0.68	1.06
33.0		0.06	0.56	-0.06	0.75	0.62	0.06	0.80	0.62	1.37
34.5	0.06	-0.06	0.62	-0.06	0.68	0.62	0.06	0.62	0.25	1.68
36.0	0.12	0.12	0.80	0.06	0.62	0.50	0.00	0.43	0.30	1.50
37.5	0.12	0.06	0.62	-0.12	0.80	0.43		0.37		1.62
39.0	0.00	-0.12	0.50	-0.12	0.80	0.50	0.12	0.43	0.25	1.62
40.5	-0.25	0.12	0.50	-0.12	1.18	0.50	0.06	0.50	0.31	1.31
42.0	-0.06	0.06	0.37	-0.31	0.87		0.12	0.81		1.06
43.5	0.00	0.00	0.50	-0.18	0.56	0.43	-0.18	0.81	0.31	1.12
45.0	-0.06	-0.18	0.37	-0.12	0.68	0.50	0.12	0.68		1.25
46.5	0.06	0.00	0.25		0.56	0.37	0.25	0.62	0.50	1.31
48.0	-0.25	0.06	0.06	-0.18	0.81	0.56	0.06	0.62	0.56	1.43
49.5				-0.12		0.68	0.12	0.68	0.56	1.43
51.0	0.00		-0.12	0.06	0.75	0.68	0.18	0.81		1.81
52.5	-0.32	-0.06	0.06	0.00	0.68	0.62	0.25	0.68	0.62	1.93
54.0	0.06	0.12	0.37	-0.06	0.56	0.75	0.43	1.00	0.68	
55.5	0.06	-0.12	-0.12	0.12	0.62	0.62	0.25	1.00	0.68	1.31
57.0	0.00	0.00	-0.31	0.31	0.80	0.75	0.25	0.87	0.68	
58.5	0.12	0.00	-0.43	0.31	0.87	0.75	0.18	0.68	0.68	1.31
60.0	-0.32	-0.06	-0.50	0.50	0.81	0.87	0.12	0.80		1.25

11f) Post betaxolol accommodative regression (mean sphere) following distance (D) and near (N) sustained viewing.

EMMETROPES

Time	FF		HC		JE		RD		KP		OW	
	D	N	D	N	D	N	D	N	D	N	D	N
	0.62	4.62	-0.06	3.00	0.12	4.00	-0.06	3.87	0.43	4.12	0.25	3.06
	0.50	4.50	-0.18	3.75	0.25	4.30	0.00	3.43	0.50	3.87	0.25	3.37
	0.62	4.25	-0.06	3.50	0.18	4.31	0.12	3.50	0.56	3.87	0.18	3.37
	0.56	4.00	-0.06	3.62	0.18	4.06	0.00	3.68	0.56	4.18	0.25	3.43
	0.62	4.62	-0.18	3.87	0.25	4.50	0.00	3.56	0.56	3.93	0.25	3.43
	0.37	4.43	-0.06	3.37	0.25	4.25	-0.06	3.56	0.50	4.00	0.18	3.25
	0.43	4.62	0.12	3.93	0.25	3.81	0.00	3.56	0.50	4.56	0.25	3.31
	0.50	4.43	-0.18	3.62	0.25	4.12	-0.12	3.75	0.37	4.12	0.18	3.43
	0.50	4.25	-0.18	3.56	0.25	4.50	0.00	3.25	0.43	4.18	0.18	3.12
	0.37	4.50	0.00	3.75	0.37	4.37	0.18	3.93	0.43	3.62	0.18	3.56
0.0												
1.5	0.56	3.80	0.06	0.62	0.12		0.12	2.81	0.43	3.68	0.12	3.68
3.0	1.12	3.43	-0.06		0.30	1.50	0.12	2.06	0.62	2.43	0.12	2.81
4.5	1.43	2.87	-0.18	0.68	0.43	1.30	0.25	1.93	0.68	1.87	0.18	1.62
6.0	1.62		-0.06	0.25	0.25	1.12	0.25	1.81	0.75	2.18		0.87
7.5	1.62		-0.18	0.93	0.06	1.06	0.12		0.80	1.93	0.18	1.06
9.0	1.68	2.12	-0.12	1.56	0.56	0.93	0.18	1.00	1.00		0.25	1.00
10.5	1.68	2.00	-0.12	0.75	0.25	1.06	0.31	1.00	1.00	1.93	0.18	0.68
12.0	1.68		0.30	0.25	0.37	1.12	0.06	0.93	1.12			0.75
13.5	1.68	1.87	0.30	0.18	0.25	0.93	0.18	1.12	1.25	1.62	0.30	0.81
15.0	1.12		0.18	0.06	0.75	1.06	0.37	0.75	1.43	1.43	0.25	0.75
16.5	1.12		-0.12	0.06	1.06	1.12	0.31	0.81	1.62	1.25	0.30	0.75
18.0	1.62		-0.06	-0.06	0.80	1.37	0.31	1.00		1.56	0.30	0.62
19.5	1.75	1.87	-0.06	0.00	0.87	1.25	0.56	1.37	1.30	1.31	0.87	0.56
21.0	1.37	1.75	0.00	-0.18	0.87	1.50	0.43	1.25	1.50	1.06	0.18	0.56
22.5	1.25	1.80	-0.25	-0.18	0.56	1.30	0.62	1.00	1.68		0.18	0.62
24.0	1.25	2.06	-0.31	-0.12	0.87	0.93	0.62	1.18	1.75	2.12	0.18	0.56
25.5	1.37	2.06	-0.37	-0.06	0.31	0.43	0.62	0.87	1.68	1.75	0.25	0.75
27.0	1.18	2.00	-0.25	-0.12	0.43	0.43	0.75	1.12	1.68	1.81	0.25	0.68
28.5	1.12	2.00	-0.31	-0.37	0.75	0.37	1.00	2.00	1.56		0.25	0.75
30.0	1.12		-0.31	-0.31	0.75	0.62	1.00	1.18	1.56	1.37	0.18	0.62
31.5	1.31	1.80	-0.18	-0.18	0.75	0.87	1.12	1.93	1.18	1.12	0.18	0.50
33.0			-0.18	-0.12	0.62	1.12	1.30	2.30	1.25	0.93	0.18	0.50
34.5	1.12		-0.43	-0.12	0.56	1.18	1.80	1.93	1.25	0.80	0.25	0.43
36.0	1.37	1.75	-0.50	-0.06	0.68	1.18	0.75	0.62	1.12	0.87	0.12	0.37
37.5			-0.31	-0.12	0.50	1.30	0.62	1.31	1.00	0.68	0.18	0.75
39.0	1.00	1.80	-0.37	-0.18	0.56	1.00	0.75	2.50	0.93	0.75	0.18	0.87
40.5		1.87	-0.31	-0.18	0.50	1.81	0.80	2.68	1.18	0.68	0.12	0.62
42.0	0.75	2.12	-0.50	-0.12	0.81	1.87	1.00	2.56	1.18	0.75	0.25	0.43
43.5	0.68	1.75	-0.37		0.56	2.25	0.87	0.81			0.37	0.43
45.0	0.87	1.56	-0.18	-0.12	0.50	2.12	0.87	1.12	1.30	0.87		0.37
46.5	0.87		-0.37	-0.25	0.93	0.93	0.87	1.56	1.25	0.93	0.18	0.25
48.0		1.30	-0.37	-0.18	0.87	1.06	1.00	0.80	1.37	0.75	0.30	0.37
49.5	0.87	1.75	-0.50	-0.25	0.81	1.00	1.30	1.31	1.25	0.68	0.37	0.50
51.0	1.37	1.80	-0.37	-0.25	1.00	1.00	1.18	1.50	0.93	0.62	0.30	0.50
52.5	1.30	1.87	-0.43	-0.31	0.93	1.00	1.00	1.50	1.00		0.25	0.56
54.0	1.37	3.00	-0.25	-0.31	1.12	1.37	0.93	1.00		0.43		0.50
55.5	1.56		-0.37	-0.25	1.12	0.56	0.93	0.87	1.12	0.43	1.18	0.43
57.0	1.68	1.87	-0.25	-0.31	1.00	0.50	1.12	0.75	0.81	0.43	0.68	0.37
58.5	1.56	1.87	-0.18	-0.12	1.31	1.12	0.75	0.80	1.18	0.50	0.43	0.37
60.0	1.68	2.06	-0.43	-0.43	0.93	0.87	0.93	1.18	1.18	0.56	0.31	0.37

EARLY-ONSET MYOPES

Time	AB		JB		JB		JG		MD	
	D	N	D	N	D	N	D	N	D	N.
	0.00	3.37	0.37	4.50	0.06	5.12	-0.43	3.00	0.18	3.68
	-0.12	3.12	0.43	4.50	0.12	5.12	0.25	2.93	0.00	3.37
	-0.06	3.62	0.50	4.56	0.18	4.75	-0.06	2.62	0.06	4.06
	0.06	3.50	0.43	4.43	0.31	4.75	0.25	3.25	0.00	3.75
	-0.25	3.56	0.31	4.50	0.00	5.18	0.06	3.37	0.18	3.06
	-0.06	3.56	0.37	4.50	0.06	4.68	-0.12	3.37	0.00	3.87
	-0.06	3.37	0.31	4.31	0.12	4.93	0.00	2.87	-0.18	3.37
	0.00	3.50	0.31	4.56	0.12	4.50	-0.06	3.25	0.00	3.43
	-0.12	3.00	0.31	4.62	0.18	4.68	0.18	3.00	0.06	3.31
	0.00	3.30	0.25	4.56	0.00	5.00	-0.18	3.06	0.12	2.68
0.0										
1.5	-0.12	2.37	0.56	3.93			-0.50	1.50	-0.06	2.87
3.0	-0.31	0.93	0.50	2.18		3.12	-0.06	-0.12	-0.18	-0.06
4.5	0.00	0.87	0.43	2.25	0.25	1.62	-0.18	0.12		0.06
6.0	-0.56	0.37	0.56	1.93	0.37	1.56	-0.31	-0.12	-0.12	
7.5	-0.43	0.00	0.50	1.87	0.62	1.12	-0.25		-0.37	-0.25
9.0	-0.50	0.12	0.50	1.87	0.62	1.12		-0.12	-0.62	-0.37
10.5			0.43	1.80	1.00	1.25	0.00	-0.25		-0.12
12.0	-0.56	0.00	0.30	1.62	1.00	1.25	0.12	-0.06		-0.43
13.5	-0.50	-0.12	0.37	1.56	0.87	2.30		-0.75	-0.37	-0.25
15.0	-0.43		0.43	1.81				-0.31	-0.43	-0.25
16.5	-0.32	0.00	0.37	1.80		2.50	-0.12	-0.25	-0.50	-0.37
18.0	-0.43	-0.25	0.43	1.56		2.31		-0.12	-0.68	-0.43
19.5	-0.37	-0.12	0.50	1.43		2.87	0.00	-0.12	-0.50	-0.37
21.0	-0.50	-0.25	0.37	1.18	1.00	2.43	0.00	-0.12	-0.50	-0.18
22.5	-0.37	-0.37	0.56	1.25	0.56	2.30	-0.06	-0.06	-0.43	-0.56
24.0	-0.50	-0.37	0.43	0.93	1.43	2.12	-0.06	0.00	-0.56	
25.5	-0.50	-0.43	0.50	0.87	2.12		-0.25	0.00	-0.87	-0.62
27.0	-0.56	-0.12	0.43	0.87		2.30	-0.06	-0.06		-0.75
28.5	-0.50	-0.25	0.30	0.75		2.12	-0.12	0.06	-0.12	-0.50
30.0		-0.25	0.56	0.81	2.30	2.93	-0.25	0.00		-0.87
31.5		-0.50	0.56	0.75	1.68	3.37		-0.06		-1.06
33.0	-0.62	-0.32	0.37	0.81	1.30		-0.06	-0.06	-0.43	-0.50
34.5	-0.50	-0.50		1.06	1.87	2.18	-0.12	-0.12	-0.43	-0.93
36.0	-0.37	-0.37	0.50	1.00	2.12	2.06	-0.18	-0.12		
37.5	-0.43	-0.06	0.30	0.68	2.43	1.93	-0.12	-0.12	-0.75	-0.87
39.0	-0.43	-0.50			2.12	1.50	-0.18	-0.06	-0.43	-0.56
40.5	-0.43	-0.32	0.62	0.75	2.18	1.25	-0.06		-0.56	
42.0	-0.31	-0.37	0.62	0.81	2.43	1.12	0.00	0.06		-0.25
43.5	-0.43	-0.12	0.50	0.75	2.62	1.87	0.12			-0.93
45.0	-0.50	-0.31	0.68	0.68	2.75		-0.43			-0.75
46.5		-0.31	0.62	0.56	2.00	2.62	-0.12	-0.12	-0.68	
48.0	-0.50	-0.31	0.75	0.75	0.87	2.68	-0.25		-0.18	-1.00
49.5	-0.50	-0.12	0.56	0.75		2.50	-0.31	0.00		-0.37
51.0	-0.43	-0.18	0.87	0.80	0.75	2.25	-0.12	0.06		-1.06
52.5	-0.50	-0.25	0.68	0.68	0.50	1.87	-0.12	-0.06		-0.68
54.0	-0.50	0.06	0.75	0.43	0.37	0.93	-0.12	0.00		-0.68
55.5	-0.32	-0.25	0.68	0.62		1.12	0.00	-0.18	-0.75	-0.43
57.0	-0.32	-0.25	0.75	0.50	0.18	1.00	-0.18	-0.12	-0.50	-0.68
58.5	-0.43	-0.18	0.56	0.75	1.50	1.30	-0.18	-0.12	-0.68	-0.56
60.0	-0.32	-0.25	0.50	0.62	0.75	1.00	-0.18	-0.12	-0.75	-0.50

LATE-ONSET MYOPES

Time	CH		CW		EW		JL		SB	
	D	N	D	N	D	N	D	N	D	N.
	0.06	3.37	-0.25	3.50	0.43	4.75	0.18	4.12	0.06	3.30
	0.12	3.18	0.00	3.87	0.56	4.62	0.06	4.00	0.00	3.06
	0.12	3.31	0.12	3.43	0.56	4.80	0.12	3.87	0.31	3.43
	0.06	3.43	-0.06	3.30	0.50	4.93	0.31	3.93	0.31	3.62
	0.00	3.37	0.00	3.56	0.43	4.62	0.06	3.93	0.12	3.68
	0.18	3.37	-0.06	3.93	0.43	4.75	0.12	4.00	0.18	3.56
	-0.06	3.31	-0.06	3.37	0.50	4.75	0.25	4.06	0.25	3.56
	-0.12	3.31	0.06	3.81	0.43	4.87	0.06	4.00	0.25	3.25
	0.00	3.50	0.31	3.37	0.50	4.87	0.12	4.00	0.37	3.56
	0.12	3.31	0.00	3.87	0.62	4.93	0.12	4.12	0.31	3.56
0.0										
1.5	0.06	3.43	0.06	2.93	0.37	2.62	0.00	3.87	0.31	3.25
3.0	0.18	1.37	0.06	1.62	0.31	1.37	0.25	3.56	0.43	2.68
4.5	0.12		0.43	1.37	0.31	1.81	0.25	1.50	0.56	2.68
6.0	0.06	0.12	0.43	0.87	0.31	1.93	0.25	1.43		2.00
7.5	0.12	0.12	0.18	0.62	0.31	1.25		1.56	0.56	2.06
9.0	0.12	0.25	0.00	0.62	0.37	0.93	0.37	1.80		1.87
10.5	0.00	0.18	0.06	0.06	0.30	1.00	0.25	1.80	0.50	1.81
12.0	0.00	0.18	0.25		0.37	1.12	0.37	1.62	0.62	2.31
13.5	0.00	0.18	0.25	0.12	0.37	1.25	0.31	1.56	0.56	2.25
15.0	0.06	0.12	0.37		0.37	0.93	0.43	1.62	0.31	1.81
16.5	-0.12	0.00	0.18	0.12	0.43	1.00		1.50	0.12	1.87
18.0	0.12	0.00	0.18	0.00	0.56	0.93	0.30	1.62	0.31	2.00
19.5	0.12	0.00		-0.06	1.00	1.00	0.56	1.62	0.31	1.93
21.0	0.00	0.12		0.18	0.62	1.12	0.31	1.56	0.31	1.75
22.5	0.00	0.25		0.12	0.56	1.25	0.50	2.00	0.31	
24.0	-0.06	0.12		0.30	0.50	1.12	0.50	1.37	0.31	1.50
25.5	-0.12	0.25			0.62	1.43	0.06	0.87	0.25	1.75
27.0	-0.12	0.12		0.25	0.62	1.06	0.12	1.18	0.18	1.75
28.5	-0.12	0.12	0.18	0.37	0.87	0.75	0.06	1.12	0.06	1.56
30.0	-0.18	0.25	0.12	0.43	0.87	0.75	0.18	1.00	0.18	0.93
31.5	-0.25		0.30	0.25	0.87	1.00	0.25	0.87	0.12	1.06
33.0		0.06	0.18		0.75	1.06	0.18			1.00
34.5	-0.12	0.12	0.25	0.37	0.80	0.81	0.25	1.25	0.25	
36.0	-0.18	0.00	0.30	0.25	1.00	0.75	0.31	1.18		1.75
37.5	-0.25	0.00	0.12		0.93	0.80	0.18	1.25	0.37	1.43
39.0	0.00	-0.06		-0.12	0.80	1.12	0.25	1.30		0.87
40.5	0.00	0.00	0.00	0.25	0.93	0.87	0.25	1.37		1.43
42.0		0.12	0.12	0.30	0.93	0.68	0.37	1.12	0.50	1.37
43.5	-0.06	0.06	0.25	0.37	1.00	0.87	0.12	1.25		1.25
45.0	0.00	0.06	0.37	0.31	0.87	0.75	0.31	1.25	0.37	1.31
46.5	0.00	0.00	0.25	0.30	0.93	0.80	0.25	1.12		1.30
48.0	-0.06		0.25	0.50	0.87		0.50	1.25	0.75	1.50
49.5	0.18	0.18		0.37	1.00	0.75	0.25	1.12	0.93	1.43
51.0	0.12	0.18	0.30	0.37	0.87	0.56	0.50	1.12	0.93	
52.5	0.06	0.06	0.25	0.30	0.75	0.80	0.25	1.12	0.93	1.18
54.0	0.00	0.31	0.12	0.18	0.68	0.68	0.37	1.68	1.56	1.50
55.5		0.25	0.18	0.12	0.80	0.68	0.25		1.12	
57.0	0.12	0.12	0.12	0.25	0.75	1.06	0.30	1.50		
58.5	0.06	0.12	0.25		0.68	0.87	0.37	1.56	1.00	
60.0	0.06	0.25	0.12	0.00	0.62	1.18	0.50	1.50	0.93	1.75

APPENDIX 12

SUPPORTING PUBLICATIONS

12a) Refereed published abstracts from conference proceedings

Edwards NR, Winn B and Gilmartin B (1991) The influence of non-optical factors on steady-state accommodation. Ophthal. Physiol Opt. 11: 281

Edwards NR, Winn B and Gilmartin B (1991) The influence of mental effort on measures of accommodation in emmetropia and myopia. Ophthal. Physiol Opt. 11: 400-401

Edwards NR, Winn B and Gilmartin B (1992) Open-loop accommodation responses in emmetropia and myopia. Optom. Vis. Sci. (Suppl) 69: 234-235

Edwards NR and Gilmartin B (1993) Prism adaptation in emmetropia and myopia. Optom. Vis. Sci. (Suppl) 70 (12S): 42

Supporting publications

Winn B, Gilmartin B, Mortimer LC and Edwards NR (1991) The effect of mental effort on open- and closed-loop accommodation. Ophthal. Physiol. Opt. 11: 335-339.

Gilmartin B and Winfield NR (1994) The effect of topical β-adrenoceptor antagonists on accommodation in emmetropia and myopia. Vis. Res. (in press)

TEXT BOUND INTO

THE SPINE

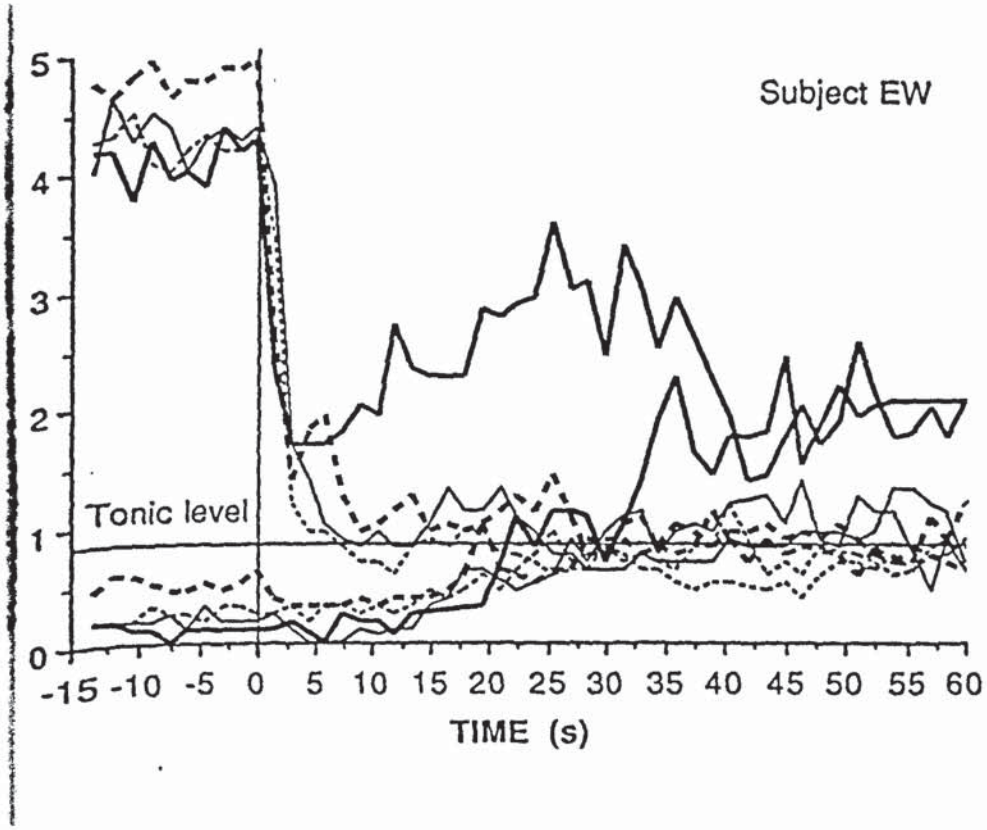
Subject EW
5
4
3
2
1
0
Tonic level
-15 -10 -5 0 5 10 15 20 25 30 35 40 45 50 55 60
TIME (s)

Fig 1

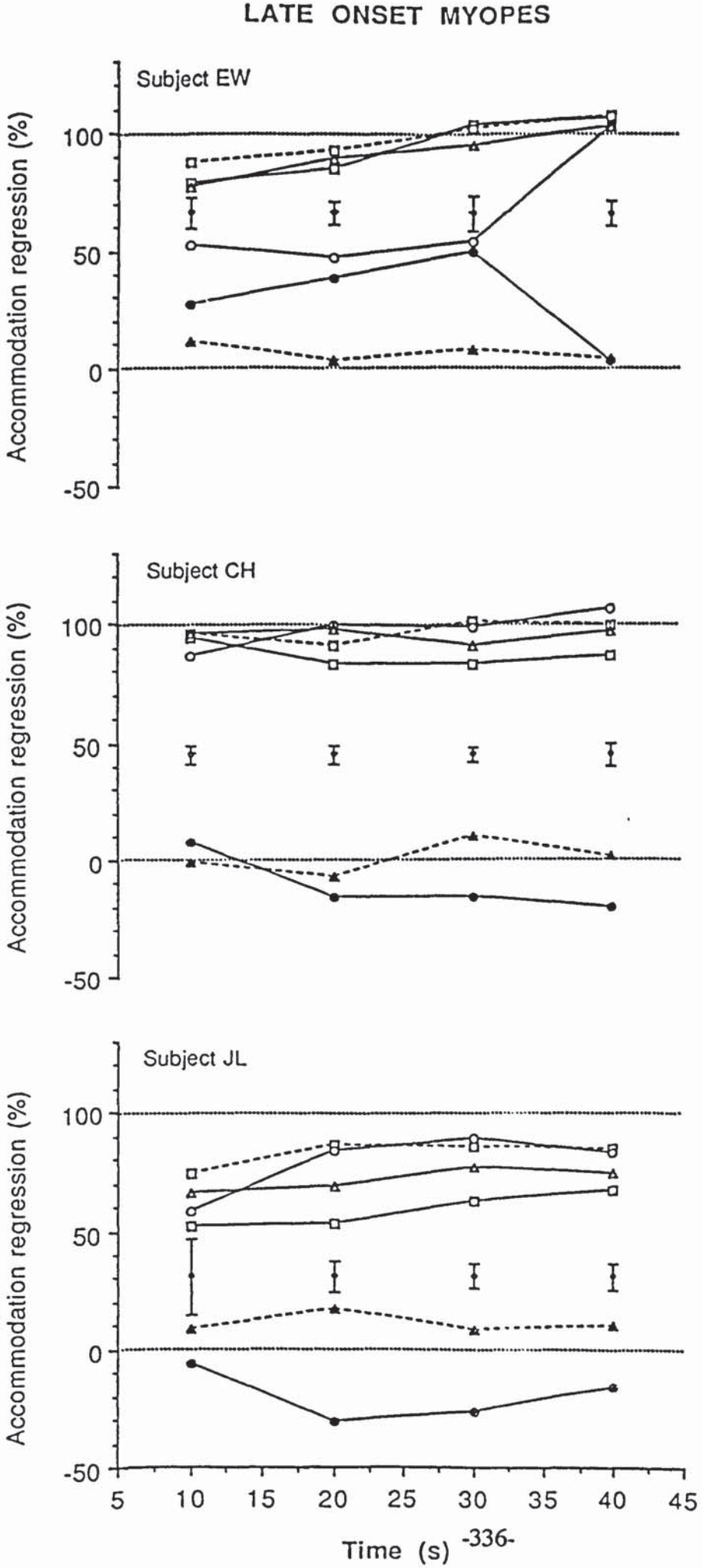
LATE ONSET MYOPES
Subject EW
Subject CH
Subject JL
Accommodation regression (%)
100
50
0
-50
5
10
15
20
25
30
35
40
45
Time (s)

Fig 2

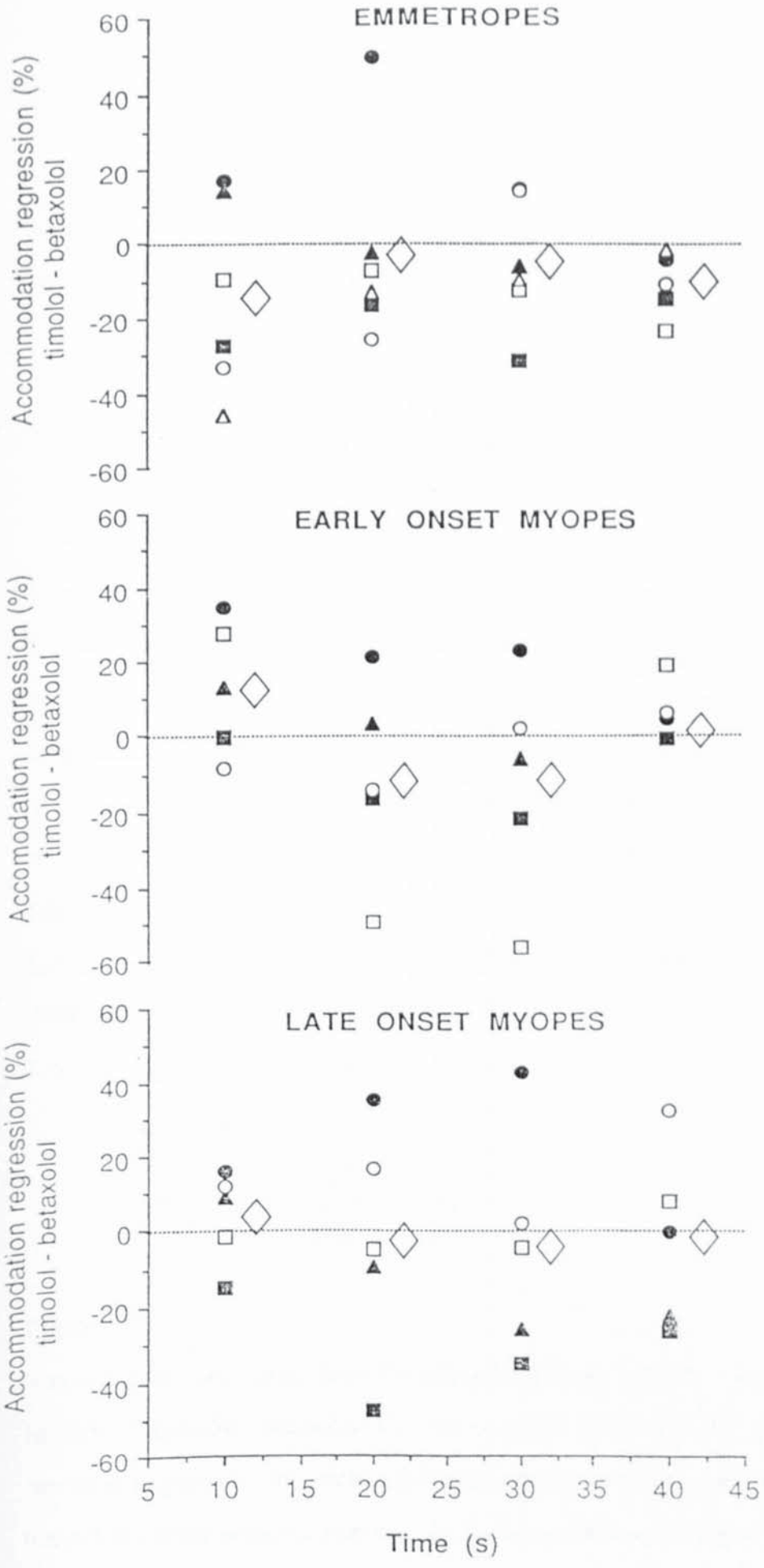
EMMETROPES
EARLY ONSET MYOPES
LATE ONSET MYOPES
Accommodation regression (%)
timolol - betaxolol
60
40
20
0
-20
-40
-60
5
10
15
20
25
30
35
40
45
Time (s)

FIG 3

FIGURE LEGENDS

Figure 1

Plot of raw data for accommodative regression (all conditions) for subject EW, a late-onset myope, following far and near tasks. The plot is over 60 s of the post-task period (40 data points per plot). Plot symbols have been omitted for clarity.

Key:

——— Post-timolol trial (far/near)
- - - - Post-betaxolol trial (far/near)
——— Pre-timolol trial (far/near)
····· Pre-betaxolol trial (far/near)

Fig 2

Condensed % accommodation regression data for each of 3 subjects drawn from the LOM group.

Upper plots: The mean of each of the 7 mean sphere readings located symmetrically about the 10, 20, 30 and 40 s data points is plotted against time (data from the initial 5 s of recording is not included). The error bars represent, for each time period, the mean standard deviation (derived from each separate set of 7 data points) for all conditions.

Lower plots: The difference, derived from each respective upper plot, between pre- and post-drug regression for timolol and betaxolol.

Key:

—□— Pre-timolol trial
---□--- Pre-betaxolol trial
—○— Post-timolol trial
—△— Post-betaxolol trial
—●— (Pre-) - (Post-) timolol
---★--- (Pre-) - (post-) betaxolol

Figure 3

The data points are derived from the subtraction, for all subjects, of the lower plots illustrated in Figure 2 (timolol - betaxolol) for each refractive group. Positive and negative values thus represent respectively the relative enhancement and attenuation of post-task hysteresis with timolol at varous post-task intervals. Different symbols are assigned to each subject within refractive groups. The group mean ( ) is displaced for clarity.

Table 1 Details of experimental subjects used: emmetropes (EMMs); early onset myopes (EOMs); late-onset myopes (LOMs).

Refractive group	EMMs (N=6; 1M, 5F)		EOMs (N=5; 2M, 3F)		LOMs (N=5; 2M, 3F)	
	X	sd	X	sd	X	sd
Age (years)	22.33	3.26	22.60	4.04	22.00	4.69
Refraction (mean sph.D)	+0.17	0.18	-3.42	1.79	-1.52	0.76
Myopia onset (years)	-	-	11.20	2.49	18.80	2.68
Tonic accommodation: all conditions (mean sph. D)	0.82	0.41	0.65	0.49	0.61	0.40

Table 2 Experimental results for refractive groups given in Table 1

Refractive groups	EMMs		EOMs		LOMs	
	X	sd	X	sd	X	sd
Task accommodation Near - Far, all conditions (mean sph. D)	4.2	0.4	4.05	0.49	3.97	0.40
IOP reduction (mm Hg)						
timolol	2.47	0.95	1.83	0.80	2.90	0.74
betaxolol	1.94	1.27	1.93	0.92	2.30	0.97