Accuracy and reliability of the Shin-Nippon SRW-5000 open-field autorefractor, and tonic accommodation and accommodative lag in Hong Kong children from 4 to 8 years of age

by

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DECLARATION

The work submitted in this dissertation is the result of investigations carried out by the author. The material in this dissertation has not been accepted in any substance for any degree, and is not being concurrently submitted in candidature for any other degree.

Signed ________________

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Signed________________

Professor Marion Edwards
(Chief supervisor)

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ABSTRACT

Introduction

The Shin-Nippon SRW-5000 autorefractor is a new open-field autorefractor which allows refraction to be measured at different fixation distances, making it suitable for the investigation of aspects of accommodation. The goals of this study were to evaluate the accuracy and reliability of this new autorefractor, and to examine tonic accommodation and accommodative lag in Hong Kong children from 4 to 8 years of age.

Results were analysed in terms of the dioptric power matrix, coordinate vector **h**. This analytical approach overcomes the problems associated with the reduction of the three-dimensional sphero-cylinder to any of the one-dimensional expressions commonly used to quantify refractive error, all of which result in loss of information. The spherical equivalent refractive error was also used in statistical analysis to permit comparison with other studies.

Methods

Subjects were children from 4 to 8 years of age. Autorefraction measures taken in the normal accommodative state (n=53) and under cycloplegic conditions (n=44)

were compared with cycloplegic refraction, as well as measures taken from a closed-field autorefractor (the Canon RK5). The reliability of the distance autorefraction was characterized by the 95 % limits of agreement between two sets of measurement taken by one observer (repeatability) and two observers (reproducibility).

Tonic accommodation (TA), the accommodation when the eye is in its resting state, was determined by measuring refractive error in 56 children in total darkness. Ocular accommodative lag, the difference between the accommodative stimulus and its response, was determined in 33 children, with a target placed at 40 cm. Three stimulus conditions were investigated, namely, white letters on a dark background in dim light, white letters on a dark background in normal room lighting and black letters on a light background in normal room lighting.

Results

The overall accuracy of the SRW-5000 was high, and similar to that reported for the Canon R-1 open-field autorefractor. As would be expected, the agreement between cycloplegic open-field autorefraction and cyclopelgic refraction was better than between non-cyclopelgic open-field autorefraction and cyclopelgic refraction. Autorefraction taken under both conditions tended to produce results which were more myopic than cycloplegic refraction. Non-cyclopelgic SRW-5000 autorefraction produced slightly more myopic results than closed-field autorefraction using the RK5, and the difference was mainly for hyperopes.

Reliability was considerably better for cycloplegic than non-cycloplegic autorefraction, and slightly better for one compared with two observers. Repeatability results from the SRW-5000 autorefractor, both with and without cycloplegia, were similar to those reported for the Canon R-1.

The mean tonic accommodation for all the children was 1.07 DS/−0.05 DC×138 and 1.09 DS/−0.04 DC×68 for children under 6 years of age. There was no relationship between tonic accommodation and age for the age range tested. Hyperopes exhibited the highest TA, followed by emmetropes and then myopes. The 95 % limits of agreement between two spherical equivalent measures was 0.83 D.

Accommodative lag was greatest for white letters on a dark background in dim light (condition DD), followed by white letters on a dark background in normal room lighting (condition LD) and black letters on a light background in normal room lighting (condition LL). Myopes tended to exhibit higher ocular accommodative lag than hyperopes. The 95 % limits of agreement obtained from three conditions were similar and was around 0.55 D in spherical equivalent.

Conclusions

This is the first report of tonic accommodation and accommodative lag presented in terms of vector **h**. Tonic accommodation values in children younger than six years of age were also presented for the first time. Tonic accommodation was found to be lower in myopes than in other refractive groups and, in agreement with the suggestions of other workers, this may reflect an overall reduction in autonomic innervation. Accommodative response tended to be lower in myopes but the results were equivocal. It is still possible that the hyperopic retinal defocus resulting from greater lag may cause myopia development in children.

Target presentation could be improved for the measurement of distance autorefraction and near accommodative response and it is suggested that measurement of tonic accommodation would be improved by use of a difference of Gaussian target in semi-darkness.

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PREAMBLE

Shin-Nippon SRW5000 is a new open-field autorefractor likely to replace the Canon R-1, which is no longer manufactured. The open-field type autorefractor is commonly used to assess accommodative functions such as tonic accommodation. Dynamic accommodation can also be measured if the autorefractor is modified. In this study, the accuracy and the reliability of refractive measurement of SRW5000 were first determined. The instrument was subsequently used to measure tonic accommodation and accommodative lag in Hong Kong children from 4 to 8 years of age. The dioptric power coordinate vector, vector **h**, was used in the analysis of refractive error.

There are three parts in the thesis: (1) literature reviews, (2) comment and result of the studies and (3) overall conclusions drawn and recommendations made. There are three chapters in the first part, Chapter 1 is a review on open-field autorefraction. As cycloplegia was used to determine the accuracy and reliability of the Shin-Nippon SRW-5000 autorefractor, a brief review of the effect of cyclopentolate hydrochloride, as well as the reliability of cycloplegic refraction is given in this chapter. Chapter 2 is a review of tonic accommodation and accommodative lag measurement. Chapter 3 reviews coordinate vector **h**, the data analysis method used in this thesis.

In the second part of the thesis, the three studies are presented. Chapter 4 is Study 1: the clinical evaluation of Shin-Nippon SRW-5000 autorefractor in children, Chapter 5 is Study 2: tonic accommodation in Hong Kong children and Chapter 6 is Study 3: accommodative lag in Hong Kong children.

In the last part of the thesis, overall conclusions are drawn and recommendations to improve the experimental setup are given.

Chapter 1

Open-field autorefraction

1.1 Introduction

Autorefractors are instruments which measure refractive error objectively. The first autorefractor was introduced in the early 1970s, and technological advances since then have resulted in a class of instrument widely used and accepted by the clinical community. Autorefractors may have either an internal or an external fixation target. Instruments with the former are called "closed-field" and with the latter are called "open-field". The closed-field design requires less office space than the open-field one, as it is not necessary to have an external target positioned some distance from the instrument. However, when the human eye looks into an optical instrument there is a tendency to accommodate, resulting in so-called instrument myopia (Schober *et al.*, 1970; Hennessy, 1975; Richards, 1976; Wesner and Miller, 1986; Miwa, 1992; Kotulak and Morse, 1994).

1.2 Open-field autorefraction

It has been suggested that instrument myopia can be eliminated using an open-field design (Miwa, 1992; Rosenfield and Chiu, 1995), as this allows natural binocular vision and should discourage instrument myopia compared with closed-field autorefraction, in which the subject looks directly into the instrument.

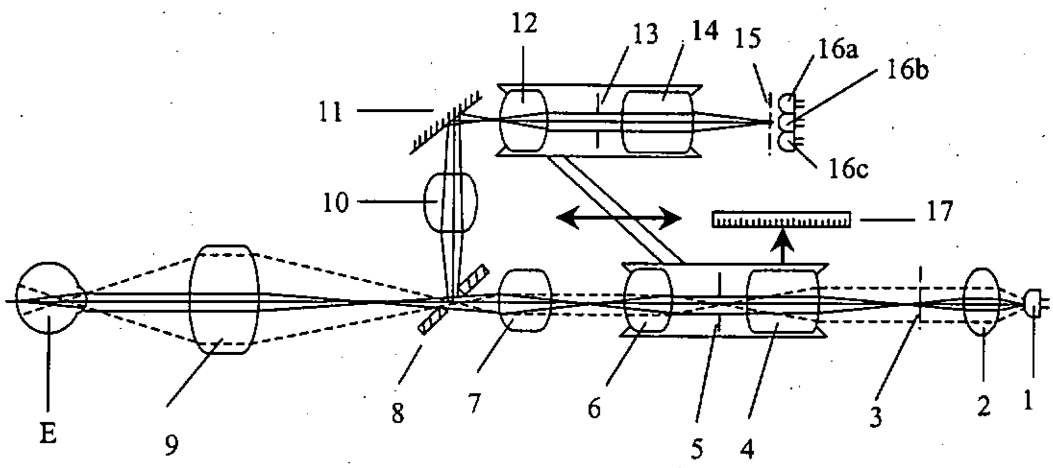
Until recently the only autorefractor utilizing this design was the Canon Autoref R-1. However, the R-1 is no longer manufactured and a new instrument, the Shin-Nippon SRW-5000 is now available and likely to replace the R-1, provided it is shown to be accurate and reliable.

1.2.1 Canon Autoref R-1

The Canon Autoref R-1 was developed by Canon Incorporated and introduced in 1981. Free-space viewing is achieved with a beam-splitter, which reflects infrared radiation and transmits visible radiation. An infrared beam is directed into the eye through the beam splitter, while the subject looks through the beam splitter to the object of interest. This feature allows refraction to be measured for different fixation distances and makes the R-1 particularly useful for research into accommodation. A brief description of the general principle underlying the R-1 design and of the specifications of the R-1, follows.

1.2.1.1 General principles

The instrument consists of an alignment system and a measuring system. The patient fixates an external target in the natural environment through a dichroic mirror. The pupil and the cornea of the subject's eye are illuminated by infrared light and then projected onto the TV camera by the objective lens. At the same time, an illuminated ring-shape pattern is projected onto the TV camera by the projection lens and can also be observed in the TV monitor, together with the patient's eye. Optimum alignment is achieved by adjusting the sharpness of the ring-pattern using a joystick, and the position of the patient's eye, so that their images appear concentric on the TV monitor (Matsumura *et al.*, 1983: p.36-42).



E: Patient's eye	1. IR light source	2. Condenser lens
3. Mask	4, 6, 12, 14. Focusing lenses	5, 13. Field stops
7, 10. Relay lenses	8. Aperture mirror	9. Objective lens
11. Mirror	15. Detecting mask	16a-c. Detector
17. Scale		

Figure 1.1 Schematic diagram of the R-1 measurement system. Redrawn from Matsumura *et al.*, 1983.

The Canon R-1 uses an image-analyzing technique. A diagram of the optical system of the R-1 is shown in Figure 1.1. An infrared light beam, which consists of rays in three planes separated by 60 deg, passes through the condenser, focusing, relay and objective lenses and forms an elliptical image on the subject's retina. The reflected image is refocused, through the detecting mask, onto the detecting devices and is finally received by the photodetector. The focusing lenses are moved along the axis of each meridian and the least blurred state is determined. The spherical power, cylinder power and its axis can then be calculated from the position of the focusing lens.

1.2.1.2 Specifications

The power range of the R-1 is ±15.0 D sphere and ±7.00 cylinder, in steps of 0.12 D. The axis is measured in 1 deg steps and vertex distances of 0 mm and 12 mm are available. The instrument requires a minimum pupil diameter of 2.9 mm.

1.2.2 Shin-Nippon Vision Autoref SRW-5000

1.2.2.1 General principles

The Shin-Nippon SRW-5000 autorefractor also uses the image analysis principle. A ring-like pattern (Figure 1.2) is projected onto the patient's retina and reflected back to the detecting device. The size of the image at the detecting device depends on the refractive error. In emmetropia, the ring will be perfectly round (Figure 1.2a). In myopia the ring will be larger (Figure 1.2b) and in hyperopia the ring will be smaller (Figure 1.2c). In astigmatism an elliptical shape is produced (Figure 1.2d). A diagram of the optical system of the R-1 is shown in Figure 1.3.

The pattern is reflected from the retina and received by the CCD (charged couple devices) camera, converted into a video signal, stored in the frame memory and analyzed. Correspondence with the manufacturer has suggested that the width and the height of the ring as well as the major axis of the ellipse are measured then the corresponding refractive error is calculated.

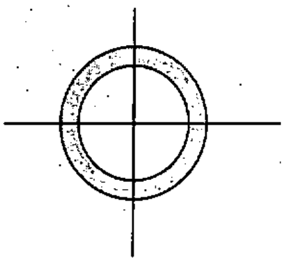


Figure 1.2a Emmetropia

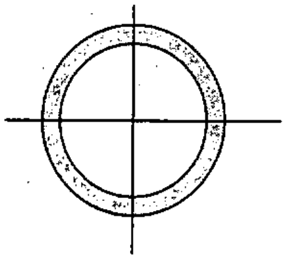


Figure 1.2b Myopia

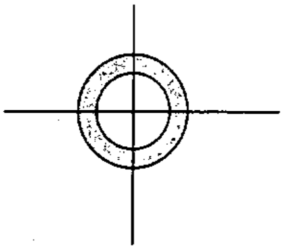


Figure 1.2c Hyperopia

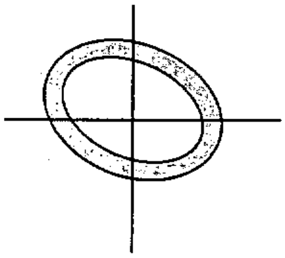
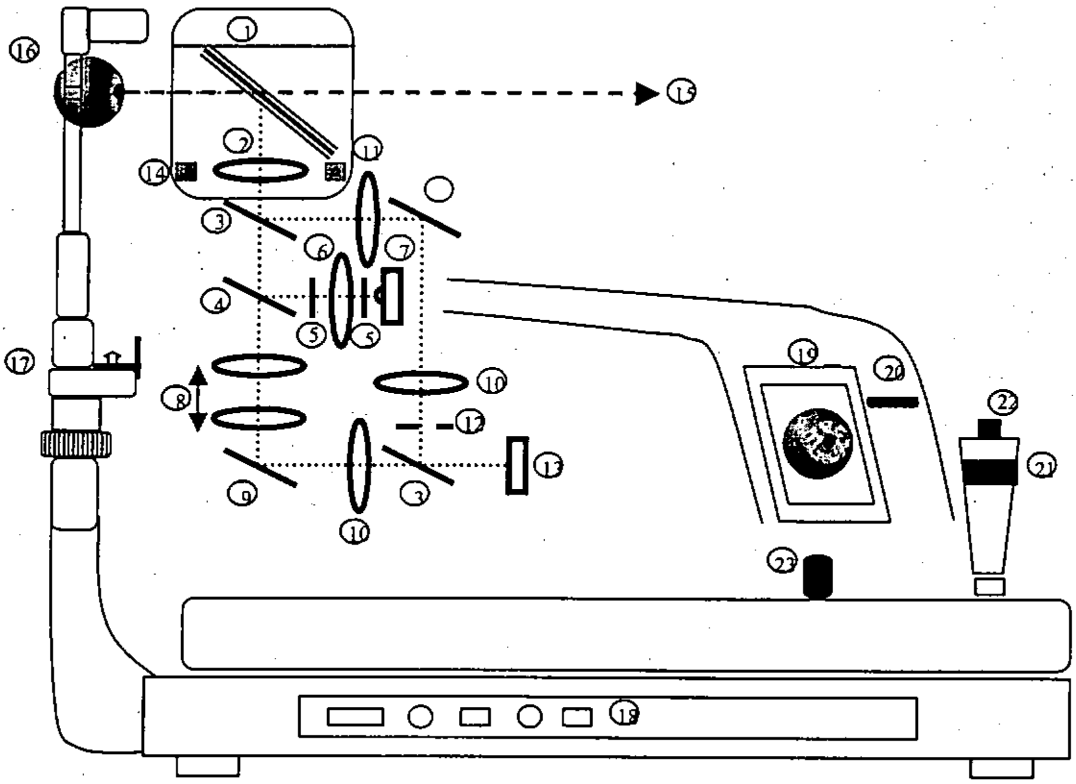


Figure 1.2d Astigmatism

Figure 1.2 Image used in SRW-5000 for determining refractive error. (a) is the ring pattern detected in emmetropes, (b) is the ring detected in myopes, (c) is the ring detected in hyperopes and (d) is the ring detected in astigmatic eye.



1. Semi-silvered mirror	2. View window lens
3. Semi-silvered viewing mirror	4. Perforated mirror
5. Masks	6. Lens
7. Infra-red light source for measuring	8. Relay lens
9. Mirror	10. Focusing lens
11. Field lens	12. Aperture
13. CCD sensor	14. Illuminating/alignment light source
15. Fixation target	16. Forehead rest
17. Chin rest	18. Power and external interface connectors
19. CRT monitor/alignment screen	20. Thermal printer
21. Joystick	22. Measurement start switch

Figure 1.3 Schematic diagram of the SRW-5000 measurement system and its external view (Mallen *et al.*, 2001). Diagram courtesy of Mallen.

1.2.2.2 Specifications

The specifications of the SRW-5000 are similar to, or better than, those of the Canon R-1. It measures spherical error up to ± 22 D and cylindrical errors of up to 10 D in 0.12 or 0.25 steps. Cylinder axis is measured in 1 deg. steps. Six vertex distance measures are available (0, 10, 12, 13.5, 15 and 16.5 mm) and the minimum pupil diameter that will allow measurement is 2.9 mm. Refractive error is measured in 0.15 sec.

1.3 Cycloplegic autorefraction

In children, more accurate and reliable results can be obtained from refraction performed under cycloplegia than without cycloplegia (Zadnik et al., 1992; Rosenfield and Chiu, 1995; Goss and Grosvenor, 1996). Zadnik and Mutti (2000) have presented data comparing the prevalence of myopia obtained in 13 to 14 year old children with and without cycloplegia. Table 1.1 shows the prevalence of myopia obtained using values for spherical equivalent of ≤ –0.50 and of ≤ –0.75 D with refraction carried out by cycloplegic and non-cycloplegic Canon R-1 autorefraction. The differences between cycloplegic and non-cycloplegic autorefraction are considerable, despite the use of the open-field design in this particular instance. Non-cycloplegic autorefraction in children of this age results in a significant over-estimation of the prevalence of myopia.

	Criterion for myopia	
	≤ −0.50 D	≤ −0.75 D
Non-cycloplegic autorefraction	44.5 %	33.6 %
Cycloplegic autorefraction	24.4 %	19.8 %

Table 1.1 Prevalence of myopia obtained by Zadnik and Mutti, 2000.

In the present study, the accuracy of autorefraction (both in cycloplegia and non-cycloplegia) will be determined by comparison with cycloplegic refraction. Cyclopentolate hydrochloride 1 % was chosen as the cycloplegic agent.

1.3.1 Cycloplegic agent

Cyclopentolate hydrochloride was introduced into clinical practice in 1951 and has been used for 50 years. Its cycloplegic effect closely parallels that of atropine, but with a relatively more rapid onset, shorter duration and far safer. Depth of cycloplegia is less than that produced by atropine, but is usually adequate for refraction.

Cycloplegia and mydriasis result from cholinergic innervation to the eye, originating in the Edinger-Westphal nucleus (EWN) located within the mesencephalon. Preganglionic parasympathetic fibers emerge from the EWN, exit the central nervous system (CNS) through the third cranial nerve (oculomotor), and proceed to the ciliary ganglion. There they synapse with postganglionic fibers, enter the globe through the short ciliary nerves, and pass to the iris sphincter muscle and ciliary body where they terminate. Acetylcholine is the neurotransmitter at the ciliary ganglion synapse and also at the sphincter and ciliary neurotransmitter at the ciliary ganglion synapse and also at the sphincter and ciliary muscle. Cycloplegic agents antagonize the muscarinic action of acetylcholine by blocking its action at the receptor sites in the ciliary body and iris, causing cycloplegia and mydriasis (Jaanus and Carter, 1995: p.167).

The onset of the effect of cyclopentolate is slower in eyes with heavily pigmented irides. This is probably because melanin pigment is able to bind cyclopentolate, leaving less available to interact with the muscarinic receptor sites in the ciliary and sphincter muscles (Manny *et.al.*, 1993). In general, the maximum cycloplegic effect is reached 40 min after instillation of the drug (Khurana, 1988; Lin *et al.*, 1988; Egashira *et al.*, 1993; Manny *et al.*, 1993) and the onset time is less if a local anesthetic, e.g. benoxinate hydrochloride 0.4 %, is used prior to cyclopentolate installation (Siu *et al.*, 1999).

There is usually some transient stinging following instillation of cyclopentolate. Allergic reaction may occur occasionally, especially after repeated doses. The symptoms consist of conjunctival injection (Jones and Hodes, 1991), and facial rash (Figure 1.4) following drug installation (Edwards, 1991).

Figure 1.4 Allergic reaction to cyclopentolate in a Chinese baby. The entire face is red except for the area of skin around the mouth and the lower half of the nose (Edwards, 1991). Photograph courtesy of M Edwards.

1.3.2 Adverse effects in cycloplegic autorefraction

The mydriatic effect of cyclopentolate may precipitate an attack of closed-angle glaucoma in individuals with narrow anterior chamber angles, due to the blockage of the angle by the dilated and immobile iris. Harris (1968) found that, in chronic open-angle glaucoma, intraocular pressure (IOP) was significantly elevated following instillation of 1 % cyclopentolate. Therefore, an assessment of the depth of anterior chamber and IOP measurement should be carried out prior to installation to minimize the risk of angle-closure glaucoma.

The central nervous system (CNS) side effects are characterized by cerebellar dysfunction as well as visual and tactile hallucinations (Jaanus and Carter, 1995: p.167-182). Reported side effects include drowsiness, ataxia, disorientation, incoherent speech, restlessness, and emotional disturbances. Psychotic reactions are associated in particular with the use of 2 % concentration of the drug (Binkhorst et al., 1963; Shihab, 1980) and we therefore chose to use 1 % concentration in the present study. Psychotic symptoms occur within 20-30 min of topical administration and generally subside within 2 hours in adults and 4-6 hours in children.

Chapter 2

Tonic accommodation and accommodative lag: a review

2.1 Tonic accommodation

In the absence of an adequate visual stimulus, the eye does not focus at the far point, but rather at some nearer point, the accommodation in play being termed tonic accommodation (TA). The value of TA is about 1 D on average (Rosenfield *et al.*, 1993), though this varies considerably from individual to individual. TA is also referred to as dark focus, open-loop accommodation or resting state of accommodation (Millodot, 1993).

2.1.1 Laser Optometry

A Helium-Neon (He-Ne) laser optometer (Figure 2.1) was used to measure TA in the early 1970s. In this system, a low energy laser beam is diverged and reflected from a slowly rotating drum. When measurement is carried out on the right eye, the reflected laser pattern is superimposed in the subject's left eye visual field, and vice versa. The subject sees dark speckles on a circular red field, and if the subject has a refractive error these are seen as moving, the direction of the movement being determined by the refractive error of the subject's eye. If the eye is accommodated for a point anterior to the drum, the speckles are perceived as moving in the same direction as the drum. If the eye is accommodated beyond the drum, movement in the opposite direction is perceived. A Badal lens is placed between the subject's eye and the drum so that the optical distance of the drum can be varied from infinity to

20-25 cm, without changing the size and the brightness of the speckle. The speckles will not act as a stimulus to accommodation during assessment because they are formed by optical interference and their clarity is independent of the eye's dioptric state.

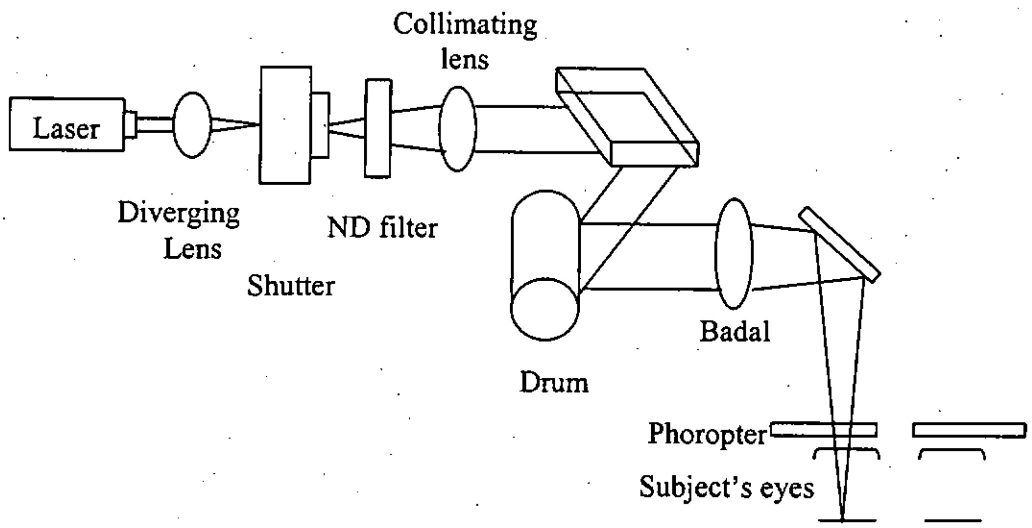


Figure 2.1 The laser optometer. Redrawn from Miller *et al.*, 1983.

Leibowitz and Owens (1975a; 1975b) assessed TA using a laser optometer in darkness. They found a mean TA of about 1.50 D, with large across subjects variation. The accommodative responses were also measured under three additional conditions namely, when a distant target was viewed through a dense filter, when subjects looked at a bright empty field, and when a grating was viewed in a microscope and these three conditions also produced similar TA values. Leibowitz and Owens (1978) reported similar TA values, using a laser optometer, for 220 college students.

Laser optometry, however, does not provide a valid measure of the tonic level, due to factors such as the mental effort required to judge the direction of speckle motion (Post *et al.*, 1984; Bullimore and Gilmartin, 1987b; Jaschinski-Kruza and Toenies, 1988), speckle exposure time (Bullimore *et al.*, 1986; Rosenfield, 1989) and speckle pattern within the visual field acting as a stimulus to proximally-induced accommodation (Bullimore and Gilmartin, 1990; Rosenfield and Gilmartin, 1990; Rosenfield *et al.*, 1990).

2.1.2 Near retinoscopy

Near retinoscopy is an objective method of measuring tonic accommodation clinically. It is performed while the subject looks at the retinoscope light at a distance of 50 cm in complete darkness. Trial lenses are then used to neutralize the reflex. Tonic accommodation is calculated as the difference between the lenses used to neutralize the reflex and –2.00 D, the latter being the correction for the working distance. However, the retinoscope light may stimulate accommodation (Owens *et al.*, 1980), and using a low spatial frequency difference of Gaussian (DOG) target may be better for tonic accommodation measurement.

Kotulak and Schor (1987) reported that blur-driven accommodation is not stimulated when viewing a low frequency (0.1 cpd) target. Thus, when dynamic retinoscopy is performed with the subject viewing a low spatial frequency DOG target, the result is equivalent to the response obtained in total darkness. This target was used in two more recent studies (Rosner and Rosner, 1989; Rosner and Rosner, 1990).

Rosenfield (1989) found no significant difference in the accommodative response using a DOG when the accommodative stimulus was varied between –1 and +5 D and thus confirmed that DOG target does not provide a blur-stimulus to accommodation.

2.1.3 Infrared optometry

An infrared optometer is the instrument of choice for measuring accommodative response nowadays, and provides a means of measurement under true stimulus-free conditions. The static mode in a modified closed-field autorefractor (Nidek AR-2000) and two open-field autorefractors (Canon R-1 and Shin-Nippon SRW-5000) are available for measuring TA. Tonic accommodation can thus be assessed objectively without being influenced by the mental effort required for judging target motion and position. Tonic accommodation can be measured by taking refraction measures in total darkness, in an illuminated perfect empty field or under accommodative open-loop conditions.

2.1.3.1 Total darkness

Blur, vergence and proximal stimuli can be eliminated in total darkness but, as mentioned above, mental activity in darkness can influence the level of tonic accommodation. Variation of the accommodative response has been reported when the subject was told to 'think near' or 'think far' (Westheimer, 1957; Malmstrom and Randle, 1976). Rosenfield and Ciuffreda (1991) investigated the effect of surroundings on TA, by taking measures in a large and a small room with and without subject awareness of the room size. There were statistically significant differences in tonic accommodation measured in different sizes of room with the subjects aware of the room sizes but no significant difference when the subjects were not aware of the room size.

2.1.3.2 Illuminated empty-field

Another way of presenting a stimulus-free environment is for the subject to view an illuminated empty-field (Westheimer, 1957; Wolf *et al.*, 1987; Bullimore and Gilmartin, 1989). It is important that a perfectly empty-field should be provided while measuring accommodative response, as any textural imperfections or luminance variations in the field surface may stimulate blur-driven or proximally-induced accommodation.

2.1.3.3 Opening the accommodation loop

An alternative method of measuring TA is to remove the stimulus to accommodation by opening the accommodation loop. The accommodation loop can be opened by viewing a target through a 0.5 mm pinhole (Hennessy *et al.*, 1976; Ward and Charman, 1987). The pinhole increases the depth of focus and removes the blur-stimulus to accommodation. However, when viewing a monocular near target under open-loop conditions, proximal accommodation may be induced (Rosenfield *et al.*, 1991). TA cannot usually be measured with an autorefractor using this condition, because autorefraction may be difficult or impossible through such a small pupil. Many autorefractors require a minimum pupil size of 2.9 mm.

2.1.4 Agreement between TA measurements

Near retinoscopy tends to result in lower tonic accommodation measures compared with others methods, both in adults (Bullimore *et al.*, 1988) and children (Rosner and Rosner, 1990). Owens *et al.* (1980) found a low but statistically significant correlation between TA measured in darkness by infrared autorefraction (mean TA= 1.50 D) and by near retinoscopy (mean TA = 0.70 D) across 22 subjects ($r=0.86$, $p<0.001$). A low correlation is of concern, as one would certainly expect a rather high correlation between two sets of measures purporting to measure the same variable. Bullimore *et al.* (1986) compared tonic accommodation measured by near retinoscopy, laser optometer and infrared autorefractor. They found no statistically significant differences between tonic accommodation measured by these three techniques. However, when correction was made for chromatic aberration and instrument calibration, in laser optometry and infrared optometry respectively, then near retinoscopy gave consistently the lowest value for TA, perhaps due to the retinoscopy beam stimulating blur-driven and proximally-induced accommodation. Subjects may accommodate for the plane of the retinoscope rather than adopting a resting state of the eye.

It should be noted that correlation is not an appropriate method to compare two measures of the same variable. The correlation is a measure of the strength of a linear trend or association between two variable which is not the same as agreement (Bland and Altman, 1986; Zadnik and Mutti, 1993; Shaw *et al.*, 1994), so that a high correlation would indeed be expected, but indicates relationship and not agreement. The 95 % limits of agreement, as discussed by Bland and Altman (1986), would provide a more appropriate statistic for this comparison, and will be used in the present study.

2.1.5 Relationship between tonic accommodation and refractive error development

Researchers have investigated whether TA is a predictor of myopia development, but failed to reveal any consistent pattern. van Alphen (1961) suggested that the intraocular pressure of the globe is counterbalanced by a combination of the tension in the choroid and the degree of scleral elasticity. The tension of the choroid depends upon the tonus of the ciliary muscle and high ciliary muscle tonus will cause increased resistance to intraocular pressure, reducing the resulting tension on the sclera. In contrast, in individuals with lower ciliary muscle tone, a higher intraocular pressure would be more likely to result in scleral stretching. According to this model of emmetropization, hyperopes would be expected to exhibit higher levels of tonic accommodation and myopes, whose increased axial length resulted from an inability to resist intraocular forces, would have lower tonic accommodation.

The majority of studies have indeed found that tonic accommodation is lowest in late-onset myopia (McBrien and Millodot, 1987; Woung *et al.*, 1993; Jiang, 1995; Jiang and Morse, 1999) and it has been suggested that myopia developing after the age of 15 years is basically environmental in origin (Goldschmidt, 1968). Jiang (1995) has, however, reported that tonic accommodation was high in emmetropes who subsequently became myopic, and declined after they became myopic. Those who were already myopic exhibited the lowest tonic accommodation. This suggests that individuals who have low tonic accommodation may not be at risk for myopia, and is in conflict with the paradigm proposed by van Alphen.

Jiang's findings were supported by those of Adams and McBrien (1993), who reported that changes in tonic accommodation occur concurrently with refractive development. There was no statistically significant difference between the initial tonic accommodation in subjects who remained emmetropic and those who developed myopia over the two-year study period of their study. However, those emmetropes who became myopic exhibited lower levels of tonic accommodation following myopia development than they had prior to myopia development.

2.2 Lag of accommodation

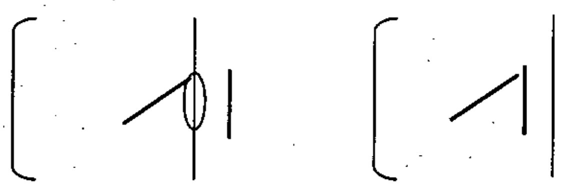
The accommodative response is a measure of the actual amount of accommodation that is present (Eskridge *et al.*, 1991: p.677). The lag of accommodation is the extent to which the accommodative response is less than the dioptric stimulus to accommodation (Millodot, 1993: p.3). In the corrected ametropic eye, the accommodative lag is calculated as follows:

$$\text{Accommodative lag (D)} = \left[\frac{1}{\text{target distance (m)}} - \text{measured accommodative response (D)}\right]$$

There are many different clinical techniques for measuring the accommodative response at near, such as the binocular cross-cylinder (BCC) technique, the near red-green (R-G) duochrome technique, dynamic retinoscopy and infrared autorefraction. The first two methods are subjective while the third and fourth are objective methods. All the methods are based on the assumption that the circle of least confusion is on the retina when the eye is accommodated correctly.

2.2.1 Binocular cross-cylinder technique

The amount of accommodative lag is estimated by placing the circle of least confusion on the retina. The target viewed consists of four to five vertical and horizontal lines, usually placed 40 cm in front of the subject's eye. A Jackson cross-cylinder lens (± 0.50 D) with the principal meridian of positive power at 90 deg is placed in front of each eye, on top of the distance refraction. If the accommodative response is equivalent to the accommodative stimulus, then the circle of least confusion will be on the retina, the horizontal focal line will be in front and the vertical focal line behind the retina (Figure 2.2a). However, if there is a lag of accommodation then the circle of least confusion will lie behind the retina, and the horizontal focal line will be closer to the retina than the vertical focal line. At this time the horizontal lines of the target will be seen clearer than the vertical lines. During the examination, the room illumination is reduced in order to minimize the depth of focus, but the target should be still clearly visible to the subject.



(a) **(b)**

Figure 2.2 Focal lines relative to the retina during BCC: (a) focal lines on retina when accommodative response is equivalent to the accommodative stimulus, (b) focal lines on retina when +2.00 D fogging lens is added to both eyes in front of the BCC.

A +2.00 D fogging lens is added to both eyes, causing the focal lines to move forward (Figure.2.2b). As the power of the plus lenses is gradually reduced, the vertical lines will first be in focus on the retina. The power of the plus lens which first makes both sets of lines appear equally clear (Figure 2.2a), is the lag of accommodation.

2.2.2 Near duochrome technique

The optical system suffers from chromatic aberration because shorter wavelengths are refracted more than longer wavelengths as white light passes through the ocular media (Millodot and Sivak, 1973; Kruger *et al.*, 1995). In the corrected ametropic eye, green light is thus focused in front of the retina and red light behind the retina equally (Figure 2.3). When there is a lag of accommodation, green light is brought to a focus closer to the retina than the focus for red light and a green target will therefore appear clearer than a red one. Accommodative lag is determined by adjusting the lens power in order to obtain equal clearness of the near duochrome.

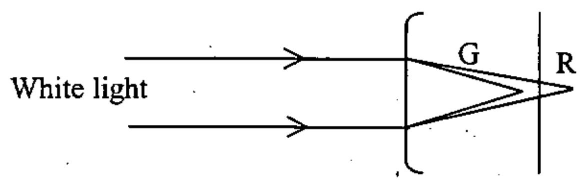


Figure 2.3 Duochrome in corrected ammetropic eye.

The near duochrome test target consists of four Verhoff circles, two on a red background and two on a green background. The subject, wearing the distance correction, is asked to view the near duochrome at 40 cm and to say which circles appear darker, sharper or clearer, the ones on the red background, or the ones on the green background. If there is a accommodative lag, the circles on the green will be clearer. Plus lenses are then added in 0.25 D steps until the circles on the red and on the green become equally clear or the circles, or the red become clearer. The power of the plus lens required to achieve equality is a measure of the accommodative lag.

Some investigators (Jenkins, 1963; Millodot and Sivak, 1973) have found that the wavelength conjugate with the retina changes from approximately 600 nm at distance to 530 nm at 40 cm. Therefore, a blue-yellow duochrome may be more appropriate than a red-green duochrome target. Rosenfield *et al.* (1996) compared the accommodative response measured subjectively and objectively using a red-green duochrome and a blue-yellow duochrome at 40 cm. However, when viewing a blue-yellow target, the subjective accommodative response was significantly greater than the corresponding objective measurement and 45 % of subjects were unable to given reliable results with the test using a blue-yellow duochrome. This suggests that a blue-yellow duochrome does not provided a useful estimation of the near accommodative response.

2.2.3 Dynamic retinoscopy

Dynamic retinoscopy is an objective method to determine the point that is conjugate with the retina when the subject is viewing a target at near, either by varying the distance between the retinoscopic plane and the subject's eye or by using plus lenses to obtain neutrality.

There are four near dynamic retinoscopy techniques; these are Sheard's retinoscopy, the Cross method, the Nott technique and the monocular estimation method (MEM).

Sheard's retinoscopy is performed with the subject fixating a near reading card at the usual working distance with the distance correction in place. Plus lenses are then added to neutralize the "with" movement and the power added is a measure of the accommodative lag (Grosvenor, 1996: p.272).

In the Cross method, the subject wears the distance correction, and retinoscopy is carried out through an aperture in a letter card placed 40 cm in front of the subject. The subject is asked to read the letters around the aperture. Plus lenses are added until neutrality is obtained, the power of the neutralizing lens being the measure of accommodative lag.

Nott retinoscopy is performed in a similar way, but the reflex is neutralized by varying the distance between the retinoscope mirror and the near point card. The lag of accommodation is determined as the dioptric distance between the retinoscope mirror and the near point card.

In the monocular estimation method (MEM), the subject reads letters on a fixation card attached to the retinoscope and the reflex is neutralized by a lens bar or hand-held trial lens introduced for a very short period (usually less than 1s) until a neutral reflex is first observed (Grosvenor, 1996: p.253-254).

The use of supplementary lenses to determine the endpoint may alter the accommodative response. Fry (1940) and Goodson and Afandor (1974) have suggested that the introduction of plus lenses in front of eyes with active accommodation will cause a decrease in the blur-driven accommodation. The measurement of accommodative lag may be contaminated by the subject's ability to relax their accommodation. Therefore, the endpoint of the measurements not only reflects the accommodative response function but also the ability to relax accommodation under such conditions.

Locke and Somers (1989) compared accommodative responses as measured by these difference techniques and found that the MEM gives the most reliable result (95 % of paired measures taken by two examiners were within 0.16 D of each other). There were no statistically significant differences between results from MEM and Cross, MEM and Nott, or Cross and Nott under binocular measuring conditions.

Rosenfield *et al.* (1996) compared several methods (infrared autorefraction, BCC and near duochrome) with dynamic retinoscopy and found that the Sheard's and Nott methods showed the best agreement (95 % of paired measures were within 0.48 D).

del Pilar Cacho *et al.* (1999) compared measures of accommodative lag made over distance static retinoscopy results and over subjective refraction results. The mean accommodative lag was 0.53 D and 0.42 D measured by Nott technique through static retinoscopy and through the subjective distance correction respectively. The mean accommodative lag measured by MEM through static retinoscopy distance correction was 0.94 D and through the subjective distance correction was 0.74 D. It is likely that the supplementary lenses used to neutralize the reflex in the MEM technique influenced the accommodative state and resulted in the differences between the Nott technique and MEM shown above.

2.2.4 Infrared autorefraction

There are two types of infrared autorefractor, namely closed-field and open-field. The major difference between them is the nature of the fixation target. In the closed-field autorefractor, the fixation target is located inside the autorefractor. However, in the open-field autorefractor, the fixation target is placed in the natural environment and is viewed binocularly through a dichroic mirror.

2.2.4.1 Open-field autorefraction

Infrared open-field autorefraction, which can measure refraction at any distance, has been widely used to measure the accommodation response objectively. It is suggested that instrument myopia can be eliminated when measurement is made in a natural environment, and therefore a more accurate assessment of accommodative response can be obtained. The accommodative response is measured by placing the target at different distances in front of the autorefractor, or by adding minus lenses in front of the subject's eye in order to stimulate accommodation. The only two open-field instruments, which have been produced are the Canon R-1 and Shin-Nippon SRW-5000, however the R-1 is no longer available.

As mentioned previously, using an open-field autorefractor the accommodative response can be measured by decreasing the target distance, by adding a series of negative lenses or by adding a series of positive lens. Gwiazda *et al.* (1993) determined the accommodative response curve using the above methods. In the decreasing target distance series, accommodative responses were measured from 4 m to 0.25 m in seven steps with an array of 20/30 letters. In the negative lens series, accommodative responses were measured through lenses from plano to –3.00 D in 0.50 D in steps and also through a –4.00 D lens, with the target fixed at 4 m from the eyes. In the positive lenses series, accommodative responses were measured through lenses from +4.00 D to plano in 0.50 D steps with the fixation target at 0.25 m. The highest accommodative lag was found by the negative lens method, and a larger accommodative lag was found in myopes than emmetropes by all three methods.

2.2.5 Comparison between accommodative lag measures

Rosenfield *et al.* (1996) compared results from accommodative response measures clinically. The results are shown in Table 2.1. Sheard's retinoscopy agreed best with autorefraction (target at 40 cm) and BCC showed the greatest differences compared with other methods.

Comparison	95 % limits of agreement (D)
Autorefraction vs BCC	1.35
Autorefraction vs Nott dynamic retinoscopy	0.91
Autorefraction vs Sheard's dynamic retinoscopy	0.65
BCC vs Nott dynamic retinoscopy	0.99
BCC vs Sheard's dynamic retinoscopy	1.02
Near duochrome vs Autorefraction	0.92
Near duochrome vs BCC	1.02
Near duochrome vs Nott dynamic retinoscopy	0.76
Near duochrome vs Sheard's dynamic retinoscopy	0.67

Table 2.1 Comparison between accommodative responses measured under binocular conditions (Rosenfield *et al.*, 1996)

The poor agreement between BCC and other methods may be due to the BCC target. The overlapping and dioptrically disparate target lines would cause fluctuation of the accommodative response (Adams and Johnson, 1991; Rosenfield and Ciuffreda, 1991) and the vertical and horizontal orientation of the target may not be conducive to maintaining the circle of least confusion on the retina (Locke and Somers, 1989). Moreover, the low illumination conditions intended to reduce the depth of focus (Grosvenor, 1996) do not provide ideal conditions for viewing the target (Rosenfield *et al.*, 1996) and may cause young subjects to over-accommodate to levels comparable to night myopia (Locke and Somers, 1989).

2.3 Summary

2.3.1 Tonic accommodation

Several techniques have been used, over the years, to measure TA; they are laser optometry, near retinoscopy, dynamic retinoscopy with DOG target and infrared optometry. Laser optometry was found to yield higher tonic accommodation values in adults than infrared optometry, the latter method being most commonly used nowadays. Testing conditions for TA measurement can be total darkness, a bright empty field or with the accommodative loop open.

In general, TA is highest in hyperopes, intermediate in emmetropes and lowest in late-onset myopes. The differences appear to follow, rather than predate, refractive development and so cannot be considered causal and no consistent pattern has been established linking tonic accommodation with myopic development.

2.3.2 Accommodative lag

There are two objective and two subjective methods to measure lag of accommodation. These are dynamic retinoscopy, infrared open-field autorefraction, the binocular cross-cylinder test and the near duochrome test. The agreement between Nott dynamic retinoscopy, which determines the end-point by varying the working distance, and infrared autorefractor is good. The reliability of tests of accommodative response is increased if there are no additional factors, such as introduction of plus lenses, to influence accommodation status during measurement.

Chapter 3

Coordinate vector h

3.1 Introduction

The usual clinical representation of refractive error $(F_s / F_c \times a)$, where F_s is spherical power, F_c is cylindrical power and a is axis in degrees, does not lend itself to mathematical or statistical treatment. However, the determination of the arithmetic mean and variance are important quantitative measurements for any statistical analysis of measures of refraction. (Throughout this thesis the above sphero-cylinder format will be used without units. It should be understood that the sphere and the cylinder are in dioptres and the axis is in degrees.)

Most researchers have analysed refractive error either by converting the sphero-cylinder to the so-called spherical equivalent refractive error, or by considering each component of the sphero-cylinder separately. Neither approach is ideal, and the reduction from a three-dimensional to one-dimensional concept results in loss of information and distortion of reality. For example, the spherical equivalents of $-5.00/-1.00 \times 90$ and $-4.00/-3.00 \times 180$ are both -5.50 D but obviously they are totally different refractive errors.

Dioptric power expressed as the 2×2 dioptric power matrix (Long, 1976), however, overcomes these shortcomings. This 2×2 dioptric power matrix is a symmetrical matrix and it can be modified into a 3×1 vector, coordinate vector **h**

(Harris, 1991). When refractive error is converted into vector **h** components, formal multivariate statistical methods can be applied.

3.2 Coordinate vector h

Coordinate vector **h** (Harris, 1991) is a 3×1 matrix and its components are

$$\mathbf{h} = \begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix}$$

or in transposed form

$$\mathbf{h}' = \begin{pmatrix} h_1 & h_2 & h_3 \end{pmatrix}$$

where

$$h_1 = F_s + F_c \sin^2 a \qquad \text{(Equation 3.1)}$$

$$h_2 = -\sqrt{2} F_c \sin a \cos a \qquad \text{(Equation 3.2)}$$

$$h_3 = F_s + F_c \cos^2 a \qquad \text{(Equation 3.3)}$$

The interpretation of h_1 is the power of a component pure cylinder with axis vertical; h_2 is the power of a Jackson-crossed cylinder with axis at 45° and 135°; h_3 is the power of a component pure cylinder with axis horizontal (Harris, 1991).

Vector **h** can be converted back into sphero-cylinder format by applying the following equations (Harris, 1998: p.208):

$$F_c = -\sqrt{(h_1 - h_3)^2 + 2h_2^2} \qquad \text{(Equation 3.4)}$$

The negative cylindrical power is used for all cases.

$$F_s = \frac{h_1 + h_3 - F_c}{2} \qquad \text{(Equation 3.5)}$$

The axis is calculated using

$$\tan a = \frac{\sqrt{2}(F_s - h_1)}{h_2} \qquad \text{(Equation 3.6)}$$

3.3 Determining the sample mean and variance-covariance using coordinate vector h

3.3.1 Determining the sample mean

Suppose a sample has a size n and powers $\mathbf{h}_i$ for i = 1, 2, ..., n. The mean is calculated separately for each component of **h**: h_1, h_2 and h_3. Then the sample mean is:

$$\bar{\mathbf{h}} = \frac{1}{n}\sum_{i=1}^{n}\mathbf{h}_i \qquad \text{(Equation 3.7)}$$

(Harris, 1990a; Harris, 1990c)

The calculation is illustrated by the following example:

Calculate the sample mean of $-5.00/-1.00\times180, -4.75/-0.75\times175$ *and*

$-4.75/-1.00\times178$.

Applying Equations 3.1 to 3.3, each sphero-cylindrical power is converted to the corresponding coordinate vector $\mathbf{h}_1$, $\mathbf{h}_2$ and $\mathbf{h}_3$, thus:

$$\mathbf{h}_1 = \begin{pmatrix} -5.00+(-1.00)(\sin^2 180) \\ -\sqrt{2}(-1.00)(\cos 180)(\sin 180) \\ -5.00+(-1.00)(\cos^2 180) \end{pmatrix} = \begin{pmatrix} -5.0000 \\ 0.0000 \\ -6.0000 \end{pmatrix} (\text{D})$$

$$\mathbf{h}_2 = \begin{pmatrix} -4.75+(-0.75)(\sin^2 175) \\ -\sqrt{2}(-0.75)(\cos 175)(\sin 175) \\ -4.75+(-0.75)(\cos^2 175) \end{pmatrix} = \begin{pmatrix} -4.7557 \\ -0.0921 \\ -5.4943 \end{pmatrix} (\text{D})$$

$$\mathbf{h}_3 = \begin{pmatrix} -4.75+(-1.00)(\sin^2 178) \\ -\sqrt{2}(-1.00)(\cos 178)(\sin 178) \\ -4.75+(-1.00)(\cos^2 178) \end{pmatrix} = \begin{pmatrix} -4.7512 \\ -0.0493 \\ -5.7488 \end{pmatrix} (\text{D})$$

The mean of $\mathbf{h}_1$, $\mathbf{h}_2$ and $\mathbf{h}_3$ is then calculated by using Equation 3.7. Thus,

$$\begin{aligned} \bar{\mathbf{h}} &= \frac{1}{3}\left[\begin{pmatrix} -5.0000 \\ 0.0000 \\ -6.0000 \end{pmatrix} + \begin{pmatrix} -4.7557 \\ -0.0921 \\ -5.4943 \end{pmatrix} + \begin{pmatrix} -4.7512 \\ -0.0493 \\ -5.7488 \end{pmatrix}\right] \\ &= \frac{1}{3}\begin{pmatrix} -5.0000-4.7557-4.7512 \\ 0.0000-0.0921-0.0493 \\ -6.0000-5.4943-5.7488 \end{pmatrix} \\ &= \begin{pmatrix} -4.8356 \\ -0.0471 \\ -5.7477 \end{pmatrix} (\text{D}) \end{aligned}$$

The mean of vector **h** is then converted back to sphero-cylindrical format using Equations 3.4 to 3.6,

$$F_c = -\sqrt{[(-4.8356)-(-5.7477)]^2 + 2(-0.0471)^2}$$
$$= -0.9145$$

$$F_s = \frac{[-4.8356+(-5.7477)]-(-0.9145)}{2}$$
$$= -4.8344$$

$$\tan a = \frac{\sqrt{2}[(-4.8344)-(-4.856)]}{-0.0471}$$
$$a = 177.91^\circ$$

Therefore, the sample mean of $-5.00/-1.00\times180, -4.75/-0.75\times175$ and $-4.75/-1.00\times178$ is $-4.83/-0.91\times178$.

3.3.2 Determining the sample variance-covariance

The variance-covariance that corresponds to vector **h** (Harris, 1990a; Harris, 1990c; Harris, 1992) is:

$$\mathbf{S} = \frac{1}{n-1}\sum_{i=1}^{n}(\mathbf{h}_i - \bar{\mathbf{h}})(\mathbf{h}_i - \bar{\mathbf{h}})' \qquad \text{(Equation 3.8)}$$

S is a 3×3 square matrix (the calculation of a column vector multiplied by its transpose is shown in Appendix 1), written in terms of its components s_{ij} as:

$$\mathbf{S} = \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{pmatrix}$$

The variance-covariance is symmetric (i.e. $s_{ij}=s_{ji}$) and has only six distinct components: three are variances (along the diagonal) and three are covariances; s_{11},

s_{22} and s_{33} are the variances of the component h_1, h_2 and h_3 respectively; s_{12} is the covariance of h_1 and h_2; s_{13} is the covariance of h_1 and h_3 and s_{23} is the covariance of h_2 and h_3.

From the above example, the variance-covariance of the three refractive errors is calculated:

$$\mathbf{h}_1 - \bar{\mathbf{h}} = \begin{pmatrix} -5.0000 + 4.8356 \\ 0.0000 + 0.0471 \\ -6.0000 + 5.7477 \end{pmatrix} = \begin{pmatrix} -0.1644 \\ 0.0471 \\ -0.2523 \end{pmatrix} (\mathrm{D})$$

$$\mathbf{h}_2 - \bar{\mathbf{h}} = \begin{pmatrix} -4.7577 + 4.8356 \\ -0.0921 + 0.0471 \\ -5.4943 + 5.7477 \end{pmatrix} = \begin{pmatrix} -0.0779 \\ -0.045 \\ 0.2534 \end{pmatrix} (\mathrm{D})$$

$$\mathbf{h}_3 - \bar{\mathbf{h}} = \begin{pmatrix} -4.7512 + 4.8356 \\ -0.0493 + 0.0471 \\ -5.7488 + 5.7477 \end{pmatrix} = \begin{pmatrix} 0.0844 \\ -0.0022 \\ -0.0011 \end{pmatrix} (\mathrm{D})$$

Then substituting these values into Equation 3.8,

$$\mathbf{S} = \frac{1}{2}\left[\begin{pmatrix} 0.027 & -0.008 & 0.042 \\ -0.008 & 0.002 & -0.012 \\ 0.042 & -0.002 & 0.064 \end{pmatrix} + \begin{pmatrix} 0.006 & -0.004 & 0.020 \\ -0.004 & 0.002 & -0.011 \\ 0.020 & -0.011 & 0.064 \end{pmatrix} + \begin{pmatrix} 0.007 & -0.000 & -0.000 \\ -0.000 & 0.000 & 0.000 \\ -0.000 & 0.000 & 0.000 \end{pmatrix}\right]$$

$$= \begin{pmatrix} 0.02 & -0.01 & 0.03 \\ -0.01 & 0.00 & -0.01 \\ 0.03 & -0.01 & 0.06 \end{pmatrix} (\mathrm{D}^2)$$

3.4 Hypothesis testing

Multivariate statistical tests can be used to analyse the familiar sphero-cylinder representation, after transformation to vector **h** and determination of the mean and variance (Harris, 1992). Testing hypotheses regarding the mean and/or variance-covariance can be done for one or more populations (Harris, 1992). Three computer programs, developed using Matlab (The MathWorks Inc, Natick, MA), were used in this study to compare the means of one, two, and more than two samples. The underlying assumptions are that the populations in question are normally distributed and have the same variance-covariance. The tests for the multivariate normality are detailed in Appendix 2.

3.4.1 Testing the mean of a single sample

This test is used to determine if the mean of a random sample is different from a known value. It is used here to test if the mean difference between two variables is equal to zero, when the measures are paired. Suppose that a population of dioptric powers represented as 3×1 vectors has a multivariate normal distribution with mean $\boldsymbol{\mu}$ and variance-covariance Σ. The population can be written in Wilks' symbol as:

$$\mathbf{h} \sim \mathrm{N}_3(\boldsymbol{\mu}, \Sigma) \qquad \text{(Equation 3.9)}$$

A random sample of size n is drawn from the population: it consists of $\mathbf{h}_1, \mathbf{h}_2, \ldots, \mathbf{h}_n$. The sample mean $\bar{\mathbf{h}}$ and the sample variance-covariance $\mathbf{S}$ are given by Equation 3.7 and 3.8 respectively.

Suppose $\boldsymbol{\mu}_0$ is some known 3×1 vector. The null hypothesis and the alternative hypothesis to be tested are:

$$H_0 : \boldsymbol{\mu} = \boldsymbol{\mu}_0 \qquad \text{(Equation 3.10)}$$

$$H_1 : \boldsymbol{\mu} \neq \boldsymbol{\mu}_0 \qquad \text{(Equation 3.11)}$$

Hotelling's T^2 (Johnson and Wichern, 1998: pp226), also known as statistic T^2, is

$$\begin{aligned} T^2 &= \left(\overline{\mathbf{h}} - \boldsymbol{\mu}_0\right)' \left(\frac{\mathbf{S}}{n}\right)^{-1} \left(\overline{\mathbf{h}} - \boldsymbol{\mu}_0\right) \\ &= n\left(\overline{\mathbf{h}} - \boldsymbol{\mu}_0\right)' \mathbf{S}^{-1} \left(\overline{\mathbf{h}} - \boldsymbol{\mu}_0\right) \end{aligned} \qquad \text{(Equation 3.12)}$$

H_0 is rejected in favour of H_1 at level of significance α if :

$$\frac{T^2}{n-1}\frac{n-3}{3} > F_{\alpha,3,n-3} \qquad \text{(Equation 3.13)}$$

where $F_{\alpha,3,n-3}$ is obtained from the F-distribution with 3 and $n-3$ degrees of freedom.

A Matlab program was written for running this multivariate analysis (*see* Appendix A3.1). This program was used in Study 1, 2 and 3 to determine whether the mean difference between two measures taken by one observer and/or by two observers was statistically significant different from zero. Thus, the population mean, $\boldsymbol{\mu}_0$, is set to zero, i.e. $\boldsymbol{\mu}_0 = \mathbf{0}$.

3.4.2 Testing the means of two samples

The test described below is used to compare the means of two samples, and it is used here when the number of measures taken is different between the two samples. Assume two populations distributed as $\mathrm{N}_3(\boldsymbol{\mu}_1, \Sigma_1)$ and $\mathrm{N}_3(\boldsymbol{\mu}_2, \Sigma_2)$. Random sample of sizes n_1 and n_2 are taken from the two populations. They are $\mathbf{h}_{11}, \mathbf{h}_{12}, \ldots, \mathbf{h}_{1n_1}$ and $\mathbf{h}_{21}, \mathbf{h}_{22}, \ldots, \mathbf{h}_{2n_2}$. The samples are independent of one another. The sample means $\overline{\mathbf{h}_1}$ and $\overline{\mathbf{h}_2}$ for each sample are given by Equations 3.7.

The samples variance-covariance are $\mathbf{S}_1$ and $\mathbf{S}_2$ for each sample are given by Equation 3.8.

Suppose $\boldsymbol{\delta}_0$ is some known 3×1 vector. The null hypothesis and the alternative hypothesis are:

$$H_0 : \boldsymbol{\mu}_1 - \boldsymbol{\mu}_2 = \boldsymbol{\delta}_0 \qquad \text{(Equation 3.14)}$$

$$H_1 : \boldsymbol{\mu}_1 - \boldsymbol{\mu}_2 \neq \boldsymbol{\delta}_0 \qquad \text{(Equation 3.15)}$$

Hotelling's T^2 now is

$$T^2 = \left(\overline{\mathbf{h}_1} - \overline{\mathbf{h}_2} - \boldsymbol{\delta}_0\right)' \left[\mathbf{S}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)\right]^{-1} \left(\overline{\mathbf{h}_1} - \overline{\mathbf{h}_2} - \boldsymbol{\delta}_0\right) \qquad \text{(Equation 3.16)}$$

where $\mathbf{S} = \frac{\left[(n_1 - 1)\mathbf{S}_1 + (n_2 - 1)\mathbf{S}_2\right]}{n_1 + n_2 - 2}$, (Equation 3.17)

$$\mathbf{S}_1 = \frac{\sum_{i=1}^{n_1} \left(\mathbf{h}_{1i} - \overline{\mathbf{h}}\right)\left(\mathbf{h}_{1i} - \overline{\mathbf{h}}\right)'}{n_1 - 1} \text{ and} \qquad \text{(Equation 3.18)}$$

$$\mathbf{S}_2 = \frac{\sum_{i=1}^{n_2} \left(\mathbf{h}_{2i} - \overline{\mathbf{h}}\right)\left(\mathbf{h}_{2i} - \overline{\mathbf{h}}\right)'}{n_2 - 1} \qquad \text{(Equation 3.19)}$$

H_0 is then rejected in favour of H_1 at level of significance α if and only if:

$$\frac{T^2}{n_1+n_2-2}\frac{n_1+n_2-3-1}{3} > F_{\alpha,3,n_1+n_2-3-1} \qquad \text{(Equation 3.20)}$$

where $F_{\alpha,3,n_1+n_2-3-1}$ is obtained from the usual table of the F-distribution with 3 and n_1+n_2-3-1 degrees of freedom.

A Matlab program was written for the purpose of running this multivariate analysis (*see* Appendix A3.2). This program was performed in Study 2 to determine tonic accommodation of which refractive groups were statistically significant different from others. The test was performed by setting $\boldsymbol{\delta}_0 = \mathbf{0}$.

3.4.3 Testing the means of three samples

Multivariate testing can be done on more than two samples, however, in the present study only three samples groups will be considered. Suppose there are 3 populations of **h** vectors distributed as $N_3(\boldsymbol{\mu}_1,\Sigma_1)$, $N_3(\boldsymbol{\mu}_2,\Sigma_2)$, $N_3(\boldsymbol{\mu}_3,\Sigma_3)$. Independent random samples of size n_1, n_2 and n_3. They are $\mathbf{h}_{p1},\mathbf{h}_{p2},...,\mathbf{h}_{pn_p}$ for $p = 1, 2$ and 3. The sample means and sample variance-covariances are $\overline{\mathbf{h}_p}$ and $\mathbf{S}_p$, again for $p = 1, 2$ and 3.

The null hypothesis is

$$H_0 : \boldsymbol{\mu}_1 = \boldsymbol{\mu}_2 = \boldsymbol{\mu}_3 \qquad \text{(Equation 3.21)}$$

and the alternative hypothesis

$$H_1 : \text{either one } \boldsymbol{\mu} \text{ was not equal to the others} \qquad \text{(Equation 3.22)}$$

This is a multivariate generalization of one-way analysis of variance (ANOVA) called MANOVA (Johnson and Wichern, 1998: p.320-322). As in ANOVA, sum of squares are calculated between-groups and within-groups, except that the squares are outer squares of vectors. The overall sample mean is

$$\bar{\mathbf{h}} = \frac{\sum_{t=1}^{3}\sum_{i=1}^{n_t}\mathbf{h}_{ti}}{n} \qquad \text{(Equation 3.23)}$$

Then the sum of squares between-group is

$$\mathbf{B} = \sum_{t=1}^{3} n_t \left(\overline{\mathbf{h}_t} - \bar{\mathbf{h}}\right)\left(\overline{\mathbf{h}_t} - \bar{\mathbf{h}}\right)' \qquad \text{(Equation 3.24)}$$

and the sum of outer squares within-group is

$$\begin{aligned}\mathbf{W} &= \sum_{t=1}^{3}\sum_{i=1}^{n_k}\left(\mathbf{h}_{ti} - \bar{\mathbf{h}}_t\right)\left(\mathbf{h}_{ti} - \bar{\mathbf{h}}_t\right)' \\ &= \sum_{t=1}^{3}(n_t - 1)\mathbf{S}_t\end{aligned} \qquad \text{(Equation 3.25)}$$

The statistic known as Wilks lambda (Johnson and Wichern, 1998: pp320-322) is defined by

$$\Lambda^* = \frac{\det \mathbf{W}}{\det(\mathbf{W} + \mathbf{B})} \qquad \text{(Equation 3.27)}$$

where $\det \mathbf{W}$ and $\det(\mathbf{W}+\mathbf{B})$ are the determinants of $\mathbf{W}$ and of $\mathbf{W}+\mathbf{B}$ respectively.

H_0 is rejected at level of significance α if

$$\frac{1-\sqrt{\Lambda^*}}{\sqrt{\Lambda^*}}\frac{n-3-2}{3} > F_{\alpha,2(3),2(n-3-2)} \quad \text{(Equation 3.28)}$$

where $F_{\alpha,2(3),2(n-3-2)}$ is obtained from table of the F-distribution with 2(3) and $2(n-3-2)$ degrees of freedom.

A Matlab program was written to compare three sample means (*see* Appendix A3.3). It was used in Study 2 to compare tonic accommodation taken in three refractive groups. It was also used in Study 3 to compare accommodative lag taken in three stimuli conditions and also the difference between accommodative lag taken in three refractive groups.

3.5 Vector dioptric distance (VDD)

As vector **h** gives little impression of the power of the lens, a scalar measure, vector dioptric distance (VDD), was used to describe the difference between two measures in a one-dimensional dioptric unit (Harris, 1990b; Harvey *et al.*, 1997; Harris, 1998; Harvey *et al.*, 2000). VDD is the distance between two data points in symmetric dioptric power space.

The formula for VDD is as follows:

$$\text{VDD} = \sqrt{(h_{11} - h_{12})^2 + (h_{21} - h_{22})^2 + (h_{31} - h_{32})^2} \qquad \text{(Equation 3.27)}$$

where h_{11} and h_{12} are h_1 for measurement 1 and measurement 2, h_{21} and h_{22} are h_2 for measurement 1 and measurement 2, h_{31} and h_{32} are h_3 for measurement 1 and measurement 2.

3.6 Summary

Refractive error is normally recorded in sphero-cylinder format $(F_s / F_c \times axis)$, a format not amenable to mathematical manipulation. Refractive error is often converted to the spherical equivalent in order to carry out statistic testing. However, this was not ideal as the reduction from a three-dimensional to one-dimensional concept results in loss of information. Coordinate vector **h** can overcome this problem.

A multivariate analysis called MANOVA was used to perform statistical analysis of coordinate vector **h**. However, as vector **h** gives little impression of the power of the lens, a scalar measure, vector dioptric distance (VDD), was used to describe the difference between two measures in a one-dimensional dioptric unit.

Chapter 4

Study 1: Clinical evaluation of the Shin-Nippon SRW-5000 autorefractor in children

4.1 Introduction

Autorefraction is commonly used for measuring refraction in children, both with and without cycloplegia. Autorefraction provides a fast assessment of refractive status, independent of the experience of the examiner, and needs little subject cooperation. Children have strong accommodation ability, and instrument myopia may be induced during autorefraction. When this occurs hyperopia will be underestimated or myopia overestimated. An open-field autorefractor allows a binocular field of view through a large beam splitter and permits fixation of an external target; hence instrument myopia should be less compared with a "closed-field" instrument in which the target is inside the autorefractor.

The purpose of Study 1 is to measure the accuracy and reliability of the Shin-Nippon SRW-5000 in a pediatric population. Accuracy is defined as the closeness of agreement between a test result and the accepted reference value (ISO 5725, 1994). In the present study, the cycloplegic subjective refraction result was used as reference value (or "gold standard").

Two measures of reliability, repeatability and reproducibility, were considered. Repeatability is the closeness of agreement between independent test results obtained under identical conditions, and reproducibility is the closeness of the results obtained with identical experimental setups but, in this case, with different examiners (ISO 5725, 1994). In clinical papers, repeatability and reproducibility are sometime referred to as intra-examiner repeatability and inter-examiner repeatability respectively.

4.2 Objectives

In Study 1, we compared the following:

Accuracy -

1) cycloplegic subjective refraction with cycloplegic SRW-5000 autorefraction,
2) cycloplegic subjective refraction with non-cycloplegic SRW-5000 autorefraction,

In relation to accuracy, but without the use of a "gold standard" -

3) cycloplegic SRW-5000 with non-cycloplegic SRW-5000 autorefraction, and
4) non-cycloplegic SRW-5000 autorefraction with non-cycloplegic conventional "closed-field" autorefraction (Canon, RK5)

Reliability -

5) two SRW-5000 measures taken by one observer both with cycloplegia,
6) two SRW-5000 measures taken by one observer both without cycloplegia,
7) two SRW-5000 measures taken by two observers both with cycloplegia, and
8) two SRW-5000 measures taken by two observers both without cycloplegia.

4.3 Methods

4.3.1 Subjects

A total of 53 children from age 4 to 8 (mean 6.45, SD 1.36) years were recruited through the Optometry Clinic at The Hong Kong Polytechnic University and from international schools in Hong Kong. The study was first described to the parent by the researcher, then the Information Sheet (Appendix 4) was read by the parent, who then had the opportunity to ask questions. An informed consent form (Appendix 5) was signed by the parent before any measurement was taken. The parents of 44 children (mean age 6.55, SD 1.37 years) agreed that they should participate in cycloplegic measurements. All subjects had correctable distance and near vision of at least 0.2 LogMAR units (6/9 Snellen) or better in each eye. No subject had heterotropia or suppression.

4.3.2 Visual acuity

Visual acuity was measured using a log MAR chart. The chart was placed at 6 m and children were encouraged to read the lowest line they could read monocularly and then binocularly. The record sheet used to record VA is shown in Appendix 6.

4.3.3 Non-cycloplegic refraction

All refractions were carried out by the same examiner (SC). Retinoscopy was performed 50 cm from the eye and a lens bar was used to neutralize the retinoscopic reflex. Subjective refraction was then used to refine the spherical power in –0.25 D steps and a ±0.25 D Jackson crossed cylinder was used to refine first the cylinder axis and then power. In the case of children who were not able to respond to this technique, a fogging technique utilizing a fan and block chart was used to determine the cylinder axis and a ±0.50 D Jackson crossed cylinder was used to find the cylinder power. The above tests were performed on first the right eye and then the left eye.

4.3.4 Non-cycloplegic autorefraction

The instrument optical axis was first lined up with the target (the detailed procedure is given in Appendix 7). Non-cycloplegic autorefraction was first carried out, using the Shin-Nippon SRW-5000 autorefractor. Reading printed out from the autorefractor was called "representative value". It was calculated by the instrument, after 4 measurements were taken. Two "representative values" were obtained by the same examiner (SC). Both eyes were tested and the order was randomized. The second examiner (PC) then took another "representative value" for each eye, with the order of measurement again being randomised. Measurement from two examiners were taken within 15 minutes. All the autorefraction measurements using SRW-5000 were taken using the same standardized procedure described in Appendix 7.

Non-cycloplegic autorefraction was also carried out using a conventional "closed-field" autorefractor, the Canon RK5. The subject was asked to fixate the red house inside the instrument and 4 measurements were taken, according to the manufacturer's instructions, and, an average value, calculated by the instrument, was printed out. Two independent average values were obtained, one followed immediately by another.

4.3.5 Cycloplegic refraction

Cyclopentolate hydrochloride 1 % was used to achieve cycloplegia. One drop of 0.4 % benoxinate hydrochloride was first instilled to reduce the time to achieve adequate cycloplegia (Siu *et al.*, 1999). One drop of cyclopentolate hydrochloride 1 % was then instilled, and a further drop 5 minutes later. The pupil reaction was checked after 30 minutes and a further single drop was instilled if the pupil still reacted vigorously to light. The refraction and autorefraction procedures were repeated, as described above, after the amplitude of accommodation was less than 2.00 D. Amplitude of accommodation was checked monocularly, using an RAF rule. A line of letters corresponding to the subject's best near VA was slowly pushed toward the subjects' eye. The subject was asked to try to keep the target clear and to report when the letter began to blur and remained blurred.

4.3.6 Cycloplegic autorefraction

After the cycloplegic refraction, two independent sets of representative SRW-5000 values were obtained by examiner SC, and a third set by examiner PC. Also an average value was obtained by examiner SC, using the RK5. All the procedures were as stated in Section 4.3.4.

4.4 Results

Findings were similar for the two eyes and are presented for the right eye only. The range of refractive errors found by cycloplegic refraction was from +4.75 D to –3.25 D in spherical power and from plano to –4.00 D in cylindrical power.

4.4.1 Accuracy

The accuracy of the SRW-5000 was determined by the differences obtained in following comparisons:

A: Cycloplegic refraction minus cycloplegic SRW-5000 autorefraction,

B: Cycloplegic refraction minus non-cycloplegic SRW-5000 autorefraction.

In order to provide clinicians with guidelines as to the use of cycloplegia with the SRW-5000, we also calculated:

C: Cycloplegic SRW-5000 minus non-cycloplegic SRW-5000 autorefraction.

The accuracy of the RK5 closed-field autorefractor was determined via:

D: Cycloplegic refraction minus cycloplegic RK5 autorefraction, and

E: Cycloplegic refraction minus non-cycloplegic RK5 autorefraction.

And finally the two autorefractors were compared:

F: Non-cycloplegic RK5 minus non-cycloplegic SRW-5000 autorefraction.

The mean differences for each comparison both in vector **h** and in sphero-cylinder format, as well as the means and standard deviations of VDD for each comparison were calculated and are shown in Table 4.1.

The mean differences between two measures were compared by multivariate analysis (data were normally distributed, *see* Appendix A2.2). The values of the T^2 statistic in each comparison are shown in Table 4.2. The values of $F_{0.05,3,n-3}$ were between 2.79 and 2.83 and the differences were statistically significant in each comparison (p=0.02 in Comparison D, p<0.001 in Comparison F and p<0.0001 in

Comparison A, B, C and E). The 95 % limits of agreement for each vector **h** component in those comparisons are shown in Table 4.3.

Comparison	$\bar{\mathbf{h}}$	Mean sphero-cylinder	Mean VDD [SD]
A (n=44)	$\begin{pmatrix} 0.186 \\ 0.088 \\ 0.290 \end{pmatrix}$	$+0.32/-0.16\times 64$	0.60 [0.33]
B (n=44)	$\begin{pmatrix} 0.627 \\ 0.104 \\ 0.612 \end{pmatrix}$	$+0.69/-0.14\times 41$	0.98 [0.51]
C (n=44)	$\begin{pmatrix} 0.441 \\ 0.016 \\ 0.323 \end{pmatrix}$	$+0.44/-0.12\times 7$	0.74 [0.56]
D (n=44)	$\begin{pmatrix} -0.117 \\ 0.064 \\ -0.008 \end{pmatrix}$	$-0.00/-0.14\times 71$	0.48 [0.39]
E (n=44)	$\begin{pmatrix} 0.382 \\ 0.091 \\ 0.578 \end{pmatrix}$	$+0.61/-0.25\times 74$	0.83 [0.64]
F (n=53)	$\begin{pmatrix} 0.249 \\ 0.004 \\ 0.027 \end{pmatrix}$	$+0.25/-0.22\times 180$	0.60 [0.32]

Table 4.1 Mean differences in vector **h** and conventional sphero-cylinder notation as well as the mean differences and the standard deviations of VDD for each comparison. The units for all components are diopters (D). See text for details of comparisons made (p.47).

Comparison	Variance-covariance matrice (D^2)	T^2
A (n=44)	$\begin{pmatrix} 0.11 & -0.03 & 0.09 \\ -0.03 & 0.06 & -0.02 \\ 0.09 & -0.02 & 0.17 \end{pmatrix}$	36.7
B (n=44)	$\begin{pmatrix} 0.18 & 0.01 & 0.13 \\ 0.01 & 0.06 & -0.01 \\ 0.13 & -0.01 & 0.21 \end{pmatrix}$	114.9
C (n=44)	$\begin{pmatrix} 0.28 & -0.01 & 0.20 \\ -0.01 & 0.05 & 0.00 \\ 0.20 & 0.00 & 0.25 \end{pmatrix}$	31.9
D (n=44)	$\begin{pmatrix} 0.18 & 0.02 & 0.06 \\ 0.02 & 0.03 & 0.00 \\ 0.06 & 0.00 & 0.16 \end{pmatrix}$	12.08
E (n=44)	$\begin{pmatrix} 0.24 & -0.01 & 0.21 \\ -0.01 & 0.04 & 0.03 \\ 0.22 & 0.03 & 0.34 \end{pmatrix}$	45.7
F (n=53)	$\begin{pmatrix} 0.17 & 0.03 & 0.06 \\ 0.03 & 0.05 & 0.03 \\ 0.06 & 0.03 & 0.17 \end{pmatrix}$	22.3

Table 4.2 The variance-covariance and the T^2 statistic values for each comparison. See text for details of comparisons made (p.47).

Comparison	h_1 (D)	h_2 (D)	h_3 (D)
A	–0.46 to 0.83	–0.41 to 0.59	–0.51 to 1.09
B	–0.21 to 1.47	–0.37 to 0.57	–0.29 to 1.51
C	–0.59 to 1.47	–0.43 to 0.46	–0.66 to 1.31
D	–0.96 to 0.73	–0.27 to 0.40	–0.78 to 0.77
E	–0.59 to 1.35	–0.30 to 0.48	–0.57 to 1.37
F	–0.60 to 1.10	–0.42 to 0.43	–0.79 to 0.84

Table 4.3 The 95 % limits of agreement for each component of vector **h**. See text for details of comparison mead (p.47).

To facilitate comparison of these results with those of others, the 95% limit of agreement for each separate sphero-cylinder component, namely sphere (negative cylinder format), cylinder and spherical equivalent are given in Table 4.4.

Comparison	Fs (D)	Fc (D)	SE (D)
A	−0.44 to 0.71	−0.48 to 0.90**	−0.24 to 0.90*
B	−0.31 to 1.35**	−0.44 to 0.84**	−0.17 to 1.41**
C	−0.49 to 1.27**	−0.65 to 0.63	−0.56 to 1.32**
D	−0.91 to 0.70	−0.88 to 1.04	−0.73 to 0.60
E	−0.60 to 1.38**	−0.65 to 1.01	−0.51 to 1.47**
F	−0.64 to 0.93	−1.04 to 0.99	−0.54 to 0.81

Table 4.4 The 95 % limits of agreement for sphero-cylinder component: sphere (Fs), cylinder (Fc) and spherical equivalent (SE). * indicates $p<0.01$ and ** $p<0.001$. See text for details of comparisons made (p.47).

4.4.1.1 Three-dimensional scatter-plots

Figure 4.1 to 4.6 are scatter plots showing the differences in paired data obtained in Comparisons A to F. The origin of the graphs represents zero difference, and the axis ticks each represent 0.50 D. The closer the data points are grouped, the smaller the variability of the difference between two means and the closer the data are grouped around the origin, the less the difference from zero of the two measures.

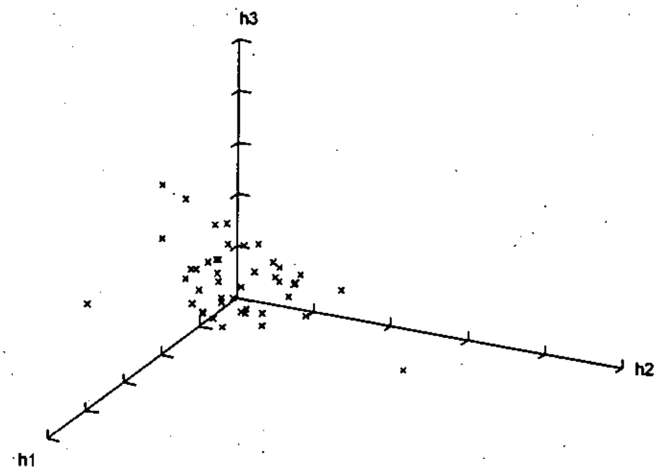


Figure 4.1 Scatter plot of the differences between cycloplegic refraction and cycloplegic SRW-5000 autorefraction measures (Comparison A).

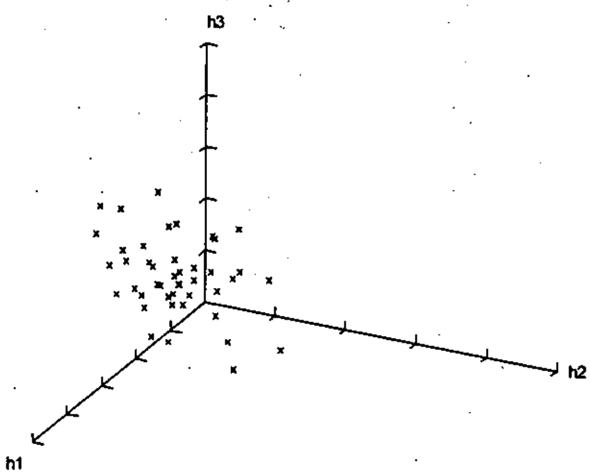


Figure 4.2 Scatter plot of the differences between cycloplegic refraction and non-cycloplegic SRW-5000 autorefraction measures (Comparison B).

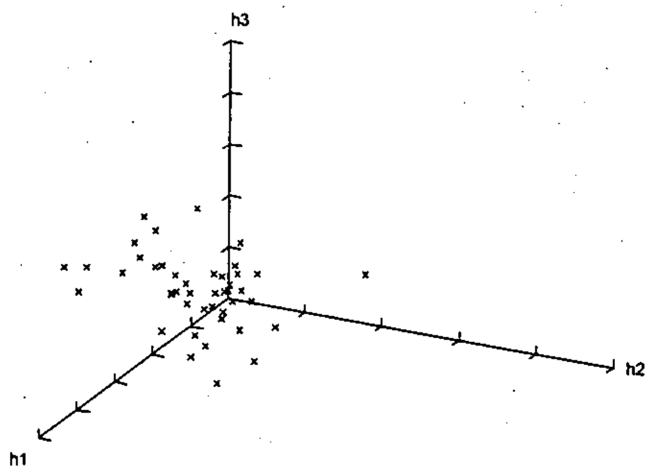


Figure 4.3 Scatter plot of the differences between cycloplegic SRW-5000 and non-cycloplegic SRW-5000 measures (Comparison C).

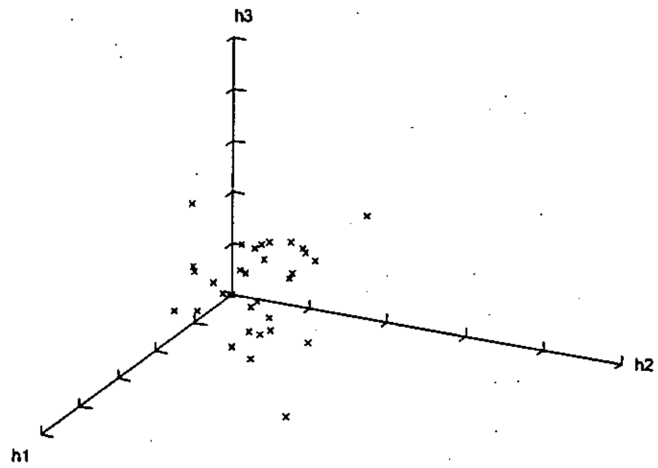


Figure 4.4 Scatter plot of the differences between cycloplegic refraction and cycloplegic RK5 autorefraction measures (Comparison D).

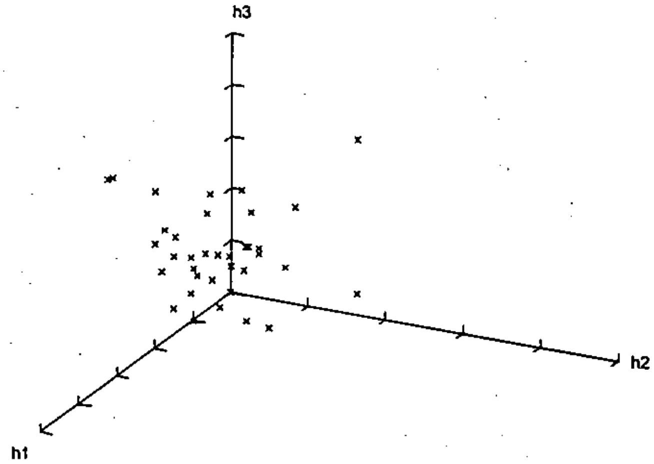


Figure 4.5 Scatter plot of the differences between cycloplegic refraction and non-cycloplegic RK5 autorefraction measures (Comparison E).

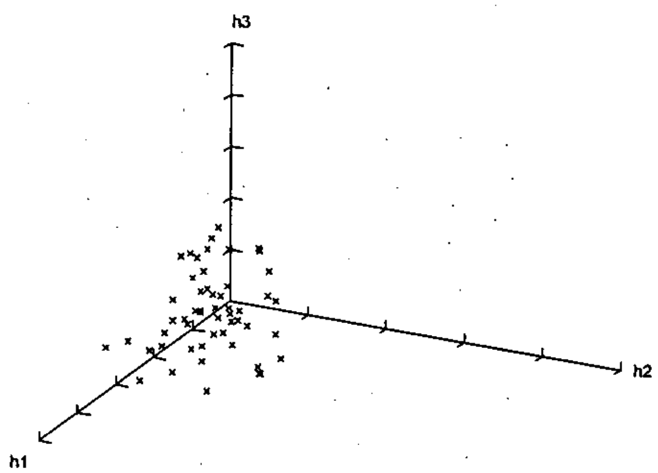


Figure 4.6 Scatter plot of the differences between non-cycloplegic RK5 and non-cycloplegic SRW-5000 measures (Comparison F).

4.4.1.2 Conventional plots

A more familiar representation of paired results is a simple x-y plot, along with a statement of correlation and linear relationship. Correlation on its own, of course, does not measure agreement, being a measure of relationship. However when presented along with the slope of the regression line, it does provide valuable information.

Figures 4.7 to 4.11 show the plot and regression line for the spherical equivalent found in Comparison A to F. In the figures, the solid lines represent perfect agreement between tested measures and the gold standard (cycloplegic refraction in this study), and the dotted line is the regression line.

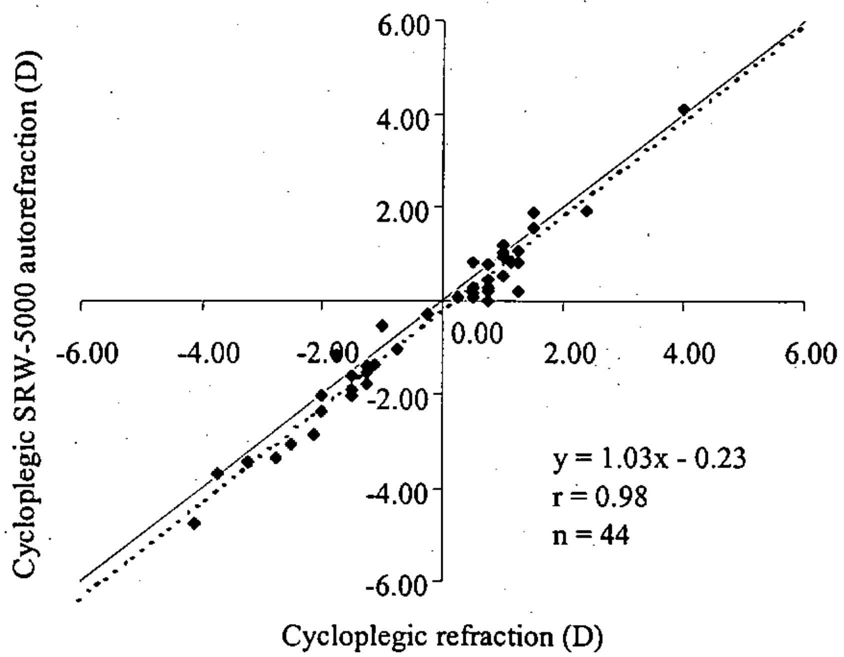


Figure 4.7 Spherical equivalent (SE) found by cycloplegic refraction (x-axis) plotted against SE found by cycloplegic SRW-5000 autorefraction.

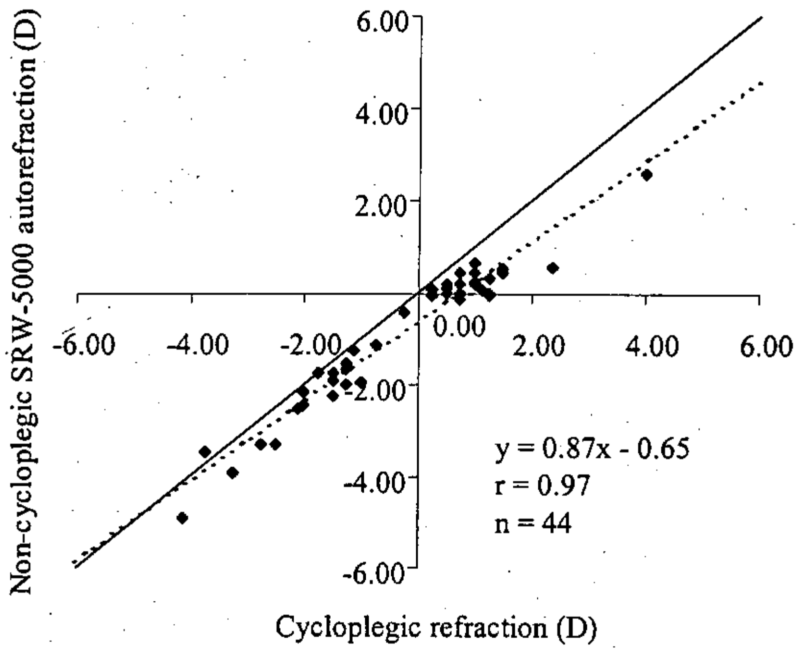


Figure 4.8 Spherical equivalent (SE) found by cycloplegic refraction (x-axis) plotted against SE found by non-cycloplegic SRW-5000 autorefraction.

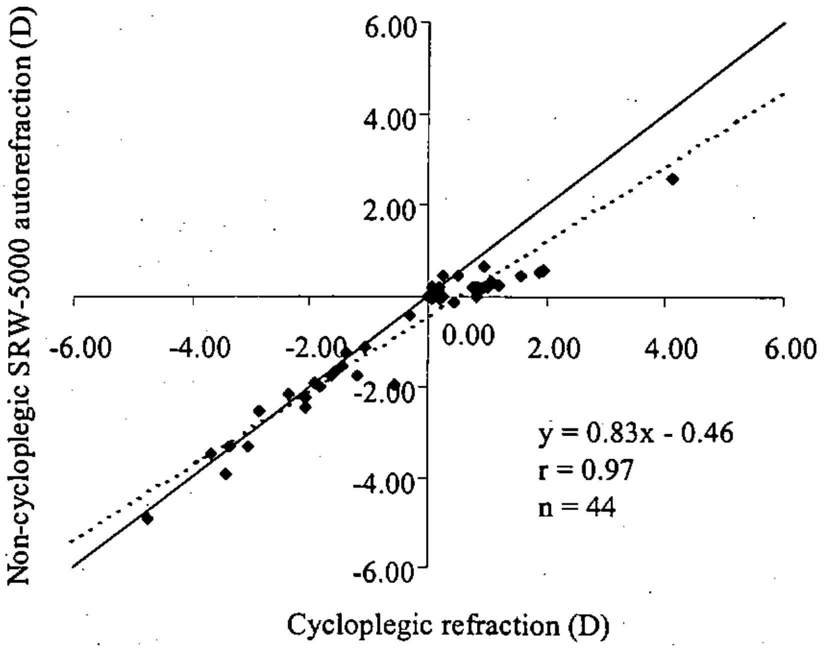


Figure 4.9 Spherical equivalent (SE) found by cycloplegic SRW-5000 autorefraction (x-axis) plotted against SE found by non-cycloplegic SRW-5000 autorefraction.

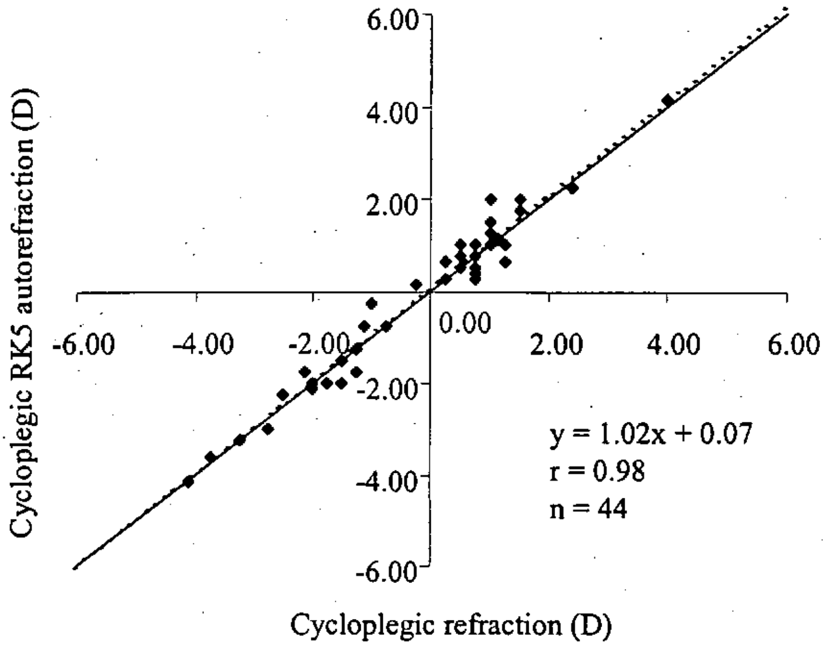


Figure 4.10 Spherical equivalent (SE) found by cycloplegic refraction (x-axis) plotted against SE found by cycloplegic RK5 autorefraction.

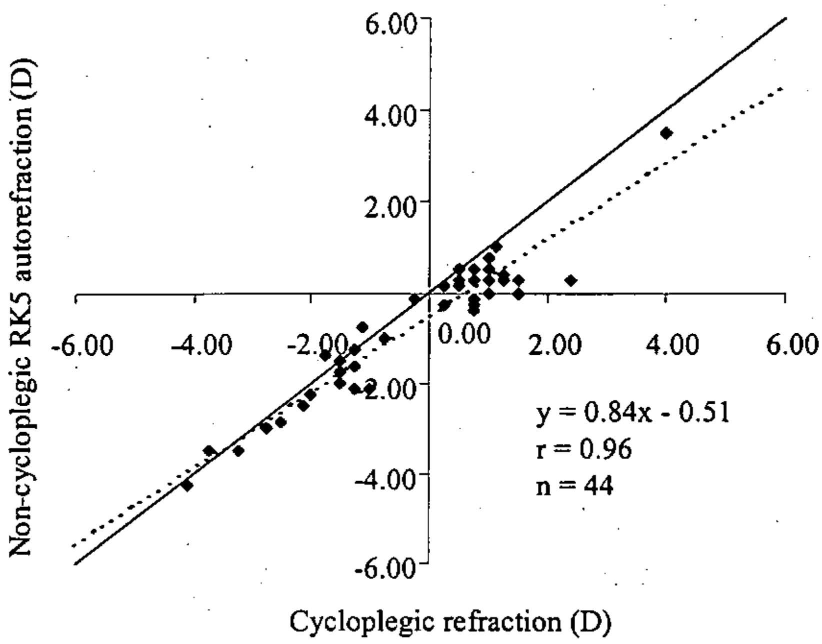


Figure 4.11 Spherical equivalent (SE) found by cycloplegic refraction (x-axis) plotted against SE found by non-cycloplegic RK5 autorefraction.

4.4.2 Reliability

The reliability of the SRW-5000 was determined for cycloplegic and non-cycloplegic conditions, namely

G: Comparison of two cycloplegic SRW-5000 measures taken by one observer

H: Comparison of two cycloplegic SRW-5000 measures taken by two observers

I: Comparison of two non-cycloplegic SRW-5000 measures taken by one observer

J: Comparison of two non-cycloplegic SRW-5000 measures taken by two observers

Figures 4.12 to 4.15 show the results for Comparisons G to J. Again the origin represents zero difference, and the axis ticks each represent 0.50 D. Visual inspection suggests that the data points are slightly less scattered under cycloplegic conditions than under non-cycloplegic conditions.

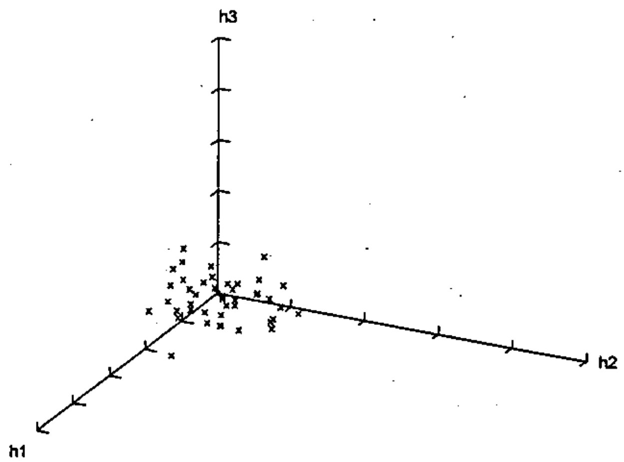


Figure 4.12 Scatter plot of the differences between two measures taken by one observer under cycloplegic conditions (Comparison G).

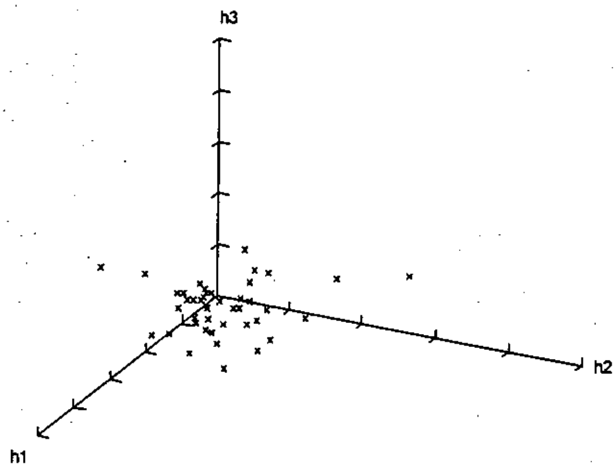


Figure 4.13 Scatter plot of the differences between two measures by two observers under cycloplegic conditions (Comparison H).

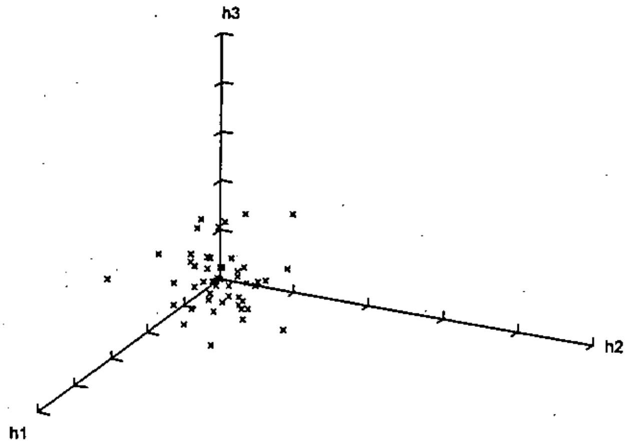


Figure 4.14 Scatter plot of the differences between two measures by one observer in non-cycloplegic eyes (Comparison I).

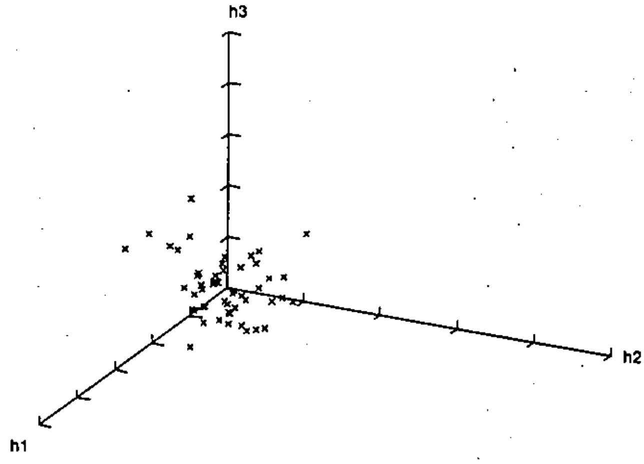


Figure 4.15 Scatter plot of the differences between two measures by two observers in non-cycloplegic eyes (Comparison J).

The mean differences between measures, in both vector **h** and sphero-cylinder format, are given in Table 4.5. The means and standard deviations of VDD were calculated for each comparison and are also shown in Table 4.5. No statistically significant differences in VDD were found for any comparison (repeated-measures ANOVA: $F_{3,43}=2.35$, $p=0.08$). Again, the mean differences between two measures were tested by multivariate analysis and the T^2 statistic for each comparison are shown in Table 4.6. No significant differences were found, except in Comparison H ($p=0.03$).

Observation of the entries along the diagonal of the variance-covariance matrices in Table 4.6, suggested that the repeatability and reproducibility of spherical power and cylindrical power were similar for cycloplegic and non-cycloplegic eyes in cases of measures taken by both one and two observers. The 95 % limits of agreement of each vector **h** component were calculated and are shown in Table 4.7.

Figures 4.16 to 4.19 show the means plotted against the difference for each pair of spherical equivalent (SE) values for Comparisons G to J.

Comparison	$\bar{h}$	Mean sphero-cylinder	Mean VDD [SD] (D)
G (n=44)	$\begin{pmatrix} 0.019 \\ 0.030 \\ -0.032 \end{pmatrix}$	$+0.03/-0.07\times 20$	0.35 [0.16]
H (n=44)	$\begin{pmatrix} -0.031 \\ 0.022 \\ -0.116 \end{pmatrix}$	$-0.03/-0.09\times 9$	0.44 [0.23]
I (n=53)	$\begin{pmatrix} 0.003 \\ 0.000 \\ 0.007 \end{pmatrix}$	$+0.00/-0.01\times 180$	0.38 [0.24]
J (n=53)	$\begin{pmatrix} -0.028 \\ -0.033 \\ -0.020 \end{pmatrix}$	$-0.00/-0.04\times 128$	0.43 [0.29]

Table 4.5 Mean differences using vector **h** and conventional sphero-cylinder notation, and the mean differences and standard deviations of VDD. See text for details of comparisons made (p.57).

Again, to enable the comparison of our results with those others, the 95 % limit of agreement for sphere, cylinder and spherical equivalent is given in Table 4.8. There were no statistic significant differences in any comparison (repeated-measures ANOVA).

Comparison	**Variance-covariance matrices (D^2)**	**T^2**
G (n=44)	$\begin{pmatrix} 0.05 & 0.01 & 0.02 \\ 0.01 & 0.05 & 0.01 \\ 0.02 & 0.01 & 0.04 \end{pmatrix}$	0.07
H (n=44)	$\begin{pmatrix} 0.10 & -0.02 & 0.03 \\ -0.02 & 0.08 & 0.01 \\ 0.03 & 0.01 & 0.07 \end{pmatrix}$	0.23
I (n=53)	$\begin{pmatrix} 0.07 & 0.01 & 0.03 \\ 0.01 & 0.04 & 0.01 \\ 0.02 & 0.01 & 0.09 \end{pmatrix}$	<0.01
J (n=53)	$\begin{pmatrix} 0.11 & 0.05 & 0.05 \\ 0.05 & 0.07 & 0.02 \\ 0.05 & 0.02 & 0.09 \end{pmatrix}$	0.02

Table 4.6 The variance-covariance and the T^2 statistic results for reliability under cycloplegic and non-cycloplegic conditions. See text for details of comparisons made (p.57).

Comparison	h_1 **(D)**	h_2 **(D)**	h_3 **(D)**
G	–0.43 to 0.47	–0.43 to 0.49	–0.44 to 0.38
H	–0.64 to 0.57	–0.52 to 0.56	–0.62 to 0.38
I	–0.54 to 0.55	–0.38 to 0.38	–0.60 to 0.62
J	–0.70 to 0.64	–0.50 to 0.64	–0.64 to 0.60

Table 4.7 The 95 % limits of agreement for each component of vector **h**. See text for details of comparisons made (p.57).

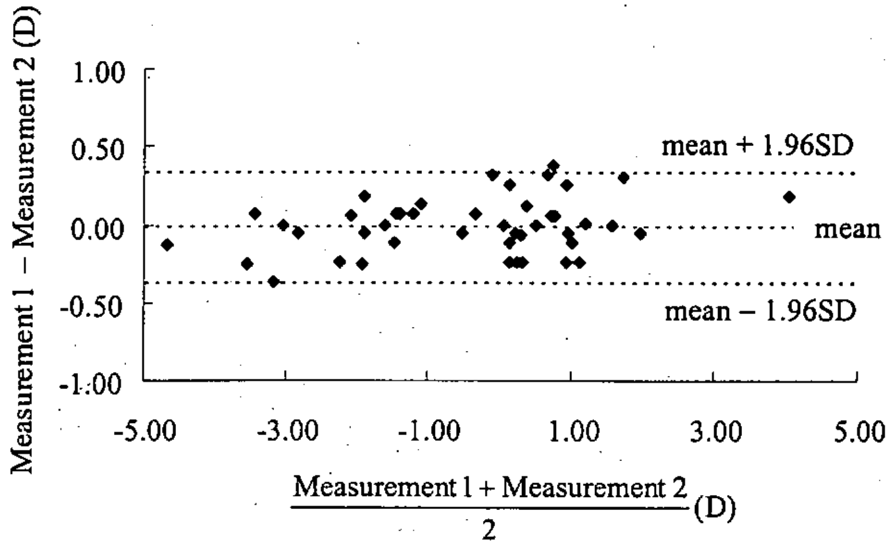


Figure 4.16 Agreement of spherical equivalent (SE) between two cycloplegic SRW-5000 autorefraction measures taken by a single examiner (Comparison G).

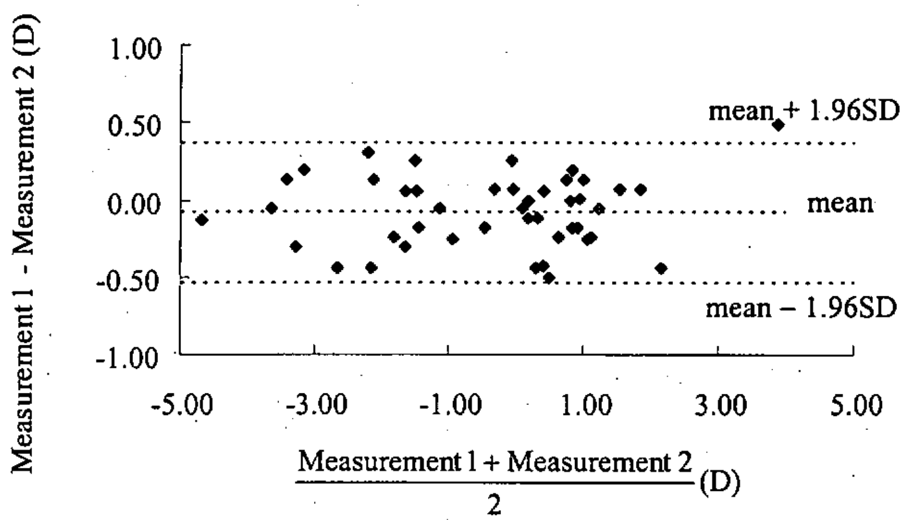


Figure 4.17 Agreement of spherical equivalent (SE) between two cycloplegic SRW-5000 autorefraction measures taken by two different examiners (Comparison H).

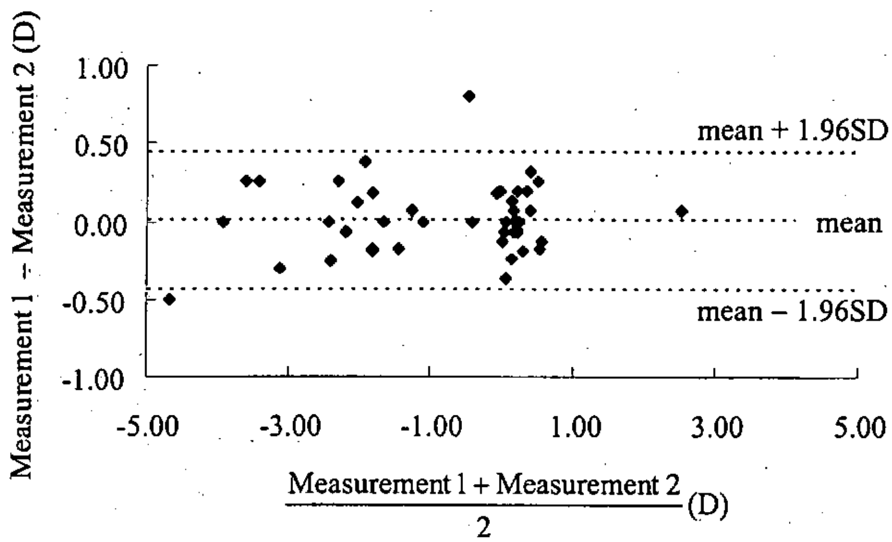


Figure 4.18 Agreement of spherical equivalent (SE) between two non-cycloplegic SRW-5000 autorefraction measures taken by a single examiner (Comparison I).

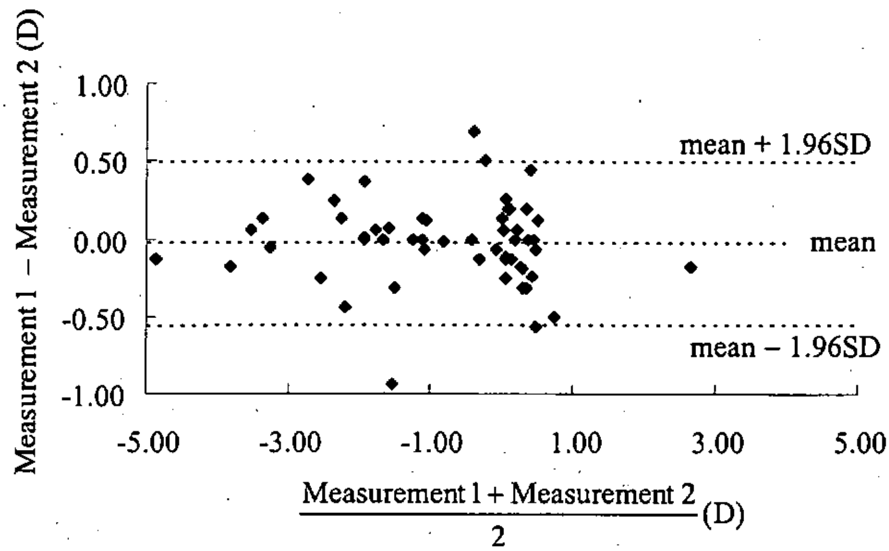


Figure 4.19 Agreement of spherical equivalent (SE) between two non-cycloplegic SRW-5000 autorefraction measures taken by two different examiners (Comparison J).

Comparison	Fs (D)	Fc (D)	SE (D)
G	–0.38 to 0.35	–0.48 to 0.51	–0.36 to 0.35
H	–0.53 to 0.44	–0.69 to 0.59	–0.53 to 0.38
I	–0.49 to 0.52	–0.58 to 0.54	–0.45 to 0.46
J	–0.60 to 0.57	–0.60 to 0.56	–0.56 to 0.51

Table 4.8 The 95 % limits of agreement for sphero-cylinder component: sphere (Fs), cylinder (Fc) and spherical equivalent (SE). See text for the detail of comparison made (p.57)

4.5 Discussion

4.5.1 Experimental setup

We tried to recruit subjects with as wide a range of refractive errors as possible. Moderate and high hyperopia are very unusual in Chinese children and we approached local international schools to recruit Western children with hyperopia. Higher amounts of myopia are, fortunately, also rare in children between the ages of 4 and 8 years.

Measurements were successfully taken in all 53 children. The pupil of one child was still reacting vigorously to light 30 minutes after drug instillation. Therefore, one more drop of cyclopentolate hydrochloride 0.5 % was used, as per the standardized procedure.

All measures, except for reproducibility, were taken by a single examiner. Although autorefraction was taken after the manifest refraction, the examiner may have recalled details of the non-cycloplegic refraction and autorefraction measures while carried out the cycloplegic refraction. The refraction measures were being used as reference or "gold standard" values, and so prior knowledge which might result in a more accurate refractive result, would not compromise the validity of the comparisons made, and indeed might improve their validity.

4.5.2 Accuracy

Cycloplegic refraction gave more hyperopic results compared with SRW-5000 autorefraction obtained in both cycloplegic and non-cycloplegic conditions (A and B in Table 4.1), although the agreement between cycloplegic refraction and cycloplegic SRW-5000 results was good ($r = 0.98$, slope = 1.03 in Figure 4.7). Non-cycloplegic SRW-5000 autorefraction, as would be expected, produced a result which was less hyperopic than cycloplegic refraction, and the agreement was not as good as in the cycloplegic condition ($r = 0.97$, slope = 0.87 in Figure 4.8).

The difference in spherical equivalent by autorefraction between the cycloplegic and non-cycloplegic conditions was less than 0.50 D (Tables 4.1and 4.4) and does not seem to vary with the magnitude of refractive error, at least over the spherical equivalent range $+4.75$ to -3.25 D (Figure 4.9). Ninety-five percent of paired measures of sphere and spherical equivalent were within ±1.27 D and ±1.32 D respectively (Table 4.4). This suggests that, except in cases where it is necessary to determine the maximum plus correction, cycloplegia may not be needed, at least for the refractive range investigated here.

The difference between cycloplegic refraction and autorefraction was mainly in spherical power. This can be observed in the variance-covariance matrix shown in Table 4.2; the corner entries are larger than the other entries. The entries in comparisons where both measures were taken in cycloplegic conditions (Comparison A and D) are smaller than those for non-cycloplegic conditions (Comparison B, C and E). Thus, the variability of agreement tends to be less in cycloplegia.

Considering the sphere and cylinder as separate components in Comparison A resulted in a smaller mean spherical difference (+0.13 D) and a slightly greater mean cylinder difference (+0.21 D) compared with the results obtained employing vector **h** calculations (mean difference +0.32/-0.16 x 64).

In the present study, 86 % of autorefraction resulted in a cylindrical correction of 0.25 D or more, compared with 55 % of refractions. Cycloplegic refraction therefore tended to produce less cylinder than SRW-5000 autorefraction. Mallen *et al.* (2001) did not find this difference in astigmatic correction in their adult subjects and it is therefore probably partly due to the difficulty associated with measuring small amounts of astigmatism subjectively in young children. The agreement between refraction and autorefraction was high for cylinders over about 1 D (Chat and Edwards, 2001).

The RK5 gave results closest to cycloplegic refraction (Comparison D in Table 4.1). The vector dioptric deviation (VDD of A and B, D and E in Table 4.1) and the spread of data point in the scatter plots (Figure 4.1, 4.4, 4.9 and 4.10) were similar for the SRW-5000 and the RK5. The results from the closed-field autorefractor (RK5) were slightly more hyperopic than those from the open-field instrument (SRW-5000), although this bias is not significant clinically. The variability in cylinder power agreement between the RK5 findings and cycloplegic refraction was slightly greater than in other comparisons, with 95 % of paired measures being within 1.04 D (Table 4.4).

It seems that there is a scope for improving the control of accommodation of the SRW-5000 (Comparisons B and C in Tables 4.1 and 4.4). The fixation target cannot be clear in subjects with more than 1.00 D myopia or in adult subjects with moderate to high hyperopia. The target blur may stimulate accommodation, and young children may also lose interest in a blurred target. The fixation target in the RK5 is a red house in the middle of a green field, and may have held the interest of the children longer than the SRW-5000 target, which is a red four-pointed "star". McBrien and Millodot (1985) reported that control over accommodation in adults was also a problem with the Canon R-1. Further work should be carried out to determine the target providing the optimum accommodative control.

Elliott *et al.* (1997) compared the accuracy of non-cycloplegic autorefraction (taken by Nikon NRK-8000 and Nidek AR-1000 autorefractors) with subjective refraction in adults. They determined the accuracy of autorefraction by calculating a "coefficient of accuracy" (1.96 standard deviations of the difference between autorefraction and subjective refraction) for each vector **h** component (*see* Table 4.9). Similar results were obtained in this study (*see* Table 4.3). It should be noted that use of a coefficient of accuracy assumes that there is no systematic bias between the two instruments or techniques being compared.

Comparison	**The coefficient of accuracy (1.96 SD) (D)**		
	h_1	h_2	h_3
Nikon – subjective (Elliott *et al.*, 1997)	0.98	0.41	0.98
Nidek – subjective (Elliott *et al.*, 1997)	0.81	0.35	0.73
Non-cycloplegic SRW-5000 – cycloplegic refraction (present study)	0.83	0.48	0.90

Table 4.9 The coefficient of accuracy for Nikon NRK-8000 (n=30, age from 22 to 85 years), Nidek AR-1000 (n=30, age from 22 to 85 years) and Shin-Nippon SRW-5000 autorefractor (n=44, age from 4 to 8years).

El-Defrawy *et al.* (1998) compared the results of cycloplegic retinoscopy with those from cycloplegic autorefraction performed using a hand-held Retinomax autorefractor (Nikon Corporation). Their subjects were between the ages of 5 and 72 months. Based on the means and standard deviations of the differences reported, the agreement of sphere and spherical equivalent values was 1.55 D and 1.39 D respectively in 95 % of cases, while the equivalent values in this study were 0.70 D and 0.91 D. The larger range of differences in the El-Defrawy *et al.* study is to be expected, given that some of their subjects were considerably younger than ours, and a direct comparison with the findings of the present study is difficult. In the same study the non-cycloplegic hand-held autorefraction was found “grossly inaccurate” compared with cycloplegic retinoscopy, though again it is very difficult to make a direct compatirosn with the present study because of the difference in ages.

Harvey *et al.* (2000) also compared cycloplegic retinoscopy and cycloplegic Retinomax measures in children aged between 3.6 and 5.6 years. These authors reported rather better agreement between cycloplegic retinoscopy and cycloplegic Retinomax measures (0.90 D for the sphere and 0.72 D for the spherical equivalent), however in addition to their subjects being older than those of El-Defrawy *et al.*, they had reduced the variability in their retinoscopy findings by taking the median of three readings.

Previous studies of the accuracy of the Canon R-1 and other autorefractors are summarized in Table 4.10. Results obtained in the present study were rather better than those taken in adults when compared with measures taken from non-cycloplegic autorefraction.

The findings of McBrien and Millodot (1985) are somewhat ambiguous. They present the absolute mean difference between R-1 and subjective results. It is strange to report an absolute mean here, as clearly readers will wish to know which instrument gave the more plus result. If the authors actually presented the mean absolute difference, then these findings are difficult to compare with our own.

Study	Subjects	Comparison	95 % limits of agreement (D)				
			Fs	Fc	Axis	SE	Other
McBrien and Millodot, 1985	93 adults	Canon R-1 vs Subjective	0.33[M]	0.41[M]	--	0.39[M]	
Yeow and Taylor, 1989	55 adults	Humphrey 530 vs Subjective	−0.91 to 0.81	−0.33 to 0.61	--	−1.01 to 0.99	
Sunder Raj *et al.*, 1992	25 adults	Humphrey 570 vs Subjective	−1.70 to 1.32	−0.99 to 0.97	−9.33 to 26.73	−1.71 to 1.45	
Sunder Raj *et al.*, 1992	25 adults	Canon RK1 vs Subjective	−1.71 to 1.15	−1.08 to 1.12	−8.13 to 27.93	−1.67 to 1.15	
Kinge *et al.*, 1996	80 adults	Nidek AR-1000 vs Subjective	--	--	--	−0.66 to 0.40	
Bullimore *et al.*, 1998	86 adults	Hoya AR-570 vs Subjective	--	--	--	−0.74 to 0.60	
El-Defrawy *et al.*, 1998	102 children	Retinomax vs Cyclo refraction	−1.52 to 1.58	−0.02 to 0.48	--	−1.30 to 1.48	VDD −0.52 to 2.46
Harvey *et al.*, 1997	22 children	Retinomax vs Cyclo refraction	−1.57 to 1.95	−0.86 to 0.36	−11.23 to 19.59	−1.58 to 1.72	VDD −0.13 to 2.19
Harvey *et al.*, 2000	36 children	Retinomax vs Cyclo refraction	−0.11 to 0.25	−0.18 to 0.22	−2.74 to 15.72	--	VDD 0.02 to 1.12
Present study	44 children	SRW-5000[A] vs Cyclo refraction	−0.44 to 0.70	−0.48 to 0.90	--	−0.43 to 0.91	VDD −0.05 to 1.33
Present study	53 children	SRW-5000[B] vs Subjective	−0.99 to 0.57	−1.00 to 0.52	--	−1.04 to 0.38	VDD −0.06 to 1.50

Table 4.10 Comparison of studies on the accuracy of autorefractors.

M= only mean was given in the study, VDD = measures calculated by vector dioptric distance, A = Cycloplegic autorefraction and B = Non-cycloplegic autorefraction.

The mean absolute difference will be greater than the mean difference (in which positive and negative values will have tended to cancel each other out). The mean absolute difference is a more useful estimate of the average size of the difference than the mean, however in this instance we are interested in the range of the differences and not in the average difference. The standard deviation of the mean absolute difference will be much smaller than the standard deviation of the mean difference.

4.5.3 Reliability

The overall trend was that reliability was better for cycloplegic than non-cycloplegic autorefraction, and slightly better for one compared with two observers. It is possible that inter-examiner differences could be due to differences in the criterion applied when focusing the corneal reflection, and these differences might be decreased by observers working together prior to taking measurements to ensure they use the same focusing criterion.

Within the refractive error range studied (SE $+4.75$ to -3.25 D) there was no trend for repeatability or reproducibility to worsen as refractive error increased, however it would be unsafe to make inferences regarding refractive errors outside this range.

Previous studies of the reliability of R-1 and other autorefractors are summarized in Table 4.11. The reliability of non-cycloplegic SRW-5000 results was no better than the reliability of results from the R-1 in non-cycloplegic conditions (McBrien and Millodot, 1985; Rosenfield and Chiu, 1995), however less reliable results might be expected in young children. The poorer repeatability in this study compared with that of McBrien and Millodot (1985) may be because they seem to have analyzed their data in terms of absolute differences, and smaller standard deviations would thereby be obtained.

Zadnik *et al.* (1992) reported repeatability limits of ±0.32 D for the Canon R-1 autorefractor for the power in the vertical meridian in adults under cycloplegia, compared with an equivalent finding here for the sphere of ±0.38 D. Estimates of the repeatability limits for non-cycloplegic repeatability of the R-1 in adults are ±0.72 D (Zadnik *et al.*, 1992) compared with ±0.58 D in children for the SRW-5000 in the present study.

The reliability of SRW-5000 results in cycloplegic conditions in children in the present study was similar to reliability results from adults in non-cycloplegic conditions. It was also comparable with the reliability of clinical refraction reported by Rosenfield and Chiu (1995) and those studies in Goss and Grosvenor (1996) review. Results for repeatability of the SRW-5000 autorefractor are therefore similar to those reported for the Canon R-1.

Study	Subjects	Instrument *Repeatability # Reproducibility	95 % limits of agreement				
			Fs	Fc	Axis	SE	Others
McBrien and Millodot, 1995	25 adults	*Canon R-1	r0.99	r0.99	r0.98	r0.96	
Yeow and Taylor, 1989	55 adults	*Humphrey 530 (Non-cyclo)	−0.69 to 0.61	−0.42 to 0.36	--	−0.63 to 0.59	--
Zadnik *et al.*, 1992	40 adults	*Canon R-1 (Non-cyclo)	--	--	--	--	V −0.26 to 0.29
Zadnik *et al.*, 1992	40 adults	*Canon R-1 (Cyclo)	--	--	--	--	V −0.72 to 0.70
Mutti *et al.*, 1994	20 children	*Canon R-1 (Cyclo)	--	--	--	--	V 0.39 to 1.57
Rosenfield and Chiu, 1995	12 adults	*Canon R-1 (Non-cyclo)	0.16SD	0.19SD	15.9SD	0.14SD	H0.16SD
Bullimore *et al.*, 1998	86 adults	#Hoya AR-570 (Non-cyclo)	--	--	--	−0.38 to 0.40	--
Harvey *et al.*, 1997	22 children	#Retinomax (Cyclo)	−0.49 to 0.29	−0.29 to 0.79	--	−0.39 to 0.23	VDD 0.65 to 1.39
Harvey *et al.*, 2000	35 children	#Retinomax (Non-cyclo)	−1.00 to 1.00	−0.59 to 0.39	--	−1.03 to 0.93	VDD −0.04 to 0.78
Present study	53 children	* SRW-5000 (Non-cyclo)	−0.50 to 0.52	−0.57 to 0.53	--	−0.45 to 0.45	VDD −0.08 to 0.93
Present study	44 children	* SRW-5000 (Cyclo)	−0.39 to 0.35	−0.47 to 0.51	--	−0.36 to 0.34	VDD −0.02 to 0.80

Table 4.11 Comparison of studies on reliability of autorefraction. r = correlation coefficient, H = power measured in horizontal meridian, V = power measured in vertical meridian, SD = only standard deviation were given in the study and VDD = measures calculated in vector dioptric distance).

4.5.4 Statistical analysis

The definition of agreement and reliability of a vector is less clear than that commonly used for scalars such as spherical equivalent. The VDD, a scalar calculated from vector **h**, therefore, was used to present the accuracy and reliability of the SRW-5000. A further problem with carrying out several multivariate analysis tests that will increase the probability of Type 1 error (Dawson-Saunders and Trapp, 1994: p.120). If each comparison is made for $p<0.05$, the probability of finding one or more comparisons significant by chance is considerably higher than 5 %. In order to lower the significant threshold, the p-value can be simply divided 0.05 by number of comparisons. However, it can only suitable for less than 10 comparisons (Motulsky, 1995: p.276).

4.6 Conclusions

The accuracy and reliability of SRW-5000 results were good, considering the influence the age of the subjects likely to have had in term of both subjective response and fluctuating accommodation. The SRW-5000 autorefractor is likely to be valuable in both clinical and research settings.

Both agreement with cycloplegic refraction and repeatability were better when SRW-5000 measures were taken under cycloplegia. The 95 % confidence limits for paired measures of spherical equivalent between subjective refraction and autorefraction both under cycloplegia was 0.91 D. Repeatability results from the SRW-5000 autorefractor, both with and without cycloplegia are similar to those reported for the Canon R-1.

The repeatability values in spherical equivalent were 0.45 D and 0.52 D with and without cycloplegia respectively. The reproducibility values for spherical equivalent were 0.36 D and 0.55 D with and without cycloplegia respectively. It seems that control of accommodation with the SRW-5000 autorefractor in young children is not ideal, despite its open-field design and there may be scope to improve control of accommodation in children.

Chapter 5

Study 2: Tonic accommodation in Hong Kong Children

5.1 Introduction

The classical theory of accommodation stated that when an emmetropic eye was focused at optical infinity, accommodation would be "at rest" (i.e. accommodation = 0 D) (Fincham, 1937; Helmholtz, 1962). It is now recognized that when there is no visual stimulus accommodation is for some position proximal to infinity, or in the case of an ametropic eye, proximal to the far point (Leibowitz and Owens, 1975a). This level of accommodation under so-called stimulus free conditions is called tonic accommodation (TA) (Hennessy and Leibowitz, 1970; Hennessy and Leibowitz, 1972). It is also known as dark focus, resting state of accommodation, or dark accommodation (Rosenfield *et al.*, 1993).

There has been only one previous report of TA in Chinese children, and no report of TA in children under the age of 6 years. Woung *et al.* (1998) reported TA values in Chinese children from 7 to 12 years of age of 1.37 D (SD 0.33) in emmetropes (n=15) and 1.03 (SD 0.56) D in early-onset myopes (n=19). There was a statistically significant difference in TA between the two refractive groups ($p=0.047$). Tonic accommodation was measured by a modified closed field autorefractor (Nidek AR-1100) under bright empty field conditions.

5.1.1 Previous work and the techniques used to measure TA

Laser optometry was first used to measure TA, measurement being carried out in total darkness, and the resultant TA value averaging around 1.5 D (Leibowitz and Owens, 1978). It was shown, however, that the mental effort required to appreciate the direction of the speckle motion in this type of instrument influenced the tonic accommodation measures (Post *et al.*, 1984; Bullimore and Gilmartin, 1987b; Jaschinski-Kruza and Toenies, 1988). Moreover, the speckle exposure time (Bullimore *et al.*, 1986; Rosenfield, 1989) and the speckle pattern within the visual field, acting as a stimulus to proximally-induced accommodation, contaminated the measures (Bullimore and Gilmartin, 1990; Rosenfield and Ciuffreda, 1990; Rosenfield *et al.*, 1990).

Objective techniques such as dynamic retinoscopy and infrared autorefractor were subsequently used to measure tonic accommodation. The TA value found by dynamic retinoscopy in darkness tended to be lower than corresponding measures found by laser optometry, probably due to the retinoscope light stimulating blur and proximal-induced accommodation.

An infrared autorefractor is now the instrument of choice for measuring tonic accommodation, as it provides a means of measurement under true stimulus-free conditions. An open-field design autorefractor is particularly useful as the subject is aware, before the room is darkened for the measurement session, that he or she can see through the instrument, and proximal accommodation is thus less likely to occur.

The R-1 (Canon, Japan) has been previously and extensively used in accommodation research, and was shown to provide reliable and accurate measures of refractive error. The reliability of TA measures using the R-1, however, has been reported only in term of the (inappropriate) correlation coefficient (Mershon and Amerson, 1980; Heron *et al.*, 1981; Baker *et al.*, 1983; Owens and Higgins, 1983; Johnson *et al.*, 1984; Gwiazda *et al.*, 1995). The coefficient of correlation is a measure of relationship, not of agreement, and unless the equation of the regression line is also given, is of little value as a measure of agreement. Repeatability is a measure of the agreement between repeated measures taken under identical conditions and it will be presented here in terms of the 95 % limits of agreement between two repeated measures (ISO 5725, 1994).

The large inter-subject variation in TA values (Leibowitz and Owens, 1975a; Leibowitz and Owens, 1975b; Leibowitz and Owens, 1978) led some investigators to wonder if there was a relationship between TA and refractive error. TA measures were, indeed, subsequently found to vary with refractive error (Maddock *et al.*, 1981; Bullimore and Gilmartin, 1987a; McBrien and Millodot, 1987; Gilmartin and Bullimore, 1991; Woung *et al.*, 1993; Gwiazda *et al.*, 1995; Jiang, 1995; Woung *et al.*, 1998; Jiang and Morse, 1999; Jiang and White, 1999; Zadnik *et al.*, 1999). TA values were shown to be lower in late-onset myopes compared with early-onset myopes and emmetropes and it has been suggested that the development or progression of myopia is related to the low TA. A cause and effect relationship, however, has not been demonstrated.

5.2 Objectives

The objectives of Study 2 are:

1) To determine the repeatability of tonic accommodation in children, as measured by the SRW-5000 open-field and
2) To characterize TA in Hong Kong children between the ages of 4 and 8 years, particularly according to refractive status.

5.3 Methods

5.3.1 Subjects

Fifty-six subjects were recruited through the Optometry Clinic at The Hong Kong Polytechnic University and from international schools in Hong Kong. All were between the ages of 4 and 8 years (mean 6.4 and SD 1.3 years) and had correctable distance vision of at least 0.2 LogMAR units (6/9 Snellen) or better in each eye. No subject had heterotropia or suppression. Parents gave informed consent prior to the measurements shown below.

5.3.2 Autorefraction using the Shin-Nippon SRW-5000 autorefractor with distance target

The target, comprising a red four-pointed "star", was placed 6 m in front of the autorefractor. Alignment of the optical axis of the axis of the instrument and the target was adjusted before any measurements were taken, as described in Appendix 6.1. The accuracy and vertex distance settings of the SRW-5000 were set to 0.12 D and 12 mm respectively.

The subject sat comfortably with his or her chin on the chin-rest, head against the forehead rest and eyes level with the eye mark, and viewing binocularly through the window of the instrument looked at the fixation target. Distance refraction measurements were taken on the right eye only. Ten readings were taken and the instrument then provided an average value, called the "representative value".

5.3.3 Autorefraction taken in total darkness

The subject's head was steadied by the chin and forehead rests, and an additional velcro strap was used to keep forehead in contact with the forehead rest. The room lights were turned off, the subject having been forewarned that this was about to happen, and the light intensity of the autorefractor monitor screen was reduced to a minimum. Any stray light from the screen of the autorefraction was shielded from the subject during the measurement.

The subject was asked to sit in the dark for 5 min to dissipate any fluctuation of the accommodation response, and then autorefraction was carried out twice, 30 sec apart. Each autorefraction consisted of ten readings and the subject was asked to look straight and to ignore the red ring (please refer to p.4) during measurement.

5.3.4 Calculation of tonic accommodation

TA was determined by the difference between distance refraction and the second autorefraction taken in total darkness as follows:

$$\text{TA} = \text{Distance autorefraction} - \text{the } 2^{nd} \text{ dark autorefraction} \quad \text{(Equation 5.1)}$$

The second autorefraction value was used as it is possible that a child would be apprehensive about the first series of measurements, but less so about the second series, so that the second measures might be generally more accurate.

5.4 Results

The range of refractive error in 56 children was from +1.00 to −4.00 D in spherical power. Refraction was recorded in negative cylinder format and the highest cylindrical correction was −4.62 D. The mean refractive error was −0.74/−0.41×175 and the mean spherical equivalent (SE) was −0.94 D (SD 1.42 D).

The distribution of TA is shown in Figure 5.1 (data were normally distributed, *see* Appendix A2.3). The mean was 1.07/−0.05×138 in sphero-cylinder notation or $(1.05 \quad -0.03 \quad 1.05)'$ (D) in vector **h** notation and the variance-covariance was $\begin{pmatrix} 0.69 & -0.03 & 0.48 \\ -0.03 & 0.08 & -0.04 \\ 0.48 & -0.04 & 0.59 \end{pmatrix}$ (D^2). The standard deviations of h_1, h_2 and h_3 were 0.83, 0.28 and 0.77 D respectively. The maximum TA was 3.68 D and the minimum was 0.09 D (in spherical equivalent).

As this appears to have been the first time TA has been measured in children aged younger than 6 years, the data was analyzed for the 18 subjects aged less than 6 years. The mean TA for this group was $(1.05 \quad 0.02 \quad 1.08)'$ in vector **h** notation or 1.09/–0.04×68 in sphero-cylinder format. The mean TA of the remaining 38 children, aged 6 years or older was $(1.05 \quad -0.06 \quad 1.03)'$ or 1.08/–0.09×142. There is no statistically significant difference in TA between these two groups (T^2=1.26, p=0.75).

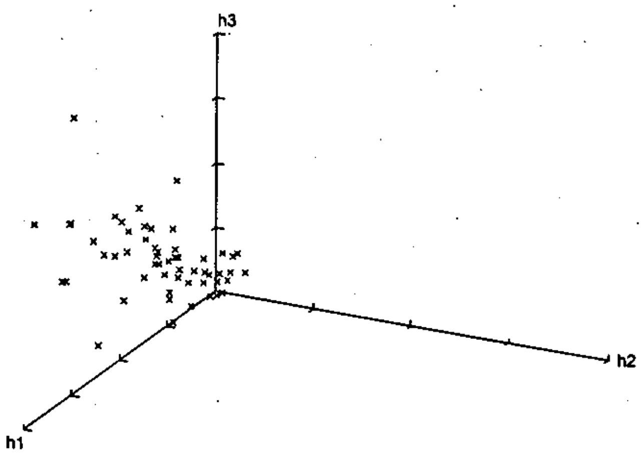


Figure 5.1 The distribution of TA in 56 children. The ticks in the axes indicate 1 D steps.

5.4.1 Repeatability

The mean difference between two measures taken by single observer was $(0.10 \quad -0.04 \quad 0.15)'$ in vector **h** notation or 0.15/–0.08 × 122 in sphero-cylinder notation. The scatter plot of the difference between two measures is shown in Figure 5.2. The variance-covariance matrix of the difference was $\begin{pmatrix} 0.17 & -0.00 & 0.09 \\ -0.00 & 0.07 & -0.03 \\ 0.09 & -0.03 & 0.17 \end{pmatrix}$ (D^2) and the standard deviations of h_1, h_2 and h_3 were 0.41, 0.27 and 0.41 D respectively.

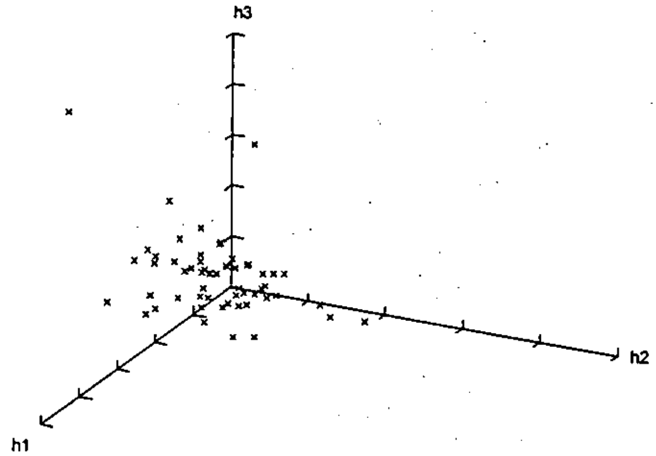


Figure 5.2 Scatter plot of the difference between two TA measurements taken by one observer. The ticks in the axes are in 0.50 D in step.

Multivariate analysis was carried out by testing whether the mean difference between two measures was equal to zero. No statistically significant difference was found between the two sets of measures (T^2=7.97, p=0.06).

The 95 % limits of agreement for the difference between two measures (Bland and Altman, 1986) are equal to the mean difference ± 1.96 times the standard deviation of the difference and these statistics were calculated for each vector **h** component; they were also calculated for the SE to enable direct comparison with results reported from other studies (Table 5.1). The agreement between the two sets of measures is illustrated in Figure 5.3.

	h_1 (D)	h_2 (D)	h_3 (D)	SE (D)
Mean difference	0.10	–0.04	0.15	0.13
1.96 × SD of the difference	0.90	0.57	0.97	0.83

Table 5.1 The mean difference between two measures taken by a single observer and the value of 1.96 × SD of the difference for each vector **h** component and SE.

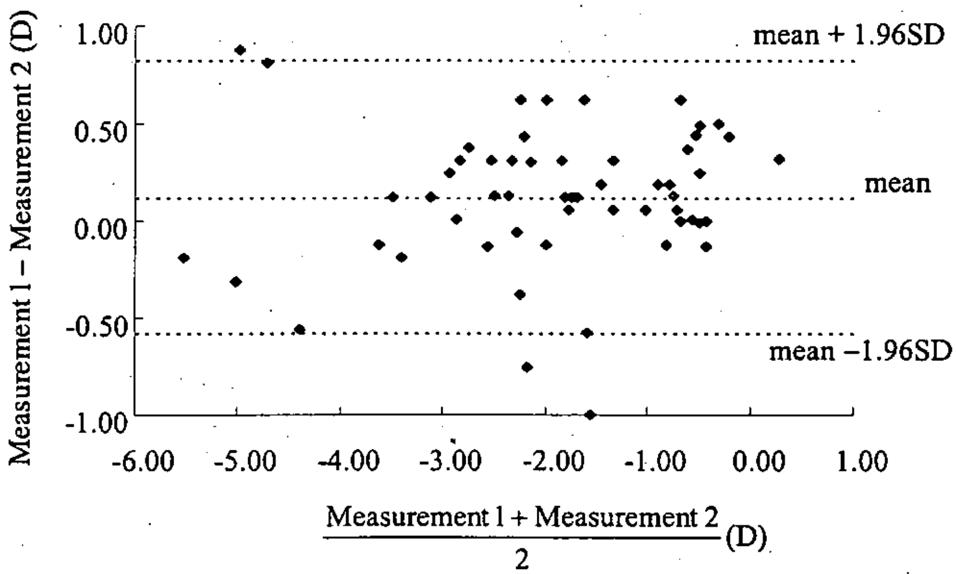


Figure 5.3 Agreement of spherical equivalent (SE) between two dark autorefraction.

5.4.2 Tonic accommodation in difference refractive groups

Subjects were divided into three refractive groups. Twenty-four subjects were myopes, (defined as spherical equivalent equal or less than –0.50 D), 14 subjects were hyperopes (defined as spherical equivalent equal or more than +0.50 D), and the remaining 18 subjects were emmetropes, (defined as spherical equivalent ranging from more than –0.50 to less than +0.50 D) . The distributions of TA in each refractive group are shown in Figures 5.4 to 5.6. The means, standard deviation and variance-covariance of TA of each refractive group are shown in Table 5.2, both in vector **h** format and in sphero-cylinder format.

Refractive group	$\bar{\mathbf{h}}$ (D)	Sphero-cylinder (D)	SE (D) [SD]	Variance-covariance (D^2)
All (n=56)	$\begin{pmatrix} 1.05 \\ -0.03 \\ 1.05 \end{pmatrix}$	1.07/–0.05×138	1.05 [0.75]	$\begin{pmatrix} 0.69 & -0.03 & 0.48 \\ -0.03 & 0.08 & -0.04 \\ 0.48 & -0.04 & 0.59 \end{pmatrix}$
Myopic (n=24)	$\begin{pmatrix} 0.57 \\ -0.08 \\ 0.73 \end{pmatrix}$	0.76/–0.20×106	0.66 [0.57]	$\begin{pmatrix} 0.25 & -0.07 & 0.25 \\ -0.07 & 0.12 & -0.14 \\ 0.25 & -0.14 & 0.55 \end{pmatrix}$
Emmetropic (n=18)	$\begin{pmatrix} 1.35 \\ -0.03 \\ 1.17 \end{pmatrix}$	1.35/–0.18×172	1.26 [0.64]	$\begin{pmatrix} 0.57 & -0.07 & 0.30 \\ -0.07 & 0.06 & -0.02 \\ 0.30 & -0.02 & 0.49 \end{pmatrix}$
Hyperopic (n=14)	$\begin{pmatrix} 1.49 \\ 0.04 \\ 1.40 \end{pmatrix}$	1.50/–0.11×15	1.45 [0.86]	$\begin{pmatrix} 0.97 & 0.02 & 0.70 \\ 0.02 & 0.05 & 0.02 \\ 0.70 & 0.02 & 0.58 \end{pmatrix}$

Table 5.2 The mean tonic accommodation for all subjects and for each refractive group.

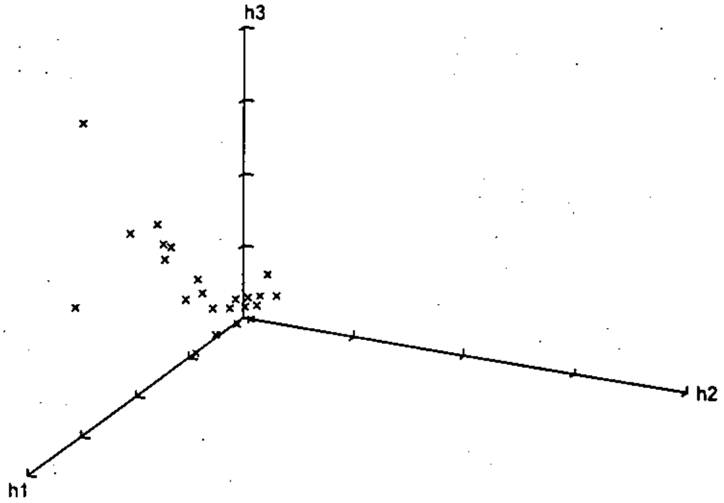


Figure 5.4 The distribution of TA for 24 myopic children. The ticks on the axes are in 1.0 D steps.

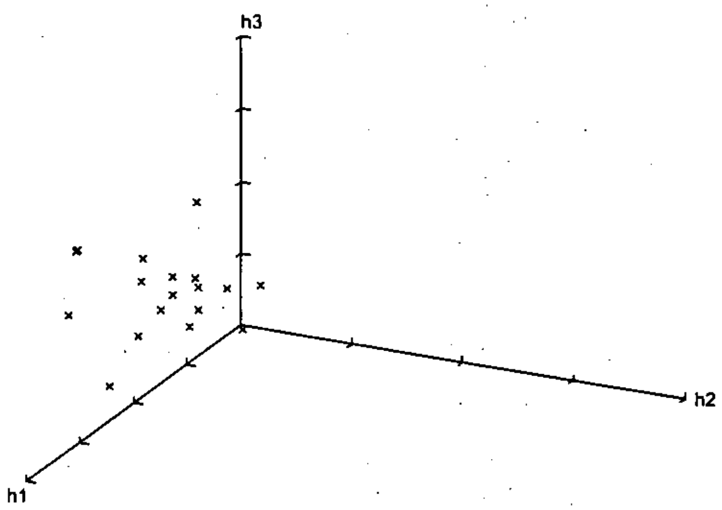


Figure 5.5 The distribution of TA for 18 emmetropic children. The ticks on the axes are in 1.0 D steps.

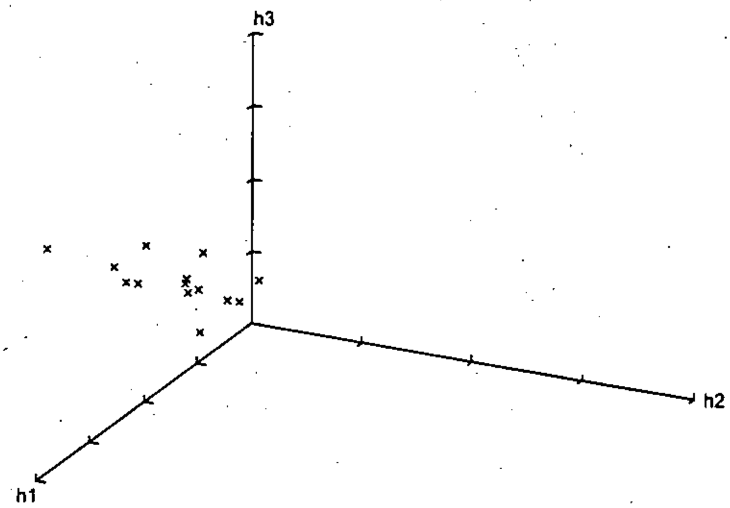


Figure 5.6 The distribution of TA for 14 hyperopic children. The ticks on the axes are in 1.0 D steps.

There was a statistically significant difference in TA between the three refractive groups (MANOVA: $p<0.001$ and $F_{0.05,2(3),2(56-3-2)} = 2.19$). There was a statistically significant difference between TA in myopes and in hyperopes ($T^2=18.00$, $p=0.03$) and between TA in myopes and in emmetropes ($T^2=20.4$, $p=0.0012$). There was no statistically significant difference between TA in emmetropes and hyperopes ($T^2=1.50$, $p=0.71$).

There was a statistically significant difference in TA (SE) between the three refractive groups (ANOVA [2,53]: $p=0.0015$). A Student-Newman-Keuls multiple comparisons test showed statistically significant differences in TA between myopes and hyperopes ($p<0.01$), and between myopes and emmetropes ($p<0.01$).

5.5 Discussion

As shown in Table 5.2, TA is essentially a spherical phenomenon and so the present results can be compared with those from previous studies using infrared optometry and reporting spherical equivalent values.

The mean TA (1.05 D) in the present study was similar to those found in studies in adults, and tended to be lower than those found in other studies in children (see Table 5.3). Statistical tests were performed to compare the present results with results from studies in which the mean, SD and sample size were reported. There was a statistically significant difference between the present results and those of Mordi and Ciuffreda (1998) and those of Rosenfield (1989), but not between the present results and those of Bullimore *et al.* (1986) or of McBrien and Millodot (1987). Statistical comparisons cannot be made for the studies of Gwiazda *et al.* (1995), Woung *et al.* (1998) and Zadnik *et al.* (1999) as insufficient data are given in these papers.

The major cause of the difference is probably the distribution of refractive errors among the subjects. The more myopes in the study, the lower the overall TA. However, Rosenfield (1989) and Mordi and Ciuffreda (1998) did not give the range of refractive error. In the study of Mordi and Ciuffreda (1998), the sample had a large age range. Tonic accommodation decreases with increasing age (Mordi and Ciuffreda, 1998) and so the age of the sample affects the TA findings. There were also differences in the way TA was measured between the studies shown in Table 5.4. In the study of Mordi and Ciuffreda (1998) and that of Gwiazda *et al.* (1995), for example, subjects wore their refractive correction and measurement was carried out under monocular conditions. In Rosenfield (1989), the dark adaptation time was 2 minutes and it should be noted that the tonic accommodation has been found to stabilize only after 7 minutes in the dark (McBrien and Millodot, 1987).

Study	Subject age (no. of subject)	Methods used and testing condition	Mean (SD)
Bullimore *et al.*, 1986	19-28 (N=25)	Canon R-1 in dark room	1.15 (0.82)
Gwiazda *et al.*, 1995	6.5-16.5 (N=87)	Canon R-1 in dark room	0.68
McBrien and Millodot, 1987	19-25 (N=62)	Canon R-1 in dark room	0.91 (0.53)
Mordi and Ciuffreda, 1998	21-50 (N=30)	Infrared optometer in dark room	1.34 (0.42)
Rosenfield, 1989	23-30 (N=12)	Canon R-1 in dark room	1.77 (0.24)
Woung *et al.*, 1998	7-12 (N=34)	Infrared optometer (AA-2000, Nidek) in bright empty-field	1.17
Zadnik *et al.*, 1999	6-15 (N=790)	Canon R-1 in bright empty-field	1.22
Zadnik *et al.*, 1999	6-15 (N=790)	Canon R-1 in dark room	1.18
Present study	4-8 (N=56)	SRW-5000 in dark room	1.05 (0.75)

Table 5.3 Previous findings for TA by infrared optometry.

5.5.1 Repeatability

This seems to be the first report of the repeatability of TA measurement using an open-field autorefractor. The repeatability was about ±0.83 D. Previously, the correlation coefficient was used, inappropriately, to describe the agreement between test and retest. Heron *et al.* (1981) found that the correlation coefficient for repeated TA measurement was 0.69 D, which seems a rather low correlation for two measures of the same parameter. Owens and Higgins (1983) reported that the intra-subject mean difference between two TA measurements, taken using a laser optometer, was 0.13 D; the standard deviation of the difference was not presented. The mean difference is of little value, as positive and negative values tend to cancel each other out. Gwiazda *et al.* (1995) calculated that Pearson's correlation coefficient between two TA measures, taken up to one-year apart, was 0.74 ($p<0.0001$).

Further work is needed to improve the reliability of this measure. One of the factors which might influence the accommodative state during measurement is the red ring which is seen momentarily by the subject during each measurement. It is used in the determination of refractive error, so it is not possible to make it invisible. Measurement taken in darkness make the red ring particularly noticeable, and this may alter the level of tonic accommodation, although the subject was told to ignore the red ring during measurement.

5.5.2 Tonic accommodation in different refractive groups

In the present study, hyperopes exhibited the highest level of tonic accommodation, followed by emmetropes and then myopes. All the myopes in this study were, of course, early onset. The results here are in general agreement with previous findings (see Table 5.4), although the present study found generally lower values in all refractive groups. This is somewhat surprising, as TA decreases with increasing age (Owens *et al.*, 1989; Jiang, 1995; Mordi and Ciuffreda, 1998; Zadnik *et al.*, 1999), and the present study had younger subjects than any other study.

Table 5.4 shows that late-onset myopes have the lowest TA, however those studies were undertaken on teenagers and young adults. In the present study, the early-onset myopes had lower TA compared with emmetropes and hyperopes. Summarizing the result from the present and previous studies, the value of TA is highest in hyperopes, followed by emmetropes, early-onset myopes and late-onset myopes.

Longitudinal studies have demonstrated that TA decreases with increasing age and the magnitude of TA may be related to the age of onset of myopia (Owens *et al.*, 1989; Jiang, 1995; Zadnik *et al.*, 1999). Jiang (1995) reported that in subjects in whom TA was evaluated when they first became myopic, TA decreased as myopia developed over a period of years. In a two-year longitudinal study Adams and McBrien (1993) found that TA decreased significantly in emmetropic subjects who developed myopia during the study period, but there was no difference in initial TA in emmetropic subjects who remained emmetropic and in emmetropic subjects who became myopic during the two-year experimental period.

Studies	Methods	Nature of refractive groups	TA (D) mean (SD)
Bullimore and Gilmartin, 1987a	Canon R-1 in dark	Emmetropes (N=15) Late-onset myopes (N=15)	1.14 (0.46) 0.81 (0.46)
Gilmartin and Bullimore, 1991	Canon R-1 in room	Emmetropes (N=61) Myopes (n=33)	1.08 (0.36) 0.75 (0.19)
Gwiazda *et al.*, 1995 *	Canon R-1 in dark	Emmetropes (N=57) Myopes (n=18) Hyperopes (n=12)	0.75 0.30 0.94
Jiang and White (1999)	Canon R-1 in dark	Emmetropes (N=5) Stable myopes Progressing myopes	~ 1 D ~ 0.75 D ~ 2.5 D
Jiang and Morse (1999)	Canon R-1 in dark	Emmetropes (N=8) Late-onset myopes (N=7)	0.75 (0.24) 0.68 (0.15)
Jiang, 1995	Canon R-1 in dark	Emmetropes (N=33) Late-onset myopes (N=11)	~ 1 D ~ 0.5 D
McBrien and Millodot, 1987	Canon R-1 in dark	Emmetropes (N=15) Early-onset myopes (N=15) Late-onset myopes (N=15) Hyperopes	0.89 (0.43) 0.92 (0.61) 0.49 (0.16) 1.33 (0.49)
Woung *et al.*, 1998 *	Nidek AA-2000 autorefractor in bright empty-field	Emmetropes (N=15) Early-onset myopes (N=19)	1.37 (0.33) 1.03 (0.56)
Zadnik *et al.*, 1999 *	Canon R-1in bright empty-field	Emmetropes (N=60) Myopes (n=644) Hyperopes (n=86)	1.92 (1.59) 1.02 (1.18) 2.25 (1.78)
Zadnik *et al.*, 1999 *	Canon R-1 in dark	Emmetropes (N=60) Myopes (n=644) Hyperopes (n=86)	1.70 (1.43) 1.07 (1.63) 1.63 (1.63)
Present study *	SRW-5000 in dark	Emmetropes (N=18) Early-onset myopes (N=24) Hyperopes (N=14)	1.23 (0.81) 0.70 (0.65) 1.41 (0.62)

Table 5.4 Previous TA findings in different refractive groups. * Indicates subjects below the age of 15 years.

5.5.3 Tonic accommodation and myopia

There is no generally accepted explanation of the differences in TA between different refractive groups. It has been proposed that TA is a balance between the parasympathetic and sympathetic components of accommodation (Toates, 1972). According to this theory, sympathetically-controlled accommodation is responsible for accommodation to distance object while parasympathetically-controlled accommodation causes accommodation for a near target. Based on this dual-innervation model, Charman (1982) suggested that myopes have weak sympathetic/strong parasympathetic innervation, and being unable to relax accommodation sufficiently for clear distance vision thus appear relatively myopic.

Garner (1983) proposed the opposite – that the growth of the myopic eye would be controlled by increased sympathetic innervation for distance (in an attempt to focus the blurred image) and suggested that this would explain the low TA observed in myopes. Gilmartin and Hogan (1985) pointed out that this implies a sympathetic response which is as rapid and extensive as that of the parasympathetic response. This, however, is not the case, as Törnqvist (1966) has shown that the sympathetic response is essentially a slow and an inhibitory response, requiring that the ciliary muscle is already in a state of contraction.

A connection between autonomic tone and refraction was proposed by van Alphen (1961). He suggested that tension in the choroid is depended on the tonus of the ciliary muscle and that resistance to IOP evaluation is a function of this tonus. van Alphen predicted that in the process of emmetropization, ciliary muscle tonus increases, causing an elevation in the resistance to IOP changes, thus reducing the tension on the sclera. According to van Alphen's paradigm, if the ciliary tone is low, scleral stretching would occur when IOP increases. A lower TA lower in myopes compared with hyperopes is compatible with this theory, the longer axial length of myopes being caused by an inability of the ocular coats to resist the IOP changes.

It is interesting to note that Woung *et al.* (1998) reported that in the dark, early-onset myopes had smaller pupils than emmetropes. They suggested that sympathetic tonus in myopes is insufficient to dilate the pupil properly. Combined with low TA value found in myopes, they concluded that myopes had both low parasympathetic innervation and insufficient sympathetic tone. This would cause elongation of the axial length in myopes (Bullimore and Gilmartin, 1987b). Gwiazda *et al.* (1995) suggested that the role of sympathetic system is to reduce the accommodation hysteresis effects following long periods of close work. A deficit in sympathetic inhibition, then, might predispose an individual to the development of myopia.

In the present study we measured pupil diameter in a dark room while children were fixating a dark computer monitor and found no significant difference in pupil diameter between myopes, emmetropes and hyperopes (Data from the accommodative lag study presented in Chapter 6).

5.5.4 Experimental design

The possibility that the red ring seen by the subject during measurement may alter the accommodative state has already been discussed. Use of a low center spatial frequency (0.1 c/deg) difference of Gaussian DOG target as fixation target in semi-darkness may give more reliable results. This type of target can eliminate blur stimulus to accommodation (Kotulak and Schor, 1987; Rosenfield, 1989) and it was adopted in some previous studies of tonic accommodation (Tsuetki and Schor, 1987; Rosner and Rosner, 1989; Rosner and Rosner, 1990). Unfortunately, reliability figures were not given for TA measurement in these studies.

The examination room was in total darkness during the measurement and the children sat in the dark for 5 minutes in order to dissipate any fluctuation of accommodation response. The children may have felt nervous when they were in dark, despite the presence of their parent.

5.6 Conclusions

Tonic accommodation values taken in children less than six years of age are reported here for the first time. The mean value of TA in children younger than 6 years was $(1.05 \quad 0.02 \quad 1.08)'$ in vector **h** notation or 1.09/−0.04×68 in sphero-cylinder format and was not significantly different from the mean value obtained in older children.

This seems to be the first report of the repeatability of tonic accommodation measurement using open-field autorefraction in darkness using 95 % limits of agreement rather than correlation. The repeatability was about ±0.83 D and there may be scope to improve this by using a difference of Gaussian DOG target in semi-darkness.

The tonic accommodation found in Hong Kong children (mean=1.07/−0.05×138) was slightly lower compared with other studies. Hyperopes exhibit highest tonic accommodation followed by emmetropes and myopes, as reported in previous studies. The lower tonic accommodation found in myopes may be due to overall reduction in autonomic innervation, as proposed by other workers.

Chapter 6

Study 3: Accommodative lag in Hong Kong Children

6.1 Introduction

Precise accommodation for the object of regard does not necessarily occur, and where accommodation is for some point beyond the object of regard, there is said to be an accommodative lag. Accommodative lag is quantified by the dioptric difference between the object of regard and the accommodation actually in play (the accommodative response).

6.1.1 Previous studies on accommodative lag measurement

Accommodation has long been implicated in the genesis of environmentally-caused myopia (Rosenfield and Gilmartin, 1998: p.91) and extensive studies have been made of the accommodative response and accommodative lag in different age and refractive groups. However, those studies used a number of different methodologies and experimental conditions, making comparison among them difficult. For example, Gwiazda *et al.* (1993) measured accommodative response using the Canon R-1 closed-field autorefractor at several target distances with a target comprising a 3×3 array of 6/9 Snellen letters viewed under monocular conditions. They found that there was typically an accommodative lag increase with decreasing target distance, for a near target. Rosenfield *et al.* (1996) measured accommodative response, also with the R-1, but with a series of 6/15 Snellen black and white letters placed at 40 cm, under both monocular and binocular conditions.

The accommodative lag was less under monocular conditions. Woung *et al.* (1998) used an asterisk-shaped target in a modified closed-field autorefractor and measured accommodative response for an accommodative stimulus of 4 D. Jiang and Morse (1999) measured accommodative responses using a 6/30 Snellen letter "E" on a dark computer monitor at several different distances. Tan and O'Leary (1985) found that accommodative response was least when viewing a 6/9 Snellen letter target for both binocular and monocular conditions at 6 m and found no obvious trend by letter size at 40 cm.

Gwiazda *et al.* (1993) presented their result as ocular accommodative demand and response (*see* section 6.3.5.1), a contact lens was used in the study by Rosenfield *et al.* (1996) and Jiang and Morse (1999) only recruited emmetropes subject who with no refractive correction.

6.1.2 Myopia and accommodative lag

As previously mentioned, accommodation has been thought to be implicated in myopia development and progression. Myopia may be classified into early-onset myopia (EOM), where myopia develops before the age of 15 years, and late-onset myopia (LOM), where myopia develops after the age of 15 years (McBrien and Millodot, 1986). The rationale for this classification is that development of myopia in Caucasian children before the age of 15 years was thought to be due to genetic factors, while the development of myopia after the age of 15 years was thought to be linked to environmental factors (Bullimore and Gilmartin, 1987a).

In the past few decades there has been a great increase in the prevalence of myopia in children of all ages, and this increase over such a short time span must be environmental in origin. This increase in myopia has occurred, however, in only a few races, Chinese (Goh and Lam, 1994; Lam *et al.*, 1994), Japanese (Hosaka, 1988; Matsumura and Hirai, 1999), Inuit (Morgan *et al.*, 1975; Norn, 1997) and to a lesser extent in Native Americans (Woodruff and Samek, 1977). This suggests that myopia is due to exposure to an environmental factor (or factors) in individuals who are genetically sensitive to that factor. The high prevalence of myopia in Chinese children has been well documented (Lin *et al.*, 1988; Lam and Goh, 1991; Yap *et al.*, 1994; Edwards, 1999), however accommodative lag has not been characterized in these myopia-susceptible populations.

Work carried out in western countries, and mainly on adult subjects, has shown that accommodative lag is greater in myopes than in hyperopes and emmetropes. In contrast, Woung *et al.* (1998) found there was no statistically significant difference in the accommodative response at 4 D between early-onset myopes and emmetropes in Chinese children. The major difference between these two studies, which may account for the difference in findings, was the measurement method. Gwiazda *et al.* (1993) measured accommodative response by varying the target distance using an open-field autorefractor (R-1), whereas Woung *et al.* (1998) measured accommodative response using a modified closed-field autorefractor with an internal target at 4 D. Ideally, a standard procedure should be established for measuring accommodative response.

The reliability of a test can be considered in terms of its repeatability and reproducibility (ISO 5725, 1994). There does not seem to be any report of the repeatability of the accommodative response measurement using an infrared autorefractor. Locke and Somers (1989) determined the reproducibility of some accommodative lag measurement techniques and found that the reproducibility of MEM was the best among MEM, Cross retinoscopy, Nott retinoscopy and BCC.

In most of the studies of accommodative lag in children (Locke and Somers, 1989; Gwiazda *et al.*, 1993; Rosenfield *et al.*, 1996), accommodative responses were measured in semi-darkness. This was to reduce the effect of depth of focus on the measurement. Depth of focus is "the variation in image distance in a lens or an optical system which can be tolerated without incurring an objectionable lack of sharpness in focus" (Cline *et al.*, 1989). Depth of focus can be conceptualized as reflecting the neurological tolerance of a system, that is, a small amount of retinal defocus is tolerated without producing the perception of blur. However, increasing retinal defocus would eventually result in perception of blur. Depth of focus is inversely proportional to ocular focal length and pupil size and directly proportional to the size of the just-detectable retinal blur circle (Green *et al.*, 1980). Reducing the room illumination therefore reduces the depth of focus; it is recognized, however, that semi-darkness is not the usual or optimal environment for reading and other near tasks.

6.2 Objectives

With the foregoing in mind, the objectives of Study 3 were:

1) To determine the reliability (repeatability) of accommodative lag measures taken using the Shin Nippon SRW-5000 Open Field Autorefractor. Repeatability was expressed as the 95 % limits of agreement between two independent measures of accommodative lag (ISO 5725, 1994).
2) To characterize lag of accommodation in Hong Kong Chinese children between 4 and 8 years of age, particularly according to refractive status. The measurements were taken under three different stimuli conditions:
    a. White letters on a dark background in dim lighting
    b. White letters on a dark background in normal room lighting
    c. Black letters on a light background in normal room lighting

6.3 Methods

6.3.1 Subjects

Thirty-four children were recruited, but one child was unable to cooperate and did not provide any accommodative response data. Thirty-three Chinese children between 4 and 8 years of age (mean 6.73 and SD 1.18 years) participated. All of them had correctable distance vision of at least 0.1 Log MAR units in each eye. No subject had heterotropia or suppression. Parents gave informed consent prior to the measurements shown below.

Statistical analysis was carried out by coordinate vector **h** and spherical equivalent (spherical power plus half of the cylindrical power). The data were normally distributed (*see* Appendix A2.4).

6.3.2 Subjective refraction

The habitual VA for distance and near (at 40 cm) was recorded using LogMAR VA charts. Alternate and unilateral cover tests were performed with the subject wearing his or her habitual Rx to screen out heterotropia. Refractive error was first measured by autorefraction and then refined by subjective refraction.

6.3.3 Residual refractive error

Autorefraction was carried out using the Shin-Nippon SRW-5000 open-field autorefractor, with subjects wearing their best distance refractive correction and viewing a line of letters equivalent to LogMAR 0.2, positioned 6 m distant. Ten measures were taken on the right eye and results were transferred to a personal computer (Li and Edwards, 2001). The average of these ten readings (vector **h**) was calculated and provided a measure of the residual refractive error (R).

6.3.4 Autorefraction for near target

The autorefraction was measured while the subject fixated a near target at 40 cm from the spectacle plane using an SRW-5000 open-field autorefractor. An LCD computer monitor was used to present a line of 5 letters equivalent to LogMAR 0.2, as a fixation target. The advantage of using the LCD monitor was that measurement could be performed in a dark environment, and the effect of depth of focus (DOF) thereby reduced. Three stimuli conditions were presented as described below and the letter size was the same in each condition. Accommodative responses were measured twice in each condition for the determination of repeatability. Pupil diameter was measured to investigate the effect on the light reflex caused by the surrounding environment in each condition.

6.3.4.1 White letters on dark background in dim lighting

White letters were presented on a dark background. The room light was dimmed until the surroundings could first not be seen and the subject was asked to fixate the letters, keeping them as clear as possible. This was called condition DD. The advantage of this condition is that constriction of pupil was discouraged by dim lighting and the dark computer screen and therefore the result should have been little influenced by DOF. However, this is not a typical reading condition.

The subject was asked to keep the letters as clear as possible. Ten successive autorefraction readings were taken and the average of these ten readings (vector **h**) was calculated. The subject was then asked to look around the examination room for 3 min before another 10 successive readings were taken. A transparent rule was attached to the monitor and the pupil diameter was measured. The scale magnification was X6.

6.3.4.2 White letters on dark background in normal room lighting

The same target was presented again in normal room lighting. This was called condition LD. The advantage of this condition was that measurement was taken in typical reading ambient lighting conditions and the black target background was expected to result in less pupil constriction than a light target background.

Again, the subject was asked to keep the letters as clear as possible and the average of ten readings was used to determine the accommodative response. After that, the subject was asked to sit back, relax and look around the examination room for 3 min before another 10 successive readings were taken. Pupil diameter was measured on the monitor of the autorefractor as before.

6.3.4.3 Black letters on light background in normal room lighting

Black letters on a light background were presented in this condition, and measurement was taken in normal lighting conditions. This was called condition LL. This is the usual reading environment, both when reading hard copy, and when reading a word processing document on a computer screen.

The subject was asked to keep the letters as clear as possible. Ten successive readings were taken from the autorefractor and the average calculated (vector **h**) was used to determine the accommodative response. The subject was then asked to sit back, relax and look around the examination room for 3 min. Another 10 successive readings were taken and the pupil diameter was measured in the monitor of the autorefractor.

6.3.5 Accommodative lag calculations

Accommodative lag was determined as follows:

Accommodative lag (D) = accommodative stimulus (D) – accommodative response (D)

6.3.5.1 Accommodative stimulus

The accommodative stimulus, measured at the spectacle plane, was 2.5 D for all subjects, however the accommodative stimulus at the eye depended on the refractive error. The ocular accommodative stimulus is found from the formula

$$A = K - L \qquad \text{(Equation 6.1)}$$

where A is the ocular accommodative stimulus,

K is the ocular refractive error, and

L is the vergence of light from the near point at the eye

The calculation is simple and inuitive as shown using the "step-along" method in the examples below.

Find the accommodative stimulus at the eye for a myope wearing −3.25 D at a BVD of 12 mm and viewing a near object with a vergence of -2.50 D at the spectacle plane.

Find K:

	D		mm
F_{SP}	−3.25	→	−307.69
			−12
K	−3.13	←	−319.69

Find L:

	D		mm
Ls	−2.50		
	−3.25		
	−5.75	→	−173.91
			−12
L	−5.38	←	−185.91

Therefore,

A = −3.31 − (−5.38) = <u>2.25 D</u>

In the present study, the accommodative stimulus at the eye of a myope of −3.25 D was therefore 2.25 D, compared with a spectacle stimulus of 2.50 D.

Consider now the accommodative stimulus at the eye of a hyperope of +3.25 D.

Find K:

	D		mm
F_{SP}	+3.25	→	307.69
			−12
K	+3.38	←	295.69

Find L:

	D		mm
Ls	−2.50		
	+3.25		
	+0.75	→	1333.33
			−12
L	+0.76	←	1321.33

Therefore,

$$A = 3.38 - 0.76 = \underline{\underline{2.62\ D}}$$

In the present study, the accommodative stimulus at the eye of a hyperope of +3.25 D was therefore 2.62 D, compared with a spectacle stimulus of 2.50 D.

The ocular accommodative stimulus at the eye is therefore less than the spectacle accommodative stimulus in myopia, and more in hyperopia.

6.3.5.2. Accommodative response

The accommodative response at the spectacle plane is calculated from the residual refractive error (*see* 6.3.3) and the refraction measured when viewing the near target (*see* 6.3.4). For example, a subject with a residual refractive error wearing his or her spectacles of −0.50 D, and whose refraction at near is measured as −2.75 D, has accommodated by 2.25 D.

This has been measured at the spectacle plane and, in this particular example (BVD 12 mm), the ocular accommodative response is calculated as follows:

	D		mm
A_{SP}	+2.25	→	+444.44
			+12
A_O	+2.19	←	+456.44

The ocular accommodative response is always less than the spectacle accommodative response, regardless of refractive error.

The calculation of the ocular accommodative response was carried out in two principal meridians and the result was expressed as a sphero-cylinder.

6.4 Results

6.4.1 Repeatability

Multivariate analysis, in term of vector **h**, was performed to compare two measures taken from each condition and the results are shown in Table 6.1. There were no statistically significant differences between two sets of measures for any stimulus condition (all p-values > 0.05). Scatter of the differences can be visualized in the three-dimensional plots shown for each testing conditions in Figures 6.1 to 6.3. The ticks on the axes indicated 0.5 D steps.

Testing conditions	$\bar{h}$ (D)	Variance-covariance (D^2)	T^2 / p-value
DD	$\begin{pmatrix} 0.04 \\ -0.04 \\ 0.05 \end{pmatrix}$	$\begin{pmatrix} 0.07 & 0.00 & 0.06 \\ 0.00 & 0.02 & -0.01 \\ 0.06 & -0.01 & 0.08 \end{pmatrix}$	$T^2 = 0.11$ $p = 0.33$
LD	$\begin{pmatrix} 0.06 \\ 0.02 \\ 0.06 \end{pmatrix}$	$\begin{pmatrix} 0.06 & 0.00 & 0.03 \\ 0.00 & 0.01 & 0.00 \\ 0.03 & 0.00 & 0.04 \end{pmatrix}$	$T^2 = 0.11$ $p = 0.35$
LL	$\begin{pmatrix} 0.05 \\ 0.05 \\ 0.02 \end{pmatrix}$	$\begin{pmatrix} 0.06 & 0.01 & 0.04 \\ 0.01 & 0.02 & 0.02 \\ 0.04 & 0.02 & 0.08 \end{pmatrix}$	$T^2 = 0.24$ $p = 0.08$

Table 6.1 The mean differences of vector h in accommodative lag for the three stimulus conditions. Variance-covariance matrices, T^2 statistics and p-values are also shown.

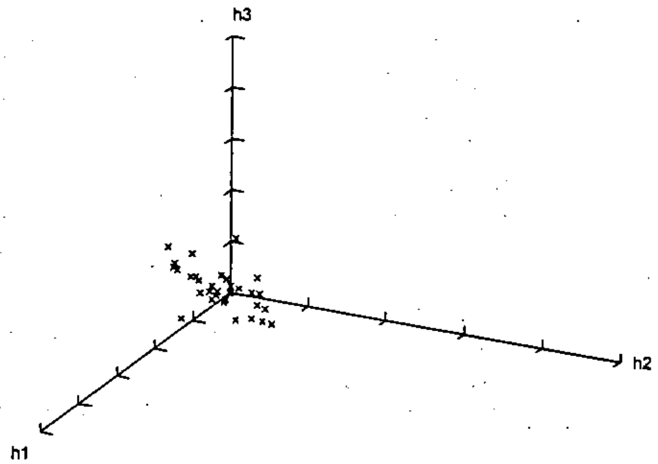


Figure 6.1 Scatter plot of the differences between two measures of accommodative lag taken under condition DD (dark room, dark background).

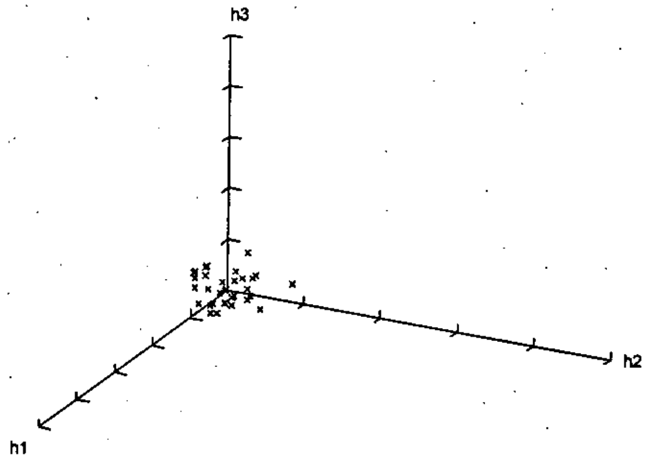


Figure 6.2 Scatter plot of the differences between two measures of accommodative lag taken under condition LD (light room, dark background).

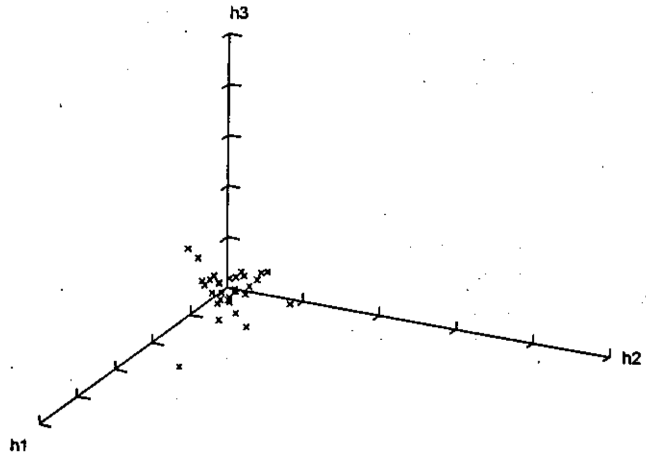


Figure 6.3 Scatter plot of the differences between two measures of accommodative lag taken under condition LL (light room, light background).

Repeated measures ANOVA was used to test the differences (in spherical equivalent) between two measures in three testing conditions. A Bonferroni multiple comparisons post-doc test showed no statistically significant differences between two measures (test and retest) in any of the three stimulus conditions.

The mean differences, standard deviations and 95 % limits of agreement between two sets of measures in each of the testing conditions are shown in Table 6.2 for each component of vector **h** and spherical equivalent. The agreements in term of spherical equivalent between two sets of measures in each condition are shown in Figures 6.4 to 6.6.

		Testing condition		
		DD	**LD**	**LL**
h_1 **(D)**	Mean diff (SD)	0.04 (0.25)	0.06 (0.25)	0.05 (0.24)
	95 % LOA	−0.45 to 0.53	−0.44 to 0.56	−0.42 to 0.53
h_2 **(D)**	Mean diff (SD)	−0.04 (0.13)	0.02 (0.09)	0.05 (0.13)
	95 % LOA	−0.30 to 0.22	−0.17 to 0.20	−0.20 to 0.29
h_3 **(D)**	Mean diff (SD)	0.05 (0.29)	0.06 (0.21)	0.02 (0.28)
	95 % LOA	−0.51 to 0.62	−0.35 to 0.46	−0.54 to 0.58
SE **(D)**	Mean diff (SD)	0.05 (0.26)	0.06 (0.21)	0.04 (0.24)
	95 % LOA	−0.45 to 0.55	−0.35 to 0.47	−0.45 to 0.55

Table 6.2 Mean differences between test and retest and the 95 % limits of agreement (LOA) between test and retest for accommodative lag measures, in the three stimulus conditions, for vector **h** components (h_1, h_2, h_3) and the spherical equivalent (SE).

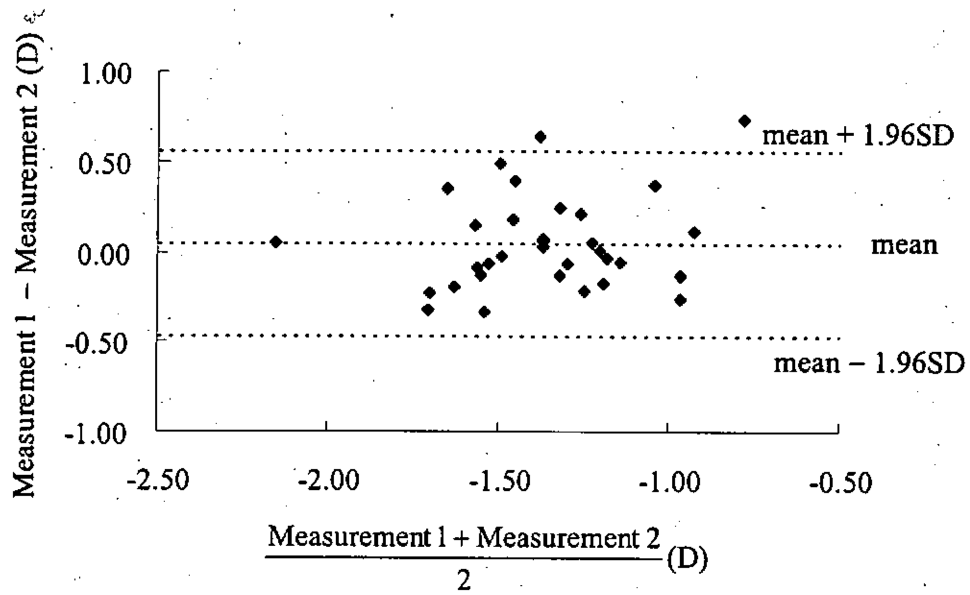


Figure 6.4 Agreement of spherical equivalent (SE) between two sets of measures of lag of accommodation taken in condition DD.

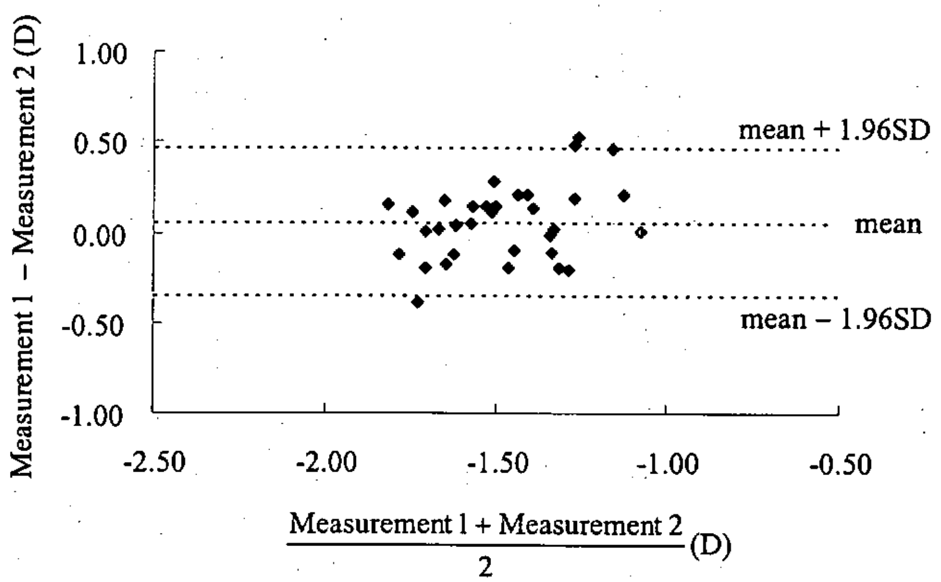


Figure 6.5 Agreement of spherical equivalent (SE) between two sets of measures of accommodative lag taken in condition LD.

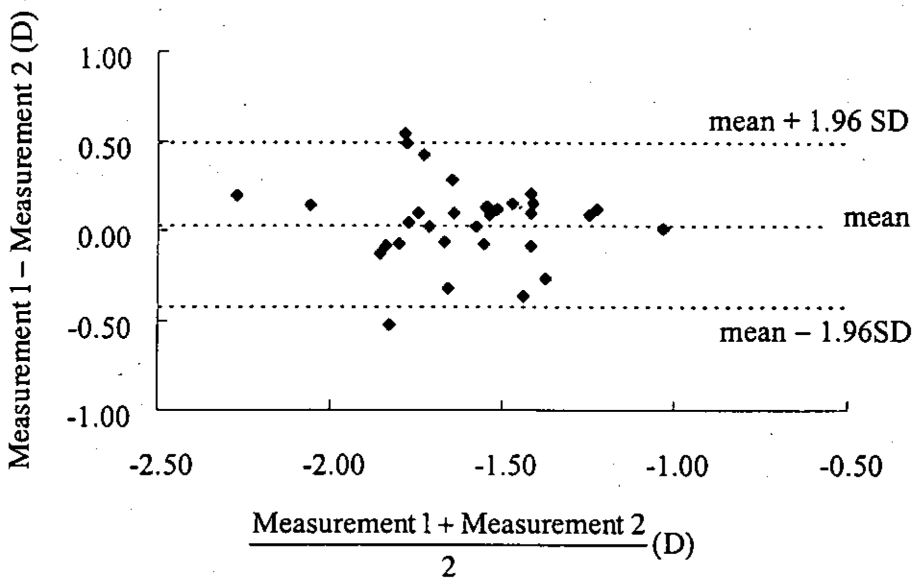


Figure 6.6 Agreement of spherical equivalent (SE) between two sets of measures of accommodative lag in condition LL.

6.4.2 Accommodative lag and stimulus conditions

The means of ocular accommodative lag found under each stimulus condition are shown in Table 6.3 and the scatter plots showing the distributions of the data for each condition are shown in Figures 6.7 to 6.9. There was a statistically significant difference in accommodative lag between the three stimulus conditions (Wilks lambda Λ^{*}=0.87, p<0.0001). The lag was greater when measured in a dark room with a dark background than when measured in a light room with a light background (T^2 =14.79 and p=0.01).

Testing condition (n=33)	$\bar{h}$ (D)	Mean sphero-cylinder (D)	Variance-covariance (D^2)
DD	$\begin{pmatrix} 1.30 \\ 0.03 \\ 1.33 \end{pmatrix}$	$1.34/-0.05\times 63$	$\begin{pmatrix} 0.15 & -0.00 & 0.16 \\ -0.00 & 0.04 & 0.01 \\ 0.16 & 0.01 & 0.22 \end{pmatrix}$
LD	$\begin{pmatrix} 1.13 \\ -0.02 \\ 1.25 \end{pmatrix}$	$1.25/-0.13\times 97$	$\begin{pmatrix} 0.13 & 0.02 & 0.11 \\ 0.02 & 0.03 & 0.02 \\ 0.11 & 0.02 & 0.13 \end{pmatrix}$
LL	$\begin{pmatrix} 1.00 \\ -0.05 \\ 1.14 \end{pmatrix}$	$1.15/-0.15\times 104$	$\begin{pmatrix} 0.18 & 0.02 & 0.17 \\ 0.02 & 0.04 & 0.02 \\ 0.17 & 0.02 & 0.21 \end{pmatrix}$

Table 6.3 Overall ocular accommodative lag obtained in the three testing conditions. The accommodative lags were different between conditions DD and LL.

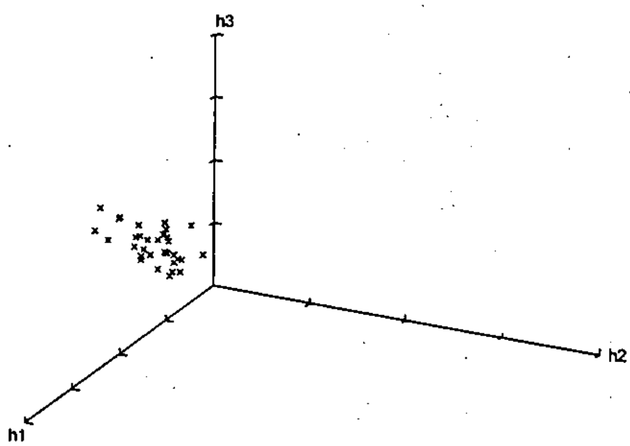


Figure 6.7 Scatter plot of ocular accommodative lag for condition DD.

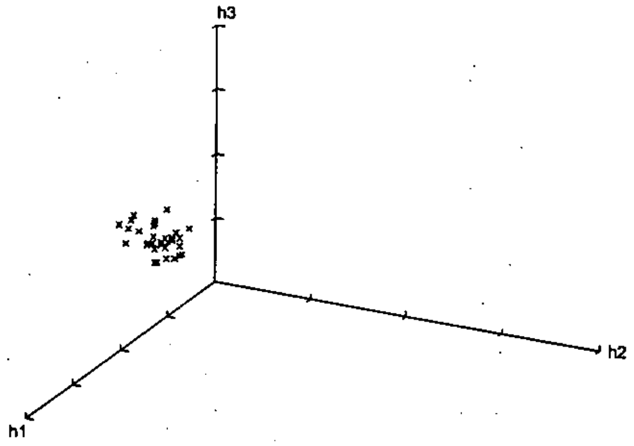


Figure 6.8 Scatter plot of the ocular accommodative lag for condition LD.

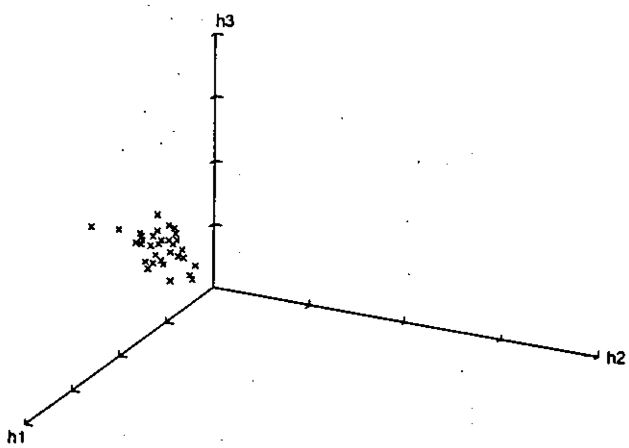


Figure 6.9 Scatter plot of the ocular accommodative lag for LL condition.

6.4.3 Pupil diameter

Subjects were divided into three refractive groups: myopes (with spherical equivalent equal or less than –0.50 D), emmetropes (less than –0.50 to less than +0.50 D) and hyperopes (equal or more than +0.50 D). There were 8 myopes (mean age 7.63, SD 0.74 years), 12 emmetropes (mean age 6.83, SD 1.03 years) and 13 hyperopes (mean age 6.08, SD 1.19 years).

The pupil diameters in different refractive group under each stimulus condition are shown in Table 6.4. Repeated-measures two-way analysis of variance was used to test whether refractive status and stimulus condition interacted to affect pupil size, and whether pupil size varied by refractive status or by stimulus condition. There was no statistically significant interaction between the factors refractive status and stimulus condition. As expected, there were statistically significant differences in pupil size according to stimulus condition ($p<0.001$ for all comparisons). Although there was a trend for the pupil size to be least in myopes and greatest in hyperopes, the differences were not statistically significant.

	Condition DD Mean (SD) mm	**Condition LD Mean (SD) mm**	**Condition LL Mean (SD) mm**
All (n=33)	6.27 (0.70)	5.30 (0.67)	3.96 (0.66)
Myopia (n=8)	5.96 (0.83)	4.98 (0.91)	3.58 (0.79)
Emmetropes (n=12)	6.24 (0.71)	5.29 (0.64)	4.11 (0.62)
Hyperopes (n=13)	6.50 (0.49)	5.50 (0.50)	4.05 (0.57)

Table 6.4 The mean and standard deviation of the pupil diameter under each stimulus conditions.

6.4.4 Accommodative lag and refractive status

The ocular accommodative lags found for myopes, emmetropes and hyperopes for each stimulus condition are shown in Table 6.5. For comparison proposes the accommodative lags calculated at the spectacle plane are shown in Table 6.6. The spectacle accommodative lag was higher than ocular accommodative lag for myopes. For hyperopes with 12 mm vertex distance, the spectacle lag would be lower than ocular lag for refractive errors greater than +1.50 D; however, there was only one hyperopic subject with refractive error over +1.50 D.

Multivariate analysis, in term of vector **h**, showed accommodative lag was statistical significant differences between the three refractive groups (Λ^{*} =0.816, p<0.001 in DD; Λ^{*} =0.86, p<0.001 in LD and Λ^{*} =0.82, p<0.001 in LL). However, there was no statistically significant difference between myopes and emmetropes, emmetropes and hyperopes and myopes and hyperopes.

Repeated-measures two-way analysis of variance was used to test whether refractive status and stimulus condition interacted to affect accommodative lag, and whether accommodative lag varied by refractive status or by stimulus condition. Accommodative lag was expressed as spherical equivalent for this analysis. There was no statistically significant interaction between the factors refractive status and stimulus condition. Accommodative lag was different between all the stimulus conditions (DD and LD, p=0.003, DD and LL, p=0.000, LD and LL, p=0.0007). There was no statistically significant difference of accommodative lag between three refractive groups in all conditions.

	$\bar{h}$ (D)	Mean sphero-cylinder (D)	Variance-covariance (D^2)
Condition DD			
Myopes	$\begin{pmatrix} 1.46 \\ 0.06 \\ 1.55 \end{pmatrix}$	$1.53/-0.10 \times 57$	$\begin{pmatrix} 0.11 & -0.01 & 0.13 \\ -0.01 & 0.02 & 0.01 \\ 0.13 & 0.01 & 0.18 \end{pmatrix}$
Emmetropes	$\begin{pmatrix} 1.35 \\ 0.03 \\ 1.33 \end{pmatrix}$	$1.36/-0.05 \times 33$	$\begin{pmatrix} 0.20 & -0.04 & 0.21 \\ -0.04 & 0.03 & -0.04 \\ 0.21 & -0.04 & 0.26 \end{pmatrix}$
Hyperopes	$\begin{pmatrix} 1.14 \\ 0.01 \\ 1.22 \end{pmatrix}$	$1.22/-0.08 \times 83$	$\begin{pmatrix} 0.05 & 0.02 & 0.07 \\ 0.02 & 0.06 & 0.03 \\ 0.07 & 0.03 & 0.15 \end{pmatrix}$
Condition LD			
Myopes	$\begin{pmatrix} 1.31 \\ 0.04 \\ 1.47 \end{pmatrix}$	$1.47/-0.17 \times 81$	$\begin{pmatrix} 0.04 & -0.01 & 0.03 \\ -0.01 & 0.02 & -0.01 \\ 0.03 & -0.01 & 0.07 \end{pmatrix}$
Emmetropes	$\begin{pmatrix} 1.13 \\ -0.07 \\ 1.20 \end{pmatrix}$	$1.20/-0.07 \times 101$	$\begin{pmatrix} 0.15 & 0.01 & 0.13 \\ 0.01 & 0.02 & 0.00 \\ 0.13 & 0.00 & 0.15 \end{pmatrix}$
Hyperopes	$\begin{pmatrix} 1.02 \\ -0.06 \\ 1.17 \end{pmatrix}$	$1.18/-0.17 \times 104$	$\begin{pmatrix} 0.11 & 0.03 & 0.09 \\ 0.03 & 0.03 & 0.04 \\ 0.09 & 0.04 & 0.10 \end{pmatrix}$
Condition LL			
Myopes	$\begin{pmatrix} 1.09 \\ 0.05 \\ 1.14 \end{pmatrix}$	$1.16/-0.09 \times 64$	$\begin{pmatrix} 0.20 & 0.00 & 0.23 \\ 0.00 & 0.01 & 0.01 \\ 0.23 & 0.01 & 0.29 \end{pmatrix}$
Emmetropes	$\begin{pmatrix} 1.04 \\ -0.10 \\ 1.16 \end{pmatrix}$	$1.20/-0.19 \times 115$	$\begin{pmatrix} 0.18 & 0.00 & 0.13 \\ 0.00 & 0.04 & -0.00 \\ 0.13 & -0.00 & 0.13 \end{pmatrix}$
Hyperopes	$\begin{pmatrix} 0.92 \\ -0.06 \\ 1.11 \end{pmatrix}$	$1.12/-0.22 \times 102$	$\begin{pmatrix} 0.10 & 0.05 & 0.13 \\ 0.05 & 0.05 & 0.06 \\ 0.13 & 0.06 & 0.24 \end{pmatrix}$

Table 6.5 The ocular accommodative lag in the three refractive groups for the three stimulus conditions. Myopes n=8; Emmetropes n=12; Hyperopes n=13.

	$\bar{h}$ (D)	Mean sphero-cylinder (D)	Variance-covariance (D^2)
Condition DD			
Myopes n=8	$\begin{pmatrix}1.63\\0.07\\1.69\end{pmatrix}$	$1.72/-0.11\times63$	$\begin{pmatrix}0.10&-0.01&0.12\\-0.01&0.02&0.00\\0.12&0.00&0.15\end{pmatrix}$
Emmetropes n=12	$\begin{pmatrix}1.42\\0.03\\1.42\end{pmatrix}$	$1.44/-0.44\times40$	$\begin{pmatrix}0.16&0.00&0.17\\0.00&0.04&0.01\\0.17&0.01&0.22\end{pmatrix}$
Hyperopes n=13	$\begin{pmatrix}1.27\\0.01\\1.26\end{pmatrix}$	$1.27/-0.08\times83$	$\begin{pmatrix}0.05&0.01&0.07\\0.01&0.05&0.03\\0.07&0.03&0.14\end{pmatrix}$
Condition LD			
Myopes n=8	$\begin{pmatrix}1.47\\0.04\\1.66\end{pmatrix}$	$1.66/-0.19\times81$	$\begin{pmatrix}0.04&-0.01&0.03\\-0.01&0.02&-0.02\\0.03&-0.02&0.06\end{pmatrix}$
Emmetropes n=12	$\begin{pmatrix}1.24\\-0.01\\1.31\end{pmatrix}$	$1.29/-0.08\times100$	$\begin{pmatrix}0.14&0.03&0.12\\0.03&0.03&0.02\\0.12&0.02&0.13\end{pmatrix}$
Hyperopes n=13	$\begin{pmatrix}0.91\\-0.14\\1.11\end{pmatrix}$	$1.23/-0.17\times103$	$\begin{pmatrix}0.11&0.02&0.08\\0.02&0.03&0.03\\0.08&0.03&0.09\end{pmatrix}$
Condition LL			
Myopes n=8	$\begin{pmatrix}1.26\\0.05\\1.34\end{pmatrix}$	$1.36/-0.11\times69$	$\begin{pmatrix}0.18&0.00&0.20\\0.00&0.01&0.01\\0.20&0.01&0.25\end{pmatrix}$
Emmetropes n=12	$\begin{pmatrix}1.13\\-0.10\\1.25\end{pmatrix}$	$1.29/-0.19\times114$	$\begin{pmatrix}0.18&0.02&0.16\\0.02&0.03&0.02\\0.16&0.02&0.19\end{pmatrix}$
Hyperopes n=13	$\begin{pmatrix}0.96\\-0.06\\1.16\end{pmatrix}$	$1.17/-0.22\times101$	$\begin{pmatrix}0.08&0.04&0.11\\0.04&0.04&0.06\\0.11&0.06&0.21\end{pmatrix}$

Table 6.6 The accommodative lag calculated on spectacle lag in the three refractive groups for the three stimulus conditions.

6.5 Discussion

6.5.1 Repeatability

The 95 % limits of agreement and the variance-covariance between two accommodative lag measures were similar in the three stimulus conditions (Table 6.1 and 6.2), suggesting that measures were equally repeatable under these conditions. The standard deviation of spherical equivalent in LD condition, i.e. using white letters in dark background in normal lighting condition, was numerically lowest (Table 6.2). Hence, a dark background with white letters may be the most reliable target for accommodative response measurement using the Shin-Nippon SRW-5000 open-field autorefractor.

The reproducibility of accommodative lag was 0.16 D by MEM, was 0.58 D by Cross retinoscopy, was 0.38 D by Nott retinoscopy and was 0.96 D by BCC (Locke and Somers, 1989). These figures were calculated by the present author from the raw data provided in the paper. The repeatability of accommodative lag measured by SRW-5000 in children was better than BCC and Cross retinoscopy but worse than MEM and Nott retinoscopy. The subjects in Locke and Somers's study were very different from those of the present study, being senior optometry students and optometry clinic staff. Such subjects would certainly provide ideal reproducibility conditions especially compared with young children.

6.5.2 Characterization of accommodative lag

6.5.2.1 General findings compared with previous studies

Accommodative lags found in the present study (in three conditions) were similar to those previously reported in children and tended to be slightly greater than those found in adults (Table 6.7 and 6.8).

Gwiazda *et al.* (1993) measured ocular accommodative responses in 64 children of age ranging from 5 to 17 years. The mean accommodative response was about 2.00 D at 33 cm viewing distance so the accommodative lag averaged approximate 1.00D. In the subsequent study by Gwiazda *et al.* (1999), AC/A ratio was measured in 101 children age from 5.8 to 21.1 year, and accommodative response averaged 1.84 D at 3 D and the calculated average lag was 1.16 D. Woung *et al.* (1998) reported that accommodative lag averaged 1.43 D at 4 D in 34 children from age 7 to 12 years. These are similar to the present findings in condition LL (Table 6.7), which had similar testing conditions (light background, light room and tested monocularly), given that Gwiazda *et al.* (1993) found that accommodative lag increased with decreasing target distance. The accommodative lag in other two conditions in this study were slight greater than others studies, and this will be further discussed later.

Goss and Rainey (1999) measured 73 myopic children and found the accommodative lag averaged 0.74 D. Their measurements were taken under binocular viewing conditions which made it difficult to compare with present study and this will be further discussed later in this chapter.

Studies	Subj no.	Target	Accommodative lag
Abbott *et al.* (1998)	N=33	Letter size equivalent to 6/9 presented at varying distance	#0.09 D at 4 D
Bullimore *et al.* (1992)	N=28	Letter subtended 0.4 deg presented at 3 distances	0.34 D at 3 D 0.67 D at 5 D
Goss and Rainey (1999)	* N=73	J5 printed letters	0.74 D at 2.5 D
Gwiazda *et al.* (1999)	* N=101	Letters equivalent to 6/30 presented at 0.33 m	#1.16 D at 3 D
Jiang (2000)	N=8	Letter 'E' equivalent to 6/30 present on dark computer screen	#~0.50 D at 2.5 D
McBrien and Millodot (1986)	N=40	Letter subtended 1.5 min of arc presented at varying distance	0.34 D at 3 D 0.46 D at 4 D
Rosenfield *et al*, (1996)	N=24 #N=15	Black on white letters	0.50 D at 2.5 D #0.31 D at 2.5 D
Tokoro (1988)	N=32	Cross target	1.09 D at 5 D
Woung *et al*, (1998)	* N=34	Internal asterisk-shaped target	#1.43 D at 4 D
Present study	*N=34	Letters equivalent to 6/9 present on computer monitor	# 1.31 D in condition DD # 1.19 D in condition LD # 1.07 D in condition LL

Table 6.7 The accommodative lag reported in other studies. Ocular accommodative lags were considered in each study except for that of Woung *et al.* in which it was not stated how the accommodative lag was calculated. * Indicates child subjects and # indicates monocular findings.

Study	Subj no.	Accommodative lag (D)		
Bullimore *et al*, (1992)	N=14 (E) N=14 (L)	0.30 (E) 0.38 (LOM) } at 3 D	0.60 (E) 0.73 (LOM) } at 5 D	
*Gwiazda *et al.* (1993)	N=21 (E) N=12 (M)	0.78 (E) 1.00 (M) } at 3 D		
*Gwiazda *et al*, (1999)	N=68 (E) N=33 (M)	1.11 (E) 1.25 (M) } at 3 D		
McBrien and Millodot (1986)	N=10 (LOM) N=10 (EOM) N=10 (E) N=10 (H)	0.48 (LOM) 0.40 (EOM) 0.30 (E) 0.19 (H) } at 3 D	0.64 (LOM) 0.56 (EOM) 0.35 (E) 0.30 (H) } at 4D	0.83 (LOM) 0.69 (EOM) 0.54 (E) 0.38 (H) } at 5D
Tokoro (1988)	N=32	1.04 (E) 1.13 (M) } at 5 D		
*Woung *et al.* (1998)	N=15 (E) N=19 (EOM)	1.47 (E) 1.40 (EOM) } at 4 D		
*Present study	N=13 (H) N=12 (E) N=8 (EOM)	1.18 (H) 1.34 (E) 1.48 (EOM) } at 2.5 D in DD condition		
		1.09 (H) 1.17 (E) 1.39 (EOM) } at 2.5 D in LD condition		
		1.01 (H) 1.10 (E) 1.12 (EOM) } at 2.5 D in LL condition		

Table 6.8 Previous result on accommodative lag in difference refractive groups. Ocular accommodative lags were considered in each study except for that of Woung *et al.* in which it was not stated how the accommodative lag was calculated. (H = hyperopes, E = emmetropes, M = myopes, LOM = late-onset myopes and EOM= early-inset myopes).

6.5.2.2 Target presentation

Most previous studies have presented their target in a light box, that is, on a light background, and this could stimulate the pupillary light reflex. Measurement was carried out in semi-darkness to eliminate the effect of depth of focus but this is unlikely to provide optimal near task measurement conditions.

In the present study the target was presented on a LCD monitor and this approach can provide better control of pupil size. In fact, the pupil was significantly smaller when the target was presented on a light background in a light room (mean 5.30, SD 0.67 mm)compared with a dark background in a light room (mean 3.96, SD 0.66 mm) (Table 6.4).

Jiang (2000) presented his letters target on a dark computer screen and found the accommodative lag was around 0.50 D at 2.5 D in adults (derived from the graph presented in Jiang's paper). All the subjects in his study were emmetropes (n=8) and so the smaller mean lag obtained may have been due to differences in lag related to refractive error.

6.5.2.3 Methodology

The values for accommodative lag obtained in the present study were higher than those reported in adult, and this may be related to the measurement method used. All measurements at near were taken under monocular viewing condition in order to eliminate the effect of convergence (Fincham and Walton, 1957; Gwiazda *et al.*, 1993; Rosenfield *et al.*, 1996). Accommodative response taken under binocular viewing conditions include input from vergence accommodation. Unfortunately, this confounds comparison with monocular blur-driven studies, as well as complicating the interpretation of results, since the drive from vergence accommodation as well as the interaction between vergence and accommodation must be considered (Ong and Ciuffreda, 1997: p.23).

The type of refractive correction used during measurement will affect the results. If trial lenses are used in a trial frame, then ocular accommodation should be calculated. The stimulus to accommodation is over-estimated in myopes and under-estimated in hyperopes, if measured at the spectacle plane, and this would be expected to result in higher measurements of lag in myopes than in hyperopes (Bennett and Rabbetts, 1984: p.121-122; Rosenfield, 1997: p.90).

Using contact lens may be a better choice for the refractive correction during measurement, as the accommodative stimulus in myopes and hyperopes will be as same as emmetropes, that is the inverse of the stimulus distance in meters. However, fitting contact lenses in young children introduces other difficulties such as initial discomfort, clack of co-operation, apprehension and so on.

During autorefraction measurement with corrective spectacle lenses in front of the subject's eye, some degree of spectacle lens tilt cannot be avoided. As a result, the spherical power would be slightly altered, and some astigmatism induced (Ong and Ciuffreda, 1997: p.24-25). In the study of Gwiazda *et al.* (1993), accommodation was measured with a pantoscopic tilt of 15 deg of the corrective spectacle lens and reported that tilting of the lenses resulted a 6 % average reduction of accommodative demand. This artificially induced error could have affected measurements in the present study, and resulted in an erroneously high accommodative lag being obtained. Therefore, the trial frame used in the study was straight.

6.5.2.4 Subject age

In this study, there was no evidence that accommodative lag varies with age in children aged between 4 and 8 years. Rouse *et al.* (1984) examined accommodative lag by MEM in approximately 100 children from kindergarten to grade six (age 5 to 12 years). They found that the relation between accommodative lag and age was low (r=0.17). Leat and Gargon (1996) measured accommodative response by the Nott method at 4 D and there was no statistically significant difference in accommodative lag between the ages of 3 and 10 years (p=0.042; at alpha level adjusted to 0.022 for the number of tests performed *see* Section 4.5.4).

6.5.3 Accommodative lag and stimuli conditions

Accommodative lag was the greatest in all three refractive groups when measured in condition DD (dark background, dark room), and least when measured in condition LL (light background, light room) (Table 6.3). With the room light turned on, the accommodative lag measured in condition LD (light room, dark background) was the most reliable condition for measuring accommodative response because the within subject variance and the between subjects variance (Fig. 6.8) was lowest for this stimulus condition. The dark stimulus background can reduce the pupil light reflex and the room light can help to keep the target clear during the measurement.

The pupil was largest in condition DD, followed be condition LD and condition LL. The mean difference was least between condition DD and LD and greatest between DD and LL and this suggests that the dark computer screen was successful in controlling the pupil constriction during the measurement, and hence minimized the effect of depth of focus.

A larger pupil results in a smaller depth of focus. If accommodative lag or related to some acceptable and fixed degree of blur then a smaller depth of focus would be expected to be associated with a smaller accommodative lag. However, this was not the case in the present study where a higher lag was associated with a larger pupil (Table 6.4). Possible explanations of this finding are given below.

(1) A dark room is probably not a good testing environment. In a dark room, there are fewer cues as to distance than in a light room. Under these circumstances one might expect that accommodation would be inaccurate - sometimes in front and sometimes behind the target. However, only positive lag was obtained in the present experiment. This implies that the accommodation system tends to relax when trying to obtain a better retinal image quality. It is possible that accommodation first fluctuated in front and then behind the target, and finally stabilized behind the target before measurement was taken. The reaction time and response time for accommodation are about 0.3 and 0.8 sec respectively (Ibi, 1997; Culhane and Winn, 1999). It would be interesting to observe the accommodative pattern under dark room conditions using continuous measures.

(2) The target under dark room conditions did not provide a good stimulus to accommodation although the effect of DOF was reduced. If the target presented could not be maintained clearly during measurement, this would have adversely affected the measurements. Several subjects and the adult subjects in a pilot study reported that it was very difficult to keep the image clear, and that the letter target was seen blurred. They could only get a clear image by paying very serious attention, and most of the time the target was seen blurred. However, the letter can still be recognized as the letter size (Snellen 6/9) allowed subjects to have some degree of optical defocus.

(3) Children may fail to keep the image clear while measurements taken. Therefore, further work should be done on improving the target to make it easier to keep clear during measurement.

6.5.4 Accommodative lag and myopia

Myopes tended to exhibit the greatest accommodative lag in the present study, in agreement with previous studies (Table 6.8), and the number of subjects in the present study may have resulted in low power of statistical test. Other researchers, who reported larger accommodative lags in myopes than in emmetropes (Gwiazda *et al.*, 1993; Goss and Zhai, 1994; Gwiazda *et al.*, 1995b; Jiang, 1995), reported that the greater accommodative lag, appears to occur more or less concurrently with the development of myopia.

Gwiazda *et al.* (1995b) found that blur-driven accommodation was reduced during myopic progression but no reduction occurred in subjects who remained emmetropic or were non-progressing myopes through the experimental period. Once myopia stabilized the level of accommodative response was similar to that in emmetropes.

Jiang (1995) also reported that the mean AC/A ratios found in young emmetropic adults who became myopic were higher than in emmetropes who remained emmetropic. The higher AC/A ratio indicates a larger accommodative lag. These findings are important, as any hypothesis proposing accommodative lag as a cause of myopia requires that a high accommodative lag exists, that it predates the onset of myopia, that it remains high while myopia is developing and that it is no longer high when myopia has stopped developing.

Assuming, for the purposes of discussion, that myopes do have greater accommodative lags, possible reasons are:

(1) Myopes may be less inclined to accommodate accurately for a near task, if the task is close to their far point. They may have greater tolerance of blur due to poor distance vision when previously uncorrected (Gwiazda *et al.*, 1995b). In contrast, emmetropes are capable of clear vision at all distances and so might accommodate more critically, being "rewarded" by clear vision (Bullimore *et al.*, 1992).

(2) Myopes have reduced blur appreciation or increased blur tolerance, although research into this has thus far been equivocal. Gwiazda *et al.* (1993) found that the threshold of blur detection increased in negative lens-induced blur in myopes. However, the response to blur was very low in both myopes and hyperopes, and this may be related to the use of negative lenses to induce accommodation. Abbott

et al. (1998) adopted the same protocol to that of Gwiazda *et al.* (1993) and found that the response to negative lens induced blur was significantly lower in myopes than in hyperopes. These findings suggest that myopes use pure blur cues less effectively than hyperopes, and hence may used other cues such as proximity and disparity to focus objects clearly. Hung *et al.* (1995), however, suggested than the contribution of proximity-induced accommodation was likely to be small and not more than 4 %, whereas closed-loop disparity-induced accommodation was indeed found to be greater for myopes than emmetropes (Rosenfield and Gilmartin, 1987; Rosenfield and Gilmartin, 1988).

Rosenfield and Abraham-Cohen (1999) found that adult myopes had reduced blur sensitivity compared with adult emmetropes. The threshold at which blur was detected was ±0.19 D in myopes compared with ±0.11 D in emmetropes, and the difference was statistically significant. Kurtev (1979), however, found no difference in blur thresholds of myopes and emmetropes. Schmid *et al.* (submitted) recently found no statistically significant difference in blur detection in myopic and non-myopic Chinese children between the ages of 8 and 12 years. Further work in this area is clearly needed.

Whether the greater lag, still assuming that is does indeed occur, is caused by greater tolerance of blur or by reduced blur detection, its effect is to produce hyperopic retinal defocus, and this has been proposed as a stimulus for axial elongation (Rosenfield and Gilmartin, 1998). The eye is presumed to adjust the location of the retina in order to obtain the clearest focus, i.e. minimum retinal bur circle size. The rationale for this theory is derived from animal models.

Hyperopic defocus has been shown to cause myopia in infant animals (for a review of animal models of myopia see Smith III, 1998). It must be remembered, however, that this type of myopia only occurs in infant animals, while human myopia typically develops at an older age and certainly well after infancy. Also, the blur induced experimentally in these animal models was much greater than that likely to be produced by accommodative lag.

6.5.5 Experimental setup

Reflections from the distance correction lenses, or tilting of these lenses, may have been a source of measurement error during measurement of accommodative lag and the use of contact lenses rather than trial lenses would avoid this and maintain the same stimulus to accommodation in subjects with different refractive errors. Contact lenses would also simplify the calculation of ocular accommodative lag.

We, and a number of other investigators, have measured accommodative lag at 40 cm (see Table 6.5). However, children have shorter arms than adults, and Rosenfield *et al.* (2001) reported average reading distances of around 27 cm in children from 6 to 11 years old. They suggested that 25 cm is a more appropriate testing distance for near-vision functions in children.

6.6 Conclusions

This is the first report of the agreement between measures of accommodative lag expressed as the 95 % limits of agreement. Although measures of accommodative lag taken under the three stimulus conditions were similar in repeatability, normal room lighting allowing a clear view of the target and its surroundings, along with a dark target background, which does not result in full pupil constriction, seems to offer the best target conditions.

The accommodative lag tended to be greater in myopes than in hyperopes. The accommodative lags found in the present study were comparable with those found in other studies for children, and tended to be greater than those found for adults by other investigators. These differences may be due to different target presentation, different methodology and different proportions of refractive error within the overall sample.

Chapter 7

Overall summary and concluding remarks

7.1 Clinical evaluation of Shin-Nippon SRW-5000 open-field autorefractor

The evaluation of the Shin-Nippon SRW-5000 comprised the determination of the accuracy and reliability of the instrument in a pediatric population.
For the evaluation of accuracy, cycloplegic and non-cycloplegic autorefraction measures using the SRW-5000 were compared with cycloplegic refraction measures. Cycloplegic SRW-5000 autorefraction was compared also with non-cycloplegic autorefraction taken with the same instrument. Finally, non-cycloplegic SRW-5000 autorefraction was compared with non-cycloplegic autorefraction using the closed-field Canon RK5 in order to investigate the relative control of accommodation with these two instruments.

The reliability of SRW-5000 was determined by its repeatability and reproducibility both in cycloplegic and non-cycloplegic condition. Repeatability was obtained by comparing two sets of measurement taken by same examiner. Reproducibility was obtained by comparing two sets of measurement taken by two different examiners.

Fifty-six children, between 4 and 8 years of age, participated in this study and 44 of them underwent cycloplegic measurement. Results, in sphero-cylinder format were converted to coordinate vector **h** and spherical equivalent refractive error for statistical analysis.

The overall accuracy of the SRW-5000 was high, and similar to that reported for the Canon R-1 open-field autorefractor. As would be expected, the agreement between cycloplegic open-field autorefraction and cyclopelgic refraction was better than between non-cycloplegic open-field autorefraction and cycloplegic refraction, and autorefraction taken under both conditions tended to produce results which were more myopic than cycloplegic refraction. Non-cycloplegic SRW-5000 autorefraction produced slightly more myopic results than closed-field autorefraction and the difference was mainly for hyperopes, suggesting that control of accommodation was not as good with the SRW-5000 as with the RK-5.

Reliability was considerably better for cycloplegic than non-cycloplegic autorefraction, and slightly better for one compared with two observers. Repeatability results from the SRW-5000 autorefractor, both with and without cycloplegia were similar to those reported for the Canon R-1.

7.2 Tonic accommodation in Hong Kong children

Tonic accommodation was determined by autorefraction carried out in total darkness using the Shin-Nippon SRW-5000 open-field autorefraction. Tonic accommodation in Hong Kong children between 4 and 8 years of age was then characterized.

The repeatability of tonic accommodation using the SRW-5000 in darkness was about ± 0.83 D. The mean tonic accommodation in 56 children was $1.07/-0.05\times138$ in sphero-cylinder notation or $(1.05 \quad -0.03 \quad 1.05)'$ in vector **h** notation. The mean value of TA in children younger than 6 years was $1.09/-0.04\times68$ in sphero-cylinder format or $(1.05 \quad 0.02 \quad 1.08)'$ in vector **h** notation, and was not significantly different from the mean value obtained in older children. The mean TA was highest in hyperopes $1.50/-0.11\times15$ (n=14), followed by emmetropes $1.35/-0.18\times172$ (n=18) and then in myopes $0.76/-0.20\times106$ (n=24).

This is the first report of the reliability of tonic accommodation measures taken in total darkness in term of the 95 % limits of agreement, and the first time vector **h** has been used in the characterization of tonic accommodation. It is also the first report of tonic accommodation values in children under 6 years of age.

In agreement with previous studies, we found that myopes have significant lower TA than emmetropes and hyperopes. The lower TA in myopes may be due to overall reduction in autonomic innervation, as proposed by other researchers, and from the results of other worker, it seems that this happens concurrently with refractive error development, rather than causing refractive error development. Nevertheless, the possibility of a cause and effect relationship between low TA and myopia cannot, at present, be completely ruled out.

7.3 Accommodative lag in Hong Kong Children

The accommodative response was measured using the SRW-5000 open-field autorefractor at 40 cm under three stimulus conditions, namely white letters on a dark background in dim light, white letters on a dark background in normal lighting and black letters on a light background in normal lighting. The ocular accommodative lag was then calculated.

While the three stimulus conditions resulted in similar repeatability values, overall, white letters on a dark background in normal light probably provide the best target conditions. This condition results in a larger pupil than dark letters on a white background and thus reduces the influence of depth of focus on accommodative lag measures. Subjects found it difficult to focus on the target when it was presented in a dark room.

Accommodative lag was greatest for white letters on a dark background in dim light $1.34/-0.05\times 63$ in sphero-cylinder formation or $(1.30 \quad 0.03 \quad 1.33)'$(D) in vector **h** notation, followed by white letters on a dark background in normal room lighting $1.25/-0.13\times 97$ or $(1.13 \quad -0.02 \quad 1.25)'$(D), and least for black letters on a light background in normal room lighting $1.15/-0.15\times 104$ or $(1.00 \quad -0.05 \quad 1.14)'$(D).

The accommodative lag values found in the present study were similar to those found in other studies in children, and greater than those in adults. It is possible that the target was not clear enough to stimulate accurate accommodation and/or the children failed to maintain the letters clear during measurement.

7.4 Overall comments

Steady-state accommodation includes blur or reflex accommodation, proximal accommodation, vergence accommodation and tonic accommodation. In this work, tonic accommodation was measured in total darkness in the absence of the other three components. Accommodation resulting from blur (lag of accommodation) was measured minimizing proximal accommodation (largely eliminated by the use of an open-field autorefractor) and excluding vergence accommodation (by monocular measurement).

This is the first report of tonic accommodation and accommodative lag presented in terms of vector **h**, so that complete refractive information was used during calculation and statistical analysis. Tonic accommodation and accommodative response were both found to be lowest in myopes, although the accommodative response results were somewhat equivocal. The lower tonic accommodation found in myopes may reflect an overall reduction in autonomic innervation. The few reports available suggest that lower tonic accommodation happens concurrently with myopia development. While the results of the present study are equivocal in terms of difference in accommodative lag according to refractive error, it is still possible that a greater lag results in hyperopic retinal defocus and may cause myopia development in children.

7.5 Further study

7.5.1 General considerations

Both tonic accommodation and accommodative lag should be measured in different age groups and in a sample with a greater refractive error range, in order to further investigate the relationship between those aspects of accommodation and refractive error.

The SRW-5000 can be modified to provide continuous measurement, as in the Canon R-1. If both accommodative functions measured in the present study were recorded continuously and averaged over a period of time, it is possible that more reliable results would be obtained.

The high prevalence of myopia in children in Hong Kong is certainly largely environmental in origin. Longitudinal data characterizing the change in tonic accommodation and accommodative lag as myopia starts and develops may shed new light on this relationship.

7.5.2 About tonic accommodation

When measuring autorefraction in total darkness, the red ring was noticeable to the subject. The red ring is used for determining refractive error and it seems that this cannot be removed. A possible improvement would be to use a low center spatial frequency (0.1 c/deg) difference of Gaussian target and to measure TA in semi-darkness. It has been shown that this type of target does not stimulate accommodation.

Accommodative adaptation is another issue in relation to myopic progression. The Shin-Nippon SRW-5000 open-field autorefractor can be used to measure the change in tonic accommodation after prolonged reading, measurement being made once the near task is removed.

7.5.3 About accommodative lag

Possible improvement to research design for future work include: (1) using a better quality LCD monitor so that the edges of the letter will be sharper and the letter size can be smaller, (2) using a cathode tube monitor instead of LCD monitor, and (3) using a mono-color monitor rather than a color monitor. Those modifications would all improve the quality of the letter presented.

Instead of measuring accommodative response at a single distance, accommodative response can be measured at several distances and plotted as an accommodation function curve.

References

Abbott, M. L., Schmid, K. L., Strang, N. C. (1998). Differences in the accommodation stimulus response curves of adult myopes and emmetropes. *Ophthal Physiol Opt*; **18**, 13-20.

Adams, C. W., Johnson, C. A. (1991). Steady-state and dynamic response properties of the Mandelbaum effect. *Vision Res*; **31**, 751-760.

Adams, D. W., McBrien, N. A. (1993). A longitudinal study of the relationship between tonic accommodation (dark focus) and refractive error in adulthood. *Invest Ophthalmol Vis Sci (Suppl)*; **34**, 1308.

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

Bennett, A. G., Rabbetts, R. B. (1984). *Clinical Visual Optics*. London: Butterworths.

Binkhorst, R. D., Weinstein, G. W., Baretz, R. M., Clahane, A. C. (1963). Psychotic reaction induced by cyclopentolate (cyclogyl). *Am J Ophthalmol*; **55**, 1243-1245.

Bland, M., Altman, D. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*; **1**, 307-310.

Bullimore, M. A., Boyd, T., Mather, H. E., Gilmartin, B. (1988). Near retinoscopy and refractive error. *Clin Exp Optom*; **71**, 114-118.

Bullimore, M. A., Fusaro, R., Adams, C. (1998). The repeatability of automated and clinician refraction. *Optom Vis Sci*; **75**, 617-622.

Bullimore, M. A., Gilmartin, B. (1987a). Aspects of tonic accommodation in emmetropia and late-onset myopia. *Am J Optom Physiol Opt*; **64**, 499-503.

Bullimore, M. A., Gilmartin, B. (1987b). Tonic accommodation, cognitive demand, and ciliary muscle innervation. *Am J Optom Physiol Opt*; **64**, 45-50.

Bullimore, M. A., Gilmartin, B. (1989). The measurement of adaptation of tonic accommodation under two open-loop conditions. *Ophthal Physiol Opt*; **9**, 72-75.

Bullimore, M. A., Gilmartin, B. (1990). Effect of target proximity on the open-loop accommodative response. *Optom Vis Sci*; **67**, 74-79.

Bullimore, M. A., Gilmartin, B., Hogan, R. E. (1986). Objective and subjective measurement of tonic accommodation. *Ophthal Physiol Opt*; **6**, 57-62.

Bullimore, M. A., Gilmartin, B., Royston, J. M. (1992). Steady-state accommodation and ocular biometry in late-onset myopia. *Doc Ophthalmol*; **80**, 143-155.

Charman, W. N. (1982). The accommodative resting point and refractive error. *Ophthal Opt*; **21**, 496.

Chat, S. W. S., Edwards, M. H. (2001). Clinical evaluation of Shin-Nippon SRW-5000 autorefractor in children. *Ophthal Physiol Opt*; **21**, 87-100.

Cline, D., Hofstetter, H. W., Griffin, J. R. (1989). *Dictionary of Visual Science*. 3rd ed. Radnor, PA: Chilton Book Co.

Culhane, H. M., Winn, B. (1999). Dynamic accommodation and myopia. *Invest Ophthalmol Vis Sci*; **40**, 1968-1974.

Dawson-Saunders, B., Trapp, R. G. (1994). Basic and Clinical Biostatistics. 2nd ed: Prentice-Hall International.

Del Pilar Cacho, M., Garcia-Munoz, A., Garcia-Bernabeu, J. R., Lopez, A. (1999). Comparison between MEM and Nott dynamic retinoscopy. *Optom Vis Sci*; **76**, 650-655.

Edwards, M. H. (1991). The refractive status of Hong Kong Chinese infants. *Ophthal Physiol Opt*; **11**, 297-303.

Edwards, M. H. (1999). The development of myopia in Hong Kong children between the ages of 7 and 12 years: a five-year longitudinal study. *Ophthal Physiol Opt*; **19**, 286-294.

Egashira, S. M., Kish, L. L., Twelker, J. D., Mutti, D. O., Zadnik, K., Adams, A. J. (1993). Comparison of cyclopentolate versus tropicamide cycloplegia in children. *Optom Vis Sci*; **70**, 1019-1026.

El-Defrawy, S., Clarke, W. N., Belec, F., Pham, B. (1998). Evaluation of a hand-held autorefractor in children younger than 6. *J Pediatr Ophthalmol*

Strabismus; **35**, 107-109.

Elliott, M., Simpson, T., Richter, D., Fonn, D. (1997). Repeatability and accuracy of automated refraction: a comparison of the Nikon NRK-8000, the Nidek AR-1000, and subjective refraction. *Optom Vis Sci*; **74**, 434-438.

Elston, R. C., Johnson, W. D. (1994). *Essentials of biostatistics*. 2nd ed. Philadelphia: F. A. Davis Company.

Eskridge, J., Amos, J., Bartlett, J. (1991). Ch: 71 Accommodative responses. In: Maum K, ed. *Clinical Procedures in Optometry*. Pennsylvania: J.B. Lippincott Company: pp677-686.

Fincham, E., Walton, J. (1957). The reciprocal actions of accommodation and convergence. *J Physiol (Lond)*; **137**, 488-508.

Fincham, E. F. (1937). The mechanism of accommodation. *Br J Ophthalmol Mongraphh (Suppl)*; **VIII**, 7-80.

Fry, G. (1940). Significance of fused cross cylinder test. *Optom Wkly*; **31**, 16-19.

Garner, L. F. (1983). Mechanisms of accommodation and refractive error. *Ophthal Physiol Opt*; **3**, 287-293.

Gilmartin, B., Bullimore, M. A. (1991). Adaptation of tonic accommodation to sustained visual tasks in emmetropia and late-onset myopia. *Optom Vis Sci*; **68**, 22-26.

Gilmartin, B., Hogan, R. E. (1985). The relationship between tonic accommodation and ciliary muscle innervation. *Invest Ophthalmol Vis Sci*; **26**, 1024-1028.

Goh, W. S., Lam, C. S. (1994). Changes in refractive trends and optical components of Hong Kong Chinese aged 19-39 years. *Ophthal Physiol Opt*; **14**, 378-382.

Goldschmidt, E. (1968). On the etiology of myopia. An epidemiological study. *Acta Ophthalmol (Suppl)*; 1-92.

Goodson, R. A., Afandor, A. J. (1974). The accommodative response of the near point crossed cylinder test. *Optom Wkly*; **65**, 1138-1140.

Goss, D. A., Grosvenor, T. (1996). Reliability of refraction--a literature review. *J Am Optom Assoc*; **67**, 619-630.

Goss, D. A., Rainey, B. B. (1999). Relationship of accommodative response and nearpoint phoria in a sample of myopic children. *Optom Vis Sci*; **76**, 292-294.

Goss, D. A., Zhai, H. (1994). Clinical and laboratory investigations of the relationship of accommodation and convergence function with refractive error. A literature review. *Doc Ophthalmol*; **86**, 349-380.

Green, D. G, Powers, M. K., Banks, M. S. (1980). Depth of focus, eye size, and visual acuity. *Vision Res*; **20**, 827-835.

Grosvenor, T. (1996). *Primary Care Optometry*. 3rd ed. Boston:

Butterworth-Heinemann.

Gwiazda, J., Bauer, J., Thorn, F., Held, R. (1995a). A dynamic relationship between myopia and blur-driven accommodation in school-aged children. *Vision Res*; **35**, 1299-1304.

Gwiazda, J., Bauer, J., Thorn, F., Held, R. (1995b). Shifts in tonic accommodation after near work are related to refractive errors in children. *Ophthal Physiol Opt*; **15**, 93-97.

Gwiazda, J., Grice, K., Thorn, F. (1999). Response AC/A ratios are elevated in myopic children. *Ophthal Physiol Opt*; **19**, 173-179.

Gwiazda, J., Thorn, F., Bauer, J., Held, R. (1993). Myopic children show insufficient accommodative response to blur. *Invest Ophthalmol Vis Sci*; **34**, 690-694.

Harris, L. S. (1968). Cycloplegic-induced intraocular pressure elevations a study of normal and open-angle glaucomatous eyes. *Arch Ophthalmol*; **79**, 242-246.

Harris, W. F. (1990a). Comparison of dioptric power. *Ophthal Physiol Opt*; **10**, 200-202.

Harris, W. F. (1990b). The mean and variance of sample of dioptric powers: the basic calculations. *Clin Exp Optom*; **73**, 89-92.

Harris, W. F. (1990c). Statistical inference on mean dioptric power: hypothesis testing and confidence regions. *Ophthal Physiol Opt*; **10**, 363-372.

Harris, W. F. (1991). Representation of dioptric power in Euclidean 3-space. *Ophthal Physiol Opt*; **11**, 130-136.

Harris, W. F. (1992). Testing hypotheses on dioptric power. *Optom Vis Sci*; **69**, 835-845.

Harris, W. F. (1998). A note on the dioptric power matrix. In: Rosenfield M, Gilmartin B, ed. *Myopia and Nearwork*. Oxford: Butterworth-Heinemann, 207-212.

Harris, W. F. (1998). Signs of surface torsion and torsional dioptric power. *Optom Vis Sci*; **75**, 670-673.

Harvey, E. M., Miller, J. M., Dobson, V., Tyszko, R., Davis, A. L. (2000). Measurement of refractive error in Native American preschoolers: validity and reproducibility of autorefraction. *Optom Vis Sci*; **77**, 140-149.

Harvey, E. M., Miller, J. M., Wagner, L. K., Dobson, V. (1997). Reproducibility and accuracy of measurements with a hand held autorefractor in children. *Br J Ophthalmol*; **81**, 941-948.

Helmholtz, H. v. (1962). *Helmholtz's Treatise on Physiological Optics*. New York: Dover.

Hennessy, R. T. (1975). Instrument myopia. *J Opt Soc Am*; **65**, 1114-1120.

Hennessy, R. T., Iida, T., Shina, K., Leibowitz, H. W. (1976). The effect of pupil size on accommodation. *Vision Res*; **16**, 587-589.

Hennessy, R. T., Leibowitz, H. (1970). Subjective measurement of accommodation with laser light. *J Opt Soc Am*; **60**, 1700-1701.

Hennessy, R. T., Leibowitz, H. (1972). Laser optometer incorporating the Badal principle. *Behav Res Meth Instru*; **4**, 237-239.

Heron, G., Smith, A. C., Winn, B. (1981). The influence of method on the stability of dark focus position of accommodation. *Ophthal Physiol Opt*; **1**, 79-90.

Hosaka, A. (1988). The growth of the eye and its components. Japanese studies. *Acta Ophthalmol (Suppl)*; **185**, 65-68.

Hung, L. F., Carwford, M. L. J., Smith, E. L. (1995). Spectacle lenses alter eye growth and the refractive status of young monkeys. *Nature Med*; **1**, 761-765.

Ibi, K. (1997). Characteristics of dynamic accommodation responses: comparison between the dominant and non-dominant eyes. *Ophthal Physiol Opt*; **17**, 44-54.

ISO 5725-1 (1994). Accuracy (trueness and precision) of measurement methods and results - Part 1. General principles and definitions. International Standards Organization, Geneva.

Jaanus, S. D., Carter, J. H. (1995). *Cycloplegics*. In: Bartlett JD, Jaanus SD, eds. *Clinical Ouclar Pharmacology*. 3th ed. Boston: Bullerworth-Heinemann, 167-182.

Jaschinski-Kruza, W., Toenies, U. (1988). Effect of mental arithmetic task on dark focus of accommodation. *Ophthal Physiol Opt*; **8**, 432-437.

Jenkins, T. (1963). Aberrations of the eye and their effects on vision. Part II. *Br J Physiol Opt*; **20**, 161-201.

Jiang, B. C. (1995). Parameters of accommodative and vergence systems and the development of late-onset myopia. *Invest Ophthalmol Vis Sci*; **36**, 1737-1742.

Jiang, B. C. (2000). A modified control model for steady-state accommodation. In: Franzen O, Richter H, Stark L, eds. *Accommodation and Vergence Mechanisms in the Visual System*. Switzerland: Birkhauser Verlag Basel.

Jiang, B. C., Morse, S. E. (1999). Oculomotor functions and late-onset myopia. *Ophthal Physiol Opt*; **19**, 165-172.

Jiang, B. C., White, J. M. (1999). Effect of accommodative adaptation on static and dynamic accommodation in emmetropia and late-onset myopia. *Optom Vis Sci*; **76**, 295-302.

Johnson, C. A., Post, R. B., Tsuetaki, T. K. (1984). Short-term variability of the resting focus of accommodation. *Ophthal Physiol Opt*; **4**, 319-325.

Johnson, R. J., Wichern, D. W. (1998). *Applied Multivariate Statistical Analysis*. 3rd ed. Upper Saddle River, N.J.: Prentice Hall.

Jones, L. W., Hodes, D. T. (1991). Possible allergic reactions to cyclopentolate hydrochloride: case reports with literature review of uses and adverse reactions. *Ophthal Physiol Opt*; **11**, 16-21.

Khurana, A. (1988). Status of cyclopentolate as a cycloplegic in children: A comparison with atropine and homatropine. *Acta Ophthalmol*; **66**, 721-724.

Kinge, B., Midelfart, A., Jacobsen, G. (1996). Clinical evaluation of the Allergan Humphrey 500 autorefractor and the Nidek AR-1000 autorefractor. *Br J Ophthalmol*; **80**, 35-39.

Kotulak, J. C., Morse, S. E. (1994). Relationship among accommodation, focus, and resolution with optical instruments. *J Opt Soc Am A*; **11**, 71-79.

Kotulak, J. C., Schor, C. M. (1987). The effects of optical vergence, contrast, and luminance on the accommodative response to spatially bandpass filtered targets. *Vision Res*; **27**, 1797-1806.

Kruger, P. B., Nowbotsing, S., Aggarwala, K. R., Mathews, S. (1995). Small amounts of chromatic aberration influence dynamic accommodation. *Optom Vis Sci*; **72**, 656-666.

Kurtev, A. (1979). Perception of blur in optometric tests. *Am J Optom Physiol Opt*; **56**, 277-278.

Lam, C. S., Goh, W. S., Tang, Y. K., Tsui, K. K., Wong, W. C., Man, T. C. (1994). Changes in refractive trends and optical components of Hong Kong Chinese aged over 40 years. *Ophthal Physiol Opt*; **14**, 383-388.

Lam, C. S. Y., Goh, W. S. H. (1991). The incidence of refractive errors among schoolchildren in Hong Kong and its relationship with the optical components. *Clin Exp Optom*; **74**, 97-103.

Leat, S. J., Gargon, J. L. (1996). Accommodative response in children and young adults using dynamic retinoscopy. *Ophthal Physiol Opt*; **16**, 375-384.

Leibowitz, H. W., Owens, D. A. (1975a). Anomalous myopias and the intermediate dark focus of accommodation. *Science*; **189**, 646-648.

Leibowitz, H. W., Owens, D. A. (1975b). Night myopia and the intermediate dark focus of accommodation. *J Opt Soc Am*; **65**, 1121-1128.

Leibowitz, H. W., Owens, D. A. (1978). New evidence for the intermediate position of relaxed accommodation. *Doc Ophthalmol*; **46**, 133-147.

Li, R. W. H., Edwards, M. H. (2001). Interfacing the Shin-Nippon autorefractor SRW-5000 with a personal computer. *Ophthal Physiol Opt*; **21**, 114-116.

Lin, L. L., Chen, C. J., Hung, P. T., Ko, L. S. (1988). Nation-wide survey of myopia among schoolchildren in Taiwan, 1986. *Acta Ophthalmol (Suppl)*; **185**, 29-33.

Locke, L. C., Somers, W. (1989). A comparison study of dynamic retinoscopy techniques. *Optom Vis Sci*; **66**, 540-544.

Long, W. F. (1976). A matrix formalism for decentration problems. *Am J Optom*

Physiol Opt; **53**, 27-33.

Maddock, R. J., Millodot, M., Leat, S., Johnson, C. A. (1981). Accommodation responses and refractive error. *Invest Ophthalmol Vis Sci*; **20**, 387-391.

Malan, D. J. *The excess of objective automatic refraction over subjective clinical refraction: methods of analysis, and results* [MPhil]. South Africa: Rand Afrikaans University; 1994.

Mallen, E. A. H., Wolffsohn, J. S., Gilmartin, B., Tsujimura, S. (2001). Clinical evaluation of the Shin-Nippon SRW-5000 autorefractor. *Ophthal Physiol Opt*; **21**, 101-107.

Malmstrom, F. V., Randle, R. J. (1976). Effects of visual imagery on the accommodation response. *Percept Psychophys*; **19**, 450-453.

Manny, R. E., Fern, K. D., Zervas, H. J., Cline, G. E., Scott, S. K., White, J. M., Pass, A. F. (1993). 1% Cyclopentolate hydrochloride: another look at the time course of cycloplegia using an objective measure of the accommodative response. *Optom Vis Sci*; **70**, 651-665.

Matsumura, H., Hirai, H. (1999). Prevalence of myopia and refractive changes in students from 3 to 17 years of age. *Surv Ophthalmol*; **44**, 109-115.

Matsumura, I., Maruyama, S., Ishikawa, Y., Hirano, R., Kobayashi, K., Kohayakawa, Y. (1983). The design of an open view autorefractometer. In: Breinin

GM, Siegel IM, eds. *Advances in Diagnostic Visual Optics.* Berlin: Springer. 36-42.

McBrien, N. A., Millodot, M. (1985). Clinical evaluation of the Canon Autoref R-1. *Am J Optom Physiol Opt*; **62**, 786-792.

McBrien, N. A., Millodot, M. (1986). The effect of refractive error on the accommodative response gradient. *Ophthal Physiol Opt*; **6**, 145-149.

McBrien, N. A., Millodot, M. (1987). The relationship between tonic accommodation and refractive error. *Invest Ophthalmol Vis Sci*; **28**, 997-1004.

Mershon, D. H., Amerson, T. L. (1980). Stability of measures of the dark focus of accommodation. *Invest Ophthalmol Vis Sci*; **19**, 217-221.

Miller, R. J., Pigion, R. G., Wessner, M. F., Patterson, J. G (1983). Accommodation fatigue and dark focus: the effects of accommodation-free visual work as assessed by two psychophysical methods. *Percept Psychophys*; **34**, 532-540.

Millodot, M. (1993). *Dictionary of Optometry*. 3rd ed. Oxford: Butterworth-Heinemann.

Millodot, M., Sivak, J. (1973). Influence of accommodation on the chromatic aberration of the eye. *Br J Physiol Opt*; **28**, 169-174.

Miwa, T. (1992). Instrument myopia and the resting state of accommodation. *Optom Vis Sci*; **69**, 55-59.

Mordi, J. A., Ciuffreda, K. J. (1998). Static aspects of accommodation: age and presbyopia. *Vision Res*; **38**, 1643-1653.

Morgan, R. W., Speakman, J. S., Grimshaw, S. E. (1975). Inuit myopia: an environmentally induced "epidemic"? *Can Med Assoc J*; **112**, 575-577.

Munro, B. H. (1997). *Statistical methods for health care research*. 3rd ed. New York: Lippincott-Raven.

Mutti, D. O., Zadnik, K., Egashira, S., Kish, L., Twelker, J. D., Adams, A. J. (1994). The effect of cycloplegia on measurement of the ocular components. *Invest Ophthalmol Vis Sci*; **35**, 515-527.

Norn, M. (1997). Myopia among the Inuit population of East Greenland. Longitudinal Study 1950-1994. *Acta Ophthalmol Scand*; **75**, 723-725.

Ong, E., Ciuffreda, K. J. (1997). *Accommodation, Nearwork and Myopia*. Santa Ana: Optometric extension program foundation, Inc.

Owens, D. A., Harris, D., Owens, R. L., Francis, E. L. (1989). Tonic accommodation and late-onset myopia: a longitudinal investigation. *Invest Ophthalmol Vis Sci (Suppl)*; **30**, 325.

Owens, D. A., Mohindra, I., Held, R. (1980). The effectiveness of a retinoscopy beam as an accommodative stimulus. *Invest Ophthalmol Vis Sci*; **19**, 942-949.

Owens, R. L., Higgins, K. E. (1983). Long-term stability of the dark focus of accommodation. *Am J Optom Physiol Opt*; **60**, 32-38.

Post, R. B., Johnson, C. A., Tsuetaki, T. K. (1984). Comparison of laser and infrared techniques for measurement of the resting focus of accommodation: Mean difference and long-term variability. *Ophthal Physiol Opt*; **4**, 327-332.

Richards, O. W. (1976). Instrument myopia--microscopy. *Am J Optom Physiol Opt*; **53**, 658-663.

Rosenfield, M. (1989). Evaluation of clinical techniques to measure tonic accommodation. *Optom Vis Sci*; **66**, 809-814.

Rosenfield, M. (1997). Accommodation. In: Zadnik K, ed. *The ocular examination: measurement and findings*. Philadelphia: W.B. Saunders.

Rosenfield, M., Abraham-Cohen, J. A. (1999). Blur sensitivity in myopes. *Optom Vis Sci*; **76**, 303-307.

Rosenfield, M., Chiu, N. N. (1995). Repeatability of subjective and objective refraction. *Optom Vis Sci*; **72**, 577-579.

Rosenfield, M., Ciuffreda, K., Hung, G., Gilmartin, B. (1993). Tonic accommodation: a review I. Basic aspects. *Ophthal Physiol Opt*; **13**, 267-284.

Rosenfield, M., Ciuffreda, K. J. (1990). Proximal and cognitively-induced accommodation. *Ophthal Physiol Opt*; **10**, 252-256.

Rosenfield, M., Ciuffreda, K. J. (1991). Accommodative responses to conflicting stimuli. *J Opt Soc Am A*; **8**, 422-427.

Rosenfield, M., Ciuffreda, K. J., Hung, G. K. (1991). The linearity of proximally induced accommodation and vergence. *Invest Ophthalmol Visual Sci*; **32**, 2985-2991.

Rosenfield, M., Gilmartin, B. (1987). Synkinesis of accommodation and vergence in late-onset myopia. *Am J Optom Physiol Opt*; **64**, 929-937.

Rosenfield, M., Gilmartin, B. (1988). Disparity-induced accommodation in late-onset myopia. *Ophthal Physiol Opt*; **8**, 353-355.

Rosenfield, M., Gilmartin, B. (1990). Effect of target proximity on the open-loop accommodative response. *Optom Vis Sci*; **67**, 74-79.

Rosenfield, M., Gilmartin, B. (1998). Accommodation and myopia. In: Rosenfield M, Gilmartin B, eds. *Myopia and Nearwork.* Oxford: Butterworth-Heinemann.

Rosenfield, M., Portello, J. K., Blustein, G. H., Jang, C. (1996). Comparison of clinical techniques to assess the near accommodative response. *Optom Vis Sci*; **73**, 382-388.

Rosenfield, M., Wong, N. N., Solan, H. A. (2001). Nearwork distances in children. *Ophthal Physiol Opt*; **21**, 75-76.

Rosenfield, M. A., Ciuffreda, K. J., Ong, E., Azimi, A. (1990). Proximally induced accommodation and accommodative adaptation. *Invest Ophthalmol Vis Sci*; **31**, 1162-1167.

Rosner, J., Rosner, J. (1989). Relation between clinically measured tonic accommodation and refractive status in 6- to 14-year-old children. *Optom Vis Sci*; **66**, 436-439.

Rosner, J., Rosner, J. (1990). Comparison of two clinical methods for measuring tonic accommodation in children. *Optom Vis Sci*; **67**, 692-694.

Rouse, M. W., Hutter, R. F., Shiftlett, R. (1984). A normative study of the accommodative lag in elementary school children. *Am J Optom Physiol Opt*; **61**, 693-697.

Schober, H., Hehler, H., Kassel, R. (1970). Accommodation during observations with optical instruments. *J Opt Soc Am*; **60**, 103-107.

Shaw, D. E., Jones, H. S., Moseley, M. J. (1994). Analysis of method-comparison data. *Ophthal Physiol Opt*; **14**, 92-96.

Shihab, Z. M. (1980). Psychotic reaction in an adult after topical cyclopentolate. *Ophthalmologica*; **181**, 228-230.

Siu, A. W., Sum, A. C., Lee, D. T., Tam, K. W., Chan, S. W. (1999). Prior topical anaesthesia reduces time to full cycloplegia in Chinese. *Jpn J Ophthalmol*; **43**, 466-471.

Smith III, E. L. (1998). Environmentally induced refractive error. In: Rosenfield M, B. G, ed. *Myopia and Nearwork*. Oxford: Butterworth-Heinemann: pp57-90.

Sunder Raj, P., Villada, J. R., Lewis, A. E., Joyce, P. W., Watsom, A. (1992). Comparative evaluation of the Allergan Humphrey 570 and Canon RK-1 autorefractors: I: Objective autorefraction in normal subjects. *Eye*; **6**, 285-289.

Tan, R. K., O'Leary, D. J. (1985). Steady-state accommodation response to different Snellen letter sizes. *Am J Optom Physiol Opt*; **62**, 751-754.

Toates, F. M. (1972). Accommodation function of the human eye. *Physiol Rev*; **52**, 828-863.

Tokoro, T. (1988). The role of accommodation in myopia. *Acta Ophthalmol (Suppl)*; **185**, 153-155.

Törnqvist, G. (1966). Effect of cervical sympathetic stimulation on accommodation in monkeys. An example of a beta-adrenergic, inhibitory effect. *Acta Physiol Scand*; **67**, 363-372.

Tsuetki, T. K., Schor, C. M. (1987). Clinical method for measuring adaptation of tonic accommodation and vergence accommodation. *Am J Optom Physiol Opt*; **64**, 437-449.

van Alphen, G. W. H. M. (1961). On emmetropia and ametropia. *Ophthalmologica (Suppl)*; **142**, 1-92.

Ward, P. A., Charman, W. N. (1987). On the use of small artificial pupils to open-loop the accommodation system. *Ophthal Physiol Opt*; **7**, 191-193.

Wesner, M. F., Miller, R. J. (1986). Instrument myopia conceptions, misconceptions, and influencing factors. *Doc Ophthalmol*; **62**, 281-308.

Westheimer, G. (1957). Accommodation in empty visual fields. *J Opt Soc Am*; **47**, 714-718.

Wolf, K. S., Ciuffreda, K. J., Jacobs, S. E. (1987). Time course and decay of effects of near work on tonic accommodation and tonic vergence. *Ophthal Physiol Opt*; **7**, 131-135.

Woodruff, M. E., Samek, M. J. (1977). A study of the prevalence of spherical equivalent refractive states and anisometropia in American populations in Ontario. *Can J Public Health*; **68**, 414-424.

Woung, L. C., Lue, Y. F., Shih, Y. F. (1998). Accommodation and pupillary response in early-onset myopia among schoolchildren. *Optom Vis Sci*; **75**, 611-616.

Woung, L. C., Ukai, K., Tsuchiya, K., Ishikawa, S. (1993). Accommodative adaptation and age of onset of myopia. *Ophthal Physiol Opt*; **13**, 366-370.

Yap, M., Wu, M., Wang, S. H., Lee, F. L., Liu, Z. M. (1994). Environmental factors and refractive error in Chinese schoolchildren. *Clin Exp Optom*; **77**, 8-14.

Yeow, P. T., Taylor, S. P. (1989). Clinical evaluation of the Humphrey autorefractor. *Ophthal Physiol Opt*; **9**, 171-175.

Zadnik, K., Mutti, D. O. (1993). Statistical analysis for method comparison data.

Arch Ophthalmol; **111**, 582-583.

Zadnik, K., Mutti, D. O. Let's define myopia: a need for consensus? In: Thorn F, Troilo D, Gwiazda J, eds. Myopia 2000: *Proceedings of the VIII International Conference on Myopia*; Boston; 2000.

Zadnik, K., Mutti, D. O., Adams, A. J. (1992). The repeatability of measurement of the ocular components. *Invest Ophthalmol Vis Sci*; **33**, 2325-2333.

Zadnik, K., Mutti, D. O., Kim, H. S., Jones, L. A., Qiu, P. H., Moeschberger, M. L. (1999). Tonic accommodation, age, and refractive error in children. *Invest Ophthalmol Vis Sci*; **40**, 1050-1060.

Appendix I

The product of a column vector and its transpose

The product of a column vector and its transpose is calculated as follows:

Suppose $\mathbf{A} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix}$ and $\mathbf{B} = \begin{pmatrix} b_1 & b_2 & b_3 \end{pmatrix}$ then

$$\mathbf{AB} = \begin{pmatrix} a_1b_1 & a_1b_2 & a_1b_3 \\ a_2b_1 & a_2b_2 & a_2b_3 \\ a_3b_1 & a_3b_2 & a_3b_3 \end{pmatrix}$$

Appendix II

Multivariate normal distribution

A2.1 Multivariate normal distribution

Hypothesis tests on the mean and/or variance-covariance are based on the assumption that the population has a multivariate normal distribution: $N_3(\mu, \Sigma)$. Visual observation of the scatter plots can identify obvious deviation from multivariate normality. The skewness, kurtosis and standardized mean deviation of the parameter are useful to characterise the normality of multivariate data (Malan, 1994). The probability for normality was also tested.

The coefficient of skewness is a measure of symmetry. For a perfectly symmetrical distribution, the coefficient of skewness should be exactly zero (Munro, 1997: p.42); the sample statistic that estimates the population values can be around zero. Negative skewness means the distribution tapers off in the negative direction. Positive skewness means the distribution tapers off in the positive direction. Hildebrand (1986) suggested that skewness value greater than 0.2 or less than –0.2 indicates severe skewness.

The coefficient of kurtosis reflects the peakedness of a distribution, and its value is zero for a normal distribution (Elston and Johnsom, 1994: p56). If the coefficient of kurtosis is a large positive value the distribution is said to be leptokurtic, that means the distribution curve is more peaked than normal. If the coefficient is a large negative value, the distribution is platykurtic, that means the distribution curve is flatter than normal.

For a perfectly symmetrical distribution, the standardized mean deviation should be about 0.7979, and this is a useful measure of symmetry for small samples (Malan, 1994).

The following equations were used in the present studies to calculate the skewness (B1), kurtosis (B2) and standardized mean deviation (A):

$$B1 = \frac{v^{-\frac{3}{2}} \sum_{i=1}^{n} (h_{ji} - \overline{h_j})^3}{n} \qquad \text{Equation A2.1}$$

$$B2 = \frac{v^{-2} \sum_{i=1}^{n} (h_{ji} - \overline{h_j})^4}{n} \qquad \text{Equation A2.2}$$

$$A = \frac{v^{-\frac{1}{2}} \sum_{i=1}^{n} \left| h_{ji} - \overline{h_j} \right|}{n} \qquad \text{Equation A2.3}$$

For

$$j = 1, 2, 3; \; v = \frac{s_{jj}(n-1)}{n} \text{ and } S = \frac{1}{n-1} \sum_{i=1}^{n} (\mathbf{h}_i - \overline{\mathbf{h}})(\mathbf{h}_i - \overline{\mathbf{h}})' = \begin{pmatrix} s_{11} & s_{12} & s_{13} \\ s_{21} & s_{22} & s_{23} \\ s_{31} & s_{32} & s_{33} \end{pmatrix}$$

When calculated the skewness (B1), kurtosis (B2) and standardized mean deviation (A) for h_1, then put j =1 into equations A2.1 to A2.3. When calculated the skewness (B1), kurtosis (B2) and standardized mean deviation (A) for h_2 and h_3, then put j =2 and j =3 into the equations A.1 to A.3 respectively.

The Matlab program "normal_sep" (section A2.5) was used to calculate the skewness, kurtosis and standardized mean deviation for h_1, h_2 and h_3 .

A2.2 Test for normal distribution in Study 1

The mean difference of two sets of measures for each comparison (in Comparisons A to J) “passed” the normality test with $p>0.05$ (Kolmogorov-Smirnov test) except those in Comparisons D and E. The coefficient of skewness (**B1**), coefficient of kurtosis (**B2**) and standardized mean deviation (**A**) for each vector **h** component (h_1, h_2 and h_3 respectively) are shown in Table A2.1. Although the distribution of Comparison D and E were not normally distributed, hypothesis tests on the mean can be carried out due to the robustness of the test in regard to deviation from normality (Malan, 1994).

Comparison	B1	B2	A
A	$(-0.26\ \ 0.26\ \ 0.20)'$	$(2.49\ \ 4.53\ \ 3.26)'$	$(0.82\ \ 0.72\ \ 0.76)'$
B	$(0.91\ \ 0.24\ \ 0.16)'$	$(3.36\ \ 2.03\ \ 3.10)'$	$(0.83\ \ 0.85\ \ 0.77)'$
C	$(0.78\ \ 0.01\ \ 0.56)'$	$(3.27\ \ 3.81\ \ 3.16)'$	$(0.80\ \ 0.76\ \ 0.79)'$
D	$(-0.37\ \ 2.42\ \ -0.13)'$	$(5.05\ \ 11.59\ \ 3.15)'$	$(0.70\ \ 0.62\ \ 0.74)'$
E	$(0.79\ \ 2.60\ \ 0.79)'$	$(4.27\ \ 11.14\ \ 3.38)'$	$(0.79\ \ 0.65\ \ 0.81)'$
F	$(0.42\ \ 0.05\ \ -0.22)'$	$(4.92\ \ 2.37\ \ 2.18)'$	$(0.71\ \ 0.80\ \ 0.82)'$
G	$(0.35\ \ 0.48\ \ -0.03)'$	$(3.02\ \ 2.29\ \ 2.77)'$	$(0.78\ \ 0.80\ \ 0.81)'$
H	$(-0.17\ \ -0.81\ \ -0.50)'$	$(2.89\ \ 6.15\ \ 2.50)'$	$(0.83\ \ 0.69\ \ 0.86)'$
I	$(1.01\ \ 0.20\ \ 0.16)'$	$(6.19\ \ 3.59\ \ 2.98)'$	$(0.74\ \ 0.72\ \ 0.76)'$
J	$(-0.26\ \ -1.07\ \ -0.36)'$	$(4.40\ \ 5.72\ \ 5.37)'$	$(0.71\ \ 0.73\ \ 0.76)'$

Table A2.1 The skewness (**B1**), kurtosis (**B2**) and standardized mean deviation (**A**) for the mean difference of two sets of measures taken for each comparison in Study 1.

A2.3 Test for normal distribution in Study 2

Data documenting the tonic accommodation "passed" the normality test with $p>0.05$ (Kolmogorov-Smirnov test). The skewness (**B1**), kurtosis (**B2**) and standardized mean deviation (**A**) for each vector **h** component (h_1, h_2 and h_3 respectively) are:

$$\mathbf{B1} = (1.30\ \ -0.36\ \ 0.96)'$$

$$\mathbf{B2} = (5.10\ \ 3.35\ \ 3.79)'$$

$$\mathbf{A} = (0.77\ \ 0.81\ \ 0.77)'$$

The mean difference between two sets of dark autorefraction taken by a single observer also "passed" the normality test with p>0.05 (Kolmogorov-Smirnov test). The skewness (**B1**), kurtosis (**B2**) and standardized mean deviation (**A**) are:

$$\mathbf{B1} = (-0.79 \quad -1.05 \quad 0.67)'$$

$$\mathbf{B2} = (3.80 \quad 5.03 \quad 4.78)'$$

$$\mathbf{A} = (0.76 \quad 0.76 \quad 0.75)'$$

A2.4 Test for sample population in Study 3

Data documenting the second ocular accommodative lag measures taken in three experimental conditions (DD, LD and LL), all "passed" the normality test with p>0.05 (Kolmogorov-Smirnov test). The skewness (**B1**), kurtosis (**B2**) and standardized mean deviation (**A**) for each vector h component (h_1, h_2 and h_3 respectively) are shown in Table A2.3.

Conditions	B1	B2	A
DD	$(0.38 \quad -0.56 \quad 0.15)'$	$(2.30 \quad 5.81 \quad 2.25)'$	$(0.84 \quad 0.70 \quad 0.85)'$
LD	$(-0.03 \quad -0.45 \quad 0.25)'$	$(2.58 \quad 4.90 \quad 2.02)'$	$(0.84 \quad 0.71 \quad 0.84)'$
LL	$(0.18 \quad -0.82 \quad -0.22)'$	$(2.51 \quad 3.19 \quad 2.35)'$	$(0.81 \quad 0.81 \quad 0.83)'$

Table A2.2 The skewness (**B1**), kurtosis (**B2**) and standardized mean deviation (**A**) for data samples in Study 3 under three experiment conditions.

The mean difference between two sets of dark autorefraction taken by a single observer was also "passed" the normality test with p>0.05 (Kolmogorov-Smirnov test). The skewness (**B1**), kurtosis (**B2**) and standardized mean deviation (**A**) are shown in Table A2.3.

Conditions	**B1**	**B2**	**A**
DD	$(0.81\ \ 0.10\ \ 0.68)'$	$(3.29\ \ 2.63\ \ 2.78)'$	$(0.79\ \ 0.83\ \ 0.80)'$
LD	$(0.39\ \ 0.23\ \ 0.25)'$	$(3.32\ \ 2.97\ \ 2.64)'$	$(0.78\ \ 0.77\ \ 0.80)'$
LL	$(-0.78\ \ -0.65\ \ -0.89)'$	$(4.19\ \ 5.50\ \ 5.95)'$	$(0.73\ \ 0.74\ \ 0.71)'$

Table A2.3 The skewness (**B1**), kurtosis (**B2**) and standardized mean deviation (**A**) for the mean difference between two sets of near refraction taken under three experiment conditions.

A2.5 Matlab program for testing a normal distribution

```
% % % % % % % % % % % % % % % % % % % % % % % % % % % %
% This matlab program is developed for                %
% assessing the assumption of normality               %
% at The Hong Kong Polytechnic University (June,2001) %
% % % % % % % % % % % % % % % % % % % % % % % % % % % %

format compact
clc
clear all

[filename, pathname]=uigetfile('*.*');
filename=[pathname filename];
h=load(filename);%h=load ('data.dat')

m=mean(h)%mean
n=length(h)%size
s=cov(h)%variance-covariance

%skewness
'b1 for h1, h2 and h3'
((s(1,1)*(n-1)/n)^(-3/2)*sum((h(:,1)-m(:,1)).^3))/n

((s(2,2)*(n-1)/n)^(-3/2)*sum((h(:,2)-m(:,2)).^3))/n

((s(3,3)*(n-1)/n)^(-3/2)*sum((h(:,3)-m(:,3)).^3))/n

%kurtosis
'b2 for h1, h2 and h3'
((s(1,1)*(n-1)/n)^(-2)*sum((h(:,1)-m(:,1)).^4))/n

((s(2,2)*(n-1)/n)^(-2)*sum((h(:,2)-m(:,2)).^4))/n

((s(3,3)*(n-1)/n)^(-2)*sum((h(:,3)-m(:,3)).^4))/n

%standardise mean deviation
'a for h1, h2 and h3'
((s(1,1)*(n-1)/n)^(-1/2)*sum(abs(h(:,1)-m(:,1))))/n

((s(2,2)*(n-1)/n)^(-1/2)*sum(abs(h(:,2)-m(:,2))))/n

((s(3,3)*(n-1)/n)^(-1/2)*sum(abs(h(:,3)-m(:,3))))/n
```

Appendix III

Matlab program

A3.1 Hypothesis test for one mean

```
% % % % % % % % % % % % % % % % % % % % % % % % % % % %
% This matlab program is developed for hypothesis     %
% testing on a single sample mean                     %
% at The Hong Kong Polytechnic University (2000)      %
% % % % % % % % % % % % % % % % % % % % % % % % % % % %


datafile=input('file name? ','s')
h=load(datafile)%h=load ('data.dat')

% Adjustable parameters
u=[0;0;0]    % population mean to be compared
maxh=2.5;    % max axis value
step=0.5;    % tick interval
tickl=0.08;  % tick length

mean_h=mean(h)
cyl_strength=sqrt(sum((mean_h').^2))
sph_strength=cyl_strength/sqrt(2)
n=length(h)

% variance-covariance
mean_h_loop=mean_h(ones(n,1),:);
q=(h-mean_h_loop);
s=1/(n-1)*(q'*q) % column vector first

w=(mean_h'-u)'*inv(s)*(mean_h'-u)*n*(n-3)/(3*(n-1));
t=w*3*(n-1)/(n*(n-3))
sprintf('f(3,%d)=%f',n-3,w)
p=1-fcdf(w,3,n-3) % 3--df of numerator; n-3--df of denominator
f=finv(0.95,3,n-3)    % 5%--0.95 1%--0.99

if w<f
   disp('no statically significant difference')
else
   disp('statistically significant difference')
end

h1=h(:,1); h2=h(:,2); h3=h(:,3);
plot3(h1,h2,h3,'xk')
%set(gcf,'color',[0 0 0])
set(gca,'fontname','times-
roman','fontsize',11,'xtick',[0:step:maxh],'ytick',[0:step:maxh],'z
tick',[0:step:maxh])
%xlabel('h1','fontsize',12); ylabel('h2','fontsize',12);
zlabel('h3','fontsize',12);
```

```
axis([0 maxh 0 maxh 0 maxh])
grid on
axis off
view(116,31)

% Axis
hold on
plot3([0 0],[0 0],[maxh 0],'k')
text(0,0,maxh+.2,'h3')
plot3([0 0],[0 maxh],[0 0],'k')
text(0,maxh+.08,0,'h2')
plot3([0 maxh],[0 0],[0 0],'k')
text(maxh+.38,0,0,'h1')

% Ticks
for counter=0:step:maxh,
   plot3([counter counter],[0 0],[0 tickl],'k')
   plot3([counter counter],[0 tickl],[0 0],'k')
   plot3([0 0],[counter counter],[0 tickl],'k')
   plot3([0 tickl],[counter counter],[0 0],'k')
   plot3([0 0],[0 tickl],[counter counter],'k')
   plot3([0 tickl],[0 0],[counter counter],'k')
end

hold off
```

A3.2 Hypothesis test for two means

```
% % % % % % % % % % % % % % % % % % % % % % % % % % % % %
% This matlab program is developed for hypothesis     %
% testing on two samples means at The Hong Kong       %
% Polytechnic University (2000)                       %
% % % % % % % % % % % % % % % % % % % % % % % % % % % % %


datafile=input('file name 1? ','s')
ha=load(datafile)%ha=load ('data.dat')

datafile=input('file name 2? ','s')
hb=load(datafile)%hb=load ('data.dat')

u=[0;0;0]    % test equality of 2 populations mean

mean_ha=mean(ha)
mean_hb=mean(hb)

Na=length(ha)
Nb=length(hb)

% variance-covariance
mean_ha_loop=mean_ha(ones(Na,1),:);
p=(ha-mean_ha_loop);

mean_hb_loop=mean_hb(ones(Nb,1),:);
q=(hb-mean_hb_loop);

s=(1/(Na+Nb-2))*((p'*p)+(q'*q)) % column vector first


%Hotelling's statistic
T_sq=(mean_ha'-mean_hb'-u)'*inv(s*(1/Na+1/Nb))*(mean_ha'-mean_hb'-
u)
d=Na+Nb-3-1;%3--df of numerator; Na+Nb-3-1--deg of freedom of
denominaor
w=(T_sq/(Na+Nb-2))*(d/3);
f=finv(0.95,3,d);
p=1-fcdf(w,3,d)

if w<f
   disp('no statically significant difference')
else
   disp('statistically significant difference')
end
```

A3.3 Hypothesis test for three means

```
% % % % % % % % % % % % % % % % % % % % % % % % % % % %
% This matlab program is developed for hypothesis     %
% testing on three samples means at The               %
% Hong Kong Polytechnic University (2000)             %
% % % % % % % % % % % % % % % % % % % % % % % % % % % %


datafile=input('file name 1? ','s')
h1=load(datafile)%h1=load ('data.dat')

datafile=input('file name 2? ','s')
h2=load(datafile)%h2=load ('data.dat')

datafile=input('file name 3? ','s')
h3=load(datafile)%h3=load ('data.dat')

m1=mean(h1)
m2=mean(h2)
m3=mean(h3)

N1=length(h1)
N2=length(h2)
N3=length(h3)

N=N1+N2+N3; %total no. of sample

%sample mean
gp1=m1*N1;
gp2=m2*N2;
gp3=m3*N3;
sm=(gp1+gp2+gp3)/N


% variance-covariance
var1=cov(h1)
var2=cov(h2)
var3=cov(h3)
sd1=sqrt(diag(cov(h1)))
sd2=sqrt(diag(cov(h2)))
sd3=sqrt(diag(cov(h3)))


%sum of outer square between samples
i=m1-sm;
j=m2-sm;
k=m3-sm;
B=N1*i'*i+N2*j'*j+N3*k'*k

%sum of outer square within samples
W=(N1-1)*var1+(N2-1)*var2+(N3-1)*var3

%Wilks lambda
V=det(W)/det(W+B)
w=((1-sqrt(V))*(N1+N2+N3-3-2))*(sqrt(V)*3);
d=2*(N1+N2+N3-3-2);
sprintf('f(3,%d)=%f',d,w)
```

```
p=1-fcdf(w,6,d)    %3--df of numerator; 2*(N1+N2+N3-3-2)--deg of
freedom
f=finv(0.95,6,d) % 5%--0.95 1%--0.99

if w<f
   disp('no statically significant difference')
else
   disp('statistically significant difference')
end
```

Appendix IV

Information Sheet

Accuracy and reliability of the Shin-Nippon SRW-5000 open-field autorefractor, and tonic accommodation and accommodative lag in Hong Kong children from 4 to 8 years of age

This study is being carried out by the Department of Optometry and Radiography at The Hong Kong Polytechnic University. The Shin-Nippon SRW-5000 Open-field Autorefractor is a new instrument, which is likely to prove very useful in the examination of children's eyes. The accuracy of the instrument will be evaluated, and compared with that of other techniques commonly used.

If you and your child decide to participate in this study, we will first measure the refractive error of your child's eyes using two different automatic instruments. Each measurement will take a few minutes. We will then assess the health, and measure the pressure, of the eyes. Neither of these will involve any contact with the eye and both are simple and routine clinical procedures. Then we will put in some eyedrops (cyclopentolate 1%) which will prevent your child from focusing on close objects. This allows more accurate measurement of the refractive error and is again routine procedure. It will take about half an hour for the eyedrops to work fully. We will then measurement the refractive error again, using two automatic instruments. Finally, we will use the conventional "old fashioned" method to measure the refractive error, by using lenses and asking simple questions.

After the examination is finished, your child will have difficulty focusing on close objects for about 4 hours. He or she can still attend class, and if you wish we will give you a letter of explanation for the teacher. Your child's pupil will be enlarged all day and so more light then usual may enter the eyes. If your child goes outside into bright sunlight, he or she should wear a sun hat or sunglasses. Rarely, a local reaction to the eyedrops may result in redness of the eyes. This will disappear within a few hours.

If you have any concerns at all after you have left our clinic, please call Sandy Chat (Tel 9218) who will be carrying out the work. Ms Chat is an optometrist registered on Part I of the Optometrists Register. The person responsible is Prof. Marion Edwards (Tel 2766) and any comments and complaints you may have about the conduct of the study should be directed to her, or addressed to the Chairman, Human Subjects Ethics Sub-committee, The Hong Kong Polytechnic University.

You are free to withdraw from the project at any time. All information collected will be confidential and neither you nor your child will be identifiable in any paper published. Appointments can be made, or further information obtained, by calling Ms Sandy Chat (9218).

Appendix V

Consent form

Accuracy and reliability of the Shin-Nippon SRW-5000 open-field autorefractor, and tonic accommodation and accommodative lag in Hong Kong children from 4 to 8 years of age

Parent consent form

Have you read the information sheet provided?	Yes / No
Have you had an opportunity to ask questions and discuss this study?	Yes / No
Have your received satisfactory answers to all of your questions?	Yes / No
Have you received enough information about the study?	Yes / No
Who provided the information / answered your questions?	
Do you understand that participation is entirely voluntary?	Yes / No
Do you understand that you are free to withdraw from the study	
• at any time	Yes / No
• without having to give a reason	Yes / No
Do you agree to take part in this study	Yes / No

Name of children who will participate:

Signature of parent: Date:

Appendix VI

Record sheet

Information

Date	/ /	Time	Record no.
Name			Male / Female
Date of birth	/ /		
Contact tel. no.			

History

Last eye examination		
General & ocular health		
Family general & ocular health		
Medication		
Allergic reaction		
Birth history		
Habitual Rx	RE	LE

Preliminary examination

	RE		LE	
	Distance	Near	Distance	Near
Unaided VA				
Habital VA				
Suppression				

	Distance	Near
Unilateral cover test		
Alternated cover test		

Non-cycloplegic refraction

	RE		LE	
Retinoscopy		VA		VA
Subjective		VA		VA

Autorefraction (SRW-5000)

Examiner 1

Examiner 2

1st

1st

Example of Autorefraction result printout

<R> SPH	CYL	AX
−0.62	−0.50	167
−0.50	−0.50	164
−0.62	−0.62	6
−0.37	−1.00	163
−0.62	−0.37	123
−0.50	−0.75	96
−0.12	−0.62	134
−0.50	−0.50	89
−0.75	−0.62	90
−0.50	−1.00	172
−0.50	−0.87	167

SHIN NIPPON SRW-5000

2nd

2nd

Tonic accommodation (autorefraction taken in dark)

1st

2nd

Autorefraction (conventional)

Non-cycloplegic

2nd

1st

Autorefraction (Conventional)

Cycloplegic

1st 2nd

Pupil diameter	
Condition DD	
Condition LD	
Condition LL	

Residual over autorefraction

Near autorefraction

Condition DD

1st

2nd

Condition LD

1st

2nd

Near Autorefraction

Condition LL

1st

2nd

Cycloplegic autorefraction (SRW-5000)

Examiner 1	Examiner 2
1st	1st
2nd	2nd

Test before drug instillation

	RE	LE
C/D ratio		
IOP		
Amp of accommodation		

Cycloplegic refraction

RE		LE	
	VA		VA

Prescription given / not given (*deleted inappropriate*)

Appendix VII

Shin-Nippon SRW-5000 measurement procedure

A7.1 Setting the fixation target for the Shin-Nippon SRW-5000 autorefractor

At the start of each recording session the fixation target, comprising a red four-pointed "star" (Figure A6.1), was positioned so that the optical axis of the instrument and the line of sight of subjects viewing the target were coincident. This is done by the examiner sighting through the wide-view window from the subject side of the instrument. When the measurement start switch is depressed, a red circle of light is seen momentarily and the position of the fixation target is adjusted by a second person such that the entire target is inside the circle.

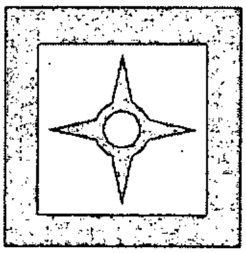


Figure A7.1 Shin-Nippon SRW-5000 fixation target

A 7.2 Alignment for taking measurement using Shin-Nippon SRW-5000

The subject was seated comfortably with his or her chin on the chin-rest, head against the forehead rest and eyes level with the eye mark, and viewing binocularly through the window of the instrument looked at the fixation target. The joystick was adjusted horizontally until the reticule circles seen on the instrument monitor were completely inside the pupil boundary of the eye to be measured, and then anterio-posteriorly until the "necklace" of corneal reflections was sharply focused (Figure A6.2). A reading was then taken by pressing the measurement start switch on the joystick. The instrument provides an average value (which can be based on between three and ten readings), called the "representative value". The SRW-5000 was interfaced with a personal computer (Li and Edwards, 2001) and this allowed the output to be directed to a Microsoft Excel file.

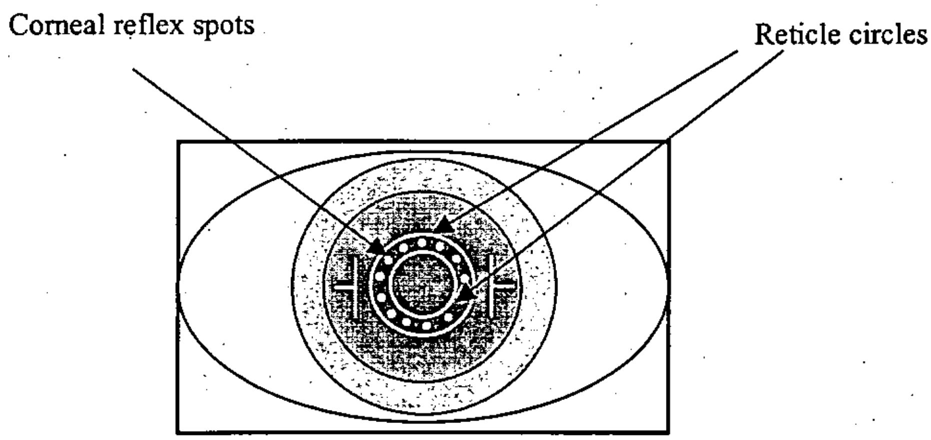


Figure A7.2 Perfect alignment taken in SRW-5000 measurement

Appendix VIII

Raw Data

A8.1 Data collected in Study 1

Subjects who did not participate in any cycloplegic measurements are written as italic font.

			Habitual				Subjective Rx			
Subject No.	**Gender**	**Age**	**Fs**	**Fc**	**Axis**	**VA**	**Fs**	**Fc**	**Axis**	**VA**
1	F	5	plano	--	--	0.0	1.00	--	--	0.0
2	F	7	plano	--	--	0.0	0.00	--	--	0.0
3	M	5	plano	--	--	0.0	0.75	--	--	0.0
4	F	8	-2.25	--	--	0.3	-3.00	-0.50	180	0.0
5	M	5	plano	--	--	0.0	0.50	--	--	0.0
6	F	7	plano	--	--	0.0	0.50	--	--	0.0
7	M	8	0.00	--	--	-0.1	0.50	-0.50	180	-0.1
8	M	8	-2.25	-0.25	165	0.2	-3.25	--	--	0.0
9	F	7	plano	--	--	0.1	1.00	-0.50	180	0.0
11	M	8	plano	--	--	0.0	0.00	--	--	0.0
12	F	8	plano	--	--	0.3	-0.75	--	--	0.0
13	F	6	plano	--	--	0.1	0.75	-0.50	180	0.1
14	M	8	-1.75	-0.75	120	0.0	-1.50	-0.50	120	0.0
15	M	7	-2.00	--	--	0.2	-2.50	--	--	0.0
16	F	4	0.00	-2.75	180	0.4	0.00	-3.00	180	0.4
17	M	7	plano	--	--	0.3	-1.00	--	--	0.1
18	M	7	plano	--	--	0.5	-1.25	--	--	0.0
19	F	4	plano	--	--	0.1	0.25	--	--	0.1
22	F	7	plano	--	--	0.0	0.50	--	--	0.0
23	M	5	plano	--	--	0.2	0.50	-0.25	90	0.1
24	F	5	plano	--	--	0.1	0.00	--	--	0.1
25	F	8	1.50	-0.50	180	0.1	1.50	-0.75	180	0.0
27	M	5	0.50	-2.00	20	0.2	1.25	-2.00	20	0.2
28	M	7	-1.00	--	--	0.3	-2.00	-1.00	180	0.1
29	F	7	plano	--	--	0.2	0.00	-0.50	5	0.0
30	F	8	-0.50	-0.50	180	0.1	-1.00	-0.50	180	0.0
32	F	7	plano	--	--	0.0		--	--	0.0
34	M	5	plano	--	--	0.1	0.50	--	--	0.0
36	F	8	-2.50	-1.50	180	0.4	-3.00	-2.25	180	0.1
37	M	4	plano	--	--	0.1	0.00	-0.50	180	0.1
38	F	5	plano	--	--	0.1	0.50	--	--	0.1
39	F	8	plano	--	--	0.5	-1.00	--	--	0.1
41	F	8	plano	--	--	0.3	-1.50	--	--	0.0
42	F	7	plano	--	--	0.1	0.25	--	--	0.1
43	M	6	plano	--	--	0.1	0.50	--	--	0.1
44	F	8	-1.50	--	--	0.1	-1.25	--	--	0.1

			Habitual				Subjective Rx			
	Gender	Age	Fs	Fc	Axis	VA	Fs	Fc	Axis	VA
45	F	7	4.75	-1.50	180	0.3	4.75	-1.50	180	0.2
46	F	8	-2.75	-0.75	180	0.2	-3.25	-1.00	180	0.1
47	F	8	plano	--	--	0.4	-1.50	--	--	0.0
48	M	5	plano	--	--	0.1	0.50	-0.50	180	0.0
49	M	5	-0.50	-2.50	10	0.0	-0.50	-2.50	10	0.0
50	M	5	plano	--	--	0.1	1.50	-0.50	90	0.1
52	*F*	*6*	plano	--	--	*0.0*	*0.25*	--	--	*0.0*
53	*F*	*8*	plano	--	--	*0.5*	*-2.00*	--	--	*0.1*
10	*F*	*8*	*-1.50*	*-1.50*	*180*	*0.1*	*-1.50*	*-2.00*	*170*	*0.0*
20	*F*	*7*	plano	--	--	*0.2*	*-0.50*	*-0.50*	*180*	*0.0*
21	*F*	*5*	plano	--	--	*0.1*	*0.25*	--	--	*0.1*
26	*M*	*7*	plano	--	--	*0.2*	*-1.25*	--	--	*0.0*
31	*F*	*7*	plano	--	--	*0.1*	*-0.50*	*-0.50*	*10*	*0.0*
33	*M*	*8*	plano	--	--	*0.0*	*0.75*	*-0.50*	*180*	*0.0*
35	*F*	*6*	plano	--	--	*0.4*	*-0.75*	--	--	*0.0*
40	*F*	*6*	*1.00*	*-2.00*	*175*	*0.2*	*1.00*	*-1.50*	*170*	*0.1*
51	*F*	*4*	plano	--	--	*0.1*	*0.75*	--	--	*0.1*

			Non-cyclo SRW-5000 by SC (1)			Non-cyclo SRW-5000 by SC (2)		
Subject No.	**Gender**	**Age**	**Fs**	**Fc**	**Axis**	**Fs**	**Fc**	**Axis**
1	F	5	0.75	-0.62	167	0.62	--	--
2	F	7	0.37	-0.37	53	0.25	--	--
3	M	5	0.25	-0.5	20	0.62	-0.75	179
4	F	8	-2.87	-0.87	157	-2.62	-0.75	158
5	M	5	0.62	-0.37	1	0.37	-0.25	163
6	F	7	0.12	-0.37	5	0.25	-0.37	5
7	M	8	0.37	-0.62	169	0.25	-0.37	163
8	M	8	-3.62	-0.62	160	-3.87	-0.12	150
9	F	7	0.50	-0.62	117	0.37	-0.25	66
11	M	8	0.12	--	--	0.37	-0.37	22
12	F	8	-1.12	--	--	-1.12	--	--
13	F	6	0.87	-0.62	170	0.62	-0.75	162
14	M	8	-1.75	-0.87	98	-2.25	-0.37	108
15	M	7	-2.87	-0.87	7	-3.25	-0.62	9
16	F	4	0.37	-4.62	175	0.50	-4.50	174
17	M	7	-0.87	-0.75	110	-1.25	-0.12	129
18	M	7	-1.37	-0.37	16	-1.25	-0.25	32
19	F	4	0.25	-0.5	25	0.25	-0.37	124
22	F	7	0.75	-0.25	171	0.50	-0.25	146
23	M	5	0.75	-0.87	117	0.75	-1.25	108
24	F	5	0.50	-0.62	115	0.50	-0.62	158
25	F	8	0.25	-0.37	146	0.25	-0.75	177
27	M	5	0.87	-1.87	8	-0.12	-1.5	17
28	M	7	-2.00	-0.87	173	-2	-0.87	174
29	F	7	-0.25	-0.37	161	-0.12	-0.62	169
30	F	8	-1.75	-0.5	166	-1.87	-0.5	177
32	F	7	0.50	-0.62	5	0.62	-0.87	15
34	M	5	0.50	-0.12	160	0.37	--	--
36	F	8	-4.00	-1.87	174	-3.62	-1.62	179
37	M	4	0.37	-0.37	3	0.37	-0.50	172
38	F	5	0.37	-0.25	108	0.37	-0.25	104
39	F	8	-1.50	-0.37	21	-1.50	-0.37	25
41	F	8	-2.00	-0.5	1	-2.00	-0.37	153
42	F	7	0.25	-0.12	113	0.25	-0.37	103
43	M	6	0.37	-0.37	8	0.50	-0.25	1
44	F	8	-1.62	-0.62	147	-1.50	-0.5	164
45	F	7	3.25	-1.37	169	3.25	-1.5	176
46	F	8	-3.00	-1	158	-3.00	-1.5	166
47	F	8	-1.50	-0.5	51	-1.87	-0.12	92
48	M	5	0.25	-0.5	180	0.00	-0.37	20
49	M	5	-0.75	-2	7	-0.75	-2.75	178
50	M	5	1.00	-1	89	1.00	-0.75	91
52	*F*	*6*	*0.00*	*-0.25*	*36*	*0.37*	*-0.25*	*56*
53	*F*	*8*	*-2.37*	*-0.37*	*173*	*-2.12*	*-0.37*	*96*
10	*F*	*8*	*-1.87*	*-1.62*	*166*	*-1.37*	*-1.75*	*169*
20	*F*	*7*	*-1.00*	--	--	*-0.75*	*-0.62*	*111*
21	*F*	*5*	*0.12*	*-0.12*	*145*	*0.50*	*-0.12*	*112*

			Non-cyclo SRW-5000 by SC (1)			Non-cyclo SRW-5000 by SC (2)		
Subject No.	**Gender**	**Age**	**Fs**	**Fc**	**Axis**	**Fs**	**Fc**	**Axis**
26	*M*	*7*	*-1.25*	*-0.87*	*79*	*-1.37*	*-0.87*	*94*
31	*F*	*7*	*-0.75*	*-0.75*	*180*	*-0.75*	*-0.87*	*180*
33	*M*	*8*	*0.37*	*-0.37*	*169*	*0.50*	*-0.50*	*166*
35	*F*	*6*	*-0.87*	*-0.37*	*19*	*-1.00*	*-0.37*	*180*
40	*F*	*6*	*0.25*	*-1.25*	*179*	*0.62*	*-1.37*	*13*
51	*F*	*4*	*0.50*	*-0.25*	*178*	*0.25*	*-0.37*	*172*

			Non-cyclo SRW-5000 by PC			Non-cyclo RK5		
Subject no.	**Gender**	**Age**	**Fs**	**Fc**	**Axis**	**Fs**	**Fc**	**Axis**
1	F	5	0.75	-0.62	174	0.75	--	--
2	F	7	0.50	--	--	0.00	--	--
3	M	5	0.12	--	--	0.25	--	--
4	F	8	-2.75	-1.00	167	-2.50	-1.00	172
5	M	5	0.75	-0.50	156	0.50	-1.00	6
6	F	7	0.25	-0.12	34	0.50	-0.25	10
7	M	8	0.25	-0.50	158	0.50	-0.75	175
8	M	8	-3.37	-0.75	141	-3.50	--	--
9	F	7	1.25	-1.00	42	0.50	--	--
11	M	8	0.50	-0.12	30	0.75	-0.50	175
12	F	8	-0.87	-0.50	107	-1.00	--	--
13	F	6	0.75	-0.62	180	0.75	-1.00	172
14	M	8	-2.00	-0.62	111	-2.00	-0.50	139
15	M	7	-3.00	-0.87	8	-2.75	-0.25	22
16	F	4	0.25	-4.37	174	0.75	-5.75	173
17	M	7	-1.12	-0.25	79	-0.75	--	--
18	M	7	-1.50	-0.25	8	-1.25	--	--
19	F	4	-0.25	-0.50	114	0.25	--	--
22	F	7	0.37	-0.37	112	0.25	--	--
23	M	5	0.87	-0.62	102	0.75	-0.75	124
24	F	5	0.12	-0.25	46	0.75	-0.50	158
25	F	8	0.25	-0.62	4	1.50	-1.00	180
27	M	5	0.25	-2.00	9	1.00	-2.50	12
28	M	7	-1.37	-1.25	6	-1.75	-1.00	179
29	F	7	-0.12	-0.62	168	0.00	-0.25	173
30	F	8	-0.75	-0.62	43	-2.00	-0.25	174
32	F	7	0.25	-0.50	9	0.75	-1.00	177
34	M	5	0.25	--	--	-0.25	-0.25	142
36	F	8	-4.00	-1.62	177	-3.25	-2.00	179
37	M	4	0.75	-0.75	21	0.25	-1.00	171
38	F	5	0.25	-0.12	101	0.25	--	--
39	F	8	-1.50	-0.37	45	-1.50	-0.25	2
41	F	8	-2.37	-0.25	135	-2.00	--	--
42	F	7	0.37	-0.87	13	0.50	--	--
43	M	6	0.62	-0.50	165	0.50	-0.75	2
44	F	8	-1.75	-0.37	129	-1.50	--	--
45	F	7	3.37	-1.25	180	4.75	-2.50	173
46	F	8	-2.87	-1.37	160	-2.75	-1.50	177
47	F	8	-1.75	-0.12	1	-1.75	--	--
48	M	5	0.25	-0.25	144	0.50	--	--
49	M	5	-1.12	-2.00	178	0.00	-2.75	1
50	M	5	1.00	--	--	0.25	--	--
52	*F*	*6*	*0.25*	*-0.62*	*8*	*0.25*	*-0.75*	*174*
53	*F*	*8*	*-2.62*	*-0.62*	*168*	*-2.25*	*-0.50*	*172*
10	*F*	*8*	*-1.62*	*-1.62*	*166*	*-1.25*	*-1.75*	*177*
20	*F*	*7*	*-1.12*	--	--	*-0.50*	--	--
21	*F*	*5*	*0.37*	*-0.37*	*86*	*0.25*	*-1.00*	*115*
26	*M*	*7*	*-0.87*	*-1.00*	*77*	*-1.50*	--	--

			Non-cyclo SRW-5000 by PC			Non-cyclo RK5		
	Gender	Age	Fs	Fc	Axis	Fs	Fc	Axis
31	F	7	-0.62	-0.87	173	-0.75	-1.25	174
33	M	8	0.37	-0.37	180	0.50	-1.00	6
35	F	6	-1.12	-0.12	26	-0.75	-0.50	1
40	F	6	0.25	-1.00	178	1.00	-1.75	1
51	F	4	0.50	-0.25	170	0.75	-0.50	173

			Cycloplegic refraction				Cyclo SRW-5000 by SC (1)		
Subject No.	**Gender**	**Age**	**Fs**	**Fc**	**Axis**	**VA**	**Fs**	**Fc**	**Axis**
1	F	5	1.00	--	--	0.0	0.75	-0.50	164
2	F	7	1.00	--	--	0.0	1.00	-0.12	73
3	M	5	1.25	--	--	0.0	0.87	-0.12	28
4	F	8	-2.50	-0.50	180	0.0	-2.87	-1.00	159
5	M	5	1.75	-0.50	180	0	1.75	-0.37	174
6	F	7	1.25	--	--	0.0	0.50	-0.62	178
7	M	8	0.50	-0.50	180	-0.1	0.25	-0.37	159
8	M	8	-3.25	--	--	0	-3.25	-0.37	13
9	F	7	1.25	-0.50	180	0.0	1.00	-0.12	171
11	M	8	0.50	--	--	0.0	0.25	-0.25	3
12	F	8	-0.75	--	--	0.0	-0.87	-0.37	92
13	F	6	2.75	-0.75	180	0.0	2.12	-0.37	170
14	M	8	-1.75	-0.50	120	0.0	-2.12	-0.50	126
15	M	7	-2.50	--	--	0.0	-2.50	-1.12	17
16	F	4	1.00	-4.00	180	0.1	1.50	-4.12	178
17	M	7	-1.00	-0.25	20	0.0	-1.12	-0.50	159
18	M	7	-1.25	--	--	0	-1.25	-0.37	20
19	F	4	0.50	--	--	0.1	0.50	-0.50	5
22	F	7	1.00	--	--	0.0	1.00	-0.12	171
23	M	5	1.50	-0.50	90	0.1	1.37	-0.62	127
24	F	5	1.00	--	--	0.1	1.25	-0.50	166
25	F	8	1.50	-0.75	180	0.0	1.00	-0.37	169
27	M	5	1.25	-2.00	20	0.2	1.00	-1.87	11
28	M	7	-1.50	-1.00	175	0	-1.50	-1.12	180
29	F	7	0.00	-0.50	5	0.0	-0.12	-0.37	174
30	F	8	-1.00	-0.50	180	0.0	-1.25	-1.12	178
32	F	7	0.75	--	--	0.0	0.50	-0.62	158
34	M	5	0.75	--	--	0.1	0.75	-1.00	62
36	F	8	-3.00	-2.25	180	0.1	-3.62	-2.25	180
37	M	4	1.00	-0.50	180	0.1	1.00	-0.50	23
38	F	5	1.00	--	--	0.0	1.25	-0.12	125
39	F	8	-1.00	-0.50	180	0.0	-1.37	-0.37	171
41	F	8	-1.50	--	--	0.0	-2.00	-0.12	77
42	F	7	0.50	--	--	0.1	0.25	-0.37	121
43	M	6	0.75	-0.50	180	0.0	1.00	-0.37	175
44	F	8	-1.50	--	--	0.1	-1.62	-0.62	142
45	F	7	4.75	-1.50	180	0.2	5.12	-2.00	169
46	F	8	-3.25	-1.00	180	0.1	-3.00	-1.37	172
47	F	8	-1.50	--	--	0.0	-1.50	-0.25	49
48	M	5	1.00	-0.50	180	0.0	0.50	-1.00	176
49	M	5	-0.50	-2.50	10	0.0	-0.12	-2.12	175
50	M	5	1.75	-0.50	90	0.0	2.00	-0.25	104
52	*F*	*6*	*0.75*	--	--	*0.1*	*0.62*	*-0.37*	*153*
53	*F*	*8*	*-2.00*	*-0.25*	*170*	*0.1*	*-2.62*	*-0.50*	*10*

			Cyclo SRW-5000 by SC (2)			Cyclo SRW-5000 by PC		
Subject No.	Gender	Age	Fs	Fc	Axis	Fs	Fc	Axis
1	F	5	0.75	-0.50	164	0.87	-0.25	170
2	F	7	0.87	-0.62	90	1.12	-0.75	83
3	M	5	1.00	-0.50	42	1.00	-0.37	125
4	F	8	-2.50	-1.00	171	-3.12	-0.75	164
5	M	5	1.75	-0.37	170	1.62	-0.25	15
6	F	7	0.62	-0.37	10	0.87	-0.50	8
7	M	8	0.25	-0.37	8	0.50	--	--
8	M	8	-3.25	-0.50	142	-3.00	-0.25	144
9	F	7	1.12	-0.25	168	1.25	-0.12	174
11	M	8	0.62	-0.50	5	0.37	-0.25	164
12	F	8	-1.12	-0.12	82	-0.62	-0.37	91
13	F	6	2.37	-0.75	164	2.75	-0.75	180
14	M	8	-2.00	-0.25	100	-1.87	-0.12	102
15	M	7	-2.75	-0.62	14	-3.00	-0.50	37
16	F	4	1.50	-4.00	174	1.75	-4.25	173
17	M	7	-1.25	-0.37	143	-1.50	-0.25	140
18	M	7	-1.25	-0.50	22	-1.37	-0.25	17
19	F	4	0.37	-0.75	153	0.37	--	--
22	F	7	1.12	-0.12	178	1.12	-0.37	144
23	M	5	1.12	-0.62	110	1.37	-0.87	99
24	F	5	1.37	-0.25	157	1.37	-0.25	9
25	F	8	1.12	-0.12	156	1.25	-0.50	21
27	M	5	0.87	-2.25	12	0.75	-1.87	11
28	M	7	-1.62	-1.00	175	-1.87	-1.00	176
29	F	7	-0.12	-0.50	170	-0.12	-0.50	157
30	F	8	-1.62	-0.75	12	-1.00	-1.00	174
32	F	7	0.62	-0.75	2	0.50	-0.62	15
34	M	5	0.75	-0.87	81	1.00	-0.50	153
36	F	8	-3.87	-1.50	5	-3.87	-1.50	175
37	M	4	1.00	-0.62	169	1.12	-0.37	1
38	F	5	1.37	-0.37	110	1.25	--	--
39	F	8	-1.25	-0.37	14	-1.37	--	--
41	F	8	-1.75	-0.12	153	-2.00	-0.37	154
42	F	7	0.37	-0.37	94	0.25	-0.25	110
43	M	6	0.87	-0.75	147	0.87	-0.37	177
44	F	8	-1.50	-0.75	140	-1.50	-0.37	141
45	F	7	4.75	-1.62	169	4.50	-1.75	180
46	F	8	-2.75	-1.37	172	-3.00	-1.25	177
47	F	8	-1.37	-0.50	179	-1.50	-0.37	167
48	M	5	0.87	-1.25	162	0.87	-1.87	160
49	M	5	-0.12	-2.25	176	0.25	-2.75	176
50	M	5	1.75	-0.37	99	2.12	-0.62	94
52	*F*	*6*	0.50	-0.37	8	0.50	-0.25	149
53	*F*	*8*	-2.50	-0.62	160	-2.37	-0.12	168

Subject No.	Gender	Age	Cyclo RK5 Fs	Fc	Axis
1	F	5	0.87	-0.25	170
2	F	7	1.12	-0.75	83
3	M	5	1.00	-0.37	125
4	F	8	-3.12	-0.75	164
5	M	5	1.62	-0.25	15
6	F	7	0.87	-0.50	8
7	M	8	0.50	--	--
8	M	8	-3.00	-0.25	144
9	F	7	1.25	-0.12	174
11	M	8	0.37	-0.25	164
12	F	8	-0.62	-0.37	91
13	F	6	2.75	-0.75	180
14	M	8	-1.87	-0.12	102
15	M	7	-3.00	-0.50	37
16	F	4	1.75	-4.25	173
17	M	7	-1.50	-0.25	140
18	M	7	-1.37	-0.25	17
19	F	4	0.37	--	--
22	F	7	1.12	-0.37	144
23	M	5	1.37	-0.87	99
24	F	5	1.37	-0.25	9
25	F	8	1.25	-0.50	21
27	M	5	0.75	-1.87	11
28	M	7	-1.87	-1.00	176
29	F	7	-0.12	-0.50	157
30	F	8	-1.00	-1.00	174
32	F	7	0.50	-0.62	15
34	M	5	1.00	-0.50	153
36	F	8	-3.87	-1.50	175
37	M	4	1.12	-0.37	1
38	F	5	1.25	--	--
39	F	8	-1.37	--	--
41	F	8	-2.00	-0.37	154
42	F	7	0.25	-0.25	110
43	M	6	0.87	-0.37	177
44	F	8	-1.50	-0.37	141
45	F	7	4.50	-1.75	180
46	F	8	-3.00	-1.25	177
47	F	8	-1.50	-0.37	167
48	M	5	0.87	-1.87	160
49	M	5	0.25	-2.75	176
50	M	5	2.12	-0.62	94
52	F	6	0.50	-0.25	149
53	F	8	-2.37	-0.12	168

A8.2 Data collected in Study 2

Subject No.	Rx gp	Age	Subject refraction			
			Fs	Fc	Axis	SE
1	M	8	-3.00	-2.25	180	-4.13
2	M	8	-3.25	-1.00	180	-3.75
3	M	8	-3.00	-0.50	180	-3.25
4	M	8	-3.25	0.00	0	-3.25
5	M	7	-2.50	0.00	0	-2.50
6	M	7	-2.50	0.00	0	-2.50
7	M	8	-1.50	-2.00	170	-2.50
8	M	7	-2.50	0.00	0	-2.50
9	M	7	-2.00	-1.00	180	-2.50
10	M	8	-2.00	0.00	0	-2.00
11	M	8	-1.50	-0.50	120	-1.75
12	M	5	-0.50	-2.50	10	-1.75
13	M	6	-1.50	0.00	0	-1.50
14	M	4	0.00	-3.00	180	-1.50
15	M	8	-1.50	0.00	0	-1.50
16	M	8	-1.50	0.00	0	-1.50
17	M	7	-1.25	0.00	0	-1.25
18	M	8	-1.00	-0.50	180	-1.25
19	M	7	-1.00	0.00	0	-1.00
20	M	5	-0.75	-0.50	170	-1.00
21	M	8	-0.75	0.00	0	-0.75
22	M	7	-0.50	-0.50	180	-0.75
23	M	7	-0.50	-0.50	10	-0.75
24	M	6	*-0.75*	0.00	0	-0.75
25	E	5	0.00	-0.50	90	-0.25
26	E	8	-0.25	0.00	0	-0.25
27	E	7	0.75	-1.75	180	-0.13
28	E	8	0.00	0.00	0	0.00
29	E	8	0.00	0.00	0	0.00
30	E	5	0.00	0.00	0	0.00
31	E	5	0.00	0.00	0	0.00
32	E	7	0.00	0.00	0	0.00
33	E	7	0.50	-0.50	180	0.25
34	E	4	0.25	0.00	0	0.25
35	E	5	0.25	0.00	0	0.25
36	E	7	1.25	-2.00	20	0.25
37	E	6	0.25	0.00	0	0.25
38	E	6	1.00	-1.50	170	0.25
39	E	7	0.25	0.00	0	0.25
40	E	5	0.50	-0.50	180	0.25
41	E	6	0.25	0.00	0	0.25
42	E	5	0.50	-0.25	90	0.38
43	H	5	0.50	0.00	0	0.50
44	H	6	*0.50*	0.00	0	0.50
45	H	7	0.50	0.00	0	0.50
46	H	7	0.50	0.00	0	0.50
47	H	8	0.75	0.50	0	0.50
48	H	7	0.50	0.00	0	0.50
49	H	5	0.50	0.00	0	0.50
50	H	6	*0.50*	0.00	0	0.50

Subject No.	Rx gp	Age	Subject refraction			
			Fs	Fc	Axis	SE
51	H	5	0.75	0.00	0	0.75
52	H	4	0.75	0.00	0	0.75
53	H	5	1.00	0.00	0	1.00
54	H	5	1.00	0.00	0	1.00
55	H	4	1.25	0.00	0	1.25
56	H	5	1.50	-0.50	90	1.25

Subject No.	Rx gp	Age	SRW-5000 autorefraction by SC						
			Fs	Fc	Axis	SE	h_1	h_2	h_3
1	M	8	-4.00	-1.87	174	-4.94	-4.0204	-0.2749	-5.8496
2	M	8	-3.00	-1.00	158	-3.50	-3.1403	-0.4912	-3.8597
3	M	8	-2.87	-0.87	157	-3.31	-3.0028	-0.4425	-3.6072
4	M	8	-3.62	-0.62	160	-3.93	-3.6925	-0.2818	-4.1675
5	M	7	-2.75	-0.62	92	-3.06	-3.3692	-0.0306	-2.7508
6	M	7	-3.00	-0.37	141	-3.19	-3.1465	-0.2559	-3.2235
7	M	8	-1.87	-1.62	166	-2.68	-1.9648	-0.5378	-3.3952
8	M	7	-2.87	-0.87	7	-3.31	-2.8829	0.1488	-3.7271
9	M	7	-2.00	-0.87	173	-2.44	-2.0129	-0.1488	-2.8571
10	M	8	-2.37	-0.37	173	-2.56	-2.3755	-0.0633	-2.7345
11	M	8	-1.75	-0.87	98	-2.19	-2.6031	-0.1696	-1.7669
12	M	5	-0.75	-2.00	7	-1.75	-0.7797	0.3421	-2.7203
13	M	6	-2.12	-0.37	86	-2.31	-2.4882	0.0364	-2.1218
14	M	4	0.37	-4.62	175	-1.94	0.3349	-0.5673	-4.2149
15	M	8	-2.00	-0.50	1	-2.25	-2.0002	0.0123	-2.4998
16	M	8	-1.50	-0.50	51	-1.75	-1.8020	0.3458	-1.6980
17	M	7	-1.37	-0.37	16	-1.56	-1.3981	0.1386	-1.7119
18	M	8	-1.75	-0.50	166	-2.00	-1.7793	-0.1660	-2.2207
19	M	7	-0.87	-0.75	110	-1.25	-1.5323	-0.3409	-0.9577
20	M	5	-1.25	-0.62	175	-1.56	-1.2547	-0.0761	-1.8653
21	M	8	-1.12	--	--	-1.12	-1.1200	0.0000	-1.1200
22	M	7	-1.00	--	--	-1.00	-1.0000	0.0000	-1.0000
23	M	7	-0.75	-0.75	180	-1.13	-0.7500	0.0000	-1.5000
24	M	6	-1.75	-0.37	176	-1.94	-1.7518	-0.0364	-2.1182
25	E	5	0.00	-0.62	83	-0.31	-0.6108	0.1061	-0.0092
26	E	8	-0.62	-0.37	169	-0.81	-0.6335	-0.0980	-0.9765
27	E	7	0.37	-1.62	2	-0.44	0.3680	0.0799	-1.2480
28	E	8	0.37	-0.37	53	0.19	0.1340	0.2515	0.2360
29	E	8	0.12	--	--	0.12	0.1200	0.0000	0.1200
30	E	5	0.50	-0.62	115	0.19	-0.0093	-0.3358	0.3893
31	E	5	0.50	-0.37	142	0.32	0.3598	-0.2539	0.2702
32	E	7	0.50	-0.62	5	0.19	0.4953	0.0761	-0.1153
33	E	7	0.37	-0.62	169	0.06	0.3474	-0.1642	-0.2274
34	E	4	0.25	-0.50	25	0.00	0.1607	0.2708	-0.1607
35	E	5	0.12	-0.12	145	0.06	0.0805	-0.0797	0.0395
36	E	7	0.87	-1.87	8	-0.07	0.8338	0.3645	-0.9638
37	E	6	0.12	-0.37	3	-0.07	0.1190	0.0273	-0.2490
38	E	6	0.25	-1.25	179	-0.38	0.2496	-0.0308	-0.9996
39	E	7	0.25	-0.12	113	0.19	0.1483	-0.0610	0.2317
40	E	5	0.25	-0.50	180	0.00	0.2500	0.0000	-0.2500
41	E	6	0.00	-0.25	36	-0.13	-0.0864	0.1681	-0.1636
42	E	5	0.75	-0.87	117	0.32	0.0593	-0.4977	0.5707
43	H	5	0.62	-0.37	1	0.44	0.6199	0.0091	0.2501
44	H	6	0.37	-0.50	9	0.12	0.3578	0.1093	-0.1178
45	H	7	0.12	-0.37	143	-0.07	-0.0140	-0.2515	-0.1160
46	H	7	0.75	-0.25	171	0.63	0.7439	-0.0546	0.5061
47	H	8	0.37	-0.37	169	0.19	0.3565	-0.0980	0.0135
48	H	7	0.50	-0.12	160	0.44	0.4860	-0.0545	0.3940
49	H	5	0.37	-0.25	108	0.25	0.1439	-0.1039	0.3461
50	H	6	0.50	-0.62	178	0.19	0.4992	-0.0306	-0.1192

Subject No.	Rx gp	Age	SRW-5000 autorefraction by SC						
			Fs	Fc	Axis	SE	h_1	h_2	h_3
51	H	5	0.25	-0.50	20	0.00	0.1915	0.2273	-0.1915
52	H	4	0.50	-0.25	178	0.38	0.4997	-0.0123	0.2503
53	H	5	0.75	-0.62	64	0.44	0.2491	0.3455	0.6309
54	H	5	1.00	-0.37	3	0.82	0.9990	0.0273	0.6310
55	H	4	0.62	-0.62	176	0.31	0.6170	-0.0610	0.0030
56	H	5	1.00	-1.00	89	0.50	0.0003	0.0247	0.9997

Subject No.	Rx gp	Age	Dark autorefraction (1)						
			Fs	Fc	Axis	SE	h_1	h_2	h_3
1	M	8	-4.50	-1.37	1	-5.19	-4.5004	0.0338	-5.8696
2	M	8	-4.87	-1.50	176	-5.62	-4.8773	-0.1476	-6.3627
3	M	8	-4.25	-0.87	164	-4.69	-4.3161	-0.3260	-5.0539
4	M	8	-4.00	-0.62	13	-4.31	-4.0314	0.1922	-4.5886
5	M	7	-3.37	-0.62	101	-3.68	-3.9674	-0.1642	-3.3926
6	M	7	-3.12	-0.75	134	-3.50	-3.5081	-0.5300	-3.4819
7	M	8	-2.25	-1.62	176	-3.06	-2.2579	-0.1594	-3.8621
8	M	7	-3.87	-1.37	2	-4.56	-3.8717	0.0676	-5.2383
9	M	7	-2.37	-1.00	176	-2.87	-2.3749	-0.0984	-3.3651
10	M	8	-2.37	-0.37	145	-2.56	-2.4917	-0.2459	-2.6183
11	M	8	-2.12	-0.62	112	-2.43	-2.6530	-0.3045	-2.2070
12	M	5	-1.50	-2.12	5	-2.56	-1.5161	0.2603	-3.6039
13	M	6	-2.25	-0.75	71	-2.63	-2.9205	0.3265	-2.3295
14	M	4	-0.50	-4.62	176	-2.81	-0.5225	-0.4547	-5.0975
15	M	8	-2.12	-0.37	155	-2.31	-2.1861	-0.2004	-2.4239
16	M	8	-2.25	-0.25	173	-2.38	-2.2537	-0.0428	-2.4963
17	M	7	-1.62	-0.25	162	-1.75	-1.6439	-0.1039	-1.8461
18	M	8	-1.87	-0.62	180	-2.18	-1.8700	0.0000	-2.4900
19	M	7	-1.50	-0.37	103	-1.69	-1.8513	-0.1147	-1.5187
20	M	5	-1.62	-0.87	162	-2.06	-1.7031	-0.3616	-2.4069
21	M	8	-1.62	-0.25	81	-1.75	-1.8639	0.0546	-1.6261
22	M	7	-1.75	-0.25	72	-1.88	-1.9761	0.1039	-1.7739
23	M	7	-1.62	-0.62	49	-1.93	-1.9731	0.4341	-1.8869
24	M	6	-2	-0.62	171	-2.31	-2.0152	-0.1355	-2.6048
25	E	5	-0.25	-0.5	103	-0.50	-0.7247	-0.1550	-0.2753
26	E	8	-2.25	-0.87	170	-2.69	-2.2762	-0.2104	-3.0938
27	E	7	-1.62	-0.12	126	-1.68	-1.6985	-0.0807	-1.6615
28	E	8	-0.37	-0.37	32	-0.56	-0.4739	0.2352	-0.6361
29	E	8	-0.25	-0.37	126	-0.44	-0.4922	-0.2488	-0.3778
30	E	5	-1.25	-2.37	109	-2.44	-3.3688	-1.0318	-1.5012
31	E	5	-0.50	-0.37	6	-0.69	-0.5040	0.0544	-0.8660
32	E	7	0.00	-0.50	170	-0.25	-0.0151	-0.1209	-0.4849
33	E	7	0.00	-0.62	160	-0.31	-0.0725	-0.2818	-0.5475
34	E	4	-1.75	-0.50	119	-2.00	-2.1325	-0.2998	-1.8675
35	E	5	-0.50	-0.75	93	-0.88	-1.2479	-0.0554	-0.5021
36	E	7	-1.00	-2.00	17	-2.00	-1.1710	0.7908	-2.8290
37	E	6	-1.5	-1.12	67	-2.06	-2.4490	0.5697	-1.6710
38	E	6	-1.25	-0.75	10	-1.63	-1.2726	0.1814	-1.9774
39	E	7	-0.12	-0.50	119	-0.37	-0.5025	-0.2998	-0.2375
40	E	5	-1.00	-0.62	10	-1.31	-1.0187	0.1499	-1.6013
41	E	6	-0.37	-0.62	5	-0.68	-0.3747	0.0761	-0.9853
42	E	5	-0.50	-1.00	125	-1.00	-1.1710	-0.6645	-0.8290
43	H	5	-0.25	-0.50	12	-0.50	-0.2716	0.1438	-0.7284
44	H	6	-1.12	-0.5	171	-1.37	-1.1322	-0.1093	-1.6078
45	H	7	-0.25	-0.37	176	-0.44	-0.2518	-0.0364	-0.6182
46	H	7	-0.50	-0.37	5	-0.69	-0.5028	0.0454	-0.8672
47	H	8	-3.00	-0.87	103	-3.44	-3.8260	-0.2697	-3.0440
48	H	7	-1.12	-0.37	144	-1.31	-1.2478	-0.2488	-1.3622
49	H	5	-1	-0.37	100	-1.19	-1.3588	-0.0895	-1.0112
50	H	6	-1.37	-0.62	179	-1.68	-1.3702	-0.0153	-1.9898

Subject No.	Rx gp	Age	Dark autorefraction (1) Fs	Fc	Axis	SE	h_1	h_2	h_3
51	H	5	-0.50	-0.37	20	-0.69	-0.5433	0.1682	-0.8267
52	H	4	-0.50	-0.62	13	-0.81	-0.5314	0.1922	-1.0886
53	H	5	-0.12	-0.5	34	-0.37	-0.2763	0.3278	-0.4637
54	H	5	0.75	-0.62	3	0.44	0.7483	0.0458	0.1317
55	H	4	0.25	-0.62	178	-0.06	0.2492	-0.0306	-0.3692
56	H	5	0.25	-0.50	99	0.00	-0.2378	-0.1093	0.2378

Subject No.	Rx gp	Age	Fs	Fc	Axis	SE	h_1	h_2	h_3
			Dark autorefraction (2)						
1	M	8	-4.12	-1.50	178	-4.87	-4.1218	-0.0740	-5.6182
2	M	8	-4.87	-1.12	168	-5.43	-4.9184	-0.3221	-5.9416
3	M	8	-3.50	-1.25	179	-4.13	-3.5004	-0.0308	-4.7496
4	M	8	-4.75	-0.75	175	-5.13	-4.7557	-0.0921	-5.4943
5	M	7	-3.25	-0.62	110	-3.56	-3.7975	-0.2818	-3.3225
6	M	7	-3.00	-0.62	148	-3.31	-3.1741	-0.3940	-3.4459
7	M	8	-2.37	-1.62	170	-3.18	-2.4188	-0.3918	-3.9412
8	M	7	-3.87	-3.12	14	-5.43	-4.0526	1.0357	-6.8074
9	M	7	-2.50	-0.75	174	-2.88	-2.5082	-0.1103	-3.2418
10	M	8	-2.75	-0.37	142	-2.94	-2.8902	-0.2539	-2.9798
11	M	8	-2.25	-0.62	126	-2.56	-2.6558	-0.4169	-2.4642
12	M	5	-0.62	-2.37	2	-1.81	-0.6229	0.1169	-2.9871
13	M	6	-2.12	-0.75	57	-2.50	-2.6475	0.4845	-2.3425
14	M	4	-0.50	-5.12	178	-3.06	-0.5062	-0.2525	-5.6138
15	M	8	-2.25	-0.37	72	-2.44	-2.5847	0.1538	-2.2853
16	M	8	-2.50	-0.37	129	-2.69	-2.7235	-0.2559	-2.6465
17	M	7	-1.62	-0.50	8	-1.87	-1.6297	0.0975	-2.1103
18	M	8	-2.12	-0.75	4	-2.50	-2.1236	0.0738	-2.8664
19	M	7	-2.12	-0.37	17	-2.31	-2.1516	0.1463	-2.4584
20	M	5	-1.62	-0.62	171	-1.93	-1.6352	-0.1355	-2.2248
21	M	8	-1.62	-0.37	135	-1.81	-1.8050	-0.2616	-1.8050
22	M	7	-1.12	-0.37	125	-1.31	-1.3683	-0.2459	-1.2417
23	M	7	-2.12	-0.87	49	-2.56	-2.6155	0.6092	-2.4945
24	M	6	-2	-0.5	163	-2.25	-2.0427	-0.1977	-2.4573
25	E	5	-0.12	-0.75	92	-0.50	-0.8691	-0.0370	-0.1209
26	E	8	-2.75	-0.5	29	-3.00	-2.8675	0.2998	-3.1325
27	E	7	-1.62	-0.37	75	-1.81	-1.9652	0.1308	-1.6448
28	E	8	-0.25	-0.62	32	-0.56	-0.4241	0.3940	-0.6959
29	E	8	-0.25	-0.37	174	-0.44	-0.2540	-0.0544	-0.6160
30	E	5	-1.25	-1.62	94	-2.06	-2.8621	-0.1594	-1.2579
31	E	5	-0.62	-0.50	13	-0.87	-0.6453	0.1550	-1.0947
32	E	7	-0.37	-0.75	2	-0.75	-0.3709	0.0370	-1.1191
33	E	7	-0.50	-0.50	161	-0.75	-0.5530	-0.2177	-0.9470
34	E	4	-1.62	-1.37	174	-2.31	-1.6350	-0.2014	-2.9750
35	E	5	-0.50	-0.50	101	-0.75	-0.9818	-0.1324	-0.5182
36	E	7	-1.50	-1.87	15	-2.44	-1.6253	0.6611	-3.2447
37	E	6	-0.75	-0.62	72	-1.06	-1.3108	0.2577	-0.8092
38	E	6	-1.37	-0.75	175	-1.75	-1.3757	-0.0921	-2.1143
39	E	7	-0.87	-0.25	99	-1.00	-1.1139	-0.0546	-0.8761
40	E	5	-1.12	-0.50	19	-1.37	-1.1730	0.2177	-1.5670
41	E	6	-0.50	-0.62	163	-0.81	-0.5530	-0.2452	-1.0670
42	E	5	-0.62	-0.87	120	-1.06	-1.2725	-0.5328	-0.8375
43	H	5	-0.12	-0.50	10	-0.37	-0.1351	0.1209	-0.6049
44	H	6	-1.37	-0.37	34	-1.56	-1.4857	0.2426	-1.6243
45	H	7	-0.62	-0.37	4	-0.81	-0.6218	0.0364	-0.9882
46	H	7	-0.62	-0.25	156	-0.75	-0.6614	-0.1314	-0.8286
47	H	8	-3.25	-0.62	109	-3.56	-3.8043	-0.2699	-3.3157
48	H	7	-1.62	-0.62	105	-1.93	-2.1985	-0.2192	-1.6615
49	H	5	-1.25	-0.50	67	-1.50	-1.6737	0.2543	-1.3263
50	H	6	-1.62	-0.75	174	-2.00	-1.6282	-0.1103	-2.3618

Subject No.	Rx gp	Age	Dark autorefraction (2) Fs	Fc	Axis	SE	h_1	h_2	h_3
51	H	5	-0.50	-0.37	60	-0.69	-0.7775	0.2266	-0.5925
52	H	4	-0.62	-0.75	173	-1.00	-0.6311	-0.1283	-1.3589
53	H	5	-0.37	-0.5	88	-0.62	-0.8694	0.0247	-0.3706
54	H	5	0.37	-0.5	163	0.12	0.3273	-0.1977	-0.0873
55	H	4	-0.25	-0.62	6	-0.56	-0.2568	0.0911	-0.8632
56	H	5	0.00	-0.87	111	-0.44	-0.7583	-0.4116	-0.1117

Subject No.	Rx gp	Age	TA SE	TA h_1	TA h_2	TA h_3
1	M	8	-0.07	0.1014	-0.2009	-0.2314
2	M	8	1.93	1.7781	-0.1691	2.0819
3	M	8	0.82	0.4976	-0.4117	1.1424
4	M	8	1.20	1.0632	-0.1897	1.3268
5	M	7	0.50	0.4282	0.2512	0.5718
6	M	7	0.13	0.0276	0.1381	0.2224
7	M	8	0.50	0.4540	-0.1460	0.5460
8	M	7	2.13	1.1697	-0.8869	3.0803
9	M	7	0.44	0.4953	-0.0386	0.3847
10	M	8	0.38	0.5147	0.1906	0.2453
11	M	8	0.38	0.0526	0.2474	0.6974
12	M	5	0.06	-0.1568	0.2252	0.2668
13	M	6	0.19	0.1593	-0.4481	0.2207
14	M	4	1.12	0.8411	-0.3147	1.3989
15	M	8	0.19	0.5845	-0.1414	-0.2145
16	M	8	0.94	0.9215	0.6017	0.9485
17	M	7	0.32	0.2316	0.0412	0.3984
18	M	8	0.50	0.3444	-0.2398	0.6456
19	M	7	1.06	0.6194	-0.4872	1.5006
20	M	5	0.37	0.3805	0.0593	0.3595
21	M	8	0.69	0.6850	0.2616	0.6850
22	M	7	0.31	0.3683	0.2459	0.2417
23	M	7	1.43	1.8655	-0.6092	0.9945
24	M	6	0.32	0.2909	0.1613	0.3391
25	E	5	0.19	0.2583	0.1431	0.1117
26	E	8	2.20	2.2340	-0.3978	2.1560
27	E	7	1.37	2.3332	-0.0509	0.3968
28	E	8	0.75	0.5581	-0.1425	0.9319
29	E	8	0.56	0.3740	0.0544	0.7360
30	E	5	2.25	2.8529	-0.1764	1.6471
31	E	5	1.19	1.0051	-0.4088	1.3649
32	E	7	0.94	0.8662	0.0391	1.0038
33	E	7	0.81	0.9004	0.0534	0.7196
34	E	4	2.31	1.7957	0.4722	2.8143
35	E	5	0.81	1.0623	0.0527	0.5577
36	E	7	2.37	2.4590	-0.2967	2.2810
37	E	6	1.00	1.4298	-0.2303	0.5602
38	E	6	1.37	1.6253	0.0612	1.1147
39	E	7	1.19	1.2622	-0.0064	1.1078
40	E	5	1.37	1.4230	-0.2177	1.3170
41	E	6	0.69	0.4666	0.4133	0.9034
42	E	5	1.37	1.3318	0.0351	1.4082
43	H	5	0.81	0.7550	-0.1118	0.8550
44	H	6	1.68	1.8435	-0.1333	1.5065
45	H	7	0.74	0.6078	-0.2879	0.8722
46	H	7	1.37	1.4052	0.0767	1.3348
47	H	8	3.75	4.1608	0.1719	3.3292
48	H	7	2.37	2.6844	0.1647	2.0556
49	H	5	1.75	1.8175	-0.3582	1.6725
50	H	6	2.19	2.1274	0.0797	2.2426

			TA			
Subject No.	**Rx gp**	**Age**	**SE**	**h_1**	**h_2**	**h_3**
51	H	5	0.69	0.9690	0.0007	0.4010
52	H	4	1.37	1.1308	0.1160	1.6092
53	H	5	1.06	1.1185	0.3208	1.0015
54	H	5	0.70	0.6717	0.2251	0.7183
55	H	4	0.87	0.8738	-0.1522	0.8662
56	H	5	0.94	0.7586	0.4363	1.1114

Subject No.	Rx gp	Age	Repeatability SE	h1	h2	h3	VDD
1	M	8	-0.32	-0.3786	0.1078	-0.2514	0.47
2	M	8	-0.19	0.0411	0.1745	-0.4211	0.46
3	M	8	-0.56	-0.8157	-0.2952	-0.3043	0.92
4	M	8	0.82	0.7243	0.2843	0.9057	1.19
5	M	7	-0.12	-0.1700	0.1176	-0.0700	0.22
6	M	7	-0.19	-0.3340	-0.1360	-0.0360	0.36
7	M	8	0.12	0.1610	0.2324	0.0790	0.29
8	M	7	0.88	0.1809	-0.9682	1.5691	1.85
9	M	7	0.00	0.1333	0.0119	-0.1233	0.18
10	M	8	0.38	0.3985	0.0080	0.3615	0.54
11	M	8	0.13	0.0028	0.1124	0.2572	0.28
12	M	5	-0.76	-0.8932	0.1434	-0.6168	1.09
13	M	6	-0.13	-0.2730	-0.1580	0.0130	0.32
14	M	4	0.25	-0.0162	-0.2021	0.5162	0.55
15	M	8	0.13	0.3986	-0.3542	-0.1386	0.55
16	M	8	0.31	0.4698	0.2131	0.1502	0.54
17	M	7	0.13	-0.0142	-0.2014	0.2642	0.33
18	M	8	0.32	0.2536	-0.0738	0.3764	0.46
19	M	7	0.62	0.3004	-0.2610	0.9396	1.02
20	M	5	-0.13	-0.0679	-0.2261	-0.1821	0.30
21	M	8	0.06	-0.0589	0.3163	0.1789	0.37
22	M	7	-0.57	-0.6079	0.3498	-0.5321	0.88
23	M	7	0.63	0.6424	-0.1751	0.6076	0.90
24	M	6	-0.06	0.0276	0.0622	-0.1476	0.16
25	E	5	-0.01	0.1444	-0.1180	-0.1544	0.24
26	E	8	0.32	0.5913	-0.5102	0.0387	0.78
27	E	7	0.13	0.2667	-0.2115	-0.0167	0.34
28	E	8	0.01	-0.0498	-0.1589	0.0598	0.18
29	E	8	0.00	-0.2381	-0.1944	0.2381	0.39
30	E	5	-0.38	-0.5067	-0.8723	-0.2433	1.04
31	E	5	0.19	0.1413	-0.1006	0.2287	0.29
32	E	7	0.50	0.3558	-0.1579	0.6342	0.74
33	E	7	0.44	0.4805	-0.0641	0.3995	0.63
34	E	4	0.31	-0.4975	-0.0984	1.1075	1.22
35	E	5	-0.13	-0.2661	0.0770	0.0161	0.28
36	E	7	0.44	0.4543	0.1297	0.4157	0.63
37	E	6	-1.00	-1.1382	0.3120	-0.8618	1.46
38	E	6	0.12	0.1031	0.2735	0.1369	0.32
39	E	7	0.63	0.6114	-0.2452	0.6386	0.92
40	E	5	0.06	0.1543	-0.0677	-0.0343	0.17
41	E	6	0.13	0.1783	0.3213	0.0817	0.38
42	E	5	0.05	0.1015	-0.1317	0.0085	0.17
43	H	5	-0.13	-0.1365	0.0229	-0.1235	0.19
44	H	6	0.19	0.3535	-0.3518	0.0165	0.50
45	H	7	0.37	0.3700	-0.0728	0.3700	0.53
46	H	7	0.06	0.1585	0.1768	-0.0385	0.24
47	H	8	0.13	-0.0217	0.0002	0.2717	0.27
48	H	7	0.63	-1.62	0.9506	-0.0296	0.2994
49	H	5	0.32	-1.34	0.3148	-0.3438	0.3152
50	H	6	0.32	-1.84	0.2580	0.0950	0.3720

Subject No.	Rx gp	Age	Repeatability				
			SE	h_1	h_2	h_3	VDD
51	H	5	0.00	0.2342	-0.0584	-0.2342	0.34
52	H	4	0.19	0.0998	0.3205	0.2702	0.43
53	H	5	0.25	0.5930	0.3031	-0.0930	0.67
54	H	5	0.32	0.4210	0.2435	0.2190	0.53
55	H	4	0.50	0.5060	-0.1217	0.4940	0.72
56	H	5	0.44	0.5205	0.3024	0.3495	0.70

A8.3 Data collected in Study 3

				Pupil Diameter			Subjective Rx			
Subject No.	Gender	Age	Rx gp	AD	AN	B	Fs	Fc	Axis	SE
1	F	8	M	5.67	5.00	3.33	-3.25	-1.00	170	-3.75
2	F	8	M	6.67	5.83	4.00	-2.25	-0.50	165	-2.50
3	M	8	M	4.67	3.00	2.17	-2.50	0.00	0	-2.50
4	F	8	M	5.17	4.67	3.00	-1.00	-1.00	5	-1.50
5	F	7	M	5.83	5.50	4.00	-1.00	-0.50	180	-1.25
6	F	6	M	5.83	5.00	4.17	-0.75	-0.50	170	-1.00
7	F	8	M	6.67	5.00	3.33	-0.50	-0.50	170	-0.75
8	F	8	M	7.17	5.83	4.67	-0.25	-0.50	170	-0.50
9	M	8	E	5.83	5.33	3.83	-0.25	0.00	0	-0.25
10	M	6	E	7.17	5.83	4.50	0.00	-0.50	90	-0.25
11	M	6	E	5.83	4.67	3.83	0.25	-0.50	175	0.00
12	F	7	E	6.67	5.33	4.17	0.50	-0.75	180	0.13
13	F	6	E	5.83	4.67	3.33	0.25	-0.25	180	0.13
14	M	5	E	5.50	5.00	4.50	0.50	-0.50	180	0.25
15	F	6	E	6.67	5.83	5.00	0.25	0.00	0	0.25
16	F	7	E	7.17	6.67	5.33	0.25	0.00	0	0.25
17	M	7	E	4.67	4.67	3.83	0.50	-0.25	5	0.38
18	M	8	E	7.00	5.83	3.83	0.50	-0.25	15	0.38
19	M	8	E	6.67	5.00	3.33	0.50	-0.25	30	0.38
20	F	8	E	5.83	4.67	3.83	0.50	-0.25	10	0.38
21	F	7	H	5.50	5.00	3.00	0.50	0.00	0	0.50
22	F	8	H	6.33	5.83	4.67	0.50	0.00	0	0.50
23	F	6	H	6.33	5.00	3.50	0.50	0.00	0	0.50
24	F	7	H	5.83	5.00	4.00	1.00	-0.75	170	0.63
25	F	5	H	7.17	5.83	3.83	0.75	-0.25	170	0.63
26	M	6	H	6.33	5.00	4.67	1.00	-0.50	110	0.75
27	F	6	H	7.00	6.33	4.17	0.75	0.00	0	0.75
28	F	5	H	7.00	5.00	4.17	0.75	0.00	0	0.75
29	M	6	H	6.33	5.50	3.50	1.00	-0.25	180	0.88
30	M	5	H	7.00	5.83	4.67	1.00	0.00	0	1.00
31	F	4	H	6.67	6.33	4.83	1.25	0.00	0	1.25
32	F	8	H	6.33	5.50	3.50	1.50	0.00	0	1.50
33	F	6	H	6.67	5.33	4.17	2.50	-1.00	10	2.00

Subject No.	Gender	Age	Rx gp	Autorefraction						
				Fs	Fc	Axis	SE	h_1	h_2	h_3
1	F	8	M	-3.17	-1.34	169	-3.85	-3.2232	-0.3561	-4.4688
2	F	8	M	-2.56	-0.35	-14	-2.73	-2.5778	-0.1160	-2.8892
3	M	8	M	-2.89	-0.37	99	-3.08	-3.2501	-0.0782	-2.9009
4	F	8	M	-1.66	-0.75	6	-2.04	-1.6699	0.1025	-2.4081
5	F	7	M	-1.71	-0.36	-7	-1.89	-1.7126	-0.0608	-2.0649
6	F	6	M	-1.25	-0.67	169	-1.58	-1.2752	-0.1795	-1.8908
7	F	8	M	-0.56	-0.64	166	-0.88	-0.5959	-0.2111	-1.1581
8	F	8	M	-0.66	-0.53	165	-0.92	-0.6928	-0.1870	-1.1515
9	M	8	E	-0.74	-0.23	-18	-0.86	-0.7655	-0.0934	-0.9515
10	M	6	E	-0.01	-0.46	80	-0.24	-0.4594	0.1102	-0.0236
11	M	6	E	0.28	-0.54	-19	0.01	0.2272	-0.2340	-0.2052
12	F	7	E	0.35	-0.74	-3	-0.02	0.3511	-0.0497	-0.3836
13	F	6	E	0.54	-0.36	2	0.36	0.5378	0.0162	0.1788
14	M	5	E	0.22	-0.35	12	0.04	0.2042	0.0972	-0.1162
15	F	6	E	-1.25	-0.67	169	-1.58	-1.2752	-0.1795	-1.8908
16	F	7	E	0.14	-0.49	170	-0.11	0.1263	-0.1142	-0.3383
17	M	7	E	0.34	-0.59	0	0.04	0.3379	0.0069	-0.2529
18	M	8	E	0.08	-0.39	175	-0.12	0.0744	-0.0464	-0.3134
19	M	8	E	-0.06	-0.20	2	-0.16	-0.0623	0.0120	-0.2587
20	F	8	E	0.28	-0.22	26	0.17	0.2389	0.1239	0.1011
21	F	7	H	0.29	-0.33	8	0.13	0.2873	0.0659	-0.0263
22	F	8	H	0.38	-0.13	-1	0.31	0.3779	-0.0026	0.2461
23	F	6	H	0.42	-0.29	60	0.27	0.1985	0.1784	0.3475
24	F	7	H	0.79	-0.70	170	0.44	0.7728	-0.1692	0.1112
25	F	5	H	0.54	-0.30	-25	0.39	0.4856	-0.1633	0.2874
26	M	6	H	1.22	-0.80	117	0.82	0.5780	-0.4512	1.0560
27	F	6	H	0.66	-0.22	7	0.55	0.6578	0.0375	0.4484
28	F	5	H	0.50	-0.48	86	0.26	0.0278	0.0504	0.4982
29	M	6	H	0.40	-0.08	-68	0.36	0.3322	-0.0403	0.3928
30	M	5	H	0.93	-0.12	2	0.87	0.9265	0.0066	0.8085
31	F	4	H	0.52	-0.55	2	0.24	0.5148	0.0275	-0.0340
32	F	8	H	0.38	-0.16	-9	0.30	0.3777	-0.0359	0.2223
33	F	6	H	1.58	-0.84	17	1.16	1.5086	0.3326	0.8114

Subject No.	Gender	Age	Rx gp	Fs	Fc	Axis	Over Rx SE	h_1	h_2	h_3
1	F	8	M	-0.08	-0.31	148	-0.24	-0.1689	-0.2006	-0.3051
2	F	8	M	-0.55	-0.21	97	-0.65	-0.7575	-0.0359	-0.5525
3	M	8	M	-0.22	-0.46	155	-0.45	-0.3023	-0.2489	-0.6027
4	F	8	M	-0.32	-0.21	96	-0.43	-0.5273	-0.0301	-0.3267
5	F	7	M	-0.26	-0.31	135	-0.41	-0.4128	-0.2170	-0.4139
6	F	6	M	-0.29	-0.46	150	-0.52	-0.4062	-0.2829	-0.6368
7	F	8	M	-0.10	-0.10	1	-0.15	-0.1007	0.0026	-0.2053
8	F	8	M	-0.48	-0.05	15	-0.50	-0.4797	0.0193	-0.5253
9	M	8	E	-0.23	-0.25	167	-0.35	-0.2399	-0.0785	-0.4634
10	M	6	E	-0.43	-0.27	50	-0.56	-0.5880	0.1898	-0.5380
11	M	6	E	0.04	-0.67	165	-0.29	-0.0011	-0.2376	-0.5749
12	F	7	E	-0.56	-0.06	158	-0.59	-0.5725	-0.0306	-0.6175
13	F	6	E	-0.15	-0.21	1	-0.26	-0.1509	0.0050	-0.3602
14	M	5	E	-0.29	-0.46	150	-0.52	-0.4062	-0.2829	-0.6368
15	F	6	E	-0.12	-0.47	174	-0.36	-0.1274	-0.0654	-0.5866
16	F	7	E	0.10	-0.24	177	-0.02	0.0954	-0.0177	-0.1434
17	M	7	E	-0.07	-0.30	145	-0.22	-0.1680	-0.2000	-0.2670
18	M	8	E	0.03	-0.03	4	0.01	0.0274	0.0032	-0.0024
19	M	8	E	0.07	-0.04	58	0.05	0.0389	0.0255	0.0571
20	F	8	E	-0.29	-0.20	177	-0.39	-0.2925	-0.0126	-0.4958
21	F	7	H	-0.28	-0.28	180	-0.42	-0.2782	0.0000	-0.5629
22	F	8	H	-0.07	-0.17	168	-0.15	-0.0760	-0.0480	-0.2300
23	F	6	H	-0.32	-0.07	76	-0.35	-0.3828	0.0224	-0.3242
24	F	7	H	0.40	-0.31	175	0.24	0.3979	-0.0348	0.0871
25	F	5	H	-0.01	-0.26	157	-0.14	-0.0486	-0.1351	-0.2303
26	M	6	H	-0.25	-0.20	116	-0.35	-0.4061	-0.1122	-0.2850
27	F	6	H	0.16	-0.32	7	0.01	0.1599	0.0526	-0.1465
28	F	5	H	0.26	-0.05	51	0.23	0.2285	0.0334	0.2378
29	M	6	H	-0.15	-0.48	113	-0.39	-0.5581	-0.2427	-0.2229
30	M	5	H	-0.04	-0.74	175	-0.41	-0.0426	-0.0901	-0.7707
31	F	4	H	0.00	-0.70	174	-0.35	-0.0064	-0.0976	-0.6916
32	F	8	H	-0.68	-0.32	2	-0.83	-0.6756	0.0183	-0.9934
33	F	6	H	0.28	-0.22	131	0.17	0.1527	-0.1541	0.1813

Subject No.	Gender	Age	Rx gp	Near Rx (DD1) Fs	Fc	Axis	SE	h_1	h_2	h_3
1	F	8	M	-0.87	-0.39	164	-1.06	-0.8969	-0.1475	-1.2292
2	F	8	M	-0.81	-0.44	102	-1.03	-1.2336	-0.1315	-0.8334
3	M	8	M	-1.14	-0.07	150	-1.18	-1.1578	-0.0424	-1.1933
4	F	8	M	-1.33	-0.10	125	-1.38	-1.4005	-0.0682	-1.3655
5	F	7	M	-1.15	-0.42	117	-1.36	-1.4832	-0.2378	-1.2358
6	F	6	M	-0.98	-0.60	138	-1.28	-1.2533	-0.4225	-1.3100
7	F	8	M	-1.23	-0.22	18	-1.34	-1.2516	0.0925	-1.4257
8	F	8	M	-0.84	-0.04	6	-0.86	-0.8425	0.0053	-0.8775
9	M	8	E	-1.09	-0.23	32	-1.20	-1.1531	0.1467	-1.2529
10	M	6	E	-0.96	-0.26	55	-1.09	-1.1400	0.1725	-1.0473
11	M	6	E	-1.05	-0.62	165	-1.36	-1.0906	-0.2167	-1.6238
12	F	7	E	-0.70	-0.33	156	-0.87	-0.7582	-0.1729	-0.9838
13	F	6	E	-1.45	-0.55	176	-1.73	-1.4535	-0.0557	-2.0015
14	M	5	E	-1.13	-0.41	83	-1.33	-1.5314	0.0740	-1.1356
15	F	6	E	-1.27	-0.44	175	-1.50	-1.2764	-0.0543	-1.7146
16	F	7	E	-1.72	-0.20	38	-1.82	-1.7915	0.1357	-1.8425
17	M	7	E	-1.02	-0.47	143	-1.26	-1.1975	-0.3229	-1.3215
18	M	8	E	-1.43	-0.14	147	-1.50	-1.4715	-0.0925	-1.5325
19	M	8	E	-1.10	-0.30	161	-1.26	-1.1345	-0.1304	-1.3772
20	F	8	E	-1.02	-0.26	103	-1.15	-1.2701	-0.0840	-1.0362
21	F	7	H	-1.30	-0.35	32	-1.48	-1.4011	0.2254	-1.5549
22	F	8	H	-1.34	-0.07	26	-1.37	-1.3498	0.0363	-1.3912
23	F	6	H	-1.37	-0.50	2	-1.62	-1.3732	0.0275	-1.8682
24	F	7	H	-0.29	-0.26	170	-0.42	-0.2953	-0.0611	-0.5397
25	F	5	H	-0.99	-0.42	140	-1.20	-1.1664	-0.2915	-1.2422
26	M	6	H	-1.99	-0.30	16	-2.13	-2.0072	0.1086	-2.2618
27	F	6	H	-1.49	-0.14	112	-1.57	-1.6167	-0.0694	-1.5143
28	F	5	H	-0.74	-0.92	133	-1.20	-1.2386	-0.6520	-1.1657
29	M	6	H	-1.63	-0.47	100	-1.87	-2.0927	-0.1196	-1.6493
30	M	5	H	-0.96	-0.48	165	-1.20	-0.9873	-0.1693	-1.4082
31	F	4	H	-1.11	-0.45	1	-1.33	-1.1061	0.0056	-1.5589
32	F	8	H	-1.59	-0.25	7	-1.71	-1.5933	0.0453	-1.8324
33	F	6	H	-1.38	-0.46	129	-1.61	-1.6578	-0.3161	-1.5592

Subject No.	Gender	Age	Rx gp	Near Rx (DD2)						
				Fs	Fc	Axis	SE	h_1	h_2	h_3
1	F	8	M	-1.55	-0.30	165	-1.70	-1.5646	-0.1051	-1.8289
2	F	8	M	-0.72	-0.35	96	-0.89	-1.0662	-0.0537	-0.7229
3	M	8	M	-0.94	-0.34	164	-1.11	-0.9703	-0.1266	-1.2560
4	F	8	M	-1.20	-0.11	84	-1.25	-1.3088	0.0159	-1.2002
5	F	7	M	-1.22	-0.33	105	-1.38	-1.5260	-0.1174	-1.2410
6	F	6	M	-0.94	-0.32	136	-1.11	-1.0990	-0.2285	-1.1135
7	F	8	M	-1.34	-0.12	29	-1.40	-1.3664	0.0691	-1.4296
8	F	8	M	-1.17	-0.11	46	-1.23	-1.2281	0.0767	-1.2239
9	M	8	E	-1.16	-0.18	18	-1.25	-1.1799	0.0777	-1.3256
10	M	6	E	-0.70	-0.27	91	-0.83	-0.9677	-0.0080	-0.7013
11	M	6	E	-0.80	-0.67	162	-1.13	-0.8649	-0.2760	-1.4041
12	F	7	E	-0.80	-0.37	149	-0.98	-0.8930	-0.2280	-1.0692
13	F	6	E	-1.32	-0.42	165	-1.53	-1.3520	-0.1464	-1.7170
14	M	5	E	-1.08	-0.36	60	-1.26	-1.3538	0.2200	-1.1742
15	F	6	E	-1.38	-0.52	9	-1.64	-1.3950	0.1088	-1.8905
16	F	7	E	-1.48	-0.23	17	-1.59	-1.4958	0.0903	-1.6842
17	M	7	E	-1.45	-0.39	176	-1.65	-1.4539	-0.0430	-1.8427
18	M	8	E	-1.40	-0.15	42	-1.48	-1.4705	0.1080	-1.4845
19	M	8	E	-1.59	-0.29	148	-1.74	-1.6750	-0.1843	-1.8050
20	F	8	E	-1.19	-0.35	170	-1.36	-1.1983	-0.0832	-1.5234
21	F	7	H	-1.52	-0.60	36	-1.82	-1.7337	0.4076	-1.9113
22	F	8	H	-1.49	-0.13	178	-1.55	-1.4857	-0.0066	-1.6103
23	F	6	H	-1.36	-0.25	180	-1.48	-1.3562	0.0008	-1.6088
24	F	7	H	-0.95	-0.40	164	-1.15	-0.9825	-0.1479	-1.3205
25	F	5	H	-1.04	-0.34	98	-1.20	-1.3666	-0.0678	-1.0423
26	M	6	H	-2.05	-0.27	148	-2.18	-2.1230	-0.1742	-2.2440
27	F	6	H	-1.49	-0.01	141	-1.50	-1.4949	-0.0092	-1.4978
28	F	5	H	-0.77	-0.78	132	-1.16	-1.1984	-0.5498	-1.1266
29	M	6	H	-1.41	-0.28	98	-1.55	-1.6807	-0.0523	-1.4133
30	M	5	H	-1.15	-0.58	8	-1.44	-1.1609	0.1104	-1.7213
31	F	4	H	-1.22	-0.37	4	-1.40	-1.2238	0.0383	-1.5857
32	F	8	H	-1.31	-0.12	170	-1.37	-1.3147	-0.0289	-1.4289
33	F	6	H	-1.43	-0.19	131	-1.52	-1.5364	-0.1344	-1.5076

				Near Rx (LD1)						
Subject No.	**Gender**	**Age**	**Rx gp**	**Fs**	**Fc**	**Axis**	**SE**	**h_1**	**h_2**	**h_3**
1	F	8	M	-1.64	-0.19	139	-1.73	-1.7174	-0.1331	-1.7426
2	F	8	M	-0.95	-0.16	85	-1.03	-1.1036	0.0200	-0.9494
3	M	8	M	-1.06	-0.24	158	-1.18	-1.0934	-0.1184	-1.2626
4	F	8	M	-1.48	-0.18	89	-1.57	-1.6544	0.0031	-1.4756
5	F	7	M	-1.23	-0.32	120	-1.39	-1.4747	-0.1945	-1.3095
6	F	6	M	-0.93	-0.13	132	-1.00	-1.0037	-0.0913	-0.9907
7	F	8	M	-1.35	-0.08	29	-1.39	-1.3670	0.0457	-1.4090
8	F	8	M	-1.30	-0.04	102	-1.32	-1.3417	-0.0131	-1.3013
9	M	8	E	-1.24	-0.14	11	-1.31	-1.2433	0.0355	-1.3694
10	M	6	E	-0.82	-0.21	63	-0.93	-0.9903	0.1229	-0.8667
11	M	6	E	-1.04	-0.63	162	-1.35	-1.1004	-0.2668	-1.6036
12	F	7	E	-1.03	-0.10	171	-1.08	-1.0304	-0.0221	-1.1236
13	F	6	E	-1.58	-0.32	179	-1.74	-1.5798	-0.0086	-1.8992
14	M	5	E	-1.37	-0.14	70	-1.43	-1.4858	0.0621	-1.3812
15	F	6	E	-1.38	-0.65	175	-1.70	-1.3837	-0.0725	-2.0223
16	F	7	E	-1.86	-0.11	109	-1.92	-1.9628	-0.0480	-1.8734
17	M	7	E	-1.45	-0.30	154	-1.60	-1.5094	-0.1678	-1.6906
18	M	8	E	-1.71	-0.18	62	-1.80	-1.8513	0.1045	-1.7517
19	M	8	E	-1.29	-0.56	113	-1.57	-1.7639	-0.2803	-1.3683
20	F	8	E	-0.97	-0.13	108	-1.03	-1.0837	-0.0530	-0.9774
21	F	7	H	-1.46	-0.41	35	-1.66	-1.5956	0.2698	-1.7324
22	F	8	H	-1.34	-0.07	26	-1.37	-1.3498	0.0363	-1.3912
23	F	6	H	-1.44	-0.11	9	-1.50	-1.4456	0.0232	-1.5504
24	F	7	H	-1.27	-0.13	131	-1.33	-1.3366	-0.0881	-1.3204
25	F	5	H	-1.08	-0.50	104	-1.33	-1.5466	-0.1688	-1.1123
26	M	6	H	-1.58	-0.22	134	-1.69	-1.6967	-0.1580	-1.6853
27	F	6	H	-1.73	-0.23	115	-1.84	-1.9198	-0.1260	-1.7688
28	F	5	H	-1.15	-0.69	121	-1.50	-1.6581	-0.4307	-1.3359
29	M	6	H	-1.32	-0.28	101	-1.46	-1.5892	-0.0709	-1.3288
30	M	5	H	-1.01	-0.90	171	-1.46	-1.0306	-0.1936	-1.8894
31	F	4	H	-1.36	-0.12	1	-1.42	-1.3553	0.0040	-1.4747
32	F	8	H	-1.59	-0.19	165	-1.68	-1.5991	-0.0679	-1.7687
33	F	6	H	-1.26	-0.58	132	-1.55	-1.5863	-0.4103	-1.5181

				Near Rx (LD2)						
Subject No.	**Gender**	**Age**	**Rx gp**	**Fs**	**Fc**	**Axis**	**SE**	**h_1**	**h_2**	**h_3**
1	F	8	M	-1.43	-0.26	154	-1.56	-1.4796	-0.1448	-1.6375
2	F	8	M	-1.01	-0.44	102	-1.23	-1.4294	-0.1249	-1.0266
3	M	8	M	-1.33	-0.07	164	-1.37	-1.3369	-0.0242	-1.3931
4	F	8	M	-1.28	-0.17	97	-1.36	-1.4469	-0.0275	-1.2821
5	F	7	M	-1.08	-0.39	112	-1.28	-1.4179	-0.1913	-1.1371
6	F	6	M	-1.23	-0.58	110	-1.52	-1.7430	-0.2628	-1.3030
7	F	8	M	-1.09	-0.18	35	-1.18	-1.1528	0.1202	-1.2142
8	F	8	M	-1.32	-0.03	100	-1.34	-1.3562	-0.0087	-1.3238
9	M	8	E	-1.35	-0.32	25	-1.51	-1.4084	0.1728	-1.6116
10	M	6	E	-1.34	-0.11	71	-1.39	-1.4347	0.0487	-1.3473
11	M	6	E	-1.00	-0.66	168	-1.33	-1.0315	-0.1983	-1.6345
12	F	7	E	-1.02	-0.11	145	-1.08	-1.0591	-0.0760	-1.0989
13	F	6	E	-1.75	-0.28	167	-1.90	-1.7672	-0.0859	-2.0248
14	M	5	E	-1.53	-0.08	175	-1.57	-1.5330	-0.0103	-1.6145
15	F	6	E	-1.32	-0.78	176	-1.70	-1.3218	-0.0842	-2.0882
16	F	7	E	-1.47	-0.14	115	-1.53	-1.5779	-0.0745	-1.4910
17	M	7	E	-1.49	-0.31	123	-1.64	-1.7055	-0.1989	-1.5785
18	M	8	E	-1.47	-0.28	156	-1.61	-1.5158	-0.1499	-1.7012
19	M	8	E	-1.51	-0.44	110	-1.74	-1.9042	-0.2043	-1.5668
20	F	8	E	-1.41	-0.19	107	-1.51	-1.5886	-0.0760	-1.4314
21	F	7	H	-1.58	-0.20	26	-1.68	-1.6143	0.1109	-1.7367
22	F	8	H	-1.55	-0.20	15	-1.65	-1.5616	0.0732	-1.7362
23	F	6	H	-1.63	-0.02	142	-1.64	-1.6380	-0.0160	-1.6434
24	F	7	H	-1.30	-0.32	145	-1.46	-1.4031	-0.2113	-1.5119
25	F	5	H	-1.33	-0.42	133	-1.54	-1.5514	-0.2965	-1.5253
26	M	6	H	-1.58	-0.44	108	-1.80	-1.9816	-0.1829	-1.6224
27	F	6	H	-1.57	-0.31	90	-1.73	-1.8811	0.0032	-1.5729
28	F	5	H	-1.04	-0.70	133	-1.40	-1.4215	-0.4965	-1.3694
29	M	6	H	-1.44	-0.27	75	-1.57	-1.6902	0.0977	-1.4548
30	M	5	H	-1.19	-0.81	172	-1.60	-1.2075	-0.1490	-1.9879
31	F	4	H	-1.02	-0.40	180	-1.22	-1.0218	-0.0011	-1.4207
32	F	8	H	-1.52	-0.07	171	-1.56	-1.5266	-0.0153	-1.5924
33	F	6	H	-1.29	-0.63	122	-1.60	-1.7427	-0.3963	-1.4613

				Near Rx (LL1)						
Subject No.	**Gender**	**Age**	**Rx gp**	**Fs**	**Fc**	**Axis**	**SE**	**h_1**	**h_2**	**h_3**
1	F	8	M	-1.77	-0.44	141	-1.99	-1.9434	-0.3022	-2.0354
2	F	8	M	-1.47	-0.19	97	-1.57	-1.6595	-0.0315	-1.4705
3	M	8	M	-1.03	-0.28	59	-1.17	-1.2328	0.1717	-1.1022
4	F	8	M	-1.46	-0.05	114	-1.48	-1.4997	-0.0242	-1.4693
5	F	7	M	-1.16	-0.42	98	-1.37	-1.5762	-0.0791	-1.1666
6	F	6	M	-1.39	-0.47	116	-1.62	-1.7678	-0.2607	-1.4797
7	F	8	M	-1.47	-0.09	23	-1.52	-1.4835	0.0489	-1.5485
8	F	8	M	-1.35	-0.09	75	-1.40	-1.4358	0.0312	-1.3592
9	M	8	E	-1.42	-0.23	30	-1.54	-1.4807	0.1416	-1.5923
10	M	6	E	-1.09	-0.22	83	-1.20	-1.3106	0.0379	-1.0934
11	M	6	E	-1.13	-0.38	167	-1.32	-1.1460	-0.1220	-1.4850
12	F	7	E	-0.78	-0.50	143	-1.03	-0.9554	-0.3378	-1.0986
13	F	6	E	-2.03	-0.30	173	-2.18	-2.0311	-0.0497	-2.3214
14	M	5	E	-1.39	-0.47	116	-1.62	-1.7678	-0.2607	-1.4797
15	F	6	E	-1.33	-0.30	15	-1.48	-1.3538	0.1048	-1.6117
16	F	7	E	-1.44	-0.13	170	-1.51	-1.4462	-0.0306	-1.5705
17	M	7	E	-1.68	-0.30	21	-1.82	-1.7141	0.1400	-1.9334
18	M	8	E	-1.79	-0.25	131	-1.92	-1.9357	-0.1770	-1.9043
19	M	8	E	-1.47	-0.47	125	-1.70	-1.7848	-0.3112	-1.6182
20	F	8	E	-1.48	-0.06	35	-1.51	-1.5001	0.0398	-1.5200
21	F	7	H	-1.56	-0.30	44	-1.71	-1.6984	0.2108	-1.7127
22	F	8	H	-1.29	-0.33	26	-1.46	-1.3552	0.1814	-1.5584
23	F	6	H	-1.50	-0.18	158	-1.59	-1.5264	-0.0869	-1.6552
24	F	7	H	-1.40	-0.19	148	-1.50	-1.4548	-0.1182	-1.5364
25	F	5	H	-1.65	-0.09	123	-1.70	-1.7169	-0.0564	-1.6806
26	M	6	H	-1.57	-0.37	67	-1.75	-1.8791	0.1868	-1.6249
27	F	6	H	-1.69	-0.29	116	-1.84	-1.9285	-0.1621	-1.7495
28	F	5	H	-1.24	-0.71	128	-1.59	-1.6804	-0.4841	-1.5096
29	M	6	H	-1.37	-0.31	94	-1.52	-1.6782	-0.0334	-1.3674
30	M	5	H	-1.19	-0.54	174	-1.46	-1.1970	-0.0780	-1.7230
31	F	4	H	-1.18	-0.31	172	-1.34	-1.1880	-0.0577	-1.4845
32	F	8	H	-1.70	-0.36	4	-1.88	-1.7030	0.0330	-2.0650
33	F	6	H	-1.37	-1.45	155	-2.09	-1.6208	-0.7811	-2.5602

				Near Rx (LL2)						
Subject No.	**Gender**	**Age**	**Rx gp**	**Fs**	**Fc**	**Axis**	**SE**	**h_1**	**h_2**	**h_3**
1	F	8	M	-1.94	-0.38	143	-2.13	-2.0733	-0.2565	-2.1797
2	F	8	M	-1.52	-0.13	66	-1.58	-1.6275	0.0685	-1.5405
3	M	8	M	-1.22	-0.13	100	-1.29	-1.3474	-0.0303	-1.2271
4	F	8	M	-1.58	-0.08	117	-1.61	-1.6364	-0.0433	-1.5916
5	F	7	M	-1.30	-0.33	114	-1.46	-1.5727	-0.1719	-1.3540
6	F	6	M	-1.07	-0.38	145	-1.26	-1.1963	-0.2513	-1.3248
7	F	8	M	-1.92	-0.26	14	-2.05	-1.9404	0.0873	-2.1682
8	F	8	M	-1.44	-0.22	88	-1.55	-1.6637	0.0107	-1.4423
9	M	8	E	-1.89	-0.26	19	-2.02	-1.9176	0.1129	-2.1254
10	M	6	E	-1.22	-0.14	90	-1.29	-1.3589	-0.0012	-1.2201
11	M	6	E	-1.25	-0.55	159	-1.52	-1.3191	-0.2652	-1.7239
12	F	7	E	-0.80	-0.47	139	-1.04	-1.0106	-0.3309	-1.0684
13	F	6	E	-2.12	-0.51	160	-2.37	-2.1767	-0.2301	-2.5647
14	M	5	E	-1.07	-0.38	145	-1.26	-1.1963	-0.2513	-1.3248
15	F	6	E	-1.57	-0.08	20	-1.61	-1.5768	0.0367	-1.6372
16	F	7	E	-1.12	-0.24	108	-1.24	-1.3364	-0.1032	-1.1424
17	M	7	E	-1.34	-0.32	167	-1.50	-1.3520	-0.0962	-1.6430
18	M	8	E	-1.68	-0.22	107	-1.79	-1.8824	-0.0882	-1.6996
19	M	8	E	-1.44	-0.70	119	-1.79	-1.9800	-0.4231	-1.6087
20	F	8	E	-1.59	-0.41	139	-1.79	-1.7593	-0.2843	-1.8222
21	F	7	H	-1.51	-0.25	44	-1.64	-1.6317	0.1798	-1.6447
22	F	8	H	-1.51	-0.12	96	-1.57	-1.6303	-0.0160	-1.5147
23	F	6	H	-1.60	-0.18	160	-1.69	-1.6220	-0.0834	-1.7590
24	F	7	H	-1.42	-0.32	136	-1.58	-1.5710	-0.2268	-1.5834
25	F	5	H	-1.53	-0.39	151	-1.73	-1.6233	-0.2344	-1.8267
26	M	6	H	-1.63	-0.32	86	-1.79	-1.9508	0.0297	-1.6342
27	F	6	H	-1.62	-0.28	119	-1.76	-1.8391	-0.1676	-1.6856
28	F	5	H	-1.15	-0.74	124	-1.52	-1.6531	-0.4835	-1.3779
29	M	6	H	-1.70	-0.48	100	-1.94	-2.1696	-0.1115	-1.7161
30	M	5	H	-1.27	-0.19	164	-1.37	-1.2893	-0.0724	-1.4537
31	F	4	H	-1.37	-0.22	180	-1.48	-1.3741	-0.0013	-1.5914
32	F	8	H	-1.65	-0.30	6	-1.80	-1.6536	0.0406	-1.9449
33	F	6	H	-1.27	-0.60	141	-1.57	-1.5068	-0.4125	-1.6242

Subject No.	Gender	Age	Rx gp	Repeatability (DD)				Repeatability (LD)			
				SE	h_1	h_2	h_3	SE	h_1	h_2	h_3
1	F	8	M	0.63	0.6678	-0.0424	0.5997	-0.17	-0.2377	0.0117	-0.1052
2	F	8	M	-0.06	-0.1876	0.0842	0.0627	0.19	0.2435	-0.0943	0.1305
3	M	8	M	-0.14	-0.1674	-0.0778	-0.1105	0.20	0.3258	0.1449	0.0772
4	F	8	M	-0.13	-0.0917	-0.0841	-0.1653	-0.20	-0.2074	0.0306	-0.1936
5	F	7	M	0.02	0.0428	-0.1204	0.0052	-0.11	-0.0568	-0.0032	-0.1724
6	F	6	M	-0.18	-0.1544	-0.1940	-0.1965	0.53	0.7393	0.1716	0.3123
7	F	8	M	0.06	0.1148	0.0234	0.0039	-0.20	-0.2142	-0.0744	-0.1948
8	F	8	M	0.37	0.3856	-0.0714	0.3464	0.02	0.0145	-0.0044	0.0225
9	M	8	E	0.05	0.0268	0.0690	0.0727	0.20	0.1651	-0.1373	0.2422
10	M	6	E	-0.26	-0.1723	0.1805	-0.3460	0.46	0.4444	0.0742	0.4806
11	M	6	E	-0.22	-0.2257	0.0593	-0.2198	-0.02	-0.0689	-0.0685	0.0309
12	F	7	E	0.11	0.1348	0.0551	0.0855	0.00	0.0287	0.0539	-0.0247
13	F	6	E	-0.19	-0.1015	0.0907	-0.2845	0.16	0.1874	0.0773	0.1256
14	M	5	E	-0.23	-0.2957	0.0454	-0.1583	-0.38	-0.3849	0.0264	-0.3825
15	F	6	E	-0.07	-0.1776	-0.1460	0.0386	0.14	0.0472	0.0724	0.2333
16	F	7	E	0.15	0.1186	-0.1631	0.1759	0.00	-0.0620	0.0118	0.0660
17	M	7	E	0.39	0.2564	-0.2799	0.5212	0.04	0.1961	0.0311	-0.1121
18	M	8	E	-0.02	-0.0010	-0.2005	-0.0480	-0.19	-0.3355	0.2544	-0.0505
19	M	8	E	0.21	-0.0718	-0.0008	0.4872	0.48	0.5049	0.0230	0.4540
20	F	8	E	0.48	0.5405	0.0539	0.4279	0.17	0.1402	-0.0760	0.1985
21	F	7	H	0.34	0.3326	-0.1822	0.3564	0.01	0.0187	0.1589	0.0043
22	F	8	H	0.18	0.1358	0.0429	0.2191	0.28	0.2118	-0.0369	0.3450
23	F	6	H	-0.14	-0.0170	0.0268	-0.2594	0.14	0.1925	0.0392	0.0930
24	F	7	H	0.73	0.6872	0.0869	0.7808	0.13	0.0666	0.1232	0.1914
25	F	5	H	0.00	0.2001	-0.2237	-0.1998	0.21	0.0048	0.1277	0.4130
26	M	6	H	-0.04	-0.0402	-0.1023	-0.0391	-0.10	-0.2367	0.0658	0.0336
27	F	6	H	-0.07	-0.1218	-0.0602	-0.0166	-0.12	-0.0387	-0.1292	-0.1959
28	F	5	H	0.05	0.1158	0.2828	-0.0178	0.11	0.2849	0.0249	-0.0629
29	M	6	H	-0.32	-0.4120	-0.0673	-0.2360	0.11	0.1010	-0.1686	0.1260
30	M	5	H	0.24	0.1735	-0.2797	0.3131	0.14	0.1769	-0.0446	0.0985
31	F	4	H	0.07	0.1177	-0.0326	0.0268	-0.19	-0.3335	0.0051	-0.0540
32	F	8	H	-0.34	-0.2786	0.0742	-0.4034	-0.12	-0.0725	-0.0526	-0.1763
33	F	6	H	-0.09	-0.1214	-0.1816	-0.0516	0.05	0.1563	-0.0140	-0.0568

Subject No.	Gender	Age	Rx gp	Repeatability (LL) SE	h_1	h_2	h_3
1	F	8	M	0.14	0.1299	-0.0457	0.1444
2	F	8	M	0.12	0.1146	0.2020	0.1249
3	M	8	M	0.02	-0.0320	-0.1000	0.0700
4	F	8	M	0.13	0.1367	0.0191	0.1223
5	F	7	M	0.09	-0.0036	0.0929	0.1874
6	F	6	M	-0.36	-0.5714	-0.0094	-0.1549
7	F	8	M	0.54	0.4569	-0.0384	0.6197
8	F	8	M	0.16	0.2279	0.0205	0.0831
9	M	8	E	0.48	0.4369	0.0287	0.5331
10	M	6	E	0.09	0.0483	0.0391	0.1267
11	M	6	E	0.21	0.1731	0.1431	0.2389
12	F	7	E	0.01	0.0552	-0.0068	-0.0302
13	F	6	E	0.19	0.1457	0.1804	0.2433
14	M	5	E	-0.27	-0.1098	0.0726	-0.4281
15	F	6	E	-0.36	-0.5714	-0.0094	-0.1549
16	F	7	E	0.12	0.2230	0.0681	0.0255
17	M	7	E	-0.33	-0.3621	0.2362	-0.2904
18	M	8	E	-0.13	-0.0533	-0.0887	-0.2047
19	M	8	E	0.28	0.2592	0.3241	0.3022
20	F	8	E	0.09	0.1952	0.1120	-0.0095
21	F	7	H	-0.07	-0.0667	0.0310	-0.0680
22	F	8	H	0.12	0.2750	0.1974	-0.0437
23	F	6	H	0.10	0.0956	-0.0035	0.1038
24	F	7	H	0.08	0.1162	0.1086	0.0470
25	F	5	H	0.03	-0.0936	0.1780	0.1462
26	M	6	H	-0.08	-0.0273	-0.0006	-0.1317
27	F	6	H	-0.08	-0.0894	0.0055	-0.0640
28	F	5	H	0.04	0.0717	0.1571	0.0093
29	M	6	H	0.42	0.4914	0.0781	0.3487
30	M	5	H	-0.09	0.0924	-0.0055	-0.2694
31	F	4	H	0.15	0.1861	-0.0565	0.1069
32	F	8	H	-0.08	-0.0495	-0.0077	-0.1200
33	F	6	H	-0.52	-0.1139	-0.3686	-0.9361

Subject No.	Gender	Age	Rx gp	Ocular accommodative response DD Fs	Fc	Axis	SE	h_1	h_2	h_3
1	F	8	M	1.58	-0.19	113	1.4858	1.4255	-0.0953	1.5534
2	F	8	M	0.31	-0.14	5	0.2402	0.3099	0.0179	0.1707
3	M	8	M	0.75	-0.18	137	0.6659	0.6735	-0.1243	0.6585
4	F	8	M	0.89	-0.11	108	0.8358	0.7889	-0.0469	0.8828
5	F	7	M	1.15	-0.33	167	0.9816	1.1283	-0.1019	0.8355
6	F	6	M	0.71	-0.23	170	0.5889	0.6986	-0.0552	0.4794
7	F	8	M	1.32	-0.11	147	1.2639	1.2852	-0.0685	1.2427
8	F	8	M	0.78	-0.10	151	0.7298	0.7553	-0.0584	0.7045
9	M	8	E	1.03	-0.24	145	0.9109	0.9508	-0.1596	0.8714
10	M	6	E	0.45	-0.36	26	0.2724	0.3817	0.1991	0.1639
11	M	6	E	0.89	-0.07	29	0.8552	0.8729	0.0392	0.8375
12	F	7	E	0.54	-0.31	58	0.3879	0.3220	0.1992	0.4544
13	F	6	E	1.44	-0.27	63	1.2989	1.2188	0.1561	1.3794
14	M	5	E	1.17	-0.84	150	0.7492	0.9601	-0.5120	0.5424
15	F	6	E	1.43	-0.26	131	1.3059	1.2874	-0.1798	1.3248
16	F	7	E	1.68	-0.17	144	1.5960	1.6222	-0.1122	1.5700
17	M	7	E	1.65	-0.38	109	1.4558	1.3062	-0.1625	1.6063
18	M	8	E	1.59	-0.15	138	1.5171	1.5253	-0.1086	1.5091
19	M	8	E	2.00	-0.35	58	1.8272	1.7501	0.2191	1.9050
20	F	8	E	1.06	-0.16	70	0.9780	0.9157	0.0723	1.0404
21	F	7	H	1.73	-0.61	140	1.4259	1.4824	-0.4217	1.3716
22	F	8	H	1.45	-0.07	148	1.4188	1.4340	-0.0429	1.4036
23	F	6	H	1.31	-0.32	87	1.1445	0.9850	0.0222	1.3047
24	F	7	H	1.50	-0.17	50	1.4177	1.4037	0.1170	1.4319
25	F	5	H	1.34	-0.53	175	1.0788	1.3392	-0.0690	0.8200
26	M	6	H	2.01	-0.27	80	1.8794	1.7531	0.0648	2.0061
27	F	6	H	1.69	-0.33	8	1.5306	1.6883	0.0640	1.3735
28	F	5	H	1.85	-0.86	43	1.4194	1.4539	0.6032	1.3892
29	M	6	H	1.32	-0.29	128	1.1728	1.1382	-0.1958	1.2079
30	M	5	H	1.22	-0.34	150	1.0474	1.1338	-0.2055	0.9618
31	F	4	H	1.26	-0.39	165	1.0693	1.2356	-0.1394	0.9039
32	F	8	H	0.65	-0.22	9	0.5408	0.6441	0.0478	0.4378
33	F	6	H	1.74	-0.03	135	1.7239	1.7241	-0.0205	1.7238

				Ocular accommodative response LD						
Subject No.	**Gender**	**Age**	**Rx gp**	**Fs**	**Fc**	**Axis**	**SE**	**h_1**	**h_2**	**h_3**
1	F	8	M	1.39	-0.08	127	1.34	1.3317	-0.0576	1.3541
2	F	8	M	0.70	-0.24	16	0.58	0.6775	0.0902	0.4768
3	M	8	M	1.13	-0.41	154	0.92	1.0479	-0.2297	0.7983
4	F	8	M	0.97	-0.04	93	0.95	0.9298	-0.0026	0.9665
5	F	7	M	1.02	-0.29	176	0.87	1.0174	-0.0262	0.7296
6	F	6	M	1.36	-0.69	179	1.02	1.3586	-0.0206	0.6715
7	F	8	M	1.13	-0.18	142	1.04	1.0656	-0.1205	1.0214
8	F	8	M	0.89	-0.09	13	0.85	0.8858	0.0286	0.8062
9	M	8	E	1.36	-0.37	137	1.18	1.1854	-0.2584	1.1647
10	M	6	E	0.94	-0.21	40	0.84	0.8555	0.1439	0.8174
11	M	6	E	1.09	-0.06	121	1.06	1.0434	-0.0404	1.0732
12	F	7	E	0.52	-0.07	43	0.49	0.4895	0.0459	0.4842
13	F	6	E	1.74	-0.14	55	1.67	1.6483	0.0946	1.6986
14	M	5	E	1.28	-0.42	146	1.07	1.1427	-0.2796	0.9898
15	F	6	E	1.53	-0.32	88	1.37	1.2117	0.0194	1.5292
16	F	7	E	1.71	-0.35	7	1.54	1.7076	0.0589	1.3698
17	M	7	E	1.57	-0.23	0	1.45	1.5663	-0.0011	1.3325
18	M	8	E	1.79	-0.28	63	1.65	1.5724	0.1592	1.7344
19	M	8	E	2.06	-0.48	23	1.82	1.9898	0.2399	1.6566
20	F	8	E	1.32	-0.38	7	1.13	1.3165	0.0651	0.9463
21	F	7	H	1.39	-0.23	158	1.27	1.3579	-0.1143	1.1906
22	F	8	H	1.61	-0.18	132	1.52	1.5127	-0.1257	1.5340
23	F	6	H	1.35	-0.09	70	1.31	1.2745	0.0396	1.3404
24	F	7	H	1.90	-0.33	26	1.74	1.8410	0.1839	1.6304
25	F	5	H	1.58	-0.32	24	1.42	1.5305	0.1669	1.3156
26	M	6	H	1.62	-0.27	11	1.48	1.6060	0.0732	1.3592
27	F	6	H	2.09	-0.65	3	1.77	2.0922	0.0515	1.4512
28	F	5	H	2.05	-0.78	43	1.66	1.6851	0.5512	1.6406
29	M	6	H	1.45	-0.51	129	1.20	1.1484	-0.3503	1.2511
30	M	5	H	1.26	-0.10	61	1.21	1.1815	0.0606	1.2353
31	F	4	H	1.04	-0.32	167	0.88	1.0280	-0.0986	0.7355
32	F	8	H	0.86	-0.26	5	0.73	0.8598	0.0342	0.6033
33	F	6	H	2.03	-0.44	27	1.81	1.9398	0.2528	1.6760

				Ocular accommodative response LL						
Subject No.	**Gender**	**Age**	**Rx gp**	**Fs**	**Fc**	**Axis**	**SE**	**h_1**	**h_2**	**h_3**
1	F	8	M	1.98	-0.09	35	1.93	1.9489	0.0585	1.9178
2	F	8	M	1.04	-0.19	116	0.94	0.8793	-0.1069	0.9999
3	M	8	M	1.11	-0.53	162	0.84	1.0587	-0.2230	0.6293
4	F	8	M	1.29	-0.16	87	1.20	1.1240	0.0136	1.2845
5	F	7	M	1.18	-0.23	172	1.06	1.1762	-0.0462	0.9509
6	F	6	M	0.80	-0.11	168	0.75	0.7977	-0.0322	0.6937
7	F	8	M	2.04	-0.18	112	1.95	1.8812	-0.0886	2.0103
8	F	8	M	1.20	-0.27	1	1.06	1.2011	0.0088	0.9272
9	M	8	E	1.85	-0.28	137	1.70	1.7123	-0.1993	1.6961
10	M	6	E	0.88	-0.29	36	0.73	0.7783	0.1944	0.6880
11	M	6	E	1.34	-0.18	6	1.25	1.3392	0.0284	1.1651
12	F	7	E	0.66	-0.43	46	0.45	0.4410	0.3035	0.4538
13	F	6	E	2.37	-0.40	59	2.17	2.0766	0.2475	2.2648
14	M	5	E	0.80	-0.11	168	0.75	0.7977	-0.0322	0.6937
15	F	6	E	1.49	-0.44	170	1.27	1.4752	-0.1053	1.0640
16	F	7	E	1.47	-0.46	8	1.23	1.4568	0.0880	1.0112
17	M	7	E	1.42	-0.25	109	1.30	1.2011	-0.1071	1.3992
18	M	8	E	1.97	-0.26	16	1.84	1.9546	0.0955	1.7326
19	M	8	E	2.27	-0.76	30	1.89	2.0704	0.4691	1.7011
20	F	8	E	1.63	-0.42	35	1.42	1.4935	0.2811	1.3483
21	F	7	H	1.43	-0.38	158	1.24	1.3760	-0.1851	1.0963
22	F	8	H	1.59	-0.28	175	1.44	1.5838	-0.0331	1.3048
23	F	6	H	1.49	-0.25	71	1.36	1.2580	0.1093	1.4600
24	F	7	H	2.07	-0.42	21	1.86	2.0168	0.2007	1.7049
25	F	5	H	1.69	-0.15	49	1.62	1.6050	0.1032	1.6277
26	M	6	H	1.62	-0.29	157	1.47	1.5740	-0.1470	1.3715
27	F	6	H	2.10	-0.58	17	1.81	2.0484	0.2299	1.5683
28	F	5	H	2.19	-0.81	35	1.79	1.9268	0.5392	1.6493
29	M	6	H	1.70	-0.23	151	1.58	1.6434	-0.1363	1.5206
30	M	5	H	1.27	-0.58	179	0.98	1.2656	-0.0181	0.6886
31	F	4	H	1.40	-0.50	172	1.15	1.3906	-0.0990	0.9097
32	F	8	H	1.00	-0.04	155	0.98	0.9896	-0.0228	0.9625
33	F	6	H	1.97	-0.41	56	1.77	1.6937	0.2695	1.8459

Subject No.	Gender	Age	Rx gp	Ocular lag (DD) SE	h_1	h_2	h_3
1	F	8	M	0.74	0.8238	0.0831	0.6486
2	F	8	M	2.05	1.9799	-0.0179	2.1191
3	M	8	M	1.62	1.6278	0.1150	1.6200
4	F	8	M	1.51	1.5815	0.0536	1.4339
5	F	7	M	1.38	1.2425	0.1019	1.5078
6	F	6	M	1.78	1.6852	0.0485	1.8784
7	F	8	M	1.12	1.1127	0.0617	1.1290
8	F	8	M	1.67	1.6568	0.0516	1.6811
9	M	8	E	1.50	1.4621	0.1596	1.5415
10	M	6	E	2.14	2.0171	-0.1991	2.2633
11	M	6	E	1.57	1.5685	-0.0427	1.5756
12	F	7	E	2.05	2.1341	-0.1992	1.9585
13	F	6	E	1.14	1.2228	-0.1561	1.0477
14	M	5	E	1.69	1.4815	0.5120	1.8992
15	F	6	E	1.14	1.1542	0.1798	1.1168
16	F	7	E	0.85	0.8340	0.1122	0.8572
17	M	7	E	0.99	1.1498	0.1643	0.8354
18	M	8	E	0.93	0.9298	0.1138	0.9335
19	M	8	E	0.62	0.7056	-0.2155	0.5370
20	F	8	E	1.47	1.5368	-0.0634	1.4048
21	F	7	H	1.03	0.9737	0.4217	1.0845
22	F	8	H	1.04	1.0222	0.0429	1.0526
23	F	6	H	1.31	1.4712	-0.0222	1.1515
24	F	7	H	1.05	1.0806	-0.1276	1.0110
25	F	5	H	1.38	1.1312	0.0655	1.6365
26	M	6	H	0.59	0.7177	-0.0648	0.4647
27	F	6	H	0.94	0.7825	-0.0640	1.0973
28	F	5	H	1.05	1.0057	-0.6166	1.0930
29	M	6	H	1.31	1.3474	0.1958	1.2630
30	M	5	H	1.44	1.3519	0.2055	1.5238
31	F	4	H	1.43	1.2650	0.1394	1.5967
32	F	8	H	1.97	1.8716	-0.0478	2.0778
33	F	6	H	0.82	0.8514	0.0354	0.7937

Subject No.	Gender	Age	Rx gp	Ocular lag (LD) SE	h_1	h_2	h_3
1	F	8	M	0.88	0.9177	0.0454	0.8479
2	F	8	M	1.71	1.6123	-0.0902	1.8130
3	M	8	M	1.37	1.2533	0.2204	1.4802
4	F	8	M	1.40	1.4405	0.0093	1.3502
5	F	7	M	1.48	1.3534	0.0262	1.6137
6	F	6	M	1.36	1.0252	0.0139	1.6863
7	F	8	M	1.34	1.3323	0.1137	1.3502
8	F	8	M	1.55	1.5262	-0.0354	1.5793
9	M	8	E	1.24	1.2275	0.2584	1.2482
10	M	6	E	1.58	1.5433	-0.1439	1.6098
11	M	6	E	1.37	1.3980	0.0368	1.3399
12	F	7	E	1.95	1.9666	-0.0459	1.9287
13	F	6	E	0.76	0.7933	-0.0946	0.7285
14	M	5	E	1.38	1.2989	0.2796	1.4518
15	F	6	E	1.07	1.2299	-0.0194	0.9124
16	F	7	E	0.90	0.7485	-0.0589	1.0574
17	M	7	E	1.00	0.8897	0.0029	1.1092
18	M	8	E	0.80	0.8828	-0.1541	0.7082
19	M	8	E	0.63	0.4659	-0.2364	0.7855
20	F	8	E	1.32	1.1360	-0.0562	1.4990
21	F	7	H	1.18	1.0982	0.1143	1.2655
22	F	8	H	0.93	0.9434	0.1257	0.9222
23	F	6	H	1.15	1.1817	-0.0396	1.1157
24	F	7	H	0.73	0.6433	-0.1946	0.8125
25	F	5	H	1.04	0.9399	-0.1705	1.1410
26	M	6	H	0.99	0.8649	-0.0732	1.1117
27	F	6	H	0.70	0.3786	-0.0515	1.0196
28	F	5	H	0.81	0.7745	-0.5646	0.8416
29	M	6	H	1.28	1.3372	0.3503	1.2197
30	M	5	H	1.28	1.3042	-0.0606	1.2504
31	F	4	H	1.62	1.4725	0.0986	1.7650
32	F	8	H	1.78	1.6558	-0.0342	1.9123
33	F	6	H	0.74	0.6356	-0.2378	0.8415

Subject No.	Gender	Age	Rx gp	Ocular lag (LL) SE	h_1	h_2	h_3
1	F	8	M	0.29	0.3004	-0.0707	0.2841
2	F	8	M	1.35	1.4105	0.1069	1.2899
3	M	8	M	1.45	1.2426	0.2137	1.6491
4	F	8	M	1.14	1.2464	-0.0069	1.0323
5	F	7	M	1.29	1.1946	0.0462	1.3924
6	F	6	M	1.63	1.5861	0.0255	1.6641
7	F	8	M	0.44	0.5167	0.0819	0.3613
8	F	8	M	1.33	1.2109	-0.0157	1.4584
9	M	8	E	0.71	0.7006	0.1993	0.7168
10	M	6	E	1.68	1.6205	-0.1944	1.7392
11	M	6	E	1.18	1.1022	-0.0319	1.2481
12	F	7	E	1.99	2.0151	-0.3035	1.9591
13	F	6	E	0.26	0.3650	-0.2475	0.1624
14	M	5	E	1.70	1.6439	0.0322	1.7479
15	F	6	E	1.17	0.9664	0.1053	1.3776
16	F	7	E	1.21	0.9993	-0.0880	1.4160
17	M	7	E	1.15	1.2549	0.1089	1.0425
18	M	8	E	0.61	0.5006	-0.0904	0.7100
19	M	8	E	0.56	0.3854	-0.4656	0.7410
20	F	8	E	1.03	0.9590	-0.2722	1.0970
21	F	7	H	1.22	1.0802	0.1851	1.3599
22	F	8	H	1.01	0.8723	0.0331	1.1513
23	F	6	H	1.10	1.1981	-0.1093	0.9962
24	F	7	H	0.60	0.4675	-0.2113	0.7380
25	F	5	H	0.85	0.8653	-0.1067	0.8289
26	M	6	H	1.00	0.8968	0.1470	1.0993
27	F	6	H	0.66	0.4224	-0.2299	0.9025
28	F	5	H	0.68	0.5328	-0.5526	0.8329
29	M	6	H	0.90	0.8423	0.1363	0.9502
30	M	5	H	1.51	1.2200	0.0181	1.7970
31	F	4	H	1.35	1.1100	0.0990	1.5908
32	F	8	H	1.54	1.5260	0.0228	1.5532
33	F	6	H	0.78	0.8818	-0.2546	0.6716