CHANGES IN OCULAR REFRACTION IN THE STRABISMIC CHILD

A LONGITUDINAL STUDY

by

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ABSTRACT

The characteristics of refractive development in the strabismic child are investigated in this thesis. The children involved were all hospital out-patients, their ages ranging, initially, from a few months to approximately twelve years. Each was examined on at least two occasions, cycloplegics being used. Changes in mean sphere, astigmatism and anisometropia have been analysed in relation to age, sex, refractive and strabismic state, strabismic angle, spectacle correction and treatment.

Refractive changes in strabismic children are characterised by a high incidence of hypermetropic increases, particularly in the first six years of life. This contrasts with non-strabismic developments found in other studies, where the main shift was towards emmetropia and myopia.

The most significant changes occur in the first six years, although these are most marked in the first three. Environmental factors, such as surgery and spectacle correction, appear to be involved to a greater extent during this period than in subsequent periods.

Sex differences were small. During the first four or five years, females are, if anything, rather more developed, refractively, than males. Maturity appears to be the causative factor.

The results indicate that hypermetropic increases are a normal feature of refractive growth, even in non-strabismic children. The high incidence in strabismic children, however, suggests that such changes may be indicative of a predisposition to the development of strabismus.

There is increasing evidence to indicate that refractive changes are not necessarily linked to axial elongation, and that axial length may decrease during ocular growth. The results add weight to the view that emmetropization is an outdated concept.

The outstanding need is for a longitudinal study, commencing at birth, to establish the exact nature of the relationship between strabismic and non-strabismic patterns of refractive development. The findings may have a bearing on the management of the strabismic child.

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M.W.
April 1971

O wad some Pow'r the giftie gie us

To see oursels as others see us!

Robert Burns
1759 - 1796

To Mum, Dad, and Suzy

CONTENTS

APPENDICES (Continued)

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SUMMARIES OF SECTIONS AND SUMMARY POINTS WITHIN SECTIONS

In view of the length of this thesis, and some of the sections in particular, a number of summaries and summary points have been prepared. It should be noted that an *overall* summary of section 6 has been omitted in view of the fact that section 7 summarises the results in relation to the original hypotheses. For an overall summary of the results, therefore, the reader is referred to section 7 which should be read in conjunction with section 4 in which the rationale and hypotheses are presented.

1. INTRODUCTION

1.1. It is well known that during the period from birth to puberty marked ocular change takes place. The research on which this knowledge is based, however, has been confined principally to subjects in whom refraction and binocular vision fall within normal limits. Few studies have dealt with the strabismic eye, and, as a result, relatively little is known about its refractive development.

The five years spent by the author in the Hospital Eye Service provided an opportunity to examine large numbers of children with strabismus and to follow-up their development during a critical period of growth. The observations made on these children led to the research on which this thesis is based.

1.2 The Hospital Eye Service (H.E.S) is one of a number of specialist branches of the National Health Service (N.H.S) of the United Kingdom. The establishment of the N.H.S. in 1948 was the outcome of the experience gained during the second World War under the Emergency Medical Services. It was, however, the Beveridge Report of 1942 that laid the foundation for a National Health Service as part of the whole social structure. In 1944, Mr. Winston Churchill, then Prime Minister, underlined the purpose and aims of such a service:

"The discoveries of healing science must be the inheritance of all: that is clear. Disease must be attacked whether it occurs in the poorest or in the richest man or woman, simply on the ground that it is the enemy: and it must be attacked in the same way that the fire brigade will give its full assistance to the humble cottage as readily as it will give it to the most important mansion ..... Our policy is to create a national health service, in order to ensure that everybody in the country, irrespective of means, age, sex or occupation, shall have equal opportunities to benefit from the best and most up-to-date medical and allied services available".

The Act drew together all the Hospital and Specialist Services and provided for their development within the Hospital structure. It set out to ensure that every patient needing hospital treatment could obtain it without delay in the hospital most appropriate to their needs. It was in this context that the Hospital Eye Service was established. It had been made clear that, taken as a whole, the treatment of the eyes was to be provided and administered in special Ophthalmic Departments and clinics within the hospital structure. In the interim period whilst the necessary hospital departments and special clinics were being developed temporary arrangements were made for ophthalmic services to be provided additionally under the Supplementary Ophthalmic Service (S.O.S) in which ophthalmic opticians and ophthalmic medical practitioners would work in their own practices. Whilst there have been a number of developments since then, in particular the establishment of the S.O.S. on a permanent footing i.e. the General Ophthalmic Services, outside of the hospital structure, this has not affected the role of the H.E.S. as a Specialist Service.

1.3. Patients attending an Eye Hospital or similar unit, do so usually as a result of having been referred for specialist opinion and treatment, either directly by their own general practitioner, or indirectly by an ophthalmic optician, or ophthalmic medical practitioner: these patients, therefore, form a highly selected sample of the whole population. The great majority of pre-school children with strabismus will be referred to hospital out-patient clinics in this way. From five years of age onwards, a certain number may be taken under the care of the school clinics, ophthalmic medical practitioners or ophthalmic opticians, although many will still be seen in hospital. With improvements in child welfare services and a growing awareness and understanding by parents, of the dangers of neglecting childrens' complaints, an increasing proportion of children with strabismus are being seen as soon as the condition manifests itself. Certainly, there is no longer the fear of hospital and doctor that existed in pre-N.H.S. days, nor is there a financial barrier involved, all children's services being free. Consequently the strabismic group of children attending hospitals, whilst undoubtedly selected, may form a representative sample of this type of child.

The National Health Service has thus provided, in a way which did not exist previously, the opportunity to study and follow-up the patterns of development in children having abnormalities, such as strabismus. Unfortunately, however, these opportunities have not always been taken, and research has not developed as it might have done, mainly because of the pressures - both physical and financial - which exist in the hospital service.

1.4. Most Eye Hospitals have large numbers of children under their care, many of them attending because strabismus is either present or is suspected. Their ages range from the newborn to the teenager: the most common age for a first attendance is about two to three years, when many squints first become manifest.

Anyone who has worked in a children's clinic or just attended one, soon realises that examination of children, particularly the very young, requires an approach quite different from that of the adult: it needs understanding, sympathy and patience on the part of the practitioner, in order to obtain the child's co-operation. One must be prepared to allow the very young to adapt themselves to strange surroundings and this requires a willingness to permit the child reasonable freedom of movement and imagination. An infant frequently presents fewer problems in terms of examination, at the reasonably inactive age of a few months, than at a year, when beginning to explore; it is not uncommon to find a child at this age, constantly removing equipment from the practitioner's hands in the search for new interests.

By the age of two years many children will be at their most restless and intensely inquisitive period. They will frequently move about and attempt to join in the examination "game". The practitioner must attempt to win their confidence and this may necessitate joining in the "game" with them. It is necessary to pitch the examination at the child's level: the author employs a glove puppet to hold the attention of the child during retinoscopy, whilst at the same time encouraging them to use their imagination to search, in the retinoscope light, for all kinds of imaginary animals. Both mental and physical agility may be required in order to keep up with an active two to three year old. Certainly, above all, patience is essential.

1.5 Examination of children not only requires a special technique, but also requires an understanding of the possible patterns of development of the refractive state of the eye. This is not an academic question, but one of great clinical and practical importance; for these children are being seen and followed-up during a critical period in their development. There is, consequently, a need to know whether the refractive state is likely to change, and if so, the possible direction of such change. This is especially so in strabismus where the refractive state of the eye may be closely related to the type and degree of strabismus present.

1.6 Many cases of changes in refraction were assumed, initially, to be false rather than real changes - the result of inaccurate assessment at the previous examination - particularly when that examination had been carried out by another practitioner. As the author's own cases returned for further examination, similar changes were observed, despite the fact that constant working conditions were being employed. It became apparent that the distinct patterns of change which were emerging could not be explained solely on the basis of human error arising in the examination of these children. Discussions with colleagues concerning the nature of such behaviour patterns, underlined how little was actually known about the ocular changes taking place in the refractive state of the young, and particularly the child with strabismus.

At about the same time, Sorsby and his colleagues (1961) published their outstanding report on changes in ocular refraction from the age of three to fourteen years; in this, the importance of investigating the "normal" child was stressed and the need for further follow-up studies emphasised. If one accepts that it is important to understand the changes occurring in the non-strabismic child, exhibiting perhaps an error of refraction but generally requiring no form of treatment apart from spectacles, one must accept that it is even more important to investigate the refractive changes occurring in the child with strabismus, where the use of an eye may be lost if treatment is not provided. Few studies, however, have dealt with this group. The need for further research in this direction was clear; the material was available; all that was required was the work.

1.7 It was from this situation that the idea of studying the strabismic child grew. The biggest problem was the lack of time and assistance available for research: the author was working full-time in a clinical post, under the constant pressure commonly found in hospitals today. Whilst it was possible to carry out the necessary clinical work, the time and the facilities required for completing this study, particularly the analytical side, were not available. As a consequence, it was not until he moved into a University teaching post that the opportunity really presented itself to follow this project through. With the co-operation and encouragement of the staff at the University and at the Eye Department of the Newcastle upon Tyne General Hospital, where all the patients had been examined, it became possible to transform an idea into reality; the product is this thesis.

1.8 Throughout the thesis, attempts have been made to standardise the terminology as far as possible. This is, however, not always feasible, particularly where quotations from other authors have been given. The term hypermetropia has been used, but hyperopia will be found, and should be regarded as synomymous. Strabismus and squint should be similarly regarded. Ametropia, refractive error and error of refraction have tended to be used freely and should be looked upon as having the same meaning.

2. BACKGROUND TO REVIEW OF LITERATURE AND RELEVANT RESEARCH

2.1. Scientific study of the refractive state of the eye began in 1864 with the publication of Donders' classic work "Accommodation and Refraction of the Eye". In this Donders defined many relevant problems and in so doing, put refractive errors into perspective for the first time. Over a hundred years later Hirsch (1967) pointed out that many of those same problems remain unresolved.

The literature published in those hundred years has been immense. A substantial volume has been devoted to the refractive changes taking place during growth. This is understandable as the early years of infancy and childhood form a critical period in the refractive development of the eye. Studies in this field have, however, all too often been limited mainly to myopia rather than to the whole range of refractive errors. Hirsch (1967) estimates that there must be in excess of ten thousand such limited papers in literature. There have, in contrast, been few comprehensive studies of the refractive state of the eye particularly during growth. (Sorsby et al 1961, 1957; Strenstrom 1946; Tron 1940; Steiger 1913.)

2.2. The emphasis laid on myopia may be explained by an examination of the historical background of refractive errors in general. Kepler first drew attention to myopia in 1611. More than two hundred years elapsed before the presence of hypermetropia was firmly established by Donders in 1864. The view that myopia is a separate entity, quite unrelated to any other refractive condition, was held at that time;

it still finds support today. This attitude prevails probably because of the failure to separate simple myopia, in which the eye is perfectly healthy, from pathological myopia in which gross degenerative changes develop. Both these conditions are still commonly presented as related anomalies of refraction. Curtin (1967) however emphasised that the refractive problem in the pathological eye is "only the symptom of a greater underlying morbidity". This condition should in reality be regarded as an actual disease, quite distinct and separate from ordinary myopia. Indeed the simple form is believed to have much more in common with hypermetropia than pathological myopia (Duke Elder 1949; Heath 1967; Hirsch and Ditmars 1969).

2.3. Just as the historical background cannot be ignored in a review of literature relevant to the refractive state of the eye, so account must be taken of factors which influence refractive development; for example, the relationship between the components of refraction, and environment and heredity. Even though such factors are not in themselves the subject of this research they are so interrelated with changes in refraction that they must be considered.

2.4. Physiological variations in refraction take place throughout life but the most significant and pronounced changes occur in the early years. In the search for an understanding of the processes involved, studies covering the period of life from birth until puberty are of great importance. Unfortunately,however, there has been a relative neglect of children in their first two or three years of life, mainly because of the problems of examination and patient co-operation at this age. Sorsby et al (1961) have drawn attention to the lack of detailed knowledge of the ocular development taking place up to the age of three years. Of this infantile phase of development they state that "we know little beyond the fact that it does occur".

Notwithstanding the difficulties that undoubtedly exist, investigations have been carried out on this age group, although few have been longitudinal in nature. These have shown that the new born child is generally ametropic. Some authorities have found that a minority are myopic with the majority hypermetropic, (Santonastaso 1930: Cook and Glasscock 1951), whilst others state that all are hypermetropic (Jackson 1928; Van Alphen 1961; Grignolo and Rivara 1968). Despite these apparent differences in findings, there is general agreement that very marked changes in this refractive state take place in the first two or three years of life. These continue as the child gets older but at a slower rate, particularly after three years of age (Sorsby et al 1961). The need to determine the factors influencing such changes has been clearly established.

2.5. Research has shown that the various refractive states - hypermetropia, emmetropia and myopia, together with astigmatism - result from the relationship between the ocular components of the eye (Steiger 1913; Tron 1940; Strenstrom 1946; Sorsby et al 1957, 1961). The variables - the powers of the cornea and crystalline lens, the anterior chamber depth, the axial length together with the vertical and transverse diameters of the globe - all combine to produce the refractive state of the eye. They cannot be considered in isolation from each other. An increase in axial length, for example, will not necessarily result in a change in refraction. Whether it does or not depends upon the behaviour of the other variables.

These components, however, do not play equal parts in determining the overall state of refraction. The axial length and the corneal power have larger roles than the crystalline lens and anterior chamber depth. In any explanation for a particular change, the inter-relationships involved must be borne in mind.

2.6. Whilst the refractive state is the product of the association of the components within the eye, the development of that state is influenced by conditions of environment and heredity. The exact extent of this influence and the relative importance of those conditions, have yet to be resolved.

Studies on twins have produced findings which suggest that refraction is genetically determined (Sorsby et al 1962). On the other hand, environment, rather than heredity, is stated to be the determinant factor (Young 1967). Close work, for example, has long been thought to be directly associated with the development of myopia. The fact that myopia develops during the school years, in children who were previously emmetropic or hypermetropic, lends support to this view. Posture and inadequate illumination have also been cited as contributory factors. (Donders 1864; Young 1967).

Exactly how wide the gulf is between the environmental and hereditary schools can be seen by studying the report of "A Workshop on Refractive Anomalies of the Eye" held in 1966 and sponsored by a committee of the United States Department of Health Education and Welfare. In this, Sorsby states "The traditional emphasis on environmental factors as productive of refractive errors finds no support in the detailed studies of today". Yet in the same report, Young points out that studies on primates indicate that the mechanisms giving rise to refractive anomalies "...are actually environmental stresses". This controversy over the precise roles of environment and heredity obviously cannot be ignored.

2.7. It should be noted that whilst considerable research has been carried out on children, it has, for the most part, been confined to the "normal" population. The "abnormal" child, particularly the child with strabismus, has been relatively neglected insofar as studies of refractive changes are concerned.

A search of the literature reveals comparatively few reports of strabismic studies. (Vorisek 1935; Nordlow 1955). The need for research in this direction is clearly indicated.

SUMMARY

2.8 In this section the historical background to the present state of knowledge on refractive errors has been discussed. It has been stressed that in any study of the refractive state of the eye and its variations with age, it is essential to consider the relationship between the components of the eye and the roles of heredity, environment and normal growth mechanisms. The lack of relevant research on such children has been pointed out. Whilst a number of the aspects referred to have not been the concern of this research project, they are fundamental to a complete understanding of the refractive changes in the strabismic child; it is for these reasons that they are included in the review of literature which follows.

3. REVIEW OF LITERATURE AND RELEVANT RESEARCH

Historical background

3.1. In a paper to the Royal Society in 1812 James Ware described instances of young people requiring convex lenses to see clearly at distance and near. In the previous year Wells (1811), already presbyopic, had referred to his own difficulty in seeing distant objects which was overcome by the use of a convex lens. The existence of hypermetropia was thus established some two centuries after Kepler (1611) had postulated a basis for myopia. Neither Ware, nor Wells, however, fully understood the nature of the condition they had found, despite the fact that Kästner in 1755 had mathematically deduced the possibility of hypermetropia. Indeed, not until 1859 was a proper name given to this condition. Helmholtz proposed the term hyperopia whilst Donders suggested hypermetropia as being more appropriate.

This condition was nevertheless still regarded by many as a serious abnormality. Mackenzie (1840) referred to patients well under presbyopic age, yet experiencing presbyopic difficulties which were relieved with convex lenses. He reported that such symptoms could, however, often be relieved by applying leaches to the forehead. In addition he found instances of aged patients requiring convex lenses for both distance and near vision but could offer no explanation for this phenomenon. Sichel (1845) described a form of congenital amblyopia in which clear distance vision could only be obtained with convex lenses.

He regarded such methods, however, as "pernicious" and forbad their usage as prejudicial to sight. As late as 1854 the confusion was such that Smee stated "although far sight occurs most commonly as a *disease*, yet I have been occasionally consulted by patients who have suffered from this *abnormal* state as a result of a congenital defect". (my italics). Donders (1864) finally established hypermetropia in its correct place; that is as part of the scheme of refractive errors. Nevertheless, in describing the hypermetropic eye as generally "a small imperfectly developed eye" he reflected the lack of understanding which had existed to that time.

3.2. Donders' outstanding treatise (1864) on refraction of the eye marked the beginning of a scientific approach to the whole question of refractive anomalies. Its basis had previously been laid when Ruete (1853) described a condition of "oversightedness" in which the eye possesses a "very slight refractive power ..." due, he believed, to a "peculiar construction of the refracting media ..." Nevertheless, it was Donders who drew attention to the importance of hypermetropia and its relationship to other refractive anomalies.

Up to the middle of the nineteenth century theories on the refractive state of the eye centred almost entirely around myopia and presbyopia. Kepler (1611) by his approach had excluded consideration of any other refractive condition. Accommodation problems were in his view the cause of anomalies of refraction. He believed that in accommodation the retina approached the crystalline lens; variations from emmetropia arose, after a period of time, as a result of this retinal shift becoming permanent. Such a theory excludes the concept of an hypermetropic condition. It was left to Robert Smith (1738) to correctly explain that accommodation lay in the ability of the eye to alter its power.

3.3. Refractive anomalies were widely thought to be due entirely to variations in axial length of the eye. Donders (1864) held this view believing it "improbable" that the lens and cornea played any part. Indeed he stated "the curvature of the cornea in ametropia does not essentially differ from that of emmetropia and the time of life also exercises scarcely any influence". He reported, however, that Boerhaave (Physician and Professor at the University of Leyden) in 1708 had listed two causative factors in myopia; (i) excessive length of the eye, (ii) excessive convexity of the cornea. In the light of present knowledge Boerhaave was not so far from the truth, for he accepted the possibility of more than one variable. To this extent Donders' views on myopia were a step backward from this position. Indeed, whilst he quoted Von Graefe as suggesting that increased axial length was the causative factor of myopia in 90 per cent of cases, he (Donders) thought the incidence to be "much nearer 100 per cent". Myopia was thus viewed simply as a long eye and hypermetropia a short eye.

3.4. Donders considered myopia more than "a simple anomaly of refraction", and regarded its development as part of a morbid process. Believing that axial elongation was unaffected by accommodation, he postulated three causative factors:-

"(a) pressure of the muscles on the eyeball in strong convergence of the visual axes;

(b) increased pressure of the fluids resulting from accumulation of blood in the eyes in the stooping position;

(c) congestive processes in the fundus oculi, which lead to softening even in the normal, but still more under the increased pressure of the fluids of the eye, give rise to extension of the membranes ..... this extension occurring principally at the posterior pole for want of macula support at that point".

Consequently, he viewed all myopias as potentially degenerative in nature, whether or not they were actually progressing. Whilst Donders looked upon hypermetropia and myopia as forming a range of refractive anomalies, he did not consider them as part of a continuum. Indeed, he found it completely inconceivable that the refractive changes in the myopic eye could be regarded as part of the same processes taking place in the hypermetropic eye.

Although Donders did not differentiate between one type of myopia and another, he did define two forms of hypermetropia:

(a) acquired - a senile form arising as a result of hardening of the outer layers of the crystalline lens and a flattening of its radii of curvature.

(b) original - a form comprised of manifest and latent components.

3.5. At about the same time that hypermetropia was first recorded clinically, the presence of astigmatism in the human eye was reported by Young (1801). His observations were the results of experiments upon his own eyes, in which he noted a distortion of a focal point. He was, however, unable to name this condition, although Newton in 1670 had noted the oblique astigmatic effect produced by a spherical lens. Later Airy (1825) drew attention to a "peculiar" defect of his own eye which required correction by an astigmatic lens. Airy regarded his condition as "novel". Such an attitude was not really surprising since astigmatic test charts were introduced only in 1866 and it was not until 1877 that cylindrical lenses were incorporated into trial cases. (Anon 1962). It was Donders (1864) nevertheless who put astigmatism into perspective amongst other refractive anomalies.

With the introduction of the ophthalmometer by Helmholtz in 1854, accurate measurement of the corneal radii became possible. Using an ophthalmometer Nordenson (1883) carried out measurements upon 226 subjects aged between seven and twenty years. His findings indicated that corneal astigmatism occurred most frequently in myopes and least in emmetropes, and, as a result, he rather questionably concluded that astigmatism predisposes towards myopia.

3.6. By the turn of the century the axial theory of ametropia was being called into question. Mauthner (1876) had already rejected the view that emmetropic eyes had a constant axial length. He believed that corneal curvature, unlike the lens, varied quite considerably, with corresponding variations in axial length. The later work of Schnabel and Herrnheiser (1895) indicated that similar components were to be found in both emmetropic and myopic eyes. Their axial length findings of 22 mm to 25 mm in twenty three emmetropic eyes, and 23 mm to 26 mm in twelve myopic eyes (-2.0 D to - 8.0 D) led them to the conclusion that axial length was not the only factor determining the refractive state in such degrees of myopia. The significance of such findings was slowly beginning to be realised: in 1909 Gullstrand observed that ".... in axially ametropic eyes and in emmetropic eyes different values of the refracting power do occur ....."

This shift in opinion as to the nature of the refractive state of the eye resulted in considerable confusion, which was clearly revealed in the literature of that period. Norris (1894) for example, agreeing with Mauthner in his approach to emmetropia, stated that ".... myopia may be produced either by an increase in curvature of the cornea or of the lens or by an elongation of the visual axis". He went on to say, however, "It is only where there is an elongation of the visual axis which is due to a stretching of the coats of the eyeball that there exists what is usually described as myopia". Brown (1902) likewise listed the causes of myopia, and also hypermetropia, as being axial or refractive. Yet, at the same time, he stated that an excessively steep corneal curvature was not the cause of myopia since "the defect is known to be dependent upon the extension of the posterior walls of the eye". Longmore (1888), Fick (1894), Hartridge (1896) and Swansky (1900), were of the opinion that myopia and hypermetropia could be either axial or refractive in origin, although there were differences of opinion concerning the relative roles of the various optical components. Nevertheless, they all agreed that the majority of cases were axial. Fick went further than most of his contemporaries in postulating that a combination of both axial and refractive factors could produce ametropia. Bartholomew-Spicer (1897), Dorrington (1900) and Higgins (1903) still supported the old axial theory. Dorrington, however, rather contradictorily, accepted that an eye could be emmetropic without having a fixed axial length providing the refractive system compensated for any variations in length.

Between the two extremes of opinion were those of Suter (1903), Juler (1904), and Gould & Pyle (1905) who accepted that hypermetropia could be axial or refractive, but believed myopia to be essentially axial in origin. They considered the possibility of other causes, but failed to define any. Indeed, Suter stated that in low degrees of myopia the size and shape of the eye may differ little from that in emmetropia, but he went no further. Lawson (1877) and Tscherning (1904) considered that myopia was due primarily to axial elongation but conceded that it could also (even if exceedingly rare) be solely the result of an anomalous refractive power. Hypermetropia, they thought to be entirely due to variations in axial length. "The hypermetropic eye is too short" stated Tscherning and thus dismissed the possibility of any other explanation.

Donders' concept of the hypermetropic eye being under-developed was still supported, (Fick 1894; Hartridge 1896, Juler 1904), as was his view that all myopias were potentially degenerative, (Norris 1894; Gould & Pyle 1905), but this was no longer universally accepted. Suter (1903) and Tscherning (1904) believed that myopia fell into two groups, both axial; the first described variously as simple or school myopia, appeared initially in the six to fifteen year age group, generally not exceeding -9.0 D, and rarely presenting complications. It was thought that close work, and the accommodative effort involved, was related to its development (Norris 1894; Suter 1903; Tscherning 1904; Morax 1907) although Suter considered that convergence was the most important factor. It was generally accepted, however, that there must be some (undisclosed) predisposing factor involved. Progressive and degenerative myopia formed the second group and was characterised by the development of pathological complications.

3.7. The importance of investigating the refractive changes occurring during growth had been realised by Donders (1864). He observed that little had been done in this direction, although he pointed out that Ed. V. Jaeger had indicated his intention of following "the course of the refraction in the same persons through their whole life". Donders himself recorded cases in which "considerable degrees of hypermetropia present in the fourth, fifth and sixth years

of life ... had not disappeared at a later period".
Myopia, he had found, frequently increased with age.
Yet, he could not envisage any normal situation in which an hypermetropic eye would become myopic; such was the extent to which these different refractive states were regarded as unrelated to one another.

Randall (1885) in analysing the refractions of infants and children concluded that hypermetropia decreases in incidence with age whilst myopia and emmetropia increases. These results, however, were based upon examinations under varying conditions, some under cycloplegia, others not: consequently their value is open to question. Indeed, five years later Randall (1890) contradicted some of his earlier findings. After examining over seven thousand schoolchildren, he contended that there was, in fact, no tendency for hypermetropia to decrease in amount or pass into myopia during school life, except as a result of disease. Erismann (1882), Reich (1883), and Cohn (1886) in independent longitudinal studies of changes in refraction associated with age, all found an overall reduction in hypermetropia or increase in myopia.

Norris (1894) unlike Donders, believed that refractive changes in youth could involve an hypermetropic eye becoming myopic. Nevertheless,he regarded an hypermetropic reduction in youth as much a cause for alarm as an increasing myopia. Suter's view (1903) was that in early life hypermetropia decreases owing to increasing axial length, possibly reaching emmetropia at the age of twelve years. Such cases he thought either become stationary at this stage or continue into myopia. Straub (1901, 1909) similarly argued that the hypermetropia present at birth, decreased such that by school age the normal refractive state is approximately emmetropia. Zentmayer's findings (1911) on the other hand, indicated that ametropia may change in any direction. He stated that hypermetropia and myopia increase in some cases and decrease in others. There was, however, little support at that time for his wide-sweeping views.

Summary Point (3.1 to 3.7)

3.8. The contributions of early researchers in the field of the refractive state of the eye, have been examined with a view to establishing their roles in the subsequent developments that have taken place. For over two centuries following Kepler's treatise (1611) in which he drew attention to myopia, almost all theories concerning the refractive state of the eye, centred around myopia. The outstanding work of Donders (1864) in which he established hypermetropia alongside myopia as an anomaly of refraction has been discussed. Although Young first described an astigmatic condition of the eye in 1801 it was again Donders who put astigmatism into perspective as a clinical entity. He thus laid the basis for a scientific study in the field of refraction and its anomalies.

It has been shown that the axial theory was regarded as the only possible explanation for ametropia at this time. The views of Mauthner (1876) and Schnabel & Herrnheiser (1895) marked the beginning of a shift from the axial theory of ametropia whilst the final break came with Steiger's treatise (1913). The confusion that existed is clearly evident from the literature of this period. Support for Donder's concept of the hypermetropic eye being underdeveloped and all myopias potentially degenerative, could still be found at the turn of this century. Myopias were, however, beginning to be regarded as falling into two distinct groups - simple myopia and degenerative or progressive myopia (3.6).

Although little attempt had been made to study the refractive changes occurring during the period of growth, Donders (1864) realised the importance of doing so. Whilst he accepted the increase of myopia with age, he could not accept the possibility of the hypermetropic eye becoming myopic. Zentmayer's view (1911) that ametropia may change in any direction, found little support at that time.

3.9 It has been pointed out that very significant and marked changes in refraction occur in the first three years of life. (Sorsby, Benjamin & Sheridan 1961). Although such changes commence shortly after birth, their significance can only be fully understood if the refractive state at birth is known. The problems and difficulties of examining the newborn, however, are such that relatively few systematic studies of this group have been carried out and the results obtained have revealed many inconsistencies.

Randall (1885) carried out an extensive analysis of a number of early studies of refraction; this revealed that amongst newborn infants 2.54 per cent were myopic, 6.19 per cent emmetropic and 91.26 per cent hypermetropic. Later Herrnheisser (1892), Ball (1919), de Schweinitz (1921), Fuchs (1924) and Jackson (1928) observed that almost all eyes are hypermetropic at birth, whilst Clarke (1924), Ellett (1926) and Van Alphen (1961) reported that all children are born hypermetropic. In contrast, Santonastaso (1930) who examined eighty-four newborn infants under atropine cycloplegia found the incidence of myopia as high as 25 per cent. Wold (1949),however, reported myopia in only 2.7 per cent of cases. Graham & Gray (1963) found hypermetropia to be the rule in full term babies with myopia only occasionally present, whilst Curtin (1963) commented that myopia is not uncommon.

One of the most detailed studies of the newborn was carried out by Cook & Glasscock (1951) who examined one thousand eyes under atropine cycloplegia (see table 1).

They observed that 74.9 per cent had hypermetropia, of which 67 per cent were less than +4.0 D, the remainder lying between +4.0 D and +12.0 D. Myopia was present in 25.1 per cent, of which 78 per cent were less than -4.0 D, the remainder not exceeding -12.0 D. Hypermetropic astigmatism was present in 29.1 per cent and myopic astigmatism in 6.4 per cent. Mehra, Khare & Vaithillingam (1965) reported that among one hundred babies, hypermetropia was present in 79 per cent, myopia in 9 per cent and astigmatism over 2.0 D in 12 per cent. Tomas (1965) similarly discovered an hypermetropic incidence of 85 per cent, whilst Utkin's results (1966) obtained from 285 infants examined under scopolamine (0.1 per cent) cycloplegia, shows that 52 per cent are hypermetropic at birth, 46 per cent astigmatic, 1.8 per cent emmetropic and 0.35 per cent myopic. Goldschmidt (1969) as the result of a hospital study involving 356 newborn infants examined under atropine cycloplegia, reports that 55.9 per cent were hypermetropic, 19.9 per cent emmetropic and 24.2 per cent myopic. (See Tables I and IA).

Goldschmidt's findings show the mean refraction to be +0.62 D ±2.24, whilst Luyckx (1966) reports the mean among forty seven newborn to be +2.60 D ±1.50. Grignolo & Rivara (1968) state that among full term babies the norm is +1.50 D whilst in premature babies at birth it is +0.50 D.

3.10 Although the results of the various investigations vary widely, there is close agreement on the incidence of myopia in three of these studies; Santonastoso (1930), Cook

TABLE I

State of refraction in the newborn

Analysis by author and refractive state

Author	Refractive state per cent				Numbers of Infants
	Hypermetropia	Emmetropia	Myopia	Astigmatism	
Santonastaso (1930)	N/A	N/A	25.0	N/A	84
Cook & Glasscock (1951)	74.9	0.8	25.1	-	1000 eyes
Mehra et al (1965)	79.0	nil	9.0	12.0 *	100
Tomas (1965)	85.0	nil	4.6	10.34 ¶	174
Utkin (1966)	52.0	1.8	0.35	46.0	285
Goldschmidt (1969)	55.9	19.9	24.2	N/A	356

N/A data not available. * only cases over 2.00 astigmatism included ¶ only cases of mixed astigmatism included

TABLE IA

Author	Refractive state per cent - adjusted for astigmatism				
	Hypermetropia	Emmetropia	Myopia	Astigmatism	Numbers
Cook & Glasscock (1930)	43.9	0.8	16.7	38.4	1000 eyes
Tomas (1965)	24.13	Nil	2.30	75.86	174 infants

When comparing these findings, it should be noted that various methods of classifying astigmatism have been adopted by the authors involved. The effect upon the figures given for the incidence of hypermetropia and myopia is clearly illustrated when the hypermetropic and myopic results of Cook and Glasscock and Tomas are corrected for their astigmatic content (Table IA).

& Glasscock (1951) and Goldschmidt (1969) Their findings of approximately 25 per cent are all the result of examinations under atropine cycloplegia and would, therefore, stand up to some scrutiny. Goldschmidt discusses the possible explanation for the inconsistencies in results generally obtained. He suggests that it may be due partly to the technical difficulties involved in examining the newborn, the method of examination employed, the differencies in genetic factors in the subjects and varying degrees of maturity of the infants. With regard to maturity he draws attention to the results of studies of premature babies (e.g. Graham & Gray 1963, Grignolo & Rivara 1968), in which children with a lower birth weight were found to be more frequently emmetropic or myopic than full term babies. Maturity, therefore, appears to be a definite factor. The effect of different methods of analysis upon the findings obtained has already been discussed. (3.9 - Table I and IA).

3.11 The need to determine the pattern of development from birth to three years of age has been stressed by Sorsby et al (1961), Hirsch (1964) and Goldschmidt (1969). This age group, however, presents similar problems to those of the newborn, especially as far as patient co-operation and involvement are concerned. Consequently, the literature is again relatively sparse.

Santonastaso (1930) followed the development of a group of newborn infants and found that the degree of myopia present at birth diminished during the first year of life until all cases had become hypermetropic at the end of that year. Curtin (1963) confirmed this shift towards hypermetropia in myopic subjects during the first months of life. Although Jackson (1932) had stated that the hypermetropia present at birth decreases in the first years of life, Brown (1938) and Slataper (1950) in follow-up studies of children from birth reported an increase in hypermetropia.

Grignolo & Rivara (1968) investigated the refractive changes in full term and in premature babies. Their results show that in full term infants the hypermetropia of about +1.5 D increases quite markedly in the first three to four months of life, stabilising at about +3.0 D. In premature infants the initial hypermetropia of about +0.5 D, increases in the same period, but at a faster rate, to reach the same level as in the full term child.

All the studies with the exception of Jackson (1932) have shown that the shift in the immediate period after birth, is in a hypermetropic direction. Indeed, Wold (1949) reports that public health surveys in both the United States and Great Britain have shown that the incidence of myopia decreases up to the age of two years. Nevertheless, there is still a need for comprehensive longitudinal studies at this period of life and this is stressed by Goldschmidt (1969).

3.12 By the age of three years the rapid infantile phase of ocular growth is replaced by a juvenile phase of much slower but definitive development. (Sorsby et al 1961). The changes in refraction, whilst perhaps not as spectacular as those in the earlier period, are nevertheless profoundly significant. The literature on these changes is extensive.

Until some forty years ago it was accepted, almost without question, that, during childhood, hypermetropia decreased and myopia increased. (Randall 1885, Erismann 1882, Reich 1883, Cohn 1886, Norris 1894, Suter 1903, Jackson 1920, Butler 1922). Zentmayer (1911) was the exception in stating that hypermetropia and myopia could both increase as well as decrease during this early period. Not until later could support be found for Zentmayer's views. Ellett and Holloway in 1926 both reported instances in which hypermetropia increased with age. Whilst commenting that this situation could not simply be explained by incomplete cycloplegia at the first examination they offered no explanation for this phenomenon.

In 1928 Sourasky studied the refractive changes occurring in a group of London schoolchildren aged between five and fourteen years (Table 2). All were examined under hyoscine (0.25 per cent) cycloplegia by one individual, thus reducing "observer errors" to a minimum. Over periods ranging from three to eight years, hypermetropia increased in 7.2 per cent, decreased in 35.4 per cent and remained unchanged in 57.4 per cent. Of the myopes, followed up for three to five years, 65.4 per cent showed an increase in the myopia whilst the remaining 34.6 per cent showed no changes.

Sourasky raised the question as to whether the cases of increased hypometropia were genuine or not, but failed

TABLE 2

Changes in refraction in children aged initially between 5 and 14 years followed up over periods of 3 to 8 years - after Sourasky (1928)

Analysis by initial refractive state and subsequent changes

Ametropia	Refractive changes per cent			Numbers
	Increase	Decrease	No change	
Hypermetropes	7.2	35.4	57.4	277
Myopes	65.4	Nil	34.6	130

to suggest any specific explanation. He thus reflected the confused state of thinking still prevalent during that period. At about this same time McIlroy (1928) reported on her investigations involving a group of 1335 unselected London schoolchildren comprising Jews and Gentiles. Unlike Sourasky's study, cycloplegics were not used and the results based on a cross-sectional analysis. These showed that hypermetropia decreased in incidence between the ages of seven and thirteen years, whilst low myopia (-0.50 to <-3.00 D) absent at seven years of age, increased in incidence during this same period.

3.13 In the twenty years from 1930 to 1950 attitudes underwent considerable change. Just as in the period prior to this, the general belief was that hypermetropia decreased and myopia increased during growth, the emphasis shifted away from this view: It became more widely accepted that ametropia, apart from remaining stationary, could change in any direction. Among ten new papers published in this period, nine supported these findings. Six of these, however, came from the same source or partially used common material. In the following twenty years - from 1950 to 1970 - the volume of literature on this aspect increased, with support, represented by the numbers of papers, for the two theories being approximately equal.

3.14 Jackson (1928, 1929) carried out a ten year (minimum) follow-up study involving a group of patients aged initially between one and twenty years. His findings revealed that in 46 per cent hypermetropia decreased or myopia increased, whilst in 31 per cent the reverse took place; in the remaining 23 per cent there was no change in refraction. He later stated, however, that in the first six years of life hypermetropia decreases. (Jackson 1932). Brown and Kronfeld (1930) had earlier found a marked increase in hypermetropia occurring in children less than six years of age, the rate of increase diminishing in each successive year after six. Their findings were the result of a follow-up study of a selected sample of 185 patients aged between two and twenty-two years. Between the ages of seven and twelve, changes took place in the greatest number of eyes during which there was an overall progress towards myopia.

This was the first of many papers to be presented by Brown and his colleagues, all of which produced evidence to support the theory that during growth the refractive state of the eye not only changes in a myopic direction, but may also change in an hypermetropic direction.

In 1932, Bothman reported a particularly high incidence of hypermetropia increasing during growth. His findings were based upon a longitudinal investigation of a group of 124 children aged between ten months and five and a half years at the first examination, all being under nine years of age at the final examination. All examinations were under atropine cycloplegia. The majority of the children had strabismus, eighty five being convergent, six divergent. Of the remainder thirty one were amblyopic. Taking the group as a whole he found that 71 per cent of eyes increased in an hypermetropic direction, the remainder being almost equally divided into those showing no change and those showing a decrease in hypermetropia. Among the non-strabismic eyes 65 per cent increased, 25 per cent decreased, and 10 per cent remained unchanged. Bothman offered no explanation for the high incidence of increasing hypermetropia compared with previous findings.

3.15. In a report to the London County Council, McIlroy (1932) disclosed that as a result of a longitudinal investigation over a number of years involving 354 children aged between five and fourteen, all of whom were examined under cycloplegia, three patterns of changes in refraction had emerged:-

(a) decrease in hypermetropia or increase in myopia
(b) no change
(c) increase in hypermetropia or decrease in myopia.

Among myopes, she found that the average annual change was an increase of 0.45 D for boys, and 0.59 D for girls: whereas among hypermetropia there was a decrease of 0.26 D and 0.30 D for boys and girls respectively. (See Table 3).

McIlroy regarded those cases showing an increase in hypermetropia or decrease in myopia as being due to "examination errors", rather than any real change in this direction. She explained such findings as being the result of difficulty in suppressing the active accommodation found in young children even with atropine. Believing cycloplegia to be more complete the older the patient, she stated that increases in hypermetropia must, therefore, be the result of an under-estimation of the degree present initially and "... not one of increased hypermetropia at all". No evidence, however, was presented to

TABLE 3

Changes in refraction in children

Analysis by author and refractive change

Author	Refractive changes per cent			Numbers	Age at first examination years
	Hypermetropia increase/ Myopia decrease	Hypermetropia decrease/ myopia increase	No change		
Jackson (1928) (1929)	31.0	46.0	23.0	123	1 - 20
Bothman (1932)	71.0	14.5	14.5	124	$\frac{10}{12} - 5\frac{1}{2}$
McIlroy (1932)	11.0 *	83.1 *	5.9 *	354	5 - 14
Brown (1936)	63.0	29.0	8.0	302	<9 ¶
Sorsby et al (1957)	9.1	77.3	13.6	23	7 - 16

¶ Age at the final examination

* McIlroy analysed her results according to sex and found for the three groups above the incidence per cent for males and females respectively to be as follows:- 8.7 : 13.0, 82.6 : 83.7, 8.7: 3.3.

substantiate this viewpoint. The possibility of changes other than in a myopic direction was clearly ruled out.

3.16 Brown in 1936 reported the results of a study involving a group of 302 children, the majority of whom had strabismus; (74.0 per cent of the 604 eyes involved). Examinations were carried out under atropine cycloplegia at intervals of not less than one year, all the children being under nine years of age at the time of the final examination. Taking the group as a whole, hypermetropia increased in 63 per cent, decreased in 29 per cent and remained stationary in 8 per cent. Brown considered that these findings constituted a challenge to the generally accepted view that eyes become less hypermetropic in the pre-school and early school years.

Two years later Brown (1938) presented the results of a more detailed investigation of refractive changes occurring from birth up to middle life. His findings lent strong support to the concept of the eye changing refractively in more than one direction. Although criticisms have been raised concerning the validity of his conclusions in view of the biased nature of his sample, his study represented one of the major contributions of that period.

A selected sample of 1203 patients were followed up and examined by retinoscopy under atropine cycloplegia. In the age group birth to seven years, an increase in hypermetropia took place in each successive year compared to the previous year. Little difference was found between strabismic children (over two-thirds of the total in this group) and non-strabismic children; nor between males and females.

From the eighth to the thirteenth year of life, the trend was reversed with hypermetropia showing a reduction in each year. The shift towards myopia continued from the fourteenth to the twentieth year, but at a slower rate. (See Table 4).

Brown (1942) later confirmed his own findings although he now reported that hypermetropia ceased to increase at the end of the sixth year of life rather than the seventh. Ciocco (1938) in a study for the U.S. public health service followed up 1481 children whose ages ranged from six to over fourteen years. Having examined them under cycloplegia (2 per cent homatropine hydrobromide), he came to the similar conclusion that hypermetropia and myopia may increase, decrease, or remain unchanged, the incidence of change decreasing with age.

Brown (1938) discussed the possible explanation for the hypermetropic increases he had found. Unlike Sourasky (1928) and McIlroy (1932) who had inferred that the results arose through experimental error, he postulated that its cause could be a decrease in corneal or lenticular curvatures and a relative backward displacement of the crystalline lens. He did not, however, discuss the possible processes involved in the shift towards myopia.

Brown finally rejected the possibility of a reduction of hypermetropia as being the pattern of development in the period from birth to about seven years of age, but in doing so he made no attempt to examine the possible reasons for the dissimilarity between his findings of an increase in hypermetropia and the widely accepted views of a decrease, that had been held

TABLE 4

Mean changes in refraction from the second to thirteenth year of life - after Brown 1938

Analysis by age, annual refractive changes and numbers involved

Year of life	Annual changes in hypermetropia - dioptres			Numbers involved			Total
	Increase	Decrease	Mean	Increase	Decrease	No Change	
2	+0.76	-0.72	+0.41	58	17	4	79
3	+0.62	-0.38	+0.43	132	20	15	167
4	+0.49	-0.31	+0.27	158	49	24	231
5	+0.41	-0.24	+0.21	298	114	45	457
6	+0.42	-0.30	+0.13	188	117	44	349
7	+0.37	-0.39	+0.02	182	164	41	387
8	+0.31	-0.35	-0.10	139	273	57	469
9	+0.27	-0.40	-0.19	109	372	52	533
10	+0.29	-0.40	-0.27	88	330	48	466
11	+0.26	-0.37	-0.27	72	358	36	466
12	+0.23	-0.41	-0.28	69	361	39	469
13	+0.26	-0.40	-0.29	63	366	27	456

for so long. He recognised that his sample included a high proportion of strabismic subjects but having compared the refractive changes in strabismic and non-strabismic patients and found little difference, he inferred that these results were representative of the normal population as a whole. He did not apparently consider the possibility that the disparity between his findings and others, could have arisen due to the characteristics of his highly selected sample of clinic and private practice patients. Indeed, no one up to this time had, it seems, examined the feasibility of both views being correct where different populations are sampled.

3.17 Slataper's findings (1950), based upon a very full longitudinal study confirmed those of Brown (1938). His material comprised practice patients aged between two and thirty years of age, and examined with cycloplegics. Excluding myopia over -6.00 D, hypermetropia over +8.00 D and all pathological cases, he found that from birth to seven years of age, hypermetropia increased at an average rate of +0.231 D per year throughout the period. After the age of seven the refraction changed in a myopic direction steadily each year, during which period the rate of change in myopia was approximately twice that of hypermetropia. Morgan & Pashby (1950), however, found the rate to be equal for both myopes and hypermetropes (-0.50 D) in the eight to fourteen year age group.

Refractive changes in the strabismic child

3.18 Few studies of the refractive state of the eye have been designed specifically to investigate the characteristics of the changes occurring in the patient with strabismus. Whilst a considerable number of investigations have involved strabismic cases, most of these have sought to simply establish these cases within the "normal" pattern of growth, rather than investigating whether the changes and the factors involved in strabismus could in any way be peculiar to this type of eye. Comparisons made between strabismic and non-strabismic eyes have not been based upon a searching critical analysis, despite the fact that nearly all the studies involving patients with strabismus have produced results widely differing from those investigations without a strabismic weighting.

3.19 In one of the few investigations specifically related to changes in refraction occurring in strabismic children, Vorisek (1935) confined his study to subjects with convergent strabismus only (Table 5). Among 101 patients aged between two and eleven years initially, and three and thirteen years finally, followed up over a period of two years, he found that hypermetropia increased in 55 per cent with a mean change of +0.77 D, remained unchanged in 8 per cent and decreased in 37 per cent, the mean decrease being -0.51 D. Comparing the strabismic with the non-strabismic (fixating) eyes little difference was found.

In a number of studies, attention had been drawn to the high proportion of strabismic patients involved, but in each of these little significant difference was found between the

TABLE 5

Changes in refraction in children with concomitant convergent strabismus

Analysis by author and refractive change

Author	Changes in hypermetropia per cent			Initial Mean Age	Final Mean Age	Numbers
	Increase	Decrease	No change	Years	Years	
Vorisek (1935)	55.0	37.0	8.0	5.5	8.2	101
Nordlöw (1951)	4.1	52.5	43.4	5.1	15.1	122

refractive development in strabismic and non-strabismic groups (Bothman 1932, Brown 1936, 1938).

Brown in 1950 published the results of a comparative study of one thousand strabismic and one thousand five hundred non-strabismic eyes. Like some of his earlier investigations this showed that hypermetropia increased in both groups up to the end of the seventh year of life, followed then by a decrease. In the strabismic eye the reduction in hypermetropia occurs after the age of eleven, reaching a maximum rate of 10 per cent per annum of its original level, between twelve and fifteen years of age. This compares with over 20 per cent between the eighth and eleventh years in the non-strabismic eye, with the period of decrease commencing immediately after the seventh year of life. The year of greatest change was found to be the twelfth and ninth for the strabismic and non-strabismic eyes respectively.

A detailed investigation of the spontaneous changes in refraction occurring in children with concomitant convergent strabismus was also carried out by Nordlöw (1951) (Table 5): 122 children, whose average age initially was five years and finally fifteen years, were examined periodically under atropine cycloplegia. As a result, the mean change in refraction over the whole ten year period was found to be a decrease in hypermetropia of +1.0± 0.183 D for the squinting eye and +0.9± 0.195 D for the fixating eye: at the commencement of the study there was no significant difference in the average refractive state of the two eyes, it being a little over

3.00 D of hypermetropia. Nordlöw points out, however, that this average change of an hypermetropic decrease, obscures and incorrectly reflects the individual variations in development taking place. By examining his results on a longitudinal instead of a cross-sectional basis he finds the cases can be divided into three groups:-

(a) no change

(b) decrease

(c) increase in refraction.

Of these groups 43.4 per cent showed no definite change, taking variations in refraction with ±1.00 D as the random error of the method and, therefore, part of the "no change" group; in 52.5 per cent hypermetropia decreased within the range 0.50 D to 5.0 D, whilst in 4.1 per cent it increased. the change varying from 0.75 D to 0.50 D. No definite relationship could be demonstrated between refractive change and alteration in the angle of strabismus.

Nordlöw's results of individual variations appear to differ quite markedly from those of Vorisek (1935). This could partly be explained by the differences in the age groups and the time spanned by each study. Vorisek covered a 2.5 - 3.0 year period involving children whose average age initially was approximately 5.5 years and finally 8.2 years whilst Nordlöw's subjects had a mean age of 5.1 years at the commencement of the study and were followed up for ten years. In addition, Nordlöw used a correction factor for the random error of the method amounting to ±1.10 D which would account for the higher incidence of "no change" together with the lower incidence of increased hypermetropia. However, even allowing for the unlikely occurrence that this correction factor was weighted entirely against the hypermetropic increase, this alone would still not account for the difference of 55 per cent found by Vorisek and 4.1 per cent by Nordlöw.

The absence of further strabismic studies leaves the question of the nature of the refractive changes in this type of eye unresolved. The evidence as to whether strabismic eyes really do differ in their refractive development from non-strabismic eyes is on the whole inconclusive. Nordlöw's results appear to have as little in common with those of Vorisek as they have with those of McIlroy (1932), in which there was no apparent strabismic weighting.

Cross-sectional v longitudinal studies

3.20 Nordlöw illustrated quite clearly the limitations of averaging processes by comparing the results of a cross-sectional investigation with those of a longitudinal analysis of the same material. This revealed how individual variations can be concealed in studies in which subjects in different age groups are compared to each other. Hirsch (1964 b) reiterated this point and stated that even when the standard deviation is used to measure the extent of variation from the mean the individual changes are still obscured. Nevertheless, such cross-sectional studies do provide invaluable information. In addition they have the advantage of being less time consuming and easier to carry out than follow-up investigations in which the same individuals are re-examined over a period of time; it is for these reasons such studies are carried out.

Pendse, Dan De Kar & Bhare (1951) in a cross-sectional investigation of 590 Indian children aged between six and twelve years, found a definite reduction in hypermetropia, thus confirming Nordlöw's findings for the five to fifteen years age group. Hirsch (1952) and Young, Beattie, Newby & Swindal (1954) in two similar studies involving children aged between five and fourteen years and five and fifteen years respectively, found that hypermetropia increased between five and six years of age, thereafter steadily decreasing although Hirsch noted that this pattern was not so clearly demonstrated in girls. These findings would appear to partially substantiate the earlier work of Brown & Slataper (1950). Young et al also reported that myopia increases with age, the age of onset being at about nine to ten years in girls and eleven to twelve in boys. In neither investigation, however, were cycloplegics used and, therefore, accommodation factors cannot be entirely excluded.

3.21 In the three year follow-up study of Blum, Peters & Bettman (1959) involving children aged initially between five and thirteen, examinations were carried out once again without cycloplegics. Up to ten years of age a mean increase in hypermetropia occurred in children with +1.50 D or more (sixteen eyes only), whilst above this age no change took place. Myopia ($\geq$-0.50 D) present in thirty eight eyes, increased in all age groups, it being most marked in the eight to ten year group. For the 325 eyes classified as normal (-0.25 D to +1.25 D) the mean changes in refraction were towards myopia, it again being most marked in the eight to ten year age group.

The results of this study are open to a number of criticisms. Accommodation factors could account for any of the refractive changes, although it must be noted that the hypermetropic findings do tend to agree with those of Brown (1938). Comparison with other data, however, is complicated by the use in this investigation of the "mean subjective sphere" in which the spherical components only, extracted from the subjective results written in minus cylinder form, are taken as the basis of the refractive state of the eye. Other investigators have used the mean equivalent sphere in which half the cylindrical power is added to the sphere, (Brown 1938, Slataper 1950 etc.), whilst some have used the refraction in the vertical meridian only (Sorsby et al 1957, 1961). Instances of the use of mean refractive state can be found in which the average of the two principal meridians of the two eyes is used as a measure of the refraction (Hirsch 1961). This lack of standardisation undoubtedly complicates inter-study comparisons, and is a factor which must be borne in mind when these are made.

3.22 Sorsby, Benjamin, Davey, Sheridan & Tanner in 1957 reported the results of a small follow-up study on twenty-three children aged between seven and sixteen years, designed to ascertain the effect of growth upon the eye. Each child was examined twice under hyoscine cycloplegia at intervals varying from one to three years. Excluding one subject owing to inconsistencies, they found that ocular refraction remained stationary in six eyes (13.6 per cent), decreased in hypermetropia or increased in myopia in thirty-four eyes (77.3 per cent), increased in hypermetropia or decreased in myopia in four eyes (9.1 per cent). The limitations imposed by such a small sample were such that no attempt was made to draw any conclusions. It demonstrated, however, the need for further investigations of this type.

3.23 Sorsby's work on the development of ocular refraction during growth is outstanding. His theories have arisen from his own considerable research, and these in turn have inspired further research. In 1961, together with Benjamin & Sheridan, he published the results of a long term investigation into refraction and its components during the growth of the eye. (Sorsby, Benjamin & Sheridan 1961). The importance and significance of their findings is such that they justify reviewing in some detail.

The investigations consisted of two main parts:-

(1) a cross-sectional study involving 671 boys aged three to fourteen years, 761 girls aged three to fifteen years and 98 National Service recruits aged nineteen to twenty-two years.

(2) a follow-up study of 436 of the original children who presented themselves for re-examination at intervals varying from two to six years.

All the examinations were carried out using cycloplegics, assessment being made upon the findings for one eye only - mainly the right. Comparisons were based upon the ocular refraction in the vertical meridian. The "extremes of ocular refraction which might represent pathological abnormalities" were excluded by omitting all those children whose ocular refraction differed by more than two standard deviations from the mean for their age group; forty three boys and forty four girls were thus excluded from the cross-sectional investigation.

The cross-sectional results showed that between the ages of three and thirteen years refraction alters in a myopic direction (myopia increasing, hypermetropia decreasing), rapidly at first, then more slowly. The total change was -1.4 D for boys, - 2.3 D for girls. It has already been pointed out that the inherent limitation of this method of comparing age groups is that its averaging mechanism often obscures considerable individual variations (3.19: 3.20). This indeed was the case here. Whereas the cross-sectional series indicated an annual change in ocular refraction of - 0.14 D for boys and - 0.24 D for girls, the follow up study revealed individual changes varying between nil and over - 1.2 D.

In addition to the ocular refraction the individual optical components were measured, with a view to establishing their role in the refractive changes taking place. This involved measuring the corneal radii by ophthalmometry (keratometry) whilst depth of the anterior chamber and thickness and radii of the crystalline lens were determined by photographic methods. The axial length was then computed, the refractive indices being taken as constants.

As with ocular refraction, considerable differences were revealed between the two studies. The cross-sectional analysis indicated an annual increase in axial length of 0.1 mm during the period between three and thirteen years of age, compared to individual variations in the follow-up between nil and 0.7 mm per annum; in about 30 per cent of individuals the increase was between nil and 0.1 mm; 56 per cent between 0.2 and 0.3 mm and 15 per cent 0.4 mm or more. The greatest changes in axial elongation were found to occur in the youngest children, i.e. before the age of ten years. Corneal power showed a mean annual decrease of - 0.06 D compared to individual variations between nil and - 0.6 D to - 0.8 D, whilst the lens power showed a mean annual change of - 0.19 D compared to variations individually between nil and - 0.9 D.

Changes in refraction, they concluded "...are therefore determined by axial elongation...", the main trend being towards emmetropia. This process of emmetropization was thought to be due to the corneal and lenticular flattening tending to lag behind the increase in axial length. The extent to which axial elongation is compensated by changes in the other components thus determines the actual refractive changes that take place. Consequently, they envisaged certain patterns of refractive development during growth:

(a) No change in refraction, due to full compensation. They point out that apart from this "the axial length may remain stationary and the refraction unchanged".

(b) A decrease in hypermetropia or an increase in myopia due either to partial compensation or a complete failure of compensation. Reduced hypermetropia, emmetropia or myopia could thus emerge as a result of such a process.

The possibility of an increase in hypermetropia, or a reduction in myopia, as an alternative mode of development is not discussed: no reference is made in the main body of their report to any cases having been found in which such changes occurred.

The complete absence of any case in which there was an hypermetropic increase is in itself an unexpected finding, particularly in view of the fact that even in the small follow-up study carried out by Sorsby et al (1957) this pattern of development was observed. In these circumstances it is perhaps rather surprising that no attempt was made to examine the causes of the wide discrepancy between the findings of this (1961) study and those of other workers such as Brown (1938) and Slataper (1950) in which increases in hypermetropia were recorded.

Further study, however, of the data on which this report is based (Sorsby, Benjamin & Sheridan - unpublished data 1961) as well as the appendices in the report itself, reveals a somewhat different situation. These results in fact show that in the follow-up investigation a number of cases were found in which either hypermetropia increased or myopia decreased. In the group under ten years of age 11 per cent of boys and 6.7 per cent of girls, showed such changes, whilst in the group ten years and over, the incidence is 19.6 per cent for boys and 9.5 per cent for girls. In all these instances the axial length remained stationary whilst the refraction changed between + 0.1 D and + 0.4 D per annum.

It should be noted that of the original 440 subjects available for the follow-up investigation, fifty four were excluded from the analysis, of which fifty one were discarded because the axial length was found to be shorter at the second examination than the first. Included among the 386 cases remaining are the forty one children in whom the refractive changes were in an hypermetropic direction. Although these were not officially excluded, they were nevertheless, not included in the analysis. No explanation for this omission can be found in the report. Sorsby et al (1961) do state, however, that changes in refraction are determined by axial elongation. Indeed they excluded three cases because "there seemed to be an increase in power without any change in axial length". The total number of exclusions was in reality ninety five out of 440 - an incidence of 21.6 per cent. The ambiguity surrounding the rejection of such a high proportion of cases inevitably raises some serious doubts with regard to the validity of their conclusions concerning the patterns of refractive changes during growth.

3.24 In 1970 Sorsby & Leary presented the results of a further follow-up study of 129 of the original 440 children. Their findings largely confirm the pattern of their earlier results; their conclusions, however, differ considerably.

Among forty nine children who were followed up over the whole or greater part of school life, changes in refraction were found to occur in a myopic direction in some cases and in an hypermetropic direction in others. The range of total changes lay between 0.51 D for increases in hypermetropia (or decrease in myopia) and 1.31 D for increases in myopia (or decreases in hypermetropia), the mean annual change being 0.09 ± 0.07 D in a myopic direction. The total axial elongation in these cases varied between + 0.1 mm to + 1.9 mm with changes in corneal power varying between + 1.0 D and - 1.6 D and lens power between - 0.10 D and - 2.2 D.

In a further nineteen children, followed up over a similar period, total changes in refraction were found to be between 1.52 D and 6.02 D, all in a myopic direction; with a mean annual rate of 0.38 ± - 0.14 D. In these cases, whilst the total axial elongation was much greater than in the former group - varying between + 0.7 mm and + 3.5 mm - the changes in corneal and lens powers were almost identical with the former group. This is clearly illustrated in table 6. It would appear that whilst normal axial elongation may be compensated by reductions in corneal and lens powers, this compensation does not occur in cases of excessive axial change.

Among children followed up over short periods, changes in refraction were found to be distinctly larger in the three to six year age group than in the seven to nine year age group. Sorsby & Leary point out, however, that their ".....most striking finding is that after the age of fourteen there are no significant changes in refraction or in its components". Changes that do occur are slight ".....of the order of experimental error". They did observe, nevertheless, a few cases in which changes after the age of fourteen do occur.

TABLE 6

Changes in refraction and its components in 68 children followed up over the whole or greater part of school life (ages between 3 and 14 years) (Sorsby & Leary 1970)

A : 49 children with slight or moderate increase in refraction (not exceeding 1.31 D)

	Refraction (D) Initial	Refraction (D) Change observed	Axial length (mm) Increase	Corneal power (D) Change	Lens power (D) at corneal vertex Decrease
The 49 children as one group					
25 boys (a mean of 6.5 years between the two examinations)					
Range	-0.12 to +5.78	-0.51 to +1.30	+0.1 to +1.5	+0.7 to -1.2	-0.2 to -2.1
Mean per case		+0.61±0.49	+0.93±0.33	-0.32±0.37	-1.28±0.46
Mean annual rate		+0.09±0.08	+0.14±0.05	-0.05±0.06	-0.20±0.07
24 girls (a mean of 6.5 years between the two examinations)					
Range	+0.50 to +6.30	-0.01 to +1.20	+0.3 to +1.9	+1.0 to -1.6	-0.1 to -2.2
Mean per case		+0.61±0.37	+0.83±0.30	-0.33±0.57	-0.98±0.41
Mean annual rate		+0.09±0.06	+0.13±0.05	-0.05±0.09	-0.15±0.06
49 children (a mean of 6.5 years between the two examinations)					
Range	-0.12 to +6.30	-0.51 to +1.30	+0.1 to +1.9	+1.0 to -1.6	-0.1 to -2.2
Mean per case		+0.61±0.44	+0.88±0.32	-0.32±0.48	-1.13±0.44
Mean annual rate		+0.09±0.07	+0.14±0.05	-0.05±0.07	-0.17±0.07

TABLE 6 (Continued)

B : 19 children with a marked increase in refraction (over 1.31 D)

	Refraction (D) Initial	Refraction (D) Change observed	Axial length (mm) Increase	Corneal power (D) Change	Lens power (D) at corneal vertex Decrease
	19 children examined at 3 - 8 and at 9 - 14 years				
	10 boys (a mean of 7.0 years between the two examinations)				
Range	+0.02 to +6.47	+1.52 to +6.02	+0.7 to +3.5	+1.4 to -0.9	-0.3 to -2.4
Mean per case		+2.78±1.26	+1.71±0.78	0.0±0.37	-1.31±0.60
Mean annual rate		+0.40±0.18	+0.24±0.11	0.0±0.05	-0.19±0.09
	9 girls (a mean of 6.5 years between the two examinations)				
Range	+0.50 to +5.26	+1.53 to +2.85	+0.7 to +2.3	+0.8 to -1.1	-0.5 to -2.1
Mean per case		+2.29±0.45	+1.52±0.53	+0.39±0.54	-1.18±0.51
Mean annual rate		+0.35±0.07	+0.23±0.08	-0.06±0.08	-0.18±0.08
	19 children (a mean of 6.8 years between the two examinations)				
Range	+0.02 to +6.47	+1.52 to +6.02	+0.7 to +3.5	+0.8 to -1.1	-0.3 to -2.4
Mean per case		+2.55±0.97	+1.62±0.67	-0.18±0.46	-1.25±0.56
Mean annual rate		+0.38±0.14	+0.24±0.1	-0.03±0.07	-0.18±0.08

Note: Increase in refraction denotes decrease in hypermetropia or increase in myopia

Analysis of their results on an individual basis show how widely individuals do in fact vary, even when the initial refraction is the same. In some cases although the compensatory changes which took place in the cornea and lens as a result of axial elongation were adequate, in others these were inadequate to the extent of increasing the refractive error beyond that produced by axial elongation. Thus in a few instances, instead of a decrease in corneal power, an increase occurred. In other cases an over-compensation took place due to an excessive reduction in lens power, the result being a slight increase in hypermetropia.

Further analysis of individual variations revealed a number of findings that were "...contrary to expectation, namely a decrease in refraction and in axial length and an increase in the powers of the cornea and of the lens". (Decrease in refraction indicates in this case an increase in hypermetropia or decrease in myopia). Sorsby & Leary observed that these changes were all of a low order and "...as the means were around zero it was assumed that the observations represented experimental errors...". This could account for the fact that similar findings in their 1961 study, particularly with regard to refraction, were disregarded.

On this occasion, however, some of these "paradoxical" findings were analysed. In sixty two observations a decrease of axial length was recorded, forty two of these involving a decrease of 0.1 or 0.2 mm, whilst the remaining twenty involved substantial decreases of 0.3 - 0.5 mm. The subjects in whom these results were found were aged between five and twenty-one years at the time of the examination, but the greater proportion of these cases were observed in those aged fourteen or more. Such findings raise the whole question as to whether shortening of the axial length is a phenomenon that may occur as a physiological process in some cases during growth. Sorsby & Leary suggest that it could come about through a ".....toughening of the sclera after puberty". One cannot ignore, however, the fact that in approximately 11.5 per cent of the total cases included in the 1961 study (fifty one cases out of 440) a decrease in axial length was found to occur. Whilst these cases were discarded from the study, because of this decrease, all these changes were recorded in subjects who were less than fourteen years of age; in these circumstances, the possibility of such changes occurring before puberty, as well as after puberty, cannot be excluded.

Increases in lens power were recorded in sixty five observations, the increase being less than 0.5 D in forty nine cases, 0.5 - 0.9 D in twelve cases, and 1.0 - 1.5 D in four cases. Once again the majority (forty nine out of sixty five) were found in children aged fourteen years or more.

Increases in corneal power were observed in 116 instances, eighty three of which were less than 0.5 D. Of the remainder twenty nine fell between 0.5 and 0.9 D and four between 1.0 and 1.5 D. These corneal changes were more evenly distributed over the age groups than with the other findings, forty three occurring below fourteen years and sixty three above this age.

The results of this study clearly illustrate that compensatory changes in the ocular components, associated with increases in axial length, do not necessarily keep pace with this elongation. In some cases the decrease in corneal and lens power is inadequate resulting in a shift towards myopia. In a few individual cases an excessive reduction in the power of the lens occurred, resulting in a small increase in hypermetropia (of the order of + 0.25 D); such alterations in refraction were far less frequent and of a much lower order than those occurring in a myopic direction. In the light of such findings, the concept of refractive changes being determined by axial elongation, as postulated by Sorsby et al (1961), can no longer be regarded as acceptable.

3.25 In 1961, Hirsch presented a preliminary report of the first six years of the Ojai longitudinal study in which 214 children had been examined twice yearly from the age of approximately six and a half to twelve and a half years. By plotting the results graphically for each child, the patterns of refractive changes were found. In approximately 87 per cent these were linear; either no change, increasing or decreasing hypermetropia. Although no figures were given, the majority were stated to have shown a decrease in hypermetropia or increase in myopia. A curvilinear pattern of variation was found in 13 per cent; hypermetropia increased initially followed by a decrease in approximately 7 per cent, this tending to be the pattern in the higher degrees. The reverse took place in about 6 per cent, occurring in particular, in the lesser degrees of hypermetropia.

Although Hirsch's results appear to confirm the findings of Brown (1938) and Slataper (1956) the methods of examination and of analysis are open to some criticisms. Firstly cycloplegics were not used at any time throughout the six years covered owing to the fact that American State laws do not permit the use of cycloplegics by optometrists. The problem of variation in accommodation at each examination cannot be ignored especially as stress factors at six years are quite different from those at twelve years of age. It should be noted, however, that especial care was taken to relax accommodation as far as possible, by the use of motion picture cartoons as fixation devices. Secondly, the mean refractive state was taken as the measure of the degree of ametropia present. This was found by taking the average of the two principal meridians of both eyes to obtain one figure for each child. The criticism of this method of analysis is that it obscures considerable information about individual eyes which might usefully have been retained. It infers that the changes affecting the two eyes are going to be similar if not the same. In the event of the variations being dissimilar the averaging method used may present serious errors.

In a later report of the Ojai study, Hirsch examined the relationship between the initial degree of ametropia and the subsequent refractive change (Hirsch 1962). All but two of the 214 children were initially hypermetropic. Those who had more than + 1.50 D at six years of age showed a greater rate of change than those with lower refractive errors, the pattern of this change being either an increase, a decrease, or no alteration at all. The incidence of increased hypermetropia was approximately 11 per cent for ametropia <+1.50 D compared to 36 per cent in the group above + 1.50 D; only nineteen children, however were involved in the latter group. It is perhaps of interest to note that the incidence of 11 per cent corresponds quite closely to that found by Sorsby et al (1961), although it must be borne in mind that Hirsch, unlike Sorsby, did not use cycloplegics.

3.26. The relationship between initial refractive error and subsequent change had been examined earlier by Sourasky in 1928. A group of hypermetropic children aged initially between five and fourteen years were followed up over a period of three to five years. His results revealed little significant difference between two refractive groups, + 0.75 to + 3.00 D, + 3.25 D and over: 66.3 per cent showed no change and 33.7 per cent a reduction in the lower group, whilst 63.9 per cent showed no change and 36.1 per cent a reduction in the higher group. Although a number of cases did show an increase in hypermetropia these were inexplicably included in the no change group. With regard to myopia he reported that low myopia (up to - 3.0 D) showed a greater tendency to increase than medium myopia (- 3.25 to - 6.00 D).

In 1964 Hirsch analysed his results with a view to establishing whether the refraction at the age of fourteen years can be predicted on the basis of that found at six years of age (Hirsch 1964a). Using the mean sphere of each eye, rather than both eyes, as the measure of refraction, he found a highly significant relationship between these two ages.

Hirsch points out:

> "If, at age five-six, the child has any degree of myopia, we may be sure it will remain and probably increase. If the child has hypermetropia in excess of 1.50 D (and most certainly if in excess of 2.00 D), he will very likely remain as hypermetropic or nearly so; the hypermetropia may even increase. If the child entering school has a spherical refraction between + 0.50 D and + 1.25 D, he has the greatest chance of being emmetropic. Finally if the child has a refraction between 0 and + 0.50 D, there is a very high probability that he will be myopic before he finishes school".

Table 7 indicates the manner in which an individual refraction is likely to change.

Hirsch concludes that the final refraction of the young adult is largely determined by the age of five or six years, thus confirming the conclusion of Sorsby et al (1961).

In the same year Hirsch (1964b) reported that in 9.0 per cent of the children in his study, hypermetropia increased or myopia decreased. The remainder showed the opposite pattern of change.

3.27 Whilst the literature on changes in refraction has increased in the last ten years, the divergence of opinion as to the nature of these changes remains as wide as ever. Van Alphen (1961), Francis (1963), Hori (1964), Kimura (1965), Wanspa & Limpaphayou (1965), Herm (1965), Tokoro, Nakao & Otsuka (1967), have stated that myopia increases and hypermetropia decreases during growth although Herm (1965) has pointed out that high hypermetropia remains

TABLE 7

Predictability of refractions - After Hirsch (1964)

Analysis by initial refraction at age 5 or 6 years

and ultimate refractive state at age 13 or 14 years

Numbers of eyes

Initial Refraction at 5 or 6 years	Final Refractive state Myopia	Emmetropia	Hypermetropia
More than -0.26 D	4		
-0.25 to -0.01 D	6		
0.00 to +0.24 D	7	6	
+0.25 to +0.49 D	37	4	
+0.50 to +0.74 D	21	33	5
+0.75 to +0.99 D	15	41	10
+1.00 to +1.24 D	2	15	14
+1.25 to +1.49 D		1	7
Over +1.50 D			33
TOTALS	92	100	69

Note: Myopia = -0.50 D or more

Hypermetropia = +1.00 D or more

Emmetropia = -0.49 to 0.99 D

All refractions are equivalent sphere

unchanged with age. It should be noted, however, that their respective findings are based upon studies carried out on differing age groups and nationalities. A similar pattern of change was found by Litvinova, Volokitenko & Pikalova (1964) who examined 2,060 nursery-school children aged between three and seven years. Cavicchi & Saraux (1965) observed that whilst myopia does increase with age, after eight years of age approximately 20 per cent remain stationary, whereas between the ages of four and eight years <u>all</u> cases of myopia increased. They conclude that the later myopia commences the slower its rate of progress. This was later confirmed by Morra (1967). Goldsmith (1968) also states "It is certain that the course of myopia is influenced by the time of onset".

Here we have then, a strong body of opinion postulating that refractive changes take place in one direction - towards decreased hypermetropia and increased myopia. In contrast the studies of Korablev (1964) and Pacyńska, Ogielska & Czerek-Jaguczańska (1968) indicate that there are three possible patterns of refractive development:

(a) reduction in hypermetropia or increase in myopia

(b) no change

(c) increase in hypermetropia or decrease in myopia.

Korablev's results are based upon a two year follow-up study of 251 children aged between five and seventeen years at the time of the first examination. Whilst an increase in myopia or a decrease in hypermetropia, occurred in the majority of cases, 4 - 5 per cent showed changes in a hypermetropic direction in each of the three refractive groups - myopia, hypermetropia and emmetropia. This is clearly illustrated in table 8.

TABLE 8

Changes in refraction in children aged initially between 5 and 17 years, followed up over a period of two years - after Korablev (1964)

Analysis by initial refractive state and subsequent changes

Refractive state	Refractive changes per cent			Numbers (eyes)
	Increased myopia/ Decreased hypermetropia	Decreased myopia/ Increased hypermetropia	No change	
Myopia	65.6	4.6	29.8	262
Hypermetropia	85.3	4.0	10.6	198
Emmetropia	45.0	5.0	50.0	40

Pacyńska et al in their study followed up three groups of children aged initially eight, twelve and sixteen years, examining them with cycloplegics each year over a three year period. In the majority of children in each group, the refraction remained unchanged; the higher the refractive error the greater the tendency for there to be no alteration with age. Reduction in hypermetropia or increase in myopia was the pattern observed most frequently. Nevertheless, changes in the opposite direction were found in all age groups except the eldest boys, the highest incidence - 8 per cent - occurring amongst girls in the youngest age group.

Utkin's (1966) study of over 5,000 children revealed that, between birth and the fifth year of life the hypermetropia increased in incidence from 52 per cent to 84 per cent, emmetropia from 1.8 per cent to between 6 and 7 per cent, with myopia remaining unchanged at about 0.35 per cent; the remainder were classified as astigmatic. By the seventh year hypermetropia decreased markedly in incidence and degree, whilst myopia increased as did the incidence of emmetropia. The study of Hong, Kim & Lee (1967) largely confirms these findings whilst Goldschmidt (1968) reports finding a solitary case of myopia decreasing with age and another of myopia remaining constant; although he states that in most cases myopia increases during childhood. Ruskell (1967) goes as far as to argue that there is little evidence to support the theory of a reduction in hypermetropia in the pre-school years.

3.28 Whilst a considerable number of workers have reported cases showing changes in an hypermetropic direction, there has been little attempt to explain the aetiology of this mode of development. In most cases discussion of this particular phenomenon has been completely avoided. Korablev (1964) for example appears unable to explain the movement towards hypermetropia except on the basis of experimental error, even though he refers to the fact that others have found such changes - Lobasov in 1912 and Kazas in 1913 reported their findings of 30.5 per cent and 11.2 per cent of emmetropic eyes respectively becoming hypermetropic. He considers, as did McIlroy (1932), that this occurrence is due to accommodative spasm, and postulates "It is possible that this spasm was so severe that it yielded to the influence of atropine in repeated investigations". It must be noted, however, that each examination was preceded by ten days atropinization. It seems highly remarkable that any accommodative spasm could survive one such period of cycloplegia. The 'spasm' explanation for these changes appears, therefore, to be little more than speculation. Nevertheless, Snydacker (1964) is also of the opinion that hypermetropic increases are the result of relaxation of accommodation, brought about, in his view, by the wearing of spectacles.

Pacyńska et al, unlike Korablev, do not discuss the aetiology of such changes, even though they specifically refer to cases in which hypermetropia increased or myopia decreased. Yet, for the range of ametropias, + 1.0 D to - 1.0 D, in which such changes were recorded, it is stated "....observations on the dynamics of development of errors of refraction showed that hypermetropia changes to emmetropia which in turn changes to myopia".

Neither Pacyńska et al nor Korablev appear to have considered the possibility that such changes may be associated with the growth of the eye.

Summary Point (3.9 to 3.28)

3.29 (I) Although the results of studies on the refractive state of the newborn are inconsistent, all have shown that the majority of infants are hypermetropic at birth. Goldschmidt (1969) discusses the possible explanation for the inconsistencies found; he points out that these may be due to technical difficulties in examining the newborn, methods of examination employed, genetic differences in the subjects and differences in the maturity of the infants involved. Studies involving premature infants do suggest that maturity is a definite factor. (3.9 - 3.10).

(II) As with data on the newborn, that concerning the pattern of refractive development in the period after birth, is sparse. All the studies concerned, with the exception of Jackson (1932), have shown that in the immediate period after birth, the shift is in an hypermetropic direction and that this is a period of marked change.

Sorsby et al (1961) have shown that from the age of three years, the rapid phase of ocular growth is replaced by a period of much slower but definite growth. Up to the 1920's it was generally held that this pattern of growth involved a decrease in hypermetropia and an increase in myopia. From the middle twenties until the 1950's, an increasing number of studies revealed data indicating that refraction could also change in the opposite direction - towards hypermetropia - as well as remain unchanged. (3.11 - 3.15).

(III) Brown's work (1938) in this field has been described in some detail. He firmly rejected the view that a decrease in hypermetropia is the rule during the first six years of life, having found the pattern of change to be an increase in hypermetropia. He failed, however, to examine critically the causes of the wide discrepancy between his results and those of previous studies. Slataper's findings (1950) strongly support those of Brown (3.16 - 3.17).

(IV) It has been shown (3.18) that although a considerable number of studies have involved strabismic subjects few have been specifically designed to investigate the characteristics of the refractive changes taking place. The contributions of Vorisek (1935), Brown (1950), and Nordlöw (1951) have failed to establish conclusively the patterns of development in such eyes (3.18 - 3.19).

(V) Nordlöw's study (1951), in which he analysed his results on both a cross-sectional and a longitudinal basis, clearly illustrated the limitations of cross-sectional investigations in obscuring the wide individual variations taking place. It has already been shown that both types of studies are invaluable (3.20 - 3.22).

(VI) The work of Sorsby et al (1961) in this field has been described in some detail in view of its importance. Their results indicate that between the ages of three and thirteen years, ocular refraction decreases, rapidly at first, then more slowly. Their conclusions indicate that during the period of growth, refraction may either remain unchanged or alternatively show a decrease in hypermetropia or increase in myopia.
Although the possibility of increased hypermetropia or decreased myopia appears to have been ruled out as a pattern of refractive

development (3.23), the later report (Sorsby & Leary 1970) shows that such changes may indeed occur (3.24).

(VII) The longitudinal study of Hirsch (1964a) shows that not only do such studies permit the individual variations in refraction to be seen, they also enable predictions to be made as to the developments likely to occur as growth proceeds. His findings after a period of eight years, confirm those of Sorsby et al (1961), that the refraction of the young adult is largely determined by the age of five or six years (3.26).

(VIII) It has been shown that the divergence of opinion as to the nature of the changes in refraction still remains as wide as ever. On the one hand there is strong support for the view that refraction changes in youth take place in the direction of myopia, whilst on the other hand a considerable number of studies in the past ten years have shown that if changes take place at all, they may occur in either direction. Throughout all the work reviewed little attempt has been made to explain the aetiology of those cases showing a shift in the direction of hypermetropia (3.28).

Changes in astigmatism

3.30 Amongst the many reported investigations into the refractive development of the eye, there are relatively few which refer to the specific changes in astigmatism taking place during growth: nevertheless, there is considerable divergence of opinion as to the nature of these changes. In 1911 Zentmayer reported that astigmatism increases in some cases and decreases in others, whilst Jackson (1918) noted that in childhood there is a tendency for with the rule astigmatism to increase. This is followed in later life by a decrease producing a trend towards against the rule astigmatism although occasionally this results from a shift in the resultant axis. These findings were confirmed by Butler (1922) and Duke Elder (1949). Jackson found the incidence of astigmatic changes to be at its highest level during the period of growth: of those children examined initially before the age of ten years, only 23 per cent remained stationary between examinations. Of the remainder, with the rule astigmatism increased in 55 per cent and decreased in 32 per cent, (13 per cent were oblique).

A follow up study of 123 patients, all initially under twenty years of age, largely confirmed Jackson's earlier results. (Jackson 1928). This revealed no change in 31 per cent, an increase in 52 per cent, and a decrease in approximately 11 per cent. In 28 per cent the principal meridian altered by more than 10 degrees. Vorisek (1935) reported similar findings for a group of 101 children with convergent strabismus: astigmatism remained stationary in 23 per cent, increased in 41 per cent and decreased in 36 per cent.

Kronfeld and Devney (1930), Ciocco (1938) and Duke Elder (1949), all state that astigmatism changes with age. Ciocco found that it increases, this increase being most marked in the period six to seven years of age and also twelve to thirteen years. Morgan and Pashby (1950), in contrast, state that astigmatism quite often slowly disappears in children, especially in the five to eight year age group. This is largely confirmed by Utkin (1966) who reports his findings of astigmatism decreasing from 46 per cent at birth to 9.5 per cent at five years of age, this decline continuing still further up to at least seven years of age. On the other hand, Blum, Peters & Bettman (1959) found that in the age group five to thirteen years, the astigmatic changes were not significant; whilst Pacyńska, Og'elska & Czerek-Jaguczańska (1968) in their study of children whose ages ranged from eight to nineteen years, observed that astigmatism tends to remain unchanged. Hirsch (1963) in following up 167 children from six and a half years until twelve and a half years of age, noted that the majority - about 75 per cent - changed by less than 0.25 D over the whole of this six year period. The changes that do occur, however, may be either in the direction of with the rule or against the rule. He later stated (Hirsch 1964) that against the rule astigmatism slowly disappears in 7 per cent of children.

3.31 It is generally accepted that astigmatic variations in childhood are primarily corneal rather than lenticular (Jackson 1928, 1933), although Jackson did state in 1918 that against the rule alterations were non-corneal in origin. Marin-Amat (1956) in studying the physiological variations in corneal curvature with age found that changes take place in nearly all astigmatic cases, either increasing or decreasing, whilst a few do remain unchanged. Some spherical corneae became astigmatic whilst some astigmatic corneae became spherical. In other instances each eye changed in opposite directions. The axis of corneal astigmatism changed in 72 per cent of all cases. The incidence of corneal astigmatism was found to increase with age in children, from 33 per cent at three years of age, increasing each year until by seven years of age it was 95 per cent, the majority being with the rule.

Influence of spectacle correction upon ametropia

3.32 Considerable controversy exists over the extent to which spectacle correction influences the development or regression of ametropia. Lyle's view (1950) that "....the wearing in childhood of a 'correction' for a normal degree of hypermetropia may influence adversely the attainment of adult emmetropia", is one that is far from universally held. Equally so, there is considerable opposition to the view, expressed by Jackson in 1931, that myopia is largely controlled by the constant use of spectacles fully correcting the error. Morgan and Pashby in 1950 commented that spectacles could not affect the growth of the eye, whilst Miles (1962) stated that the pattern of myopic change in children showed little or no difference whether the correction was worn continuously or not. Similarly, Hirsch (1964c) observes that the development of any refractive state appears to be unaffected by the extent to which the error is under or over corrected, whilst Herm (1965) and Brissimis (1965) state that the wearing of glasses has little effect upon the progression of myopia. Korablev (1964), however, holds the view that stationary myopia occurs as the result of a full correction.

Tokoro & Kabe (1965) in a study of the effects of fully correcting and under correcting low myopia concluded that myopia increased least when under corrected. Of the 33 eyes followed up over a period of three years, the mean changes were -0.747 ± 0.265 D when fully corrected, compared to -0.543 ± 0.387 D when under corrected. With regard to hypermetropia, Morgan (1967) observed that young hypermetropes tend to remain strongly hypermetropic if fully corrected; he points, however, to the lack of conclusive evidence available.

Some of the most comprehensive studies of the effect of correction upon the development of ocular refraction have come from the Soviet Union. (Table 9) Mizina (1967) studied the changes in 580 myopic schoolchildren over a period of three to ten years. Among the 215 children using their correction constantly, myopia increased in 64.4 per cent; of the 187 wearing their spectacles intermittently the incidence was 48.6 per cent, whilst among the 178 who did not use a correction at all it was 37 per cent. She concludes that the constant use of spectacles tends to aggravate, rather than control, the progress of myopia. Mizina believes this to be due to the excessive burden placed upon the accommodative ability of the eye when doing close work compared to the reduced effort required when reading without a distance correction. Balabanov's (1967) findings agree largely with those of Mizina. He followed up two groups of myopic schoolchildren over a period of three years. In one

TABLE 9

Spectacle correction related to increases in myopia in schoolchildren

Analysis by author, use of spectacles and incidence of increase in myopia

Author	Increase in myopia - per cent			Numbers involved	Period observed
	Spectacle use Constant	Spectacle use Intermittent	No correction	Children	Years
Balabanov (1967)	Nil	85.3	68.9	244 (eyes)	3
Mizina (1967)	64.4	48.6	37.0	580	3 - 10
Savolyuk (1968)	65.0	3.3	32.0	315	2.5 - 6

group spectacles were prescribed 0.50 to 0.75 D below the full correction; to be worn intermittently. In the other group no spectacles at all were worn. Myopia increased in both groups but this increase was most marked and occurred most frequently amongst those who wore glasses. Savolyuk (1968) carried out a controlled study of changes occurring in 315 myopic schoolchildren over periods varying between two and a half and six years. Amongst the group prescribed spectacles for constant use (123 children), myopia increased in 65 per cent, compared to only 3.3 per cent for those prescribed for distance use but not for close work (120 children), and 32 per cent for those using their glasses only occasionally or not at all. As with the other two Soviet studies the indication is that the rate of progress of myopia is related to the degree of accommodative effort exerted for close work.

The measure of agreement in the findings of these three studies suggests that the development of refraction can be controlled, at least in myopia, by the degree of correction prescribed and the manner in which it is worn. It could be argued, however, that those who wear their correction constantly do so because of, and as a result of, their myopia increasing, rather than the reverse. This could explain the high incidence of increasing myopia and the difference between these findings and those of Jackson (1931), Korablev (1964), Herm (1965), and Brissimis (1965). Nevertheless, the real cause of these differences has yet to be explained.

Changes in anisometropia

3.33 In the majority of studies of refractive changes the development of anisometropia has been largely ignored. Indeed, there is a conflict of opinion as to what actually constitutes anisometropia. Horwich (1964) for example defines the condition as one in which there is a difference of 0.25 D between the two eyes; he shows that at this level it can produce significant degrees of amblyopia in susceptible patients. Jackson (1964) on the other hand regards it as a condition in which the difference is not less than 2.0 - 3.0 D.

There is general agreement that anisometropia is an acquired rather than a congenital characteristic. Sourasky (1928) in his study of 621 children aged initially between five and fourteen years, found an asymetrical development of the right and left eyes in a number of hypermetropes and myopes. Utkin (1966) reports similar findings in a study of over 5,000 children. He found that anisometropia of 1.0 D or more increased from 1.75 per cent at birth to 8.97 per cent at around six years of age, reaching an incidence of about 15 per cent during the school years. Hirsch (1967) also found anisometropia developing in children during the period from approximately six years to eighteen years of age, although only thirty out of a total of 359 had 1.0 D or more at any stage of this study. Kubistova (1968) in following up the development of infants from the age of seven months until four years of age, observed that in the majority of cases, anisometropia develops during growth and is not congenital. In contrast to these findings Blum Peters & Bettman (1959) report that during a three year follow up investigation of children aged initially between five and thirteen years, anisometropia showed no significant changes.

In a study involving twenty three strabismic children Keiner (1968) observed that over the age of two and a half years nearly all cases of untreated strabismus with amblyopia showed a difference in refraction between the two eyes which appeared to be larger, the longer the amblyopia had been present. In contrast he found that under two years of age, the refractive error is nearly always the same, irrespective of the presence or absence of amblyopia. He assumed, therefore, that the normal emmetropization process begins at the age of two and a half years, but does not occur in the amblyopic eye, thus giving rise to anisometropia: this refractive difference persists once it has been established. Keiner notes that the results from such a small series of cases cannot be regarded as statistically significant; they are nevertheless of interest.

Sex differences

3.34 The relationships between males and females have been examined with a view to determining whether sex differences exist in the refractive state of the eye and its patterns of development. Tomas (1965), Luyckx (1966) and Goldschmidt (1969) all report that there is little difference in the refraction of newborn males and females. Among children in the five to fourteen year age group McIlroy (1932) found hypermetropia over 5.0 D to be more common in boys than girls, whereas hypermetropia and myopia under 2.0 D occurred more frequently in girls: no significant difference was present for myopia above 2.0 D. Sorsby, Benjamin & Sheridan (1961), however, observed no significant refractive difference at all between sexes in the three to fourteen year age group, except perhaps at three years of age when it was found to be + 2.62 D (standard error ± 0.32) for boys and + 3.51 D (Standard error ± 0.61) for girls.

In a study of components in myopia, Baldwin (1964) reports that no significant differences were found between males and females. Baldwin (1967), in reviewing the results of studies in this field, points out that "....no consistent differences between sexes in the incidence of myopia or hypermetropia can be found when general groups are considered". Nevertheless, when the degree of error is taken into consideration some differences have been shown to exist. Goldschmidt's (1968) results show that myopic girls have significantly higher errors than myopic boys of the same age; this phenomenon, he suggests, is probably due to girls being more mature for their age than boys. Low myopia, he found, has the same frequency in both sexes but high myopia (over 9.00 D) is more common in women. With regard to astigmatism, Duke Elder (1949) points out that some observers have shown a greater frequency in females. He feels, however, that any difference between sexes is probably without significance.

In one of the few studies in which changes in refraction have been analysed on a sex basis, Sorsby et al (1961) found no obvious differences, but point out that evidence from unselected material is necessary for confirmation of their findings.

Goldschmidt's observations on maturity factors are worthy of note; there can be no doubt that such factors do play a part in determining the stage refractive changes have reached at any point in life. Where differences between males and females have been found to exist, the cause is more likely to be associated with maturity than with any real sex difference.

3.35 There appear to be no data on the effects of surgery upon the refractive development of the eye in the strabismic child.

Summary Point (3.30 - 3.35)

3.36

(I) Studies of the development of astigmatism during growth have shown that it may either increase, decrease, or remain unchanged. The majority of such studies indicate that changes do, in fact, take place, these being most marked in the period up to approximately seven years of age. The findings of Blum et al (1959) and Pacyńska et al (1968), however, suggest that the changes are not significant, particularly in the period after the age of seven years. The causes of astigmatic variations in childhood appear to be corneal rather than lenticular. (3.30 - 3.31).

(II) The literature relating to the effect of spectacle correction upon development of errors of refraction reveals considerable disparity in the results of the studies involved. It has been shown that whilst there is substantial support for the view that the development of any refractive state appears to be unaffected by the extent to which the error is under, over, or fully corrected, the opposition to this view is considerable; Jackson (1931) and Korablev (1964) state that myopia is controlled by the use of a full correction, whereas the findings of Tokoro & Kabe (1965) together with Mizina (1967), Balabanov (1967), and Savolyuk (1968) suggest that it can be controlled by under correction and by the manner in which the correction is worn. (3.32)

(III) From the limited evidence available, anisometropia has been shown generally to develop after growth and is, therefore, not congenital. Blum et al (1959) do, however, suggest that it does not change with growth, at least after the age of five years. Keiner's small study (1968) of strabismic children indicates that amblyopia inhibits the process of emmetropization in the eye involved and thus results in the development of anisometropia. (3.33).

(IV) There is little evidence to suggest any significant refractive difference between sexes during the period of growth. The findings of Goldschmidt (1968) that in myopia, girls have a significantly higher refractive error than boys of the same age has been explained by the higher degree of maturity in young females than in young males. The investigation of Sorsby et al (1961) into changes in refraction, indicate that no sex differences exist in the pattern of such changes; further conclusive evidence, however, is necessary. (3.34).

Components of refraction and their relationship

3.37. This review would not be complete without taking account of the research that has been carried out into the behaviour of the refractive components of the eye. Changes in ocular refraction are the result of alterations in one or a number of the components of the eye: an understanding of their relationship, therefore, is essential in any investigation of variations in refraction with age, even though this is not directly the subject of the research itself.

In 1913 Steiger made what was probably the most important contribution towards an understanding of the nature of the refractive state of the eye since the publication of Donder's treatise (1864). As the result of his observations on 5,000 eyes, he concluded that all refractive states arose out of a combination of two variables - the corneal power and the axial length, thus confirming the conclusions of Mauthner (1876) and Schnabel & Herrnheiser (1895). The crystalline lens, he stated, showed little variation in power. Steiger was convinced that the association between the two variables was one of pure chance. Consequently, he argued that the refractive states in the population as a whole, followed a normal distribution; that myopia and hypermetropia were just as likely to occur as emmetropia. Although his assumption of a free interplay of components producing a chance distribution of refractive states, was subsequently shown to be incorrect, his findings marked the beginning of a new approach to the nature of emmetropia and ametropia.

3.38 Steiger's theory as to the mode of development of the various states of refraction was not accepted by Straub (1901, 1909, 1918) who as early as 1901 had argued that, from school age upwards, emmetropia was the normal refractive state, arising not on a chance basis but as a result of a desire for clear distance vision. Straub regarded emmetropisation as an essential feature of the process of growth, the lens associated with innervation to the ciliary body being directly involved in the refractive changes taking place. Sorsby (1940) later confirmed that, far from being free variables, the components must be involved in a correlating process bringing about the trend towards emmetropia.

Tron (1929, 1931), in analysing the results from fifty three emmetropic eyes, found that the values of axial length, corneal, lenticular and total refractive power varied widely, whilst Sorsby (1932) and Tron (1940) observed that a combination of the normal variants found in emmetropia could produce ametropia. Tron (1940) described such cases as "combination ametropia". By excluding hypermetropia over 4.0 D and myopia over 6.0 D he found that axial length played no part in the low and medium ametropias: in the higher degrees, however, he believed axial length to be an important factor. Sorsby (1940) similarly envisaged the possibility of axial length playing no part in the changes occurring in myopia, particularly after the age of eight years. He postulated that increases in myopia could be explained by increases in corneal and lens power and a decrease in the depth of the anterior chamber; each could produce myopia in the absence of changes in axial length. Nevertheless, Kanefuji (1953) considered that myopia arises mainly as a result of axial elongation together with an increase in the power of the lens.

Stenström (1946, 1948), like Straub, Sorsby and Tron, found that the optical components do not vary independently but are more or less correlated. He stated, however, that axial length is the most important factor of all those determining the refractive error; ametropias up to 8.0 D he observed, have axial lengths falling within the range found in emmetropic eyes. Stenström demonstrated that refractive error is highly correlated with axial length, but shows no correlation at all with the lens and is only slightly correlated with the cornea and anterior chamber. The majority of ametropic eyes, he believed, have components found in emmetropic eyes.

Hirsch & Weymouth (1947) re-analysed Stenström's (1946) results and found that variation in corneal curvature could play a much larger part as a determinant of refraction than had been suggested. Alterations in corneal curvature could, it was shown, account for a change of 7.7 D, compared to 17.1 D for the axial length and only 1.1 D for the anterior chamber depth. They confirmed that the crystalline lens accounts for little in terms of refractive change.

3.39 Sorsby & Sheridan in 1953 pointed out that the variation in the axial length (of the eye) from about 16 mm at birth, to 23 or 24 mm in the adult would in itself produce a refractive change of some 20.0 to 30.0 D. The fact that no such change takes place means that this elongation must be compensated by a reduction in the refractive power of the cornea and crystalline lens system. In order to establish some evidence for this compensatory mechanism they studied the shift in corneal power in the rabbit over a period of six months commencing at the fourth week of life, these findings being related to the overall refraction determined under cycloplegia. During the period of observation the corneal power declined from over 60.0 D to well below 50.0 D and was still declining, even though the rabbits were almost fully grown by that time. Overall refraction, on the other hand, showed little alteration, thus confirming the presence of a compensatory mechanism.

In a further study on the rabbit, Stone & Leary (1957) found that from the seventh to the twentieth week of life the corneal power decreased by 9.22 D whilst the refraction - hypermetropia - increased from + 1.40 D to + 2.22 D. The corneal power continued to decrease by a further 5.57 D up to the eightieth week, with the hypermetropia also decreasing up to the fortieth week and remaining virtually stationary thereafter. These findings indicate that the increase in axial length occurs initially at a relatively slower rate than the decrease in power in the cornea - lens system; the elongation then becomes relatively faster accounting for the greater part of the refractive change. Finally both optical system and axial length develop at the same rate.

3.40 Sorsby, Benjamin, Davey, Sheridan & Tanner (1957) carried out a comprehensive and significant study into the correlation of the optical components of the eye. Their findings show that whilst the components of refraction follow a normal distribution in the population, a definite correlating mechanism exists which gives rise to a high proportion of emmetropic eyes.

Taking all refractions together little correlation was found between corneal power and axial length (-0.290). Good correlation was, however, shown when taking emmetropia on its own (-0.877): the greater the axial length the lower the corneal power and vice-versa. The higher the degree of ametropia, the lower the correlation; above 8.0 D it approaches zero. The lens on the other hand tends to be highly correlated with axial length irrespective of the degree of ametropia - high powered lenses being associated with short axis, low powered with long axis; its role in the development of ametropia is, therefore, not significant. The depth of the anterior chamber was found to show little relationship to either axial length or corneal power.

Sorsby et al clearly demonstrated that emmetropia arises as a result of the three variables - axial length, lens power and corneal power - being fully correlated. The ametropias of up to ± 4.0 D, in which basically the emmetropic range of component values was found, were shown to be due to a failure of correlation. This failure must be attributable to the cornea or axial length rather than the lens, their roles being probably equally signifcant. Where only one component was at fault, it was shown to be the cornea rather than the axial length. The different degrees of ametropia up to about ± 4.0 D reflect the degree of failure in correlation. In the higher degrees of ametropia it was found that the refractive state arose essentially as the result of an anomalous axial length. It should be noted, however, that ocular refractions of more than ± 8.0 D, astigmatic cases of more than 2.0 D and anisometropia of more than 1.0 D, were all excluded from the analysis on the basis that they "...are clearly outside the range of normality", although the nature of this range of normality was not clearly defined.

These findings were largely confirmed by the further study of Sorsby, Leary & Richards (1962a) which was designed to exclude duplication and genetic similarity. They point out, however, that the roles of the cornea and the lens in modifying the degree of ametropia (i.e. the correlation) has still to be determined.

3.41 Sorsby et al (1957) postulated that the retina itself is the "organiser" of emmetropia determining the correlating mechanism involved and that indirectly, it is also the organiser of the ametropias which arise through faulty correlation. They concluded that within this mechanism "the axial length appears to determine the character of the other components". As the eye elongates the ocular surfaces flatten as an adaptive process, but where the corneal curvature fails to decrease or decreases only partially then a movement towards myopia takes place. No consideration appears to have been given to the possibility of an excessive flattening of the cornea and its effect upon refraction, i.e. a trend towards hypermetropia. Attention was drawn to just such a possibility by Morgan in 1960. He argued that as the refractive power of the eye is dependent upon a number of variables, changes in each of these variables could result in an increase in hypermetropia just as logically as they result in increases in myopia.

The view that emmetropization is a retinal linked process is also held by Van Alphen (1961, 1967). He states that the eye, which is hypermetropic at birth, becomes emmetropic as the result of a feed back system between the macula and ciliary muscle linked to the choroid; the ensuing loss of parasympathetic tone leads not only to an increase in the size of the globe, but also a change in shape as well. This mechanism he describes as "stretch". "Stretch drives the ocular refraction ..... in a myopic direction despite the fact that the relative myopic gain is partially offset by an increase in chamber depth and decrease in lens power ..... Any discrepancy between the stretch of the eye and its total refractive power results in ametropia".

3.42 A small study of myopic children aged between nine and eighteen years carried out by Francis (1961), revealed a fairly high degree of correlation between axial length and ocular refraction. The correlations of ocular refraction with corneal power, equivalent power of the lens, equivalent power of the eye, and anterior chamber depth were, on the other hand, found to be low. Baldwin (1964) observed that in myopes the correlation between axial length and corneal curvature is highly negative and concluded that they act together as an emmetropization mechanism. He states that essentially, axial elongation is the major factor in the refractive state of the myope, although in rare cases in children, corneal changes may be the major cause. Sato (1965), however, postulates that acquired myopia arises as a result of increases in the power of the crystalline lens rather than axial elongation.

3.43. The specific role of the crystalline lens in changes in refraction, especially in the development towards emmetropia, has been investigated in detail by Franceschetti & Luyckx (1967). With the aid of ultrasonic methods they found that a large number of emmetropic eyes are emmetropic due to adaptation of the crystalline lens to the length of the eye. In the absence of such an adaptation, they calculate that 26.5 per cent of all emmetropic eyes would be hypermetropic and 35.3 per cent myopic. The lens in the myopic eye, they find, has a lower power than in the emmetropic eye and, therefore, contributes towards a reduction in the degree of myopia that might otherwise be present. This finding conflicts with Sato's (1965) theory concerning acquired myopia.

Gernet & Olbrich (1968) similarly found that it is the ability of the crystalline lens to adapt its power that plays the decisive role and is responsible for the excess of emmetropia in the population. Believing that adaptation of the lens occurs as a result of differences in tension of the suspensory ligaments which in turn is related to the size of the eye, they state "The process of emmetropisation .....

depends entirely upon the appropriate structure of the eye, and thus has no connection with heredity nor with an external factor".

3.44 Longitudinal data on changes in the ocular components are limited, especially for the early post-natal period. In one of the few studies covering the first year of life, Grignolo & Rivara (1968) show that the power of the crystalline lens and the total power of the eye diminish progressively, particularly in the first three - four months of life. The power of the cornea diminishes at a constant rate whilst the axial length increases throughout the year, but this increase is again most marked in the first three months. They conclude that the reduction in the total power of the eye, in particular the reduction in the power of the lens, not only compensates for the axial elongation which takes place but also causes the increase in hypermetropia which occurs during this period of life.

Sorsby et al (1957) carried out a small follow-up study of children aged between seven and sixteen years. Over periods varying from one to three years they found axial length increasing in forty out of forty-six eyes at a rate of approximately 0.2 to 0.3 mm per year. In a larger investigation involving children between three and fifteen years of age, Sorsby et al (1961) observed that annual changes in axial length varied between nil and 0.7 mm. This compared to mean annual changes of

0.1 mm found in a cross-sectional study. Variations in corneal power were between nil and - 0.6 to - 0.8 D per annum compared to a mean of approximately - 0.06 D, whilst the lens changes were between nil and - 0.9 D and over, compared to - 0.19 D. As a result of their longitudinal findings they conclude that corneal flattening is perhaps as active as the lens in the part it plays in the compensating process during the definitive phase of growth.

The findings of Tokoro & Kabe (1964) on the other hand indicate that within the compensating mechanism the role of the cornea is much smaller than that of the lens. As a result of studying the changes occurring in twenty-eight children, initially under fifteen years of age, over periods varying between two years six months and three years seven months, they found that whilst axial length increased annually (+ 0.319 ± 0.133 D) the cornea remained relatively stationary (-0.048 ± 0.081 D) and the lens decreased in power (- 0.301 ± 0.256 D). Ocular refraction changed in a myopic direction (-0.646 ± 0.323D). Similar findings were reported by Tokoro, Nakao & Otsuka (1967).

In a further investigation of children involved in the 1961 study of Sorsby et al, Sorsby & Leary (1970) analysed the ocular components of a small group of myopes. This showed no direct relationship between axial length and the amount of myopia present. Examination of the compensating mechanism associated with axial elongation involved in the change towards myopia, revealed that whilst changes in lens power appear to be of a similar order in both large and small increases in myopia, the reduction in corneal power seems to be less in cases where the myopic increases are marked, (over 1.31 D), compared to those in which it is slight, (below 1.31 D). In some cases the cornea even increased its power. This was even more clearly illustrated when the myopes were compared with a control group of non-myopes. The group of myopes, however, was small, only twenty five, and further studies are obviously indicated.

It is suggested that the evidence indicates, "....just as axial myopia is more than anomalous axial elongation so correlation myopia is more than a failure in the compensatory mechanism. ....it is now clear that the degree of compensation not only fails to keep pace with the axial elongation but actually falls below the values for non-myopic eyes, presumably as a result of paradoxical changes in the cornea and possibly also the lens".

Sorsby & Leary argue that the ocular change occurring during growth can no longer justifiably be classified as "emmetropization" in view of the fact that some ten per cent of children become myopic and considerably more retain moderate or high hypermetropia. They regard the concept of emmetropization as out-dated, and out of place in any present day analysis of refraction.

Rejection of the emmetropization theory makes it possible to accept that, during growth, not only may refraction alter in any direction, but alterations in power of the corneo-lens system need not be related to changes in axial length.

3.45 Van Alphen (1961) points out that ocular growth is a process involving the eye as a whole, in which the globe expands in all directions, although not necessarily in all directions at the same rate. This point is re-emphasised by Hirsch (1964c); he states "The markedly myopic eye usually is not a long eye - it is a large eye. The markedly hypermetropic eye is not short - it is small". Despite this fact, many workers have concerned themselves with changes only along the anterior-posterior axis (Weale 1963). Indeed there have been relatively few studies in which the principal diameters of the eye have been measured or even considered: Sorsby & Sheridan in 1960 drew attention to the paucity of data in this field, particularly concerning the transverse and vertical diameters.

In a notable study involving forty-eight cadavers, Sorsby & Sheridan (1960) established important data on the dimensions of the eye at birth. Their findings show that in full term babies the vertical diameter is shorter whilst the transverse diameter is similar or slightly longer than the axial length. Much the same relationship obtains in prematures. The mean results for male babies surviving less than twenty four hours were : sagittal 17.9 ± 0.49 mm; vertical 17.3 ± 0.53 mm: transverse 18.4 ± 0.608 mm. Measurements of the cornea showed the transverse diameter to be consistently larger than the vertical diameter, the mean results for twenty four hour males being: vertical 10.4 ± 0.35 mm; transverse 9.8 ± 0.33 mm: Similar results were obtained for females.

The validity of post mortem measurements is always open to question, but results obtained from living eyes, although limited in number, do tend to substantiate these findings: Gernet (1964), by using ultrasonic methods, has shown the axial length in the newborn child to vary between 16.5 and 17.5 mm. Accepting the values obtained in their study for newborn eyes, Sorsby & Sheridan point out, "It is clear that the growth of the cornea follows a different pattern from that of the globe as a whole .... The increase in the cornea is ..... of the order of some 20 per cent and that of the axial length of some 33 per cent." Whilst comparing corneal with axial length changes they do not include possible changes in the vertical and transverse diameters. Unfortunately there is little data available as to the individual changes taking place in these diameters. It is, therefore, possible that corneal growth could be related to vertical and transverse development rather than sagittal. It should, nevertheless, be borne in mind that with refracting surfaces such as the cornea and lens, alterations in curvature are more significant than dimensional growth.

Deller, O'Connor & Sorsby in 1947 measured the diameter of the living eye using X ray techniques. They found that among fifteen myopic eyes ranging from - 0.50 D to - 16.0 D (mean - 5.8 D), both transverse and vertical diameters are generally shorter than axial length: the transverse diameter was shorter in thirteen cases, longer in one, and equal in the other, whilst for the vertical, fourteen were shorter and one equal.

Of the eleven hypermetropic eyes, refraction ranging from + 0.50 D to + 3.0 D (mean + 1.2 D), in five cases the transverse diameter exceeded the axial length, three were smaller and three equal. The vertical diameter was larger in four cases, smaller in three and equal in three.

Among the nineteen emmetropic eyes, the transverse diameter exceeded axial length in six cases, was smaller in five and equal in eight cases. The vertical diameter was larger in seven cases, smaller in ten and equal in two.

3.46 It can be seen from these results that differences between the diameters of the eye do exist. The question arises as to whether growth affects these diameters equally. If not, then their method and rate of change must have a significant bearing upon the refractive development taking place.

Weymouth & Hirsch in 1950 analysed the results of three separate studies in which the diameters of the eye were measured - Collins (1890), Weiss (1897) and Deller et al (1947) - with a view to assessing the comparative rates of growth of these meridians and their effect upon refractive development. They observed that whilst the transverse and vertical diameters grow at essentially the same rate, the axial diameter after birth increases less rapidly at first, and later at about the same rate as the vertical. Tanner (1963) also reported a difference in the axial growth rate compared to that of the other diameters, but found the axial length developing more rapidly than either the horizontal or transverse meridians. Weymouth & Hirsch concluded that the type of growth indicated by their analysis "...would lead us to expect in the first year or two of life, a shift of the refraction towards hyperopia and in later childhood a shift toward myopia".

3.47 The literature on the optical components in anisometropia is very limited indeed. Sorsby, Leary & Richards (1962b) in one of the few investigations carried out in this field, reported that amongst subjects aged between three and fifty-five years axial length was found to be the predominant cause of the anisometropia in forty-nine cases out of a total of sixty-eight. In only seven cases did it account for less than 50 per cent of the anisometropia and in only two cases did it make no material difference. The cornea and lens were contributory factors in thirteen and fourteen cases respectively, whilst the condition was counteracted by the cornea in ten cases and the lens in one case only. Axial length was found to be the prime factor in the higher levels of anisometropia whilst the lens and the cornea are of greater importance in the lower levels (up to 5.0 D).

Summary Point (3.37 - 3.47)

3.48

(I) It has been shown that in any studies of refraction an understanding of the role of the refractive components of the eye is essential. Steiger's work (1913) has been described, and his contribution analysed. It has been demonstrated, however, that far from there being a free interplay of the components of refraction, as assumed by Steiger, a correlating process exists which determines the relationship of the components. Whilst views differ as to the precise role of axial length it has been shown that of the components, corneal curvature and axial length play the major role as determinants of the refractive state. (3.37 - 3.38).

(II) Studies on the rabbit indicate that initially the corneo-lens system decreases in power more rapidly than the increase in axial length, producing an hypermetropic increase. This is followed by a reversal, whilst finally, both optical system and axial length develop at the same rate. (3.39).

(III) Sorsby et al (1957) confirm the existence of a correlating mechanism, giving rise to a high proportion of emmetropes. Whilst the lens is highly correlated with axial length irrespective of the degree of ametropia, the correlation between corneal power and axial length decreases as the degree of ametropia increases. Ametropias up to ± 4.0 D, in which the emmetropic range of components is found, are the result of a failure of correlation. (3.40) It has been postulated that the retina is the "organiser" of emmetropia, determining the correlating mechanism; in turn axial length appears to determine the character of the other components. Failure in the adaptive processes associated with axial elongation, results in a movement towards myopia; the possibility of a shift towards hypermetropia is not discussed (Sorsby et al 1957). Morgan (1960), however, suggests that such refractive changes are possible (3.41).

Studies of the exact role of the crystalline lens, indicate that it is the ability to adapt its power that is decisive in the production of the emmetropic excess in the population (3.43).

(IV) Longitudinal data covering the first year of life show that the reduction in the total power of the eye and in particular the lens, not only over-compensates for axial elongation but also causes the increase in hypermetropia. There is evidence indicating that after the age of three years, corneal flattening is perhaps as important as that of the lens in the compensating process; support for this view, however, is not universal. The later study of Sorsby & Leary (1970) suggests that changes in the corneo-lens system need not be related to changes in axial length and that refraction may alter in any direction. The concept of emmetropization is rejected as being outmoded (3.44).

(V) Ocular growth has been shown to be a process involving the eye as a whole in which the globe expands in all directions and not solely along the anterior-posterior axis. Studies involving measurements of the principal diameters of the eye do show that in the early period of life the axial diameter develops at a different rate to the transverse and vertical diameters. Analysis suggests this type of growth would produce a shift in refraction initially towards hypermetropia and in later childhood towards myopia. (3.45 - 3.46).

(VI) Studies of components in anisometropia have shown axial length to be a predominant cause, particularly in the higher degrees: the lens and cornea are of greater importance in levels up to 5.0 D (3.47).

Relationship between refractive states

3.49 Although myopia has occupied the attention of research workers to a far greater extent than hypermetropia, its incidence in the population is far lower. Duke Elder (1949) reports that the incidence of myopia has most frequently been found to be between 19 and 27 per cent compared with 56 to 65 per cent for hypermetropia, although racial and regional studies have produced wide variations from these results. Sorsby, Sheridan, Leary & Benjamin in 1960 carried out a detailed investigation of the distribution of refractive errors among 1056 National Service recruits aged between seventeen and twenty-seven years; all were examined under cycloplegia. Myopia accounted for 11 per cent of the total, but only 2 per cent of the total were myopes above - 4.0 D: 75 per cent had ocular refractions between 0 and +2.0 D, 10 per cent between +2.0 D and +4.0 D, and 4 per cent above +4.0 D. Some degree of astigmatism was found in 60 per cent of all cases, but less than 20 per cent of the astigmatic cases were greater than 0.5 D: table 10 clearly illustrates the distribution. Astigmatism was generally found to be associated with moderate spherical values $\leq \pm 2.0$ D, rather than with extreme refractions.

3.50 Taking all refractions 90 per cent fell between - 1.0 D and + 4.0 D. Whilst such figures are generally accepted as being fairly representative of the population in this country, there is still considerable difference of

TABLE 10

Percentage distribution of astigmatism in men 17 - 27 years of age

After Sorsby, Leary & Benjamin(1960)

Degree of Astigmatism (D)	In 2,066 eyes	In 1,033 Men (by better eye)
0.0. or less than 0.2	38.6	44.4
0.2 to 0.3	26.3	25.9
0.4 to 0.5	16.4	14.6
0.6 to 1.0	8.9	7.6
1.1 to 2.0	5.0	4.3
2.1 to 3.0	2.5	1.8
3.1 to 4.0	1.2	0.9
4.1 to 5.0	0.7	0.3
5.1 to 6.0	0.3	0.2
6.1 to 7.0	0.1	0.0
	100.0%	100.0%

opinion concerning the nature of the relationships between the various refractive states. Duke Elder in 1949 commented that it is indefensible to regard emmetropia as the perfect and normal condition, and variations from this as abnormal or pathological; he considered simple myopia to be no more abnormal than hypermetropia. Sorsby et al (1957) following their study of emmetropia and its aberrations strongly contend that the simple myopic eye behaves no differently from the emmetropic or hypermetropic eye - each following a common pattern of development. Nevertheless, throughout the 1930's any form of myopia was looked upon with suspicion. Apart from viewing all cases of myopia occurring in youth as pathological, Jackson (1932) considered the continuous decrease of hypermetropia, changing eventually into myopia, irrespective of the degree, to be essentially a pathological process. Myopia was, and sometimes still is, looked upon as something to be feared. Inumerable cures have been suggested and an incredible amount of time, effort and money has been channelled into trying to prove that it need not, and should not, develop. In the twenties and thirties London County Council instituted special classes for myopic children in some of their schools in an attempt to prevent myopia increasing, even though these children had no visual disability once corrected. (London County Council Reports 1929, 1930, 1931, 1932, 1933).

The logic underlying the specific division of refractive conditions into myopia, emmetropia and hypermetropia has been seriously questioned by Heath (1967) who regards such a division as highly arbitrary. Like Hirsch & Ditmars (1969) he argues that a one or two dioptre myope has much more in common with an emmetrope or low hypermetrope than with a high myope. It is partly the result of this restrictive classification, Heath believes, that such emphasis has been placed on the aetiology of myopia to the exclusion of the other refractive states. Certainly much of the confusion over myopia stems from failure to distinguish the simple form of myopia from the pathological condition. As Curtin (1967) points out, pathological myopia is frequently presented as an anomaly of refraction rather than a disease. He believes that it should be reclassified as a "single disease entity", completely distinct from ordinary myopia. There is certainly a need to re-define and to separate these conditions more clearly than is the case at present.

The view that myopia is interrelated with the other refractive states is still far from being universally accepted. Young (1967) believes that the placing of all refractive errors on a continuum is wrong. He questions whether the individual who is moderately hypermetropic and either shows no change or becomes more hypermetropic, is the same type of individual as the one who becomes less hypermetropic or becomes myopic with age. In contrast Goldschmidt (1968) states "It is obvious that low myopia should not be considered in isolation but only in connection with other low ametropias and not least with emmetropia".

Roles of environment and heredity

3.51 The relationship between myopia, emmetropia and hypermetropia cannot really be considered without taking account of the roles of environment and heredity. Considerable difference of opinion exists as to whether refraction is environmentally or genetically determined. Even before Donders (1864) had postulated the causes of myopia, environment was considered to be a factor of prime importance in its development. Strong support for the environmental approach is still forthcoming. Nevertheless, Sorsby (1964) states "The traditional emphasis on environmental factors .... finds no support in the detailed studies of today". The results of studies on twins certainly suggest that refraction is genetically determined. (Sorsby, Sheridan & Leary 1962).

3.52 Most of the literature dealing with the influence of environment upon the development of refraction has been confined to the problem of myopia. Few workers in this field have given attention to hypermetropia. Straub in 1918 expressed the widely held view that school work played a considerable part in the aetiology of myopia, whilst Jackson in 1931 argued that it increases only as a result of excessive convergence. Removal of this cause, he stated, results in the condition becoming stationary. Brown & Kronfeld (1930) in contrast stated that their results showed no direct relationship between the amount of close work which children do and myopic development.

In a report to the London County Council, McVail (1929) described special methods of teaching the myopic child that had been employed at a number of London schools. Believing that close study exerts "an adverse influence on visual conditions", the children were given large print books where possible, encouraged to write in large letters, taught "touch" typing to avoid writing and even read to by a teacher or another child in order to avoid reading. McVail regarded such an approach to be "..... opening a way to reduce the serious handicap from which such pupils have suffered in the past when they were practically forced to choose between risking their eyesight or refraining from study".

After approximately four years of these experiments McVail (1932) reported that among fifteen myopes at one school, the mean increase was 0.214 D per eye per year, and at another school among fifteen myopes it was 0.195 D, the period covered in each case being not less than two years. The ages of the children were not given.

In 1933 McVail concluded that close work and work involving strenuous exercise and the lifting of weights, are to be avoided. Consequently these children were directed into jobs which avoided such tasks. Indeed she went as far as to report that "....it is only in exceptional cases of non-progressive myopia without fundus changes that medical sanction has been given for occupations such as teaching". The outlook at that time for the young myope, job-wise, certainly appeared grim.

Although close work was widely held to be the prime causative factor of changes in a myopic direction, Duke Elder (1930) in a three year follow-up study of young trainee printing workers (excluding compositors) found little difference in the proportions of myopes showing no change and those increasing. Amongst the hypermetropes, the majority remained stationary, 20 per cent became myopic and 2 per cent more hypermetropic. The emmetropes all remained unchanged. These results indicate that perhaps close work might not be as important a factor in changes in a myopic direction as had been suggested at that time.

Environment, nevertheless, is still thought to be a major factor influencing refractive changes in youth. Research on primates has produced evidence indicating that prolonged close work produces myopic refractive changes (Young 1961). In a series of experiments on monkeys Young (1965a, 1965b) found that among those enclosed in an environment allowing only near objects to be seen, two-thirds showed a development towards myopia. This did not occur amongst monkeys in a normal environment. Arrest of the refractive changes took place on reversion to normal visual conditions. Similarly, long term instillation of atropine daily reversed the progression towards myopia and the condition stabilised. In caged animals the range of refractive states was also found to be much wider than in wild monkeys; the incidence of myopia was similarly higher. These findings indicate that close work may have some significance in the trend towards myopia, although no explanation was proposed as to why a third of the monkeys in restricted environment showed no change.

In addition to primates, studies on children have been carried out to ascertain the way in which environment affects the eye, particularly in myopia. The results indicate that accommodation rather than convergence is primarily involved in the changes that take place. Bedrossian (1964) investigated the effect of the prolonged use of atropine in myopic children who were progressing at an average rate of two-thirds of a dioptre a year prior to the time of the study. He observed that the atropinised eyes either stabilised, or regressed approximately 0.25 D. When the atropine was discontinued the former rate of progress recommenced. Gostin (1964) in his study used scopolamine together with bifocals over a period of one year. Here again the progression towards myopia was halted whereas previously it had been increasing in all the children involved. Young (1967) points out that in such cases convergence is still being exerted in close work even though accommodation is eliminated. Accommodation is thus implicated in the refractive changes taking place. Sato (1965) believes that the process involved is one in which this accommodative effort brings about adaptive changes in the ciliary muscle which in turn accounts for the overall change in the power of the eye. Young (1968) is of the opinion that accommodation eventually leads to an increase in axial length. Whatever the actual process may be, if environment is indeed the determinant factor in changes in refraction, then this means that control of the environment could result in control of refractive development.

3.53 Numerous methods have been suggested for arresting the progress of myopia, yet ".....no single method of reduction or prevention of myopia has sufficient proof of its efficacy to justify its promotion as having general clinical use". (Baldwin (1967). The proponents of these methods would hasten to deny this statement, but one cannot overlook the fact that the rate of progress of myopia usually decreases as the child grows older. This occurs irrespective of the use or non-use of any "cure".

Young (1967a) states that it is environmental stresses that play the essential part in producing the shift from the "low plus errors to very low plus errors or to most of the low myopic refractive errors" (up to approximately 8.0 D). Studies on primates, suggest that up to three-quarters of refractive errors arise as a result of near environmental working conditions, and the accommodative effort involved. Morgan (1967), however, argues that if myopia develops as the result of the stress of accommodation and possibly convergence, then one would expect the hypermetrope to show greater changes than the myope as it is the hypermetrope who experiences the greater stress. If environment is the factor that determines such changes, then how is environmental stress related to those cases in which either the refraction remains unchanged or the shift is in a hypermetropic direction, away from myopia? Perhaps it is that the individuals involved have differing characteristics, some being predisposed to the shift that environment triggers off, others not. If this is the case then this predisposition has yet to be explained. Perhaps heredity is the governing factor?

3.54 The results of a study on twins carried out by Sorsby, Sheridan & Leary (1962) indicate that genetic factors are primarily involved in the development of refraction and its components. In 70.5 per cent of uniovular twins, ocular refraction corresponded closely - the difference not exceeding 0.50 D. This contrasted with 30.0 per cent for binovular twins, and 29.2 per cent for a control group. Similar differences were observed for the various components - corneal power, anterior chamber depth, curvatures and thickness of the lens and axial length. All refractive states, they concluded - emmetropia, the correlation ametropias and the component ametropias - are genetically determined. Environmental factors, whilst possibly having some influence, were thought unlikely to be a contributory factor. These findings were confirmed statistically by Sorsby & Fraser in 1964. A study of ocular refraction and its components among twenty-eight families carried out by Sorsby, Leary & Fraser (1966) revealed a substantial degree of correlation between parent and child. This evidence further supports the inheritance theory.

Although environment is widely held to be the major factor involved in the development of myopia, Goldschmidt's (1968) study suggests that its causes cannot simply be explained on an environmental basis. Goldschmidt contends that "genetic factors are of decisive importance in the aetiology of myopia", although he emphasises it is extremely improbable that all myopes have a common genetic background. He continues "It is likewise improbable that all myopia is genetically determined, since this hypothesis can hardly explain the very high frequency of myopia in certain occupations. A number of cases must, therefore, be environmentally determined ...." It is likely, he observed, that only a few cases of low myopia originate in this way; high myopia (above approximately 9.0 D) is, however, to a far greater extent, environmentally determined. In contradistinction to the majority of workers who have studied the problems of myopia and in particular "school" myopia, Goldschmidt expresses the view that low myopia developing during growth has its aetiology in the genetic substance and is not related to ordinary school work. On the other hand, myopia which develops after growth is of another type and is due to environmental influences. Having carried out statistical analyses of the results obtained by Sorsby, Sheridan & Leary (1962) he states ".....it seems reasonable to conclude that environmental factors have a greater influence on myopia than on hypermetropia".

Goldschmidt has attempted to look at both environmental and genetic factors in the one study and his contribution is all the more significant for his having done so. Young (1968) points out that unfortunately few investigators have examined both factors at the same time; the problems of such investigations may be insurmountable, yet without such an approach ".....no conclusions can be drawn or, rather, should be drawn". Goldschmidt has at least illustrated that the roles of environment and heredity are not irreconcilable, but may be correlated to a certain degree. The exact nature and extent of this relationship has yet to be resolved.

3.55 A number of other factors have been implicated as being involved in the refractive development of the eye. Studies on monkeys have shown that the level of illumination under which close work is carried out may be related to the development of myopia, intermediate levels tending to predispose to the greatest extent (Young 1967b).

Changes in myopia occurring in children were found by Gardiner (1954, 1955) to be closely related to bodily growth: it was also observed that these children tend to be heavier than non-myopes. In contrast, Sorsby et al (1961) found little association between such growth and changes in ocular refraction.

The effect of diet upon the refractive state of the eye in children has been studied by Sood & Gupta (1966) Their findings show that malnutrition produces a marked shift in the direction of myopia whilst improvement in diet reverses the trend. McLaren (1963), however, has shown that in experimental animals, at least as far as general malnutrition and protein deficiency are concerned, the eye is one of the most resistant organs to such adverse conditions. He regards as ill-founded the various theories and trials designed to control and influence the refractive condition of the eye by dietary means. McLaren points out that the eye receives preferential treatment for nutrients over most other organs when these are in short supply; "Once myopia, or any other refractive error has become established it is unlikely that it will be influenced by dietary or any other means". Goldschmidt (1968) nevertheless suggests that just as final height depends on nutritional conditions, so the growth of the eye is undoubtedly affected by many diseases and deficiences. He goes on to say "We cannot rule out either the possibility of such diseases and deficiences having a weakening effect upon the correlative processes, thereby promoting the development of ametropia in general, and they may conceivably also alter the rhythm without altering the final result".

Gardiner (1963) in a study of children attending a school for the physically handicapped, found that in those suffering with brain damage, hypermetropia is more common than in normal children, whilst in those physically handicapped from other sources myopia is more common. Both groups, he observed, have more refraction anomalies than normal children. Fantl & Perlstein (1967) also found that children with cerebral palsy tend to be hypermetropes, maintaining their degree of ametropia throughout the teens, as opposed to the normal pattern of development in which there is a definite decrease of hypermetropia. Their findings suggest that the higher degrees of hypermetropia are associated with brain damage. It appears, however, that an abnormal pattern of refractive development takes place only in those cases in which brain damage occurred before or around birth. On the basis of such results Gardiner (1963) questions the genetic explanation for the various refractive states as postulated by Sorsby, Sheriden & Benjamin (1962) and calls for further research in this field.

Incidence of strabismus

3.56 Although it is not the purpose of this thesis to investigate the incidence of strabismus in the population, it is nevertheless of value to review some of the relevant literature bearing in mind that the author's research has been concerned, almost entirely with the strabismic child.

Strabismus has been reported to be present in some 2 - 3 per cent of the population as a whole (Downing 1945, Crone & Velzeboer 1956, Molnar 1967). Among children variations have been found to occur with age. Barrie (1922) reported a figure of 2.01 per cent at the age of five years, increasing to 2.18 per cent at seven years and decreasing thereafter to 1.37 per cent at thirteen years. In a study of Danish children Frandsen (1960) found an incidence of 1.0 per cent at six months, increasing to a peak of 7 per cent at six to seven years, then declining to approximately 1.0 per cent at eighteen to nineteen years of age. Miller, Court, Walton & Knox (1960) studied the development of children in Newcastle upon Tyne during their first five years of life: persistent strabismus was observed in 4.7 per cent with a further 1.8 per cent having a history of intermittent strabismus. Adelstein & Scully (1967) discovered a similar incidence of 4.3 per cent at six years of age. Amongst kindergarten children aged between three and seven years, 2.4 per cent were found to have "marked" strabismus by Litvinova, Volokitenko & Pikalova (1964), whilst a figure of 2.0 per cent was reported by Mazepa (1967). A study of seven year olds revealed the presence of strabismus in 3.1 per cent, although 6.3 per cent had a history of established or suspected strabismus: little difference was found between sexes. (Kellmer Pringle, Butler & Davie 1966). Dobromyslov (1957) noted an incidence of 3.3 per cent among schoolchildren in general; this compares to Pilman's (1959) findings of 2.5 per cent. In a study involving National Servicemen aged between seventeen and twenty seven years, strabismus was observed in 4 per cent of all cases (Sorsby et al 1960).

Some specific regional variations have been recorded from time to time. Thompson (1924) found that in the counties of Lanark and Stirling 2.94 per cent of children aged five to six years had strabismus, compared to 3.2 per cent in the City of Glasgow, although such small differences are of questionable significance. He noted the incidence to be highest amongst children from poor background, it being almost twice that of other children. In a survey of 12,000 West Berlin children, four years of age, Scholz (1967) discovered that 7.4 per cent had strabismus, whereas in a comparable study undertaken in Kiel it was only 3.7 per cent.

Differences between sexes have been found but these are not very marked. McNeil (1955) reports that in the five to fifteen year age group strabismus is present in 2.9 per cent of females compared to 2.4 per cent of males; this cannot be regarded as significant. Frandsen (1960) found little difference between sexes.

The majority of all strabismic cases are convergent. Downing's (1945) survey indicates that 69 per cent are convergent with 31 per cent divergent. This compares with 94 per cent convergent and 6 per cent divergent, reported by Crone & Velzeboer (1956), a similar incidence being found by Adelstein & Scully (1967). Their results show that during the third year of life in which the incidence of onset was at its highest, 96.2 per cent were convergent (77.4 per cent unilateral, 18.8 per cent alternating) and only 3.8 per cent divergent (2.2 per cent unilateral, 1.6 per cent alternating).

Amblyopia has been recorded by Frandsen (1960) in approximately 60 per cent of all strabismic cases, whilst Crone & Velzeboer (1956) found its presence in 50 per cent of untreated cases of strabismus. Amblyopia is a serious complication of strabismus and requires treatment at the earliest opportunity. Its development must be avoided, particularly in the first five or six years of life. If it develops and remains untreated in this period, poor vision may become a permanent feature of the eye involved.

On the basis of a 2 per cent incidence of strabismus in the population, over one million persons in the United Kingdom have this condition. It is essential to establish the patterns of ocular change in such cases particularly in view of the fact that the extent to which the refractive error is corrected may have a distinct bearing on the course of treatment and prognosis in general.

It has already been shown how limited is our understanding of the refractive development in the child with strabismus. The outstanding need is to establish the pattern of ocular growth in such cases. It is essential, therefore, for research to be carried out in this direction rather than solely concentrating on the normal, non-strabismic, child.

Summary Point (3.49 - 3.56)

3.57

(I) Studies on the incidence of the various refractive states in the population show that myopia occurs less frequently than either emmetropia or hypermetropia (3.49).

There is considerable difference of opinion as to the nature of the relationships between these refractive states. Duke Elder (1949), Sorsby et al (1957), Heath (1967), Hirsch & Ditmars (1969) hold the view that simple myopia is no more abnormal than emmetropia and hypermetropia, and behaves no differently, whereas Young (1967) believes that the placing of refractive errors on a continuum is wrong (3.50).

(II) Research on the effects of environment in the development of refraction has been confined almost exclusively to myopia. The evidence from studies on both children and primates indicates that the trend towards myopia results from close work, accommodation being implicated as the causative factor rather than convergence. Attention is drawn to the fact that if environment is the determinant factor involved in refractive changes, then by controlling the environment refractive development can be controlled. Nevertheless, of the numerous methods which have been used to arrest the progress of myopia, there is insufficient proof of their efficacy to justify general clinical use. If accommodation is the prime factor, the uncorrected hypermetrope would be expected to show the greatest refractive changes. The question is raised as to how environmental stress is related to those cases in which refraction remains stationary or shifts in an hypermetropic direction, away from myopia. Is it that some individuals are predisposed to the refractive change that environment triggers off, and, if so, is the predisposition an inherited factor?

The study on twins carried out by Sorsby, Sheridan & Leary (1962) indicates, in contrast, that all refractive states are genetically determined, environmental factors being thought unlikely to be a contributory factor. Goldschmidt (1968) attempts to look at both environmental and genetic factors in one study and shows that both heredity and environment play a part, at least in myopia. He illustrates that their roles are not irreconcilable, but may be correlated to a certain degree. (3.51 - 3.54)

(III) Other factors have been implicated as being involved in the refractive development of the eye (3.55). Studies on primates indicate that the level of illumination under which close work is carried out is a factor in the development of myopia (Young 1967b). Bodily growth rate has been suggested as being involved but the evidence is not conclusive. Diet has been shown to play a part in producing at least temporary changes in refraction, but McLaren (1963) believes that nutritional factors play little part in the post-natal development of the eye. There is evidence pointing towards brain damage as being a causative factor in cases of hypermetropia.

(IV) Studies of the incidence of strabismus have shown that it is present in 2 - 3 per cent of the population as a whole The incidence amongst children has been shown to be as high as 7.0 per cent, but figures vary considerably. The incidence, however, has been found to diminish with age. The majority of strabismic cases are convergent. Amblyopia is reported as being present in 50 - 60 per cent of all cases (3.56). Attention is drawn to the need to establish the patterns of refractive development in such cases.

SUMMARY

3.58 This review of literature has intentionally encompassed a wider field than is covered by the research itself. It is felt that it would be helpful to have the broad background presented to refractive development in children generally, rather than simply the work previously carried out in the field of refractive changes in the strabismic child. The review does not present contributions in a simple chronological order, but groups the relevant material into certain basic aspects in order to obtain a more coherent approach to the subject generally.

Donders established hypermetropia and astigmatism alongside myopia, as anomalies of refraction, although he viewed all ametropias as axial in origin. He was shown, however, to be incorrect in his rigid axial theory. Widespread support was to be found for his view that myopia and hypermetropia were unrelated, and that a hypermetropic eye could not become myopic. Zentmayer stood alone in 1911 in stating that the eye could change refractively in any direction.

Studies on the refractive state of the newborn, although inconsistent in their findings, all show that the majority of infants are hypermetropic at birth. Goldschmidt (1969) discusses the possible explanation for such inconsistencies and suggests variations in degree of maturity as being a factor.

The data on refractive changes in the period immediately after birth, indicate that the changes are marked and are in a hypermetropic direction. After the age of three years there is a period of much slower, but definitive growth.

The findings of Brown (1938), later supported by Slataper

(1950), indicate that in the first six years of life an increase in hypermetropia is the rule, thus conflicting with the previously widely held view that the reverse pattern is the rule. Brown failed to examine the causes of this fundamental discrepancy.

The limited number of studies of the refractive changes in strabismic children have failed to establish conclusively, the patterns of development in such children owing to the divergence of their respective findings.

Sorsby et al (1961) show that amongst "normal" children between the ages of three and thirteen years ocular refractive changes are in a myopic direction. The possibility of changes in an hypermetropic direction is not discussed, although the findings of Sorsby & Leary (1970) indicate that such development does take place.

Astigmatism has been shown to either increase, decrease, or remain unchanged. Changes are most marked in the period up to seven years of age.

There is far from universal support for the view expressed by Hirsch (1964c), that development of any refractive state appears to be unaffected by the extent to which the error is under, over, or fully corrected.

The evidence concerning the development of anisometropia indicates that it is not present at birth. Keiner's (1968) results suggest that amblyopia might be a causative factor.

There is little evidence to suggest refractive differences between the sexes.

No data is available on the effects of surgery upon refractive development in the strabismic child.

The role of the refractive components of the eye in the variations in refraction occurring with age has been examined. It has been demonstrated that a correlating mechanism exists which determines the relationships between the components, thus showing Steiger's assumption of a free interplay between the components, to be incorrect.

Sorsby et al (1957) examined the effect of the correlating mechanism upon refractive development. They postulated that the retina is the "organiser" of emmetropia, determining the correlating mechanism involved. Franceschetti & Luyckx (1967) and Gernet & Olbrich (1968) suggest that the crystalline lens plays a decisive role in the production of emmetropia.

Studies on the rabbit indicate that changes in the components initially produce an hypermetropic increase, followed by a decrease, after which the refraction remains stationary.

Longitudinal study of the changes in components occurring in the first year of life, shows that reduction in the total power of the eye and in the power of the lens, over-compensates for axial elongation, resulting in an increase in hypermetropia.

It has been shown that ocular growth takes place in all meridians of the eye, not solely along the anterior - posterior axis. Analysis suggests that the different rate of growth of the principal diameters results initially in an increase in hypermetropia, followed later by a shift towards myopia.

The incidence of the various refractive states in the population, as well as their inter-relationships, has been examined.

Numerous studies have shown environment to be a factor in the development of refraction, particularly myopia. Close work, and accommodation in particular, is considered to be of importance. In contrast heredity and not environment is stated to be the determinant involved, (Sorsby, Sheridan & Leary 1962). Goldschmidt (1968), however, suggests that the two roles are not incompatible, as has been inferred. Illumination, body growth, diet and brain damage, have all been implicated as causative elements.

Finally, the incidence of strabismus has been described. Studies show variations from 2 - 3 per cent in the population as a whole,and as high as 7.0 per cent among some groups of children. Amblyopia is present in 50 - 60 per cent of all cases. The need to establish the patterns of refractive development in such case is clearly underlined, thus providing strong support for the author's reasons for studying this group of children.

4. RATIONALE AND HYPOTHESES

Rationale

4.1. The importance of ocular development occurring in childhood has long been recognised and has led to considerable research being undertaken. This particular study was stimulated by the results of such research and by a knowledge of some of the outstanding problems involved.

The provisions title of this thesis - "Physiological Variations in the Refractive State of the Human Eye during the Formative Years - a longitudinal study", reflected the original intention to investigate the refractive development of children in general. It became obvious, however, that as the majority of the subjects involved were found to have strabismus, the study should be directed towards identifying the characteristics of ocular growth of the strabismic type of child.

The literature on refractive changes was found to contain relatively little information on the characteristics of strabismic children, and this emphasised the need to concentrate attention specifically on this group. The final title of the thesis, "Changes in Ocular Refraction in the Strabismic Child - a longitudinal study", underlines its main aim; that is, to determine the pattern of refractive changes in the child with strabismus and to investigate the factors influencing this development.

4.2 The underlying motive for this research was that it should add to the body of existing knowledge concerning the refractive development of children in general, and the strabismic child in particular; further, that it should be of value to those concerned with the welfare and education of children. Although many questions require investigation, it was one in particular - the effect of spectacle correction upon refraction during growth - that prompted the investigations leading to this research project. Lyle (Worth and Chavasse's Squint 1950) in dealing with the developmental control of errors of refraction, and the strength of glasses to be ordered, stated:

> "When prescribing spectacles for a growing child, it should be borne in mind that the normal developmental changes in the refraction of the eyes are probably influenced by the use of these optical aids ......there is a possibility that the wearing in childhood of a "correction" for a normal degree of hypermetropia may influence adversely the attainment of adult emmetropia".

The author had accepted, almost without question, the view that as a direct result of fully correcting young hypermetropes, the hypermetropia will not normally decrease with age, and in this respect their development differs from those under-corrected or without any correction at all.

A number of fully-corrected cases, however, were seen, in which a reduction in the degree of hypermetropia did in fact occur; a note of these was, therefore, made for further follow-up. Unfortunately, no details were taken of the majority of cases showing different patterns of change, such as hypermetropic increase, as these were regarded as following a normal pattern of growth. At this stage no formal research was being undertaken or even envisaged.

4.3 In 1961, Sorsby et al published their notable report on Refraction and its Components during the Growth of the Eye from the Age of Three: this indicated that, amongst normal children, a decrease in hypermetropia may be expected during this period of life. Whilst they did not examine the effect of spectacle correction upon refractive state of the eye, their findings did at least suggest that reduction in hypermetropia, occurring in some fully-corrected patients, might not after all be related to the degree of correction being worn. A subsequent search of the literature on the effect of spectacle correction, indeed revealed little evidence to support the theory that fully-corrected young hypermetropes differ in development from those under-corrected.

The conclusions of Sorsby et al, concerning the patterns of refractive change with age raised questions as to the validity of the author's finding of an hypermetropic increase in a number of patients. The cases recorded by the author up to this stage were, within the group of strabismic children, undoubtedly highly selected, and, as a consequence, no conclusion could be drawn. It was decided, therefore, to carry out a pilot survey on a follow-up basis, of all the refractive changes occurring in the children being examined. Control of working conditions was required in order to ensure that the results could be related to each other: accommodation factors were eliminated in all cases by the use of cycloplegics, whilst in order to reduce observer error to a minimum, only those patients examined by the author were included. In view of the fact that a longitudinal rather than a cross-sectional basis was being used to study the individual variations taking place, at least two examinations on each patient were required. The refractive changes were simply graded qualitatively on a scale indicating the direction of change, - increased positive, no change, decreased positive (+, 0, -).

The results of the survey indicated that the previous findings had been reasonably correct; that amongst these children, most of whom had strabismus, there were a considerable number showing an increase in hypermetropia. Nevertheless, in the report of Sorsby et al (1961) on normal (non-strabismic) children, no reference whatsoever was made to the possibility of an increase in hypermetropia as being one of the expected patterns of growth; the refraction, they stated, could be expected, either to remain stationary, or to show an hypermetropic decrease or myopic increase.

4.4 There was an obvious need to study the refractive changes occurring in these children, and to find an explanation, if possible, for the apparent difference between the author's preliminary results and the findings of other workers in this field, such as Sorsby et al (1961). It was also obvious, from work previously carried out, that a longitudinal study would provide the maximum information concerning the important individual variations taking place, although it was recognised that such studies are more time-consuming than their cross-sectional counterparts.

The question arose as to the form the investigation should take; whether it should be prospective, in which only future developments would be taken into account, or retrospective, in which the considerable quantity of data already recorded would be used, although, unfortunately, this data was not readily accessible. Prospective studies, undoubtedly, have the advantage that they can be planned and controlled in a manner which is not possible in a retrospective study, and as a consequence they will, in general, be the "method of choice". It may not, however, be a practical possibility for a number of reasons, as was found to be the case here.

In the first place the time scale necessary for a prospective longitudinal study was clearly prohibitive, particularly bearing in mind that some four years had elapsed since these children were first examined. In the second, account had to be taken of the fact that the author was attempting to carry out research whilst fully employed in a non-research post, and was without assistance throughout a major part of the clinical and clerical side of this work. In this situation, a retrospective approach was the only possible course of action.

4.5 The subject matter on which this research is based, is unquestionably highly selected; it has already been shown how this situation arises (1.3). Whilst children with strabismus, undoubtedly, form only a small proportion of the total population they nevertheless constitute an extremely important group. The formative years, from birth up to the age of five is an especially critical period as far as the development of vision is concerned; lack of treatment or even incorrect diagnosis, at this stage, may result in the development of uniocular amblyopia, in which critical vision of one eye is effectively lost.

Correction of refractive errors, either in part or in full, is generally regarded as part of the treatment; yet despite the fact that the refractive state of the strabismic child is usually determined at reasonably regular intervals, all too little is actually known about the patterms of refractive change that may occur in such children. Undoubtedly, the more information that is available concerning the behaviour of the strabismic type of eye, and the factors affecting it, the better the outlook for the child. Hence the need for further study in this direction.

4.6 To summarise then, the rationale of this thesis is to carry out an exploratory investigation into patterns of refractive change taking place in the strabismic child and to examine the factors which are related to such change. It is an attempt, to find the answers to some outstanding problems, and to identify areas for further research.

4.7 The use of modern methods of data processing have increased vastly the potential of this research beyond that possible prior to the introduction of computer techniques.

Nevertheless, its scope has been determined in large measure by the limited assistance available to the author.

Certain obvious questions need to be answered - others are not so obvious; but all stem basically from the central question: What are the patterns of refractive development in the strabismic child? Although a number of hypotheses have been proposed, it has not been possible to investigate them all, in view of design limitations of the research programme itself, and in some cases, lack of data; they are, nevertheless, listed because they represent the problems and questions which have been encountered, whilst working in clinical practice; they are, in themselves, an important by-product of such field experience.

Hypotheses

4.8. All these hypotheses are related to children with strabismus unless otherwise stated.

1. Refractive changes in children alter in character as age increases.
2. The initial refractive state determines the subsequent type and degree of refractive change, and, therefore, the final refractive state.
3. Refractive changes continue in the same direction as age increases; that is, final change is in the same direction as initial change.
4. Refractive changes in right and left eye are dissimilar, but become equalised with age.
5. Refractive changes in children with strabismus differ from those without strabismus.
6. Refractive changes in the strabismic eye differ from those in the fixating eye.
7. Refractive changes are related to the type of strabismus present.
8. Initial refractive error in strabismic cases determines the refractive change to a greater extent than the error in non-strabismic cases.
9. Refractive changes are related to the angle of strabismus.
10. Refractive changes are determined by the extent to which the refractive error is fully corrected or under corrected.
11. Surgical intervention influences the type and degree of refractive change.
12. The larger the initial refractive error, the greater the effect of surgery upon refractive change.

13. Surgery on one eye only affects both eyes equally in relation to refractive changes.
14. The level of astigmatism is related to age.
15. Initial degree of astigmatism is related to the degree of spherical error.
16. Initial astigmatism determines the type and degree of overall refractive change.
17. Initial astigmatism determines the subsequent type and degree of astigmatic change.
18. Strabismic eyes have a greater degree of astigmatism than non-strabismic eyes.
19. Astigmatic changes are greater in strabismic eyes than in non-strabismic eyes.
20. Changes in astigmatism are greater in cases of surgical intervention than in non-surgical cases.
21. Axis changes in astigmatism are related to age.
22. Axis changes in astigmatism are related to the initial degree of astigmatism.
23. Axis changes in astigmatism are related to dioptric changes in astigmatism.
24. Axis changes in astigmatism are greater in strabismic eyes than in non-strabismic eyes.
25. Axis changes in surgical cases are greater than in non-surgical cases.
26. Anisometropia decreases with age.
27. Changes in anisometropia are determined by the initial level of anisometropia.
28. Changes in anisometropia are related to surgical intervention.
29. Patterns of refractive behaviour are related to sex.

5. METHODS AND PROCEDURES

5.1. Although the children involved in this study had much in common - they were all hospital out-patients and the majority had strabismus - they differed in a number of respects. Their ages at the time they were first seen ranged between less than one year and thirteen years. The frequency of visits and intervals between refractive examination also varied from child to child, these being determined by such factors as age, parental co-operation, nature of strabismus and treatment. In this situation it was impractical to employ subjective methods as a means of assessing refraction, particularly for the younger age groups; consequently retinoscopy was used exclusively to assess the refractive state of the eye. In order to eliminate variations due to accommodation, refractions were carried out under cycloplegia. Examinations without cycloplegia were included only where it could be verified that accommodation was not a factor in the results obtained: this involved examinations on only sixteen eyes out of a total of 891 (Table 11).

Methods of examination

5.2. The cycloplegic agent most commonly used was Atropine Sulphate ointment I per cent, particularly for the group up to seven years of age. Homatropine Hydrobromide solution 2 per cent was also used, either on its own or combined with cocaine I per cent. From I960 onwards Cyclopentolate Hydrochloride I per cent solution (Mydrilate) was increasingly employed, in view of its ease of use and effectiveness, and eventually almost replaced Homatropine as a cycloplegic agent. Tables II and I2 illustrate the use of the various cycloplegics within each age group both at the first and the subsequent examination.

Atropine is the strongest cycloplegic agent available (Mitchell I959): none of the numerous comparative studies that have been undertaken have shown a more effective cycloplegic than this. Marron (I940) in a study of three drugs (Atropine Sulphate I per cent, Scopolomine Hydrobromide 0.5 per cent and Homatropine Hydrobromide 5 per cent, Paredrine I per cent combination, all in solution) - found the average cycloplegic effect to be similar in each case, although their rate of action differed: Scopolomine was the fastest and Atropine the slowest. Nevertheless, Homatropine has been stated by various authors, to be less effective than Atropine. Buckley and Ogle (I953), however, contend that Homatropine cycloplegia is complete, and that the various figures given for residual accommodation are based upon measurement errors. These errors arise, they believe, from the problems of interpreting the blur

TABLE 11

Method of examination - use of cycloplegics

Analysis by cycloplegic agent and age - initial examination

Distribution within each age group - per cent

Cycloplegic Agent	Age (years) less than													All ages
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Atropine	100	94.4	100	93.7	96.6	81.2	88.9	63.0	37.8	28.6	33.3	16.7	0	82.4
Homatropine	0	0	0	0	3.4	16.7	7.4	25.9	56.8	71.4	50.0	83.3	100	13.8
Cyclopentolate	0	5.6	0	6.3	0	2.1	3.7	11.1	5.4	0	16.7	0	0	3.8
Nil	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. of eyes	4	36	67	127	116	96	54	54	37	14	12	12	2	631

TABLE 12

Method of examination - use of cycloplegics

Analysis by cycloplegic agent and age in years - subsequent examination

Distribution within each age group - per cent

Cycloplegic Agent	Age less than																All ages
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Atropine	0	100	100	100	87.0	72.5	58.3	51.5	34.5	28.9	22.2	18.2	20.0	0	0	0	55.3
Homatropine	0	0	0	0	2.2	11.6	10.6	13.2	23.6	15.8	27.8	24.2	40.0	27.3	0	0	13.2
Cyclopentolate	0	0	0	0	10.9	14.5	27.8	33.8	40.0	52.6	50.0	57.6	20.0	72.7	100	50.0	29.5
Nil	0	0	0	0	0	1.4	2.6	1.5	1.8	2.6	0	0	20.0	0	0	50.0	1.8
No. of eyes	0	4	28	47	92	138	151	136	110	76	36	33	10	22	4	4	891

point, which is aggravated by such factors as depth of focus of the eye and size of target. Hyoscine solution 1/20 per cent has also been shown, by Sorsby, Sheridan, Moores & Haythorne (1955) to be as effective as, but no better than, Atropine 1 per cent, although Mitchell (1959) did not find Hyoscine in this concentration to be as good a cycloplegic as the results of Sorsby et al indicate.

Cyclopentolate Hydrochloride has been used widely in recent years and has tended to replace Homatropine as a cycloplegic, mainly because of its speed of action and rate of recovery. Many comparative studies involving this drug have been carried out, but the one of Robb & Petersen (1968) is of particular interest, confined as it is to the important age group - under six years - in whom accommodation is most active. The children were first examined with 1 per cent Cyclopentolate Hydrochloride solution, and then some weeks later with 1 per cent Atropine ointment or 1/8 to 1/2 per cent solution. In hypermetropic children, Atropine uncovered from one-third to one-half dioptre more hypermetropia by retinoscopy than Cyclopentolate. In myopic children, no signifcant difference was found in the results.

The difference found in hypermetropic cases could be, and indeed has been, explained by the greater relaxation of tonus in Atropine cycloplegia. It has been estimated that tonus accounts for 1.0 D in Atropine cases and only approximately 0.5 D with Cyclopentolate. (Tonus with Homatropine is usually regarded as 0.75 D). It should be borne in mind that such figures are only estimates and that different figures (lower) have been variously given for both Cyclopentolate and Homatropine. Adjustments for tonus would produce a similar if not identical result by the two methods.

5.3. Instillation of Atropine ointment was generally carried out at home by the parents involved. The normal routine was twice daily for three days prior to, but not on, the day of the appointment. Homatropine and Cyclopentolate, both used in solution, were instilled in the clinic itself, approximately one hour prior to the examination, although this period was often considerably extended, owing to the numbers of patients requiring examination. The standard dose for Homatropine was three drops at ten minute intervals, whilst for Cyclopentolate only one or two drops were required.

Pupil reactions were used as a gross check on the effectivity of the instillation, always bearing in mind that full mydriasis does not necessarily indicate cycloplegia is complete. As the majority of subjects were too young to have their accommodation measured quantitatively, residual accommodation was assessed by noting any variations in reflex movements during retinoscopy. Where accommodation appeared to be active, or any doubt existed as to the depth of cycloplegia obtained, the patient was re-examined after the use of further cycloplegics.

5.4. As has already been pointed out, many children were too young to respond reliably to a subjective examination and, therefore, the assessment of ocular refraction was based solely upon retinoscopy findings (5.1). A spot retinoscope with an internally illuminated near fixation target was used for this purpose, the children being directed to look at this target. The room was, in most cases, darkened completely in order to avoid any distracting influences, so that the only point for fixation was the light from the retinoscope. In addition, to assist in maintaining the attention of the very young, a glove puppet was utilised to hold the retinoscope itself; this method of approach has already been described (1.4).

In the majority of cases the eye not under examination was occluded, to ensure that retinoscopy was being carried out along the visual axis. This was particularly important in view of the presence of strabismus in so many children. In those cases where poor or eccentric fixation was present, the better eye was used to fixate a target other than the retinoscope light, so arranged that the eye being examined was straight relative to the examiner. Where possible an adjustable trial frame was used, but where a child was apprehensive about having such a frame upon its face, the lenses were simply held in front of the child's eyes. The final lenses were then inserted into a trial frame which was held in situ, briefly, in order to assess the result more accurately. This, however, was not always possible. A standard working distance of half metre was used for the majority of children. This ensured greater control of the child than was possible at the normal, adult, distance of two-thirds metre.

5.5. As cycloplegics were being used, allowance for relaxation of tonus of the ciliary muscle had to be made. This varied according to the type of ametropia present. In the case of hypermetropia a standard allowance for Atropine of 1.0 D was generally made; for Homatropine or Homatropine and Cocaine, 0.75 dioptre, whilst for Cyclopentolate 0.25 dioptre. With regard to myopia, as innervational tonus is usually lower than in hypermetropic cases (Mitchell 1959), allowances were generally reduced to 0.50 D or 0.25 D and nil for Atropine, Homatropine and Cyclopentolate respectively. Undoubtedly, tonus is not a constant factor for all eyes and errors must, therefore, arise here. As the allowance, however, was kept constant for subsequent examinations the errors will be reasonably constant and will tend to cancel themselves out. It must, nevertheless, be borne in mind that the tonus factor may change with age; to assess this presents considerable problems and must be regarded as outside the scope of this project.

To arrive at the spectacle refraction 2.0 dioptres for the working distance, together with the allowance for tonus, had to be deducted from the retinoscopy findings; thus for hypermetropes under Atropine cycloplegia, 3.0 dioptres would be deducted. For the purpose of this research results were converted to ocular refraction. The mean back vertex distance was found to be 10 mm and ocular refraction was calculated from this figure.

The use of a constant back vertex distance undoubtedly gives rise to a source of error for in practice this measurement varied between 8 and 12 mm approximately. The error, however, only becomes significant at the 0.25 D level in the higher ranges of refraction. The highest degrees of ametropia found were + 10.25 D and - 8.75 D and for such levels the back vertex distance was checked to ensure that it was the same on the various occasions the child was examined. Allowing for a possible variation of 2 mm in the distance recorded this would produce differences in ocular refraction of approximately 0.25 D for a spectacle refraction of +10.25, and 0.15 D for a spectacle refraction of - 8.75 D. It is clear from this that changes in refraction of up to ±0.25 D must be regarded as falling within the scope of experimental errors and, therefore, not significant.

Selection factors

5.6 Observer errors present considerable problems in a study of this type. Precise evaluation of changes in refraction presupposes that the state of refraction is accurately assessed at each examination or, at least, the inaccuracies associated with such measurement are constant throughout the study. If the degree of accuracy varies appreciably from one examination to another, then the findings must be regarded as of doubtful significance. It is, therefore, essential to standardise each examination as far as possible, thus providing a base line from which the findings can be meaningfully interpreted. Unfortunately, the standards adopted by the various practitioners working in the hospital resulted in so many variables that it was not possible to draw any conclusions with regard to the patterns of refractive change in such eyes. A reliable base line could only be established by ensuring that all refractions were carried out by the same individual. This meant that only those children who had been examined by the author himself, on at least two occasions, could be included in the study. In those cases where a child had been examined by another practitioner, the findings of that particular examination were ignored unless checked by the author. As a result, fewer cases were available for analysis than would otherwise have been the case.

5.7. The adoption of this procedure introduced a very definite selection process. This in turn was aggravated by the numbers of patients attending each clinic. These were such that it was not possible for the author to examine all the children involved: new patients tended to be directed to him for examination rather than being evenly distributed amongst the staff in the clinic. It was possible, therefore, that the children included in the study were not representative of the sample attending the hospital.

In order to assess the extent to which a selection process was at work, a small survey was carried out with a view to ascertaining the age and state of binocular vision of every child attending the ophthalmic clinic during a period of two weeks. This was undertaken in July 1968. As with the main investigation, any child showing pathological abnormalities was excluded. The findings were analysed on the basis of age and the type of strabismus present, and the results compared with the main sample. The ages were grouped on a yearly basis up to thirteen years whilst those above this age were grouped together. Binocular vision was analysed on the basis of four groups:

(a) convergent strabismus

(b) divergent strabismus

(c) vertical strabismus

(d) nil strabismus.

The findings are shown in tables 13 and 14.

Both of these reveal considerable differencesbetween the two groups. This is particularly marked for the distribution of strabismus. The Chi-square test shows that in both cases these differences could not have arisen by chance. Results of the analyses are as follows:

Age distribution:

$\chi^2 = 245.067$

(degrees of freedom = 13)

$\rho = < 0.001$

State of binocular vision:

$\chi^2 = 174.685$

(degrees of freedom = 3)

$\rho = <0.001$

It is obvious that the sample of children included in this investigation cannot be regarded as truly representative of the children attending this hospital. Whilst undoubtedly the selection factors already described must be playing a decisive role in producing this state of affairs, the possibility should also be borne in mind that the survey sample itself may not represent a true cross-section of young patients attending the clinic over the whole year. This could only be clarified by further random surveys at different times of the year. Nevertheless, the results of this study will still provide valuable data on the growth patterns of strabismic children, although care will have to be taken in drawing conclusions about the strabismic population as a whole.

5.8. Selection factors always present problems in studies of this type and this is especially so in follow-up studies. Patients attending a hospital clinic present a highly

TABLE 13

Age distribution of children within control and study groups

Analysis by group and age in years

Distribution within each group - per cent

Group	Age less than 1	2	3	4	5	6	7	8	9	10	11	12	13	No. of eyes
Control	3.24	6.94	7.41	8.8	10.65	6.48	6.48	8.8	7.41	6.94	5.09	5.56	10.65	432
Study	0.45	4.49	9.76	16.27	18.63	16.61	10.33	9.88	6.85	2.69	1.80	2.02	0.22	891

TABLE 14

State of Binocular Vision within Control and Study Groups

Analysis by group and type of strabismus present

Distribution within each group - per cent

Group	Convergent	Divergent	Strabismus Vertical	Nil	Nos. of eyes
Control	60.65	6.48	1.39	31.48	432
Study	90.8	1.79	0	7.41	891

selected sample in themselves and can never be regarded as representative of the normal population. Sourasky in 1928 drew attention to this problem and its implications. He observed that children seen in a school clinic comprise selected cases -

> "that have found it necessary to maintain attendance; if a low hypermetrope has an extensive reduction of his hypermetropia he becomes a myope and thus remains under observation, and any further progress is regarded as the progression of the myopia - but if a medium or a high hypermetrope has his hypermetropia reduced extensively, he finds he can see better and quite comfortably without his glasses and simply discards these, and is no longer seen in the treatment centre. It is, therefore, not surprising that in a 'follow-up series' there should be comparatively little direct evidence of a rapidly diminishing hypermetropia..."

Sourasky's observations highlight the manner in which self selection operates; it should, nevertheless, be appreciated that its effect may be felt in other ways. For example, the hypermetrope and the myope who show no change in their refractive state, are less likely to attend for re-examination than those in whom the ametropia alters. In these circumstances, amongst clinic patients one may reasonably expect to find fewer cases remaining stationary than normal.

It can be seen, therefore, that self selection processes in longitudinal investigations tend to be very marked; - patients with refractive problems are most likely to return whilst those without, tend to fall away. In the case of strabismic subjects, however, this situation does not arise to such an extent since the motivation for continuing to attend is the strabismus rather than the refractive error, this being a secondary factor. A follow-up study of refraction in the strabismic child is, therefore, less likely to be affected by the selection processes normally at play with clinic patients; certainly the need, or otherwise, for spectacles is unlikely to determine the attendance rate in such cases.

Experimental errors

5.9. Standarisation is essential to this type of study and this requirement has already been emphasised (5.6). Experimental error - both human and instrumental - can produce completely erroneous results: therefore errors arising from these causes must be recognised, and attempts made to assess their extent. This is particularly so in relation to changes in refraction. Accurate assessment of the degree of ametropia by retinoscopy depends, in part, upon a constant known working distance. Should this distance be altered, compensation must be made in calculating the results otherwise these will be incorrect. If the working distance for one particular subject is assumed to be 0.5 metre on two separate occasions, but in practice is inadvertently increased on the second occasion to 0.67 metre, an apparent change in the refractive error of 0.50 D will be recorded: this will be due solely to the change in working distance. In order to avoid this error arising the working distance must be checked at each examination.

Even though one examiner may be carrying out all the measurements involved, considerable variations may still arise. Each examiner will work within his own limits of tolerance, and this factor will determine the degree of accuracy to which findings can be repeated. This in turn will partly establish the level at which changes can be regarded as real. It is, therefore, necessary to assess the experimental error associated with the method of working employed - in this case by the author.

To measure the accuracy of a retinoscopic examination, it is necessary to have an absolute result as a base line, against which one can compare other findings. Unfortunately this is not really feasible when dealing with living subjects who in themselves are variable. No matter how efficient a practitioner, his results could never be regarded as absolute, for individual interpretation will always play its part. The only practical way to establish a base line is to determine the extent to which the findings of one examiner vary when repeatedly examining the same patient. Care must be taken to avoid alterations in the state of refraction occurring during the assessment, and, therefore, such a procedure must be completed in a relatively short period of time. This necessitates a "blind" approach in which all normal clues are removed and in which no information is passed to the examiner at any stage of the examination.

An experiment was, therefore, designed to assess the experimental errors associated with the author's retinoscopy technique. Two subjects were presented for examination, care being taken to ensure that no details of visual acuity, symptoms or history were available. The examiner was not permitted to view the uncorrected retinoscopic reflex nor to have any knowledge of the lens powers being used during the examination since this would have provided clues concerning the ametropia and may have biased the results when repeating the examinations. The following procedure was, therefore, adopted. "Dummy" trial lenses were inserted into the trial frame by an assistant prior to the commencement of each examination, care being taken to ensure that any markings on these lenses were obscured. The trial case itself was removed from view throughout the experiment, whilst retinoscopy was carried out with the examiner, having interpreted the reflex movements, stating the alteration in lens power required. The lenses themselves were then changed by the assistant, who in turn recorded the results of each examination after the examiner had indicated when he considered the "reversal point" had been reached. The procedure was repeated twenty times on both subjects, using different dummy lenses on each occasion. Throughout the experiment care was taken to avoid comments being made concerning the spread of the results being obtained.

Analysis of results revealed a maximum variation on the sphere of ± 0.12 D from the mode and a standard deviation of ±0.06 from the mean; similar findings were obtained for the power of the cylinder. The axis varied by $\pm 5^{\circ}$; it should, however, be noted that the axis markings on the lenses could not be obscured from view, thus providing clues during the assessment of the astigmatic error which did not arise when assessing the spherical error.

Although this method of approach provides a reasonable measure of the human experimental errors associated with a particular clinical routine, it does not take into account certain factors, such as fatigue, which arise during normal clinical conditions. Fatigue affects both patient and examiner: its effect, however, is difficult to assess since it is a variable factor, although there can be no doubt that it influences ability to correctly interpret retinoscopic findings. What is certain is that examiner fatigue during this experiment is unlikely to have been the variable that it is under normal conditions, in view of the fact that the examinations were carried out over a relatively short period. On top of this, the two subjects involved were unusually co-operative compared to the average young patient. The errors are, therefore, likely to be somewhat greater than indicated here. Nevertheless the results do provide a useful guide as to the dividing line between real and false changes.

It can be seen that refractive changes of ±0.25 D cannot be regarded as significant in view of the experimental errors involved. Changes in spectacle refraction of less than ±0.50 D have consequently been classified as "no change". When converted to ocular refraction this beco0.32±0.38 D at the highest levels of ametropia recorded in this study. "No change" in terms of ocular refraction constitutes anything less than ±0.38 D.

0.33

Data Retrieval

5.10. The advantages and disadvantages of retrospective studies were discussed in section 4.4, as were the reasons for adopting a retrospective rather than a prospective approach in this work. Although much of the necessary data had already been recorded, its retrieval presented considerable problems. The hospital record system did not readily lend itself to this task. Whilst a classification system, designed for the retrieval of data, was in use, the major problem stemmed from its being based upon a simple manual system in which no cross-referencing was employed. Thus, although refractive errors and strabismus were coded, it was not always possible to identify whether or not the case had been entered elsewhere. The coding system did not provide any means of ascertaining the age of the patient concerned, nor who had carried out the examination. The only possible way to find the necessary information was to examine all the record cards with the relevant codings, necessitating a search through every appropriate card in use over a period of five and a half years. Each record then had to be checked to eliminate adults and to determine whether the author had examined the patient concerned, on at least two occasions. The relevant data were then transferred to specially designed record sheets. Care in the transference of such data was essential to avoid duplication arising in those cases where more than one coding had been used.

This stage of the study took more than eighteen months Over 15,000 records were examined in detail, a task which had to be carried out largely without assistance. The final number of cases from which follow-up data could be extracted totalled 317.

Exclusions

5.11. It is necessary in studies of this kind to define the terms of reference and to specify the subject matter to be included and excluded in the investigation. The problem concerning which cases to reject is a difficult as well as a controversial one, and is likely to remain so until the nature of emmetropia and ametropia is finally resolved. In the meantime, the decision on the type of cases to be excluded must be taken at an early stage of the investigation; in this respect the present study was no exception.

The criteria for exclusions vary from study to study. Sorsby et al(1957), for example, rejected cases on the basis of the level of ametropia present; subjects with ocular refractions of more than ±8.0 D, astigmatism of more than 2.0 D or astigmatism exceeding the sphere portion of the refraction, and anisometropia of 1.0 D or more, were all excluded. They considered such cases to be abnormal, but failed to explain why. As a result of this approach, the paradoxical position exists in which little is known about the behaviour patterns of the very group whose ametropia is such as to necessitate attention at reasonably regular intervals during youth, and possibly throughout life.

In most studies, pathological cases have been separated from the non-pathological. Since this division is well defined it was accepted as the sole criterion for making exclusions. Subjects with obvious developmental or structural abnormalities of the eye as a whole, such as microphthalmos and buphthalmos were excluded as were those with anomalies of the media and retina. The presence of normal media and fundi was used as one of the criteria to determine whether the case could be included in the investigation; myopia was thus classified as pathological, not by the extent of the refractive error, but by the presence of degenerative changes in the retina. Paretic anomalies such as non-comitant strabismus were also regarded as abnormal as were cases of nystagmus.

The information finally extracted from each patient's record was as follows:-

Hospital index

Sex

Date of birth

Intervals between refractive examinations

Cycloplegics used

Retinoscopy results

Details of spectacle correction prescribed

Strabismus or heterophoria - classified according to type

Angle of strabismus before treatment

Treatment - surgery, orthoptics, or both

Examiner

Methods of analysis

5.12 Longitudinal studies of refraction present a considerable problem in terms of analysis of results. Hirsch (1961) drew attention to this, and, indeed, it is reflected in the numerous methods which have been used from time to time. The difficulties arise from the fact that each subject has two eyes which do not necessarily behave in an identical manner, on top of which most eyes are astigmatic. The problem is further aggravated if the intervals between examination are not constant and the ages at the commencement of the study are not uniform.

In the ideal investigation a sample of children, all of the same age, would be followed up at regular intervals as they grow older. Unfortunately, this was not possible, here, as the children involved were attending hospital for treatment rather than for the purposes of this study. The use of the retrospective approach in turn, also helped to produce a sample having far from uniform characteristics, particularly with regard to age and intervals between examinations.

Although the majority of children were initially in the three to six year age group, their ages ranged from less than one year to thirteen years when they were first examined for the purposes of this investigation (5.1). The problem was further complicated by the fact that whilst some children had never been previously examined, others had been seen prior to the commencement of the study, and in some cases were already wearing spectacles and under treatment.

Intervals between examinations also varied considerably from less than six months to over five years. Similarly, the number of examinations carried out on each child was not constant: all had a minimum of two, but some had only two whilst others had as many as five. The distribution is shown in table 15.

As with previous studies, analysis of the available data presented many problems, these being greatest in those cases where more than two examinations had been carried out. Analysis is unquestionably easier where only an initial and a final examination are involved, since the intervening changes are occurring over a single period in time, rather than a number of periods as is the case when results from more than two examinations are available. The problem that had to be resolved was how to handle the data from subjects having three, four or even five examinations. Bearing in mind the fact that some children had been examined prior to the commencement of the study, it was finally decided to treat each pair of examinations as a separate case: care was taken to record any treatment the child had previously been receiving in order that this could be taken into account in the analysis. This procedure meant that the interval between the first and second, second and third, third and fourth, fourth and fifth examinations would each represent a follow-up period and, therefore, a case, each case being looked upon as covering an "initial" examination and its corresponding follow-up. Every case was then classified by age at "initial" examination and in this way constituted part of

TABLE 15

Distribution of subjects having 2, 3, 4, and 5 examinations

Analysis by numbers of examinations and sex

No. of examinations	Distribution per cent		Numbers of children
	Males	Females	
2	28.07	39.43	214
3	15.46	9.78	80
4	3.78	2.21	19
5	0.32	0.95	4
Totals	47.63	52.37	317

the appropriate age group.

The advantage of this method is that the data concerning changes between one period and another in the child's development can be more fully utilised than is possible by other methods. Its disadvantage lies in the fact that it raises the question of duplicity with regard to the data, although the extent of the problem is difficult to assess. An alternative approach, regarding the first and last examinations as the only ones of importance, would have resulted in loss of valuable information concerning development in the intermediate periods involved. The further alternative of grouping the children together on the basis of those with common starting ages, intervals and terminal ages, is the most attractive, having fewer objections than the other two methods. Unfortunately, however, it requires a larger sample than was available and, therefore, proved to be impracticable.

The loss of subject material is a serious problem in longitudinal studies; it arises as a result either of failure to attend for re-examination or of failure to comply with the continuing requirements of the study. All such studies of the eye have suffered from a high wastage rate. Sorsby et al (1961) commenced with 1432 children but only 436 were available for one re-examination at intervals which varied from two to six years. Hirsch (1961, 1964) commenced his study with 1200 subjects but this was reduced to 500 after six years and only 383 were left after eight years. It has already been pointed out that in the present investigation only 317 cases were available for analysis after a period covering between five and six years (5.10).

In this study each eye has been regarded as a separate unit for the purposes of analysis. This approach has been used in preference to analysing on the basis of subjects, in which either only one eye is used (Sorsby et al 1961) or the mean refractive state is calculated from the findings of both eyes to give a single result for each subject (Hirsch 1961). The use of both eyes as separate units increases the volume of material available, although it again raises the criticism of duplicity.

5.13. Some of the available data could not be readily handled in its original form. For example, interpretation of refractive changes is complicated by the presence of astigmatism. To examine the changes in each individual meridian presents tremendous problems, particularly in the analysis and interpretation of the findings. This is complicated still further if changes in the axis of the meridians occur. A compromise has, therefore, always been adopted in order that only one value for each eye need be considered. Reference has already been made to the lack of uniformity between the various studies in dealing with this problem (3.21). Those cases in which only one meridian has been utilised, whether this is the spherical component only (Blum et al 1959) or the power in one specified meridian, e.g. the vertical, (Sorsby et al 1957, 1961), are open to the criticism that the astigmatic error is either partially or completely ignored. This does not apply in the "mean sphere" or "best sphere" approach, in which half the relevant cylinder is added to the spherical component, thus taking account of the astigmatism present. Yet, this method can also be critcised, for undoubtedly it is a compromise, ignoring, among other things, axis position. It does, nevertheless, seem to have fewer objections than other methods and for this reason it was adopted here. It should be recognised, however, that use of differing approaches may produce markedly different results as the following example illustrates:-

	Ametropia	Spherical Component only	Mean Sphere
First Examination	+2.00/-0.50 axis 180	+2.00	+1.75
Second Examination	+2.00/-2.00 axis 180	+2.00	+1.00
Change in Refraction	Plano/-1.50 axis 180	Nil	-0.75

Before the mean sphere results were calculated, the retinoscopy findings (in each case) were converted to ocular refraction (5.5). Changes in refraction were processed in terms of annual as well as total changes, in view of the fact that intervals between one examination and another varied so widely. Data retrieval was greatly facilitated, by this approach, especially as at that stage it was not envisaged that computer methods would be used for analysis. Prior to any data being coded for entry on to punched cards, the following steps were, therefore, carried out, a small desk top computer (Olivetti Programma 101) being utilised for the purpose:-

(a) calculation of ocular refraction from retinoscopy findings

(b) determination of mean sphere results

(c) calculation of total and annual mean sphere changes.

5.14 It was anticipated originally that data could be processed adequately by means of a manual punched card system, in which results and information are entered, and subsequently extracted, by hand. The Paramount "Kendrew" card was selected as being one of the more versatile of the 8" x 5" manual punched card systems, providing as it does single punched holes on three sides and a bank of forty columns of five rows of holes along its leading edge.

The following information was entered on to each card:

Age at first examination

Sex

Number of examinations

Number of years covered

Ocular refraction in terms of the principle meridians at each examination

Details of correction prescribed - in terms of whether fully corrected or the extent of under-correction

Intervals to subsequent examinations

Change in refraction in principle meridians - classified as increase, decrease or no change.

Change in axis of principle meridians - classified as change or no change

Cycloplegics used

Examiner involved

Type of strabismus or phoria present

Treatment - whether surgical, orthoptics or both.

A separate card was used for each eye. Even so, it was found that the capacity of each card was insufficient for all the available data to be entered. Consequently, instead of exact results being punched, much of it had to be grouped into fairly coarse intervals; for example, ocular refraction was coded in 1.0 D steps. For the same reasons, some important data such as that relating to qualitative changes in refraction, as well as reference codings, had to be written, rather than punched, on to each card.

The real problems arose, however, when extracting data for analysis. This not only proved to be extremely time consuming but also failed to provide the detail that was really required. The fact that some of the data required for analysis was written in, largely defeated the purpose of using punched card method. It was clear that a different system would have to be used. The eighty column punched card was subsequently chosen as being the most suitable, as machine sorting could then be used.

The data, where appropriate, were coded for entry, the coding system being one which readily lent itself to visual interpretation.

The versatility of the eighty column punched card system is such as to permit any number of cards to be used to carry data for each case. Thus separate cards were used to retain data for right and left eyes as well as for each pair of examinations i.e. the "initial" examination and its follow-up. The following information was entered, either in its original form, as with details of refraction, or coded, as with type of strabismus:

Sex

Index Number

Right or left eyes

Strabismus:

Coded Nil
Right convergent
Left convergent
Alternating convergent
Intermittent convergent
Right divergent
Left divergent
Alternating divergent
Intermittent divergent
Vertical strabismus

Angle of strabismus prior to surgery:

Coded 5^{o}
$6 - 10^{o}$
$11 - 20^{o}$
$21 - 30^{o}$
$31 - 40^{o}$

Heterophoria:

Coded Nil
Esophoria
Exophoria
Hyperphoria

Other conditions:

Coded Nil
Vertical combined with horizontal deviation
Amblyopia only

Treatment:

Coded Nil
Surgery and orthoptics
Orthoptics only
Surgery and orthoptics prior to first examination

Age at each examination

Number of examinations completed

Number of years covered

Initial mean sphere ocular refraction

Initial ocular astigmatism

Initial mean sphere anisometropia

Examiner : coded

Correction prescribed - extent of undercorrection of ametropia

Method of examination - cycloplegics used

Direction of change in refraction:

Coded No change
Increase positive
Decrease positive

Total change in ocular refraction - mean sphere

Annual change in ocular refraction - mean sphere

Resultant mean sphere refraction

Change in anisometropia - mean sphere:

Coded No change
Increase
Decrease

Resultant mean sphere anisometropia

Change in ocular astigmatism:

Coded No change
Increase
Decrease

Total change in ocular astigmatism

Axis change:

Coded Nil
10^{o}
$11 - 20^{o}$
$21 - 30^{o}$

Relationship between changes in both eyes:

Coded Both no change
Both change same direction equally
Both change same direction unequally
One changes plus, other no change
One changes minus, other no change
Both change opposite directions

Surgery:

Coded Nil at any time previously

Nil in interval, but previously on R

Nil in interval, but previously on L

Nil in interval, but previously on both

Surgery in interval on R

Surgery in interval on L

Surgery in interval on both, or in interval on one and previously on the other.

A mechanical card sorter was initially used to extract the data for tabulation and preparation for analysés. This procedure necessitates recording the totals by hand and is, therefore, still extremely time consuming, particularly when carried out single handed. Assistance was subsequently sought from the University Computer Centre, but using the same methods to tabulate the data took almost six months and in the end proved abortive.

By this stage it was apparent that full computer facilities would have to be employed. The author's attention was drawn to the fact that a full computer programme - the Multiple Variate Counter (M.V.C) (Singh 1968) had been designed for exactly the kind of analysis required for this project. Utilising M.V.C. the data was processed with the aid of the Science Research Council's Atlas Computer at Chilton.

Unfortunately, owing to the fact that data had been prepared for manual rather than computer analysis, each card had to be partially repunched before they could be run through the computer. There can be no doubt that this stage of the data preparation could have been tackled more efficiently had advice been available at the time (1967 - 1968).

The programming phase was finally completed with professional assistance which greatly facilitated the completion of this work.

SUMMARY

5.15 In this section the methods and procedures used in the research are described and discussed.

Refractions were carried out under cycloplegia in order to avoid accommodation factors. Atropine was the most commonly used cycloplegic agent, followed by homatropine and cyclopentolate. The relationships between these different agents are examined (5.2).

Assessment of ocular refraction was based solely upon retinoscopy in view of the ages of the subjects involved. The method of approach is described (5.4).

Experimental errors arising as a result of this method of examination are discussed. Inaccuracies associated with tonus of the ciliary muscle and back vertex distance are evaluated (5.5).

Attention is drawn to apparent variations in refraction arising solely as a result of differences in individual interpretation of retinoscopy findings. The advantage of all examinations being carried out by the same individual is pointed out. The selection factors brought into play by this procedure are assessed; it is thereby shown that the sample involved is not representative of the children attending the hospital. Care is, therefore, needed in drawing conclusions about the strabismic population as a whole (5.7).

The problem of selection is shown to be an inherent feature of follow-up studies. This tends, however, to be less marked in strabismic studies than in other studies of refraction (5.8).

The importance of standardisation is stressed, particularly with regard to working distances during retinoscopy. The extent of experimental errors associated with a particular method of working has to be established in such studies. This involves estimating the degree of accuracy to which any individual can repeat his findings. The method of assessing such errors is described and the author's tolerance levels deduced. Changes in ocular refraction of less than ±0.38 D have been shown to arise as a result of experimental error and, therefore, insignificant (5.9).

The problems associated with retrieval of the necessary data from hospital records are described. The criteria for rejecting cases from the study have been discussed. Exclusions have been finally based solely on the criterion as to whether the case has certain pathological characteristics (5.10 - 5.11).

Methods of analysing the findings from longitudinal investigations are examined. The procedure adopted in this study is described and compared with other studies, whilst its advantages and disadvantages are discussed (5.12 - 5.13).

The limitations of manual punch card systems for processing data are pointed out, and the value of adopting computer methods explained. The data processed by such methods is listed (5.14).

6. RESULTS

Characteristics of the sample

6.1 The basic material for this study comprises 317 children of whom 151 are males and 166 females. Owing to the study being retrospective in nature (4.4), the number of examinations carried out on these children has not been uniform, - ranging from a minimum of two to a maximum of five. Consequently, the volume of data available for analysis varies from child to child. In order to make the fullest use of the data, the findings from each pair of consecutive examinations were analysed, generally, as though constituting a separate case (5.12). As a result of this procedure, the original sample of 317 was expanded to a total of 446 cases; this in turn was further expanded by utilizing the findings from individual eyes. The material was thus finally composed of 892 cases, although an injury to one eye during the course of the investigation reduced this to 891.

Of the expanded sample, 227 are males and 219 females; their distribution within age groups, together with that of the original sample, is shown in appendix A.1 . In order to ascertain the extent to which enlargement of the group had changed its characteristics, the chi-square test was applied. Analysis of the male-female distribution within the yearly age groups, from the first to the thirteenth year, revealed no significant difference, both for the original as well as for the expanded group (table 16). This indicates that expansion in this way did not materially change the male-female composition of the age groups.

Taking each group as a whole, ignoring sex differences,

TABLE 16

Chi Square analyses of the distribution of males and females within yearly age groups from birth to less than thirteen years

	Original sample	Expanded sample
χ^2	8.5167	13.7744
d.f.	12	12
n	317	446
p	<0.80 >0.70	<0.50 >0.30

the distributions within age groups were compared. This showed no significant difference existing between the two, thus confirming that expansion of the original group had done little to change its character.

$\chi^2 = 10.6379$

d.f. = 12

$p = < 0.70 > 0.50$

6.2 At an early stage of this study it became clear that it would be necessary to relate results to age, either directly or indirectly. It was essential to determine the age intervals for the various analyses to be undertaken. The original intention was to use half yearly age groups in analysing patterns of growth. With ages ranging, initially, from a few months to just under thirteen years, this produced twenty six age groups. (It should be noted that throughout this study, the age in question has been taken as age at the time of the first of each pair of examinations, unless otherwise stated). It was obvious that the size of the sample was insufficient to support such a division since the resulting distribution bore little resemblance to age distributions based on longer intervals. As a result, age groups of not less than one year were used. Even with a yearly division, the numbers proved to be inadequate to carry out some of the analyses required, particularly when more than two factors were being considered. Yearly groupings were of value when age and only one other factor such as refractive change were taken into consideration, but were of little value if, for example, refractive error was to be taken into account alongside age and change. In these cases it was found necessary to use three, or even six, yearly groupings.

6.3. Consideration of males and females separately added to the problems associated with sample size, since this reduced the numbers available to approximately half the total in each case. It was clear that treating the sample as a whole, rather than on a sex basis, would allow detailed analyses to be carried out in more areas than would otherwise have been possible. Many previous studies (e.g. Sorsby et al 1961, Goldschmidt 1968, 1969) have shown that no significant differences exist in refractive development of the sexes. Consequently in each of the fields being studied it was decided, as a first step, to examine whether any sex differences were present.

These analyses were carried out using the chi-square test, because it provides an established method for showing whether observed differences in incidence are likely or unlikely to be the result of chance (Bradford Hill 1961). For this purpose the sample was divided into two six yearly groups of males and females -birth to less than six years, and six to less than twelve years. Although it would have been of value to use three year intervals, the numbers available were insufficient for this.

Changes in refraction related to age

6.4 It has already been pointed out (4.1) that the majority of children involved in this study had strabismus. It was not possible to make comparisons between the developments occurring in strabismic children and their non-strabismic counterparts, since the two groups were so markedly different in size; (12.5 : 1). In addition, many of the non-strabismic children were suspected, but unconfirmed, cases of strabismus.

In these circumstances all the children involved in this investigation must be regarded as constituting a strabismic group. Similarly, the changes in ocular refraction involved should be seen as representing strabismic patterns of growth.

Refractive changes have been grouped in two ways for the purposes of this study:

(a) qualitatively, indicating direction of change only

(b) quantitatively, indicating degree of change.

Direction of change has been classified as follows in order to avoid confusion:

No change

Increased positive - covering increase in hypermetropia or decrease in myopia

Decreased positive - covering decrease in hypermetropia or increase in myopia.

The degree of refractive change either is presented as a total value in which the time interval is ignored, or is broken down into its annual component. Such changes have been divided into the following group intervals:

Annual:
Nil
±0.01 - ±0.20 D
±0.21 - ±0.40 D
...up to ±1.40 D
> ±1.40 D

Total:
Nil (0 - ±0.32 D)
±0.33 - ±0.50 D
±0.51 - ±1.00 D
±1.01 - ±1.50 D
±1.51 - ±2.00 D
> ±2.00 D

Sex differences

6.5 Analysis of changes in ocular refraction occurring in males and females, using the chi-square test, shows that the differences between the sexes in the age group birth to less than six years, may be significant:

$$\rho = <0.05 \quad (\chi^2 = 6.648, \quad d.f. = 2)$$

The differences for the six to twelve year age group, on the other hand, could clearly have arisen by chance:

$$\rho = 0.50 \quad (\chi^2 = 1.401, \quad d.f. = 2)$$

The distribution within each of these age groups is shown in tables 17 and 18.

In the younger age group, the major differences are found in the incidences of increasing hypermetropia (decreasing myopia) and stationary refractions. Compared to males, a higher percentage of females remain stationary. Analysis of the results on the basis of yearly changes reveals that amongst both males and females increasing hypermetropia tends to decline in incidence with age, whilst stationary refractions tend to rise. If these patterns represent the general trend during this period, then this indicates that refractive development in females is rather more advanced than in males.

In a study of the patterns of growth in forty boys and forty girls during the first eight years of life Deming & Washburn (1963) found that height velocity at birth is greatest amongst boys, but becomes equal with that of boys at about seven months. From then on, until almost four years, the boys' velocity slows down below that of the girls'

TABLE 17

Changes in refraction amongst males and females

Analysis by refractive change and sex for six yearly age groups from birth up to twelve years - percentage

A - Age group : Birth to <6 years

Changes in refraction	Sex Males	Females
No change	29.14	38.54
Increased positive	58.61	48.61
Decreased positive	12.25	12.85
Numbers of eyes	301	288

B - Age group : 6 - <12 years

Changes in refraction	Sex Males	Females
No change	44.74	47.62
Increased positive	27.63	21.77
Decreased positive	27.63	30.61
Numbers of eyes	152	148

TABLE 18

Changes in refraction amongst males and females - yearly

Analysis by 'initial'age and changes in refraction - per cent

Changes in Refraction	Initial age - age (years) less than: 1	2	3	4	5	6	7	8	9	10	11	12	13	All ages
							MALES							
No change	0	9.1	15.2	36.5	26.2	40.5	40.9	41.7	75.0	33.3	30.0	37.5	0	34.4
Increased positive	0.	72.7	82.6	52.7	63.1	41.9	38.6	10.4	12.5	50.0	50.0	37.5	0	48.2
Decreased positive	100.0	18.2	2.2	10.8	10.7	17.6	20.5	47.9	12.5	16.7	20.0	25.0	0	17.2
Numbers of eyes	2	22	46	74	84	74	44	48	24	18	10	8	0	454
							FEMALES							
No change	0.	22.2	31.7	29.6	46.3	47.3	50.0	47.5	44.7	33.3	66.7	40.0	0	41.3
Increased positive	100.0	61.1	61.0	67.6	30.5	39.2	18.8	25.0	21.1	50.0	0	20.0	100.0	39.7
Decreased positive	0	16.7	7.3	2.8	23.2	13.5	31.3	27.5	31.6	16.7	33.3	40.0	0	18.7
Numbers of eyes	2	18	41	71	82	74	48	40	38	6	6	10	2	438

These findings have subsequently been confirmed by Tanner, Whitehouse & Takaishi (1966). Between four and eleven years, the rates have been taken as identical. After the age of eleven, the typical girl becomes taller than the typical boy, and remains so until approximately fourteen.

These findings point to a definite relationship between rates of refractive development and rates of body growth. It is clear that the disparity in the nature of the refractive changes found in boys and girls occurs at about the same time in life as differences in height velocity. This indicates that sex differences in the eye are related to factors of maturity in general.

Changes in ocular refraction - overall

6.6 Refractive changes related to age, irrespective of sex, are shown in table 19 and figure 1. Instances of all three possible patterns of change - i.e. no change, increased positive, or decreased positive - were found at each age group, except in the first and the thirteenth years of life. Up to four years of age the majority of children shifted towards hypermetropia. Since the age in question represents age at the time of the 'initial' examination, the changes recorded are those occurring in the ensuing period. By relating these changes to age at the subsequent or follow-up examination, it was found that there is no longer an overall majority showing an increase in hypermetropia after six years of age. It is quite clear from tables 19 and 20, and Figure 1. that up to nine years of age, the proportions of children

TABLE 19

Changes in Ocular Refraction related to age

Analysis by initial age and changes in refraction - per cent

Age in years - less than:

Changes in Refraction	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
No change	0	15.0	23.0	33.1	36.1	43.9	45.7	44.3	57.4	33.3	43.8	38.9	0	37.8
Increased positive	50.0	67.5	72.4	60.0	47.0	40.5	28.3	17.0	18.0	50.0	31.3	27.8	100.0	44.1
Decreased positive	50.0	17.5	4.6	6.9	16.9	15.5	26.1	38.6	24.6	16.7	25.0	33.3	0	18.1
Numbers of eyes	4	40	87	145	166	148	92	88	61	24	16	18	2	891

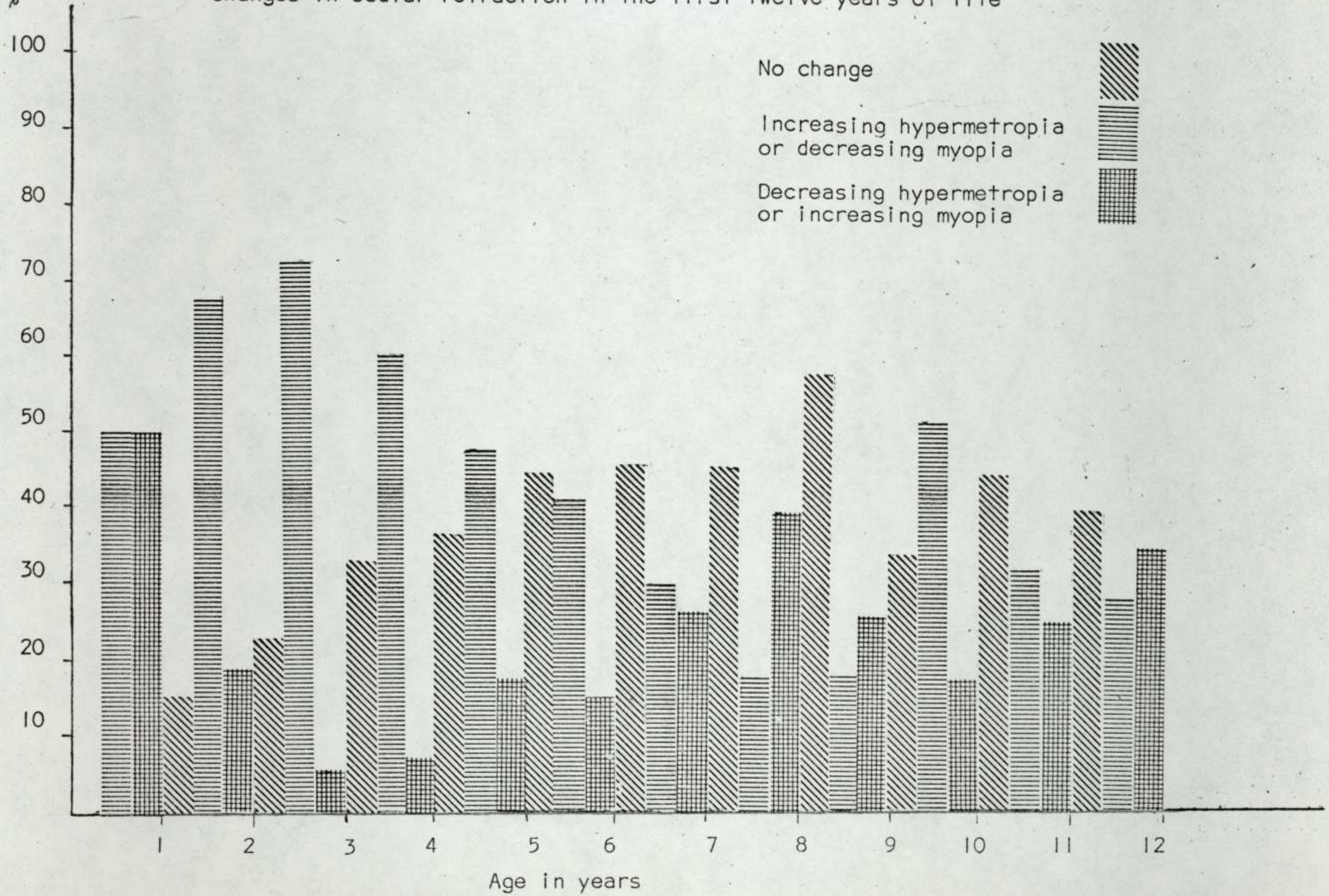
TABLE 20

Changes in ocular refraction related to age at subsequent examination

Analysis by subsequent age and changes in refraction - per cent

Changes in refraction	Age in years - less than 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
No change	0	14.3	17.0	34.8	38.4	34.4	41.2	45.5	46.1	44.4	45.5	70.0	36.4	25.0	0
Increased positive	50.0	60.7	74.5	62.0	55.8	49.0	39.7	31.8	18.4	5.6	30.3	30.0	36.4	0	50.0
Decreased positive	50.0	25.0	8.5	3.3	5.8	16.6	19.1	22.7	35.5	50.0	24.2	0	27.3	75.0	50.0
Numbers of eyes	4	28	47	92	138	151	136	110	76	36	33	10	22	4	4

FIGURE I
Changes in ocular refraction in the first twelve years of life



showing no change in their refractive state tend to rise, although this is most pronounced in the first four years of life.

The most dramatic alterations in patterns of change occur in the ratios of increased positive to decreased positive. After four years of age there is a marked increase in the percentage of cases showing changes in a myopic direction, (i.e. decreasing hypermetropia or increasing myopia), whilst there is an associated decline in the percentage showing an hypermetropic increase. By the seventh year of life (i.e. between seven and eight) more children were found to be shifting towards myopia than towards hypermetropia. The erratic patterns of change occurring from nine years of age onwards are derived from relatively small numbers; it is unlikely, therefore, that any firm conclusions can be drawn with regard to this age group.

6.7 Analysis of changes in refraction on a qualitative basis, indicating direction of change only, was carried out using the chi-square test. Related to age based upon three yearly intervals, birth up to three, three up to six etc. the results were found to be highly significant ($p = <0.001$).

Quantitative analysis of ocular refractive changes was complicated by the intervals between examinations varying from less than six months to over four years, although the most common interval was between thirteen and eighteen months. Analysis of total refractive changes in these circumstances proved to be of little value. Such changes, therefore, were broken down into their annual components. These varied from nil to over 2.0 D, the maximum changes per annum being +2.34 D and -2.73 D.

The mean annual changes for each three year age group up to twelve years of age and over, is shown in table 21 It is clear that the most pronounced mean change occurs in the youngest age group - birth to less than three, this being in the direction of increasing hypermetropia/decreasing myopia. (The findings of the twelve year and over age group have been excluded since they are based on a sample of two cases only). The degree of change, as shown by the means, diminishes with increasing age, reaching a myopic direction (decreasing hypermetropia) in the period between six and nine years of age. This trend is reversed during the following three years - up to the age of twelve (figure 2). It should be noted that the standard deviation shows the spread to be most marked in the first three years of life, after which it decreases with age.

The chi-square test indicates a clear association between age and annual changes in ocular refraction:-

$$\chi^2 = 158.665$$

$$d.f. = 24$$

$$n = 892$$

$$p = <0.001$$

TABLE 21

Annual changes in ocular refraction related to three year age groups from birth to over twelve

Analysis by age at initial examination and

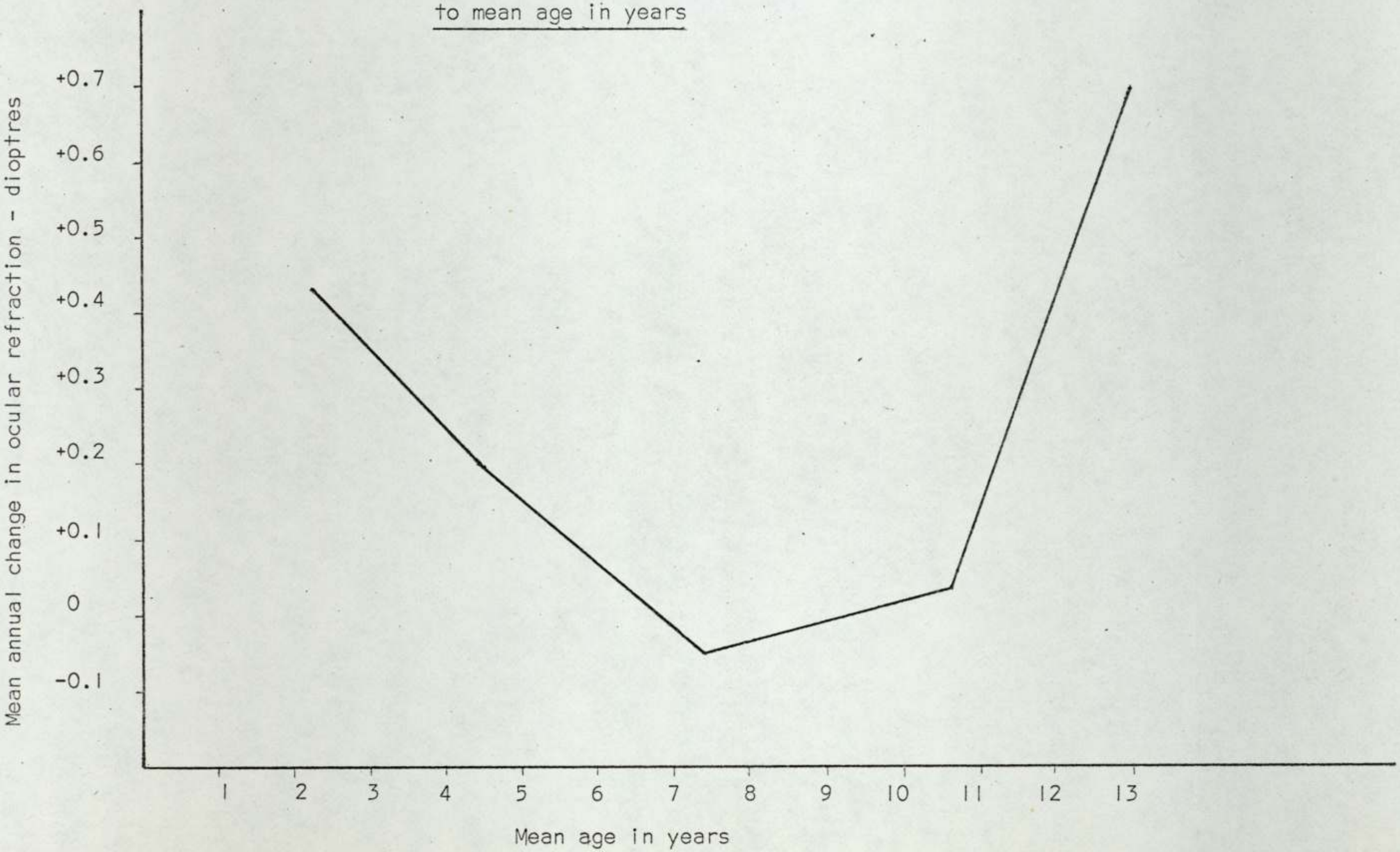
(a) Means and standard deviations of annual changes

(b) Means and standard deviations of ages.

	Age in years at initial examination					
	Birth to <3	3 to <6	6 to <9	9 to <12	Over 12	All ages
	Means and standard deviations of changes - dioptres					
Mean	+0.43	+0.20	-0.05	+0.03	+0.69	+0.16
Standard deviation	±0.74	±0.52	±0.43	±0.32	±0.23	±0.55
	Means and standard deviations of ages - years					
Mean	2.2	4.4	7.3	10.4	12.9	5.3
Standard deviation	±0.54	±0.85	±0.88	±0.85	0.0	±2.31
Numbers of eyes	131	459	242	58	2	892

FIGURE 2

Mean annual changes in ocular refraction related to mean age in years



For the purpose of this test, annual changes were grouped as follows:

Over +1.00 D

+0.51 to +1.00 D

+0.01 to +0.50 D

Nil

-0.01 to -0.50 D

-0.51 to -1.00 D

Over -1.00 D

whilst three year age groupings were used:

0 - <3

3 - <6

6 - <9

9 - <12

Over 12

In order to determine the degree of relationship between age and these changes in ocular refraction, the coefficient of correlation was calculated. Because the patterns of change for each of these age groups appeared to differ markedly from one another, indicating a curvilinear rather than a linear relationship for the sample as a whole, the sample was divided into separate three year age groups as used for the chi-square test. The correlation coefficient was then separately determined for each three year span. The results confirm that the relationships between age and refractive change do differ quite markedly, changing from positive to negative for the two youngest age groups. The degree of correlation for all age groups, however, is low - less than 0.2 - indicating a relatively loose relationship between the factors involved (table 22).

The standard error for the correlation coefficient (table 22) shows that the result for the age group three to less than six is highly significant ($p = <0.001$). The findings for the age groups, birth to less than three, and nine to less than twelve, on the other hand, are not significant indicating that sampling errors could have given rise to the respective degrees of correlation. Tentative conclusions only can be drawn for these two groups.

By calculating the regression coefficients from the correlation findings, it is possible to estimate the annual change in ocular refraction likely to occur with increases in age (table 22). These estimates show that in the first three years of life, refraction can be expected to increase in an hypermetropic direction by +0.145 D over the level of increase for the previous year, whilst between three and six years of age a decline of -0.114 D is indicated. Between six and nine years there is little relationship existing between age and changes in refraction. A small decline of -0.075 D per annum is shown between nine and twelve years of age, but it should be noted that this finding is based on the results of only fifty-eight eyes and, therefore, must be regarded with caution. The anticipated changes in ocular refraction for the first to the twelfth year of life are shown in detail in table 23.

It should always be borne in mind that the value provided by the regression line gives no more than a "best estimate" of any particular value of interest. The standard error of this estimate can be calculated and this will enable an assessment to be made of the degree of uncertainty involved (table 23).

TABLE 22

Correlation and regression coefficients for changes in ocular refraction related to initial age within each three year age group from birth to less than twelve years

	Age in years at initial examination			
	Birth to <3	3 to <6	6 to <9	9 to <12
Correlation coefficient r	+0.1063	-0.1855	+0.0076	-0.1995
Standard error of r	0.0877	0.0467	0.0645	0.1325
Regression coefficient	+0.145	-0.1141	+0.0037	-0.0753
Numbers of eyes	131	459	241	58

TABLE 23

Estimated changes in ocular refraction per annum

Related to age at initial examination

Analysis by initial age and changes estimated

to take place in the following age group

Age in years	Change in refraction - dioptres	Regression Coefficient	Standard Error of estimate
Birth to <1	+0.11	+0.1450	±0.732
1 to <2	+0.25		
2 to <3	+0.40		
3 to <4	+0.36	-0.1141	±0.513
4 to <5	+0.24		
5 to <6	+0.13		
6 to <7	-0.05	+0.0037	±0.425
7 to <8	-0.05		
8 to <9	-0.05		
9 to <10	+0.14	-0.0753	±0.314
10 to <11	+0.06		
11 to <12	-0.14		

The standard errors of estimate show how much variation from the anticipated refractive changes can arise. Since actual values fall within two standard errors of the estimate in approximately ninety-five per cent of all cases, it can be seen how wide the range of values may be. Thus, on the basis of the regression coefficient for the period three to less than six years of age where the coefficient of correlation was found to be highly significant, the actual refractive changes in ninety-five per cent of cases, will fall between the following limits:

Age in years	Change in ocular refraction - dioptres
3 to <4	+1.38 to -0.67
4 to <5	+1.27 to -0.79
5 to <6	+1.16 to -0.90

It is clear from these results that extreme care must be taken in making predictions concerning refractive changes related to age.

6.8 Intervals between examinations varied so widely from child to child, that changes in refraction were further analysed in terms of age at the subsequent (follow-up) examination. Such a method of analysis provides a means of assessing the relationship between age and those changes that have *already* taken place in the preceding period of life.

The sample was divided, as previously, into separate three year age groups. With ages ranging from one to just under sixteen years, five groups were created as opposed to four, with the youngest commencing at one year (as compared to birth in the previous analysis). The means and standard deviations for these age groups are shown in Table 24.

TABLE 24

Annual changes in ocular refraction related to three year age groups from one to less than sixteen years

Analysis by age at follow-up examination and

(a) Means and standard deviations of annual changes

(b) Means and standard deviations of ages

	Age in years at follow-up examination					
	1 to <4	4 to <7	7 to <10	10 to <13	13 to <16	All ages
			Means and standard deviations of changes - dioptres			
Mean	+0.41	+0.27	+0.02	-0.04	+0.05	+0.15
Standard deviation	±0.89	±0.56	±0.43	±0.28	±0.32	±0.55
			Means and standard deviations of ages - years			
Mean	3.1	5.6	8.3	11.1	13.7	7.1
Standard deviation	±0.58	±0.81	±0.88	±0.76	±0.65	±2.54
Numbers of eyes	79	381	322	79	30	892

The correlation between age and refractive change was again found to be low, not exceeding 0.3 for any age group, although this is somewhat higher than that found for the "initial" groups. (Table 25). The standard errors of these coefficients show the results for the four to seven year age group to be highly significant ($\rho = <0.001$) and, therefore unlikely to have been affected by sampling errors. The results for the age groups, one to less than four, seven to less than ten, and ten to less than thirteen are also significant, but to a lesser degree; ($\rho = <0.05$, <0.05 and <0.01 respectively). The regression coefficients have been calculated and from these, the estimated annual changes in ocular refraction have been determined for the preceding period of life. (Table 26).

The close similarity between the findings for the age groups, three to less than six, and four to less than seven of the "initial" and "follow-up" samples respectively, confirm the significance of the relationship between age and refractive change during this period of life. The differences between the findings of the remaining comparable age groups, on the other hand, are considerable; this underlines the need for caution in drawing conclusions from the results involved.

TABLE 25

Correlation and regression coefficients for changes in ocular refraction related to follow-up age with each three year age group from one to less than sixteen years

	Age in years at follow-up examination				
	1 to 4	4 to 7	7 to 10	10 to 13	13 to 16
Correlation coefficient r	+0.2361	-0.2112	-0.1100	+0.2986	+0.1184
Standard error of r	0.1132	0.0512	0.0558	0.1132	0.1856
Regression coefficient	+0.0362	-0.1449	-0.0536	+0.1094	+0.0585
Numbers of eyes	79	381	322	79	30

TABLE 26

Estimated changes in ocular refraction per annum

related to age at follow up examination

Analysis by follow up age and change estimated to

have taken place in the preceding age group.

Age in years	Changes in refraction dioptres	Regression coefficient	Standard error of estimate
1 - <2	-0.35	+0.03624	±0.8650
2 - <3	+0.01		
3 - <4	+0.37		
4 - <5	+0.50	-0.1449	±0.5433
5 - <6	+0.35		
6 - <7	+0.21		
7 - <8	+0.09	-0.0536	±0.4261
8 - <9	+0.03		
9 - <10	-0.02		
10 - <11	-0.16	+0.1094	±0.2658
11 - <12	-0.05		
12 - <13	+0.06		
13 - <14	+0.007	+0.0585	± 0.3188
14 - <15	+0.07		
15 - <16	+0.12		

Changes in ocular refraction related to refractive state

Distribution of refractive states

6.9 Sample size proved to be a factor which considerably restricted the scope of a number of analyses, especially those involving the relationship of refractive state to ocular change. The problems in this type of analysis arise from the necessity to consider, not only whether an eye is myopic, emmetropic or hypermetropic, but also the degree of any refractive error that may present; indeed, the effect of ametropia upon refractive change can only be determined by such an approach. Ideally, ametropia should be sub-divided into steps not exceeding 1.0 D (table 27). Such a breakdown, however, creates more divisions than the present sample size can support. Consequently 3.0 D steps were utilised where quantitative analyses of the state of refraction were involved.

For the purposes of this study, emmetropia was taken as representing an ocular refraction of zero taken to two decimal places; as a result, only one case fell into this category. In each of the separate three year age groups up to twelve years, the majority were hypermetropic (table 28). Taking all ages together 94.3 per cent were hypermetropic and only 5.6 per cent myopic. The proportion of myopes did not exceed 10 per cent in any age group except for the nine to twelve year olds, when it reached 22.9 per cent.

The total number of myopic eyes - 50 out of 892 - was too small to support any useful quantitative analyses of myopia. The myopes were, therefore, all grouped together and considered as a whole, irrespective of their degree.

TABLE 27

Initial refractive state related to age

Analysis by initial refractive state in dioptres and three yearly age groups - percentage distribution

Refractive state in dioptres	Age in years Birth to <3	3 to <6	6 to <9	9 to <12	Over 12
Over - 9.00	0	0	0	0	0
-8.01 to -9.00	0	0.65	1.24	0	0
-7.01 to -8.00	0	0.65	0.41	0	0
-6.01 to -7.00	0	0	0	1.72	0
-5.01 to -6.00	0	0.22	0.83	6.90	0
-4.01 to -5.00	0	0.22	0	3.45	0
-3.01 to -4.00	0.76	0.44	0.41	0	0
-2.01 to -3.00	0.76	0.22	0	5.17	0
-1.01 to -2.00	1.53	0.44	2.89	3.45	0
-0.01 to -1.00	0	1.09	0.41	1.72	0
0	0	0	0.41	0	0
+0.01 to +1.00	0	3.27	4.13	10.34	0
+1.01 to +2.00	11.45	7.84	10.74	12.07	0
+2.01 to +3.00	16.79	16.34	16.53	15.52	0
+3.01 to +4.00	21.37	16.34	13.22	12.07	100
+4.01 to +5.00	17.56	18.3	13.64	6.90	0
+5.01 to +6.00	13.74	13.94	11.57	3.45	0
+6.01 to +7.00	10.69	10.46	9.92	5.17	0
+.7.01 to +8.00	1.53	4.79	5.79	5.17	0
+8.01 to +9.00	0.76	1.31	4.55	5.17	0
Over +9.00	3.05	3.49	3.31	1.72	0
Numbers of eyes	131	459	242	58	2

TABLE 28

Refractive state within three yearly age groups

Analysis by age and refractive state at initial examination
Distribution within age groups - per cent

Refractive State	Age in years				
	0 - <3	3 - <6	6 - <9	9 - <12	Over 12	All ages
Emmetropia *	0	0	0.4	0	0	0.1
Hypermetropia	96.9	96.1	93.4	77.6	100.0	94.3
Myopia	3.1	3.9	6.2	22.4	0	5.6
Numbers of eyes	131	459	242	58	2	892

* Emmetropia classified as a refraction of zero taken to two decimal places

Hypermetropia, however, was analysed quantitatively as follows:-

+0.01 to +3.00 D

+3.01 to +6.00 D

+6.01 to +9.00 D

Over +9.00 D

The means and standard deviations of these groups can be found in table 35

Sex differences

6.10 The patterns of refractive changes occurring in males and females were examined for each of the five refractive groups listed (6.9). In both age groups - birth up to six years and six up to twelve years - no significant differences were found between the sexes, except in the case of the youngest group with refractions ranging from +3.01 to +6.00 D. The chi-square result shows the differences here to be highly significant (χ^2 = 14.578, d.f. = 2, n = 292, p = <0.001). The distribution for this particular age group and degree of ametropia, shows that the proportion of females with stationary refractions is much greater than males - 43.9 per cent compared to 22.9 per cent (table 29). By breaking age down into yearly groupings, it can be seen that the major differences occur in the third year of life. At this stage 8.0 per cent of the boys have stationary refractions, compared to 47.4 per cent of the girls; only in the fourth year of life does this proportion for boys increase markedly. Since this period of life - up to six years of age - appears to be characterised by an increase in the proportions of refractions

TABLE 29

Changes in refraction amongst males and females with hypermetropia +3.01 to +6.0 D, within age group birth to less than six years

Analysis by changes in refraction and sex

Changes in Refraction	Sex - per cent Males	Females
No change	22.9	43.9
Increased positive	64.7	46.8
Decreased positive	12.4	9.3
Numbers of eyes	153	139

remaining stationary associated with increasing age it would seem that girls are rather more advanced than boys in their stage of development at this particular time. (Table 30).

Small, but just significant, differences were also found for those children in the six to twelve year age groups with hypermetropia between +6.01 and +9.00 D (χ^2 = 7.651, d.f. = 2, n = 58, p = <0.05). Once more the major difference between the sexes lies in the greater female incidence of either stationary refraction or myopic change (table 31). In view of the small numbers of eyes involved care must be taken in drawing conclusions for this group. Nevertheless, it would appear that maturity is most likely to be a causative factor.

In the light of these findings, the differences in refractive changes between males and females were ignored and the results analysed for the group as a whole.

Ametropia and refractive changes - overall

6.11 In each of the ametropic groups, with the exception of hypermetropia over +9.00 D, all three possible patterns of change were exhibited, i.e.

(a) no change

(b) increased hypermetropia or decreased myopia

(c) decreased hypermetropia or increased myopia

In hypermetropic eyes, increases in hypermetropia are the predominating feature throughout the period from birth up to twelve years of age; this is especially pronounced in the first three years of life. The results indicate, however, that of all the hypermetropic groups, the lowest -

TABLE 30

Changes in refraction in males and females with hypermetropia +3.01 to +6.0 D

Analysis by changes in refraction and yearly age groups from birth to <6 - percentage distribution

Changes in refraction	Initial age - in years						
	<1	<2	<3	<4	<5	<6	All ages
MALES							
No change	0	7.7	8.0	30.3	21.4	34.2	22.9
Increased positive	0	76.9	88.0	57.6	73.8	44.7	64.7
Decreased positive	100.0	15.4	4.0	12.1	4.8	21.1	12.4
Numbers of eyes	2	13	25	33	42	38	153
FEMALES							
No change	0	10.0	47.4	30.3	51.2	55.5	43.9
Increased positive	0	70.0	42.1	69.7	29.3	41.7	46.8
Decreased positive	0	20.0	10.5	0	19.5	2.8	9.3
Numbers of eyes	0	10	19	33	41	36	139

TABLE 31

Changes in refraction in males and females with hypermetropia +6.1 to +9.0 D within age group 6 to <12 years

Analysis by changes in refraction and sex - per cent

Changes in Refraction	Sex: Males	Sex: Females
No change	42.9	59.1
Increased positive	42.9	9.1
Decreased positive	14.3	31.8
Numbers of eyes	35	22

+0.10 to +3.00 D - is most likely to show an increase, and that this will occur in the first three or four years of life; 83.8 per cent were found to be increasing during this period compared to 68.1 per cent and 58.8 per cent for the ametropias of +3.01 to +6.00 D and +6.01 to +9.00 D respectively (table 32). Children in this age group with the higher degrees of hypermetropia, on the other hand, showed a greater tendency to remain stationary or change in a myopic direction. This difference in behaviour between the higher degrees of hypermetropia remains until the sixth year of life, although it is less pronounced after the third year. This pattern suggests that in the first six years a levelling process occurs, bringing hypermetropic refractions in such eyes towards a common point. The means of the refractive errors in the two age groups up to six years indicates this level to be around +4.00 D (table 33). The standard deviations, however, are very large demonstrating that 95 per cent of the refractions will lie within the range approximately -1.00 D to +9.00 D. The significance of this levelling process must, therefore, be regarded as questionable.

The decline in the proportion of eyes showing increases in hypermetropia continues until nine years of age for each of the hypermetropic groups up to +9.00 D, although it was found to be most marked between +0.10 and +3.00 D (table 32). Associated with this decline is a rise in the proportions of eyes with stationary refractions, especially amongst the three to six year olds with the lower degrees of hypermetropia. Whilst the incidence of changes in a myopic direction also rises particularly between six and nine, this is not

TABLE 32

Changes in ocular refraction related to initial refractive state

Analysis by changes in refraction and refractive state for each three year age group from birth to less than 12 years - percentage distribution.

Changes in refraction	Refractive state - dioptres Myopia	+0.01 - +3.00 D	+3.01 - +6.00 D	+6.01 - +9.00 D	Over +9.00 D
Age: Birth to <3 years					
No change	100.0	8.1	18.8	35.3	0
Increased positive	0	83.8	68.1	58.8	100.0
Decreased positive	0	8.1	13.0	5.9	0
Numbers of eyes	4	37	69	17	4
Age: 3 to <6 years					
No change	5.6	40.5	37.2	43.4	31.3
Increased positive	44.4	51.6	52.5	39.5	31.3
Decreased positive	50.0	7.9	10.3	17.1	37.5
Numbers of eyes	18	126	223	76	16

TABLE 32 (Continued)

Changes in refraction	Myopia	+0.01 - +3.00 D	+3.01 - +6.00 D	+6.01 - +9.00 D	Over +9.00 D
			Age: 6 to <9 years		
No change	50.0	44.7	45.2	53.1	87.5
Increased positive	35.7	22.4	18.3	26.5	0
Decreased positive	14.3	32.9	36.6	20.4	12.5
Numbers of eyes	14	76	93	49	8
			Age: 9 to <12 years		
No change	7.7	50.0	53.8	33.3	0
Increased positive	38.5	36.4	38.5	44.4	0
Decreased positive	53.8	13.6	7.7	22.2	100.0
Numbers of eyes	13	22	13	9	1

TABLE 33

Means and standard deviations of initial refractive state for each three year age group

Analysis by age at initial examination and means and standard deviations in dioptres

	Age in years					
	Birth - <3	3 - <6	6 - <9	9 - <12	Over 12	Total
Mean	+4.00	+4.09	+3.85	+2.07	+3.52	+5.88
Standard Deviation	±2.17	±2.76	±3.16	±3.93	±1.15	±2.93
Numbers of eyes	131	459	242	58	2	892

as marked as the increasing predominance of stationary refractions.

Myopic eyes as a whole were found to exhibit patterns of change similar to hypermetropic eyes (table 32). As has already been pointed out, the numbers available were insufficient to support a quantitative analysis based upon the degree of myopia present (6.9). It can also be seen from table 32 that the small numbers of hypermetropic eyes over +9.00 D appear to exhibit similar characteristics to the other hypermetropic groupings; firm conclusions can not, however, be drawn with regard to this group in view of its size.

Up to the age of nine, the patterns of refractive change are characterised by a fall in the incidence of increase in hypermetropia, irrespective of the refractive state initially. Between nine and twelve years, however, this trend is reversed in each of the three hypermetropic groups up to +9.00 D. Although this age group comprised only forty-four eyes, the fact that a reversal occurred in three separate ametropic groups indicates that this period of life is one in which the refractive behaviour pattern of the eye alters course. There is nothing, however, to suggest that this is related to the degree of ametropia present.

The chi-square test shows that when the patterns of refractive change for children between birth and six years of age are analysed on the basis of direction of change only - i.e. no change, increased positive, decreased positive - and related to the five refractive groups studied (four hypermetropic and one myopic), the differences between these groups are highly significant; (p = <0.001). In contrast, differences for the following six years - up to twelve years of age - were not significant (p = <0.20 >0.10).

Analysis of the results in terms of the degree of refractive change per annum, similarly shows that the differences in the behaviour of eyes with different states of refraction are significant only for the youngest age group (table 34).

6.12 Whilst the incidence of increasing hypermetropia in the youngest age group (birth to three years) is greatest in those eyes with hypermetropia falling between +0.01 and +6.00 D, the range of increases per annum appears to bear little relationship to this initial level of hypermetropia. These increases for both the hypermetropic groups involved (+0.01 to +3.00 D and +3.01 to +6.00 D) were found to vary between a minimum of +0.01 and +0.20 D, up to a maximum exceeding +1.41 D. Within this age group, the increases most frequently occurring fell between +0.61 and +0.80 D. This compares with +0.81 to +1.00 D and +1.01 to +1.20 D for the ametropias of +6.01 to +9.00 and over +9.00 D respectively, although it should be noted that these latter results are based upon very small numbers (Appendix A.3).

For all the hypermetropic groups, the rate of annual change shows a tendency to decrease with age. Annual changes of over +1.41 D, however, were recorded in the two age groups, birth to three and three to six years, for hypermetropia up to +9.00 D. Nevertheless, it should be noted that stationary refractions become the predominant feature above three years of age.

TABLE 34

Chi-square analyses of changes in ocular refraction related to ametropic groups -

(a) Myopia
(b) Hypermetropia +0.01 to +3.00 D
(c) +3.01 to +6.00 D
(d) +6.01 to +9.00 D
(e) Over +9.00 D

for each six year age group

A: Analysis by direction of change and ametropic groups

	Age group in years	
	Birth to <6	6 to <12
χ^2	30.554	11.341
d.f.	8	8
n	590	300
p	<0.001	<0.20 >0.10

B: Analysis by change per annum and ametropic groups

	Age group in years	
	Birth to <6	6 to <12
χ^2	78.002	35.595
d.f.	24	24
n	590	300
p	<0.001	<0.10 >0.05

Reductions in hypermetropia occurred less frequently than increases. Notwithstanding this, the degree of change again seemed to bear little relationship to the initial refractive state. The most striking difference between the refractive groups was found in the range of annual changes. This was found to be lowest for the hypermetropic group +0.01 to +3.00 D, the maximum change falling between -1.01 and -1.20 D compared to over -1.41 D for the hypermetropias between +3.01 and +9.00 D.

Myopic eyes exhibited similar degrees of refractive change per annum to hypermetropic eyes - these most commonly falling within the ranges +0.61 to +0.80 D and -0.41 to -0.60 D. Between three and six years of age, however, increases in myopia show a tendency to be larger than decreases in myopia, the maximum changes being over -1.41 D on one hand and between +0.81 and +1.00 D on the other (Appendix A.3).

The similarity between the annual changes occurring in the different refractive groups is reflected in the means of these changes; this is particularly so for the hypermetropic groupings (Table 35). The greatest alterations in refraction undoubtedly take place in the first six years of life, of which those for the first three years are the most dramatic. The results indicate that myopia may be an exception to this, but since only four myopic cases were involved this finding must be treated with extreme caution.

The lack of correlation between refractive state and subsequent change in refraction was confirmed by the very

TABLE 35

Means and Standard Deviations within Refractive Groups of Annual Changes in Ocular Refraction, and of Initial Refractive State

Analysis by (a) annual changes in ocular refraction and initial refractive groups

(b) initial refractive state and initial refractive groups

in dioptres for each three year age group from birth to less than twelve.

	Refractive state in dioptres				
	Myopia	+0.01 - +3.00D	+3.01 - +6.00D	+6.01 - +9.00D	Over +9.00D
	Age: Birth to <3 years				
Annual changes					
Means	0.0	+0.59	+0.36	+0.33	+0.88
Standard Dev.	0.0	±0.57	±0.78	±0.91	±0.19
Refractive state					
Means	-2.30	+2.13	+4.37	+6.75	+9.41
Standard Dev.	±1.05	±0.69	±0.83	±0.58	±0.06
Numbers of eyes	4	37	69	17	4
	Age: 3 to <6 years				
Annual changes					
Means	-0.25	+0.25	+0.25	+0.15	-0.35
Standard Dev.	±1.03	±0.39	±0.46	±0.47	±0.93
Refractive state					
Means	-4.10	+2.02	+4.49	+6.93	+10.46
Standard Dev.	±3.12	±0.71	±0.84	±0.67	±0.68
Numbers of eyes	18	126	223	76	16

TABLE 35 (Continued)

	Myopia	+0.01 - +3.00D	+3.01 - +6.00D	+6.01 - +9.00D	Over +9.00D
	Age : 6 to <9 years				
Annual changes					
Means	+0.08	-0.07	-0.08	+0.03	-0.07
Standard Dev.	±0.37	±0.42	±0.40	±0.48	±0.18
Refractive state					
Means	-4.04	+1.90	+4.44	+7.22	+10.11
Standard Dev.	±3.00	±0.77	±0.87	±0.77	±0.33
Numbers of eyes	15	76	93	49	8
	Age : 9 to <12 years				
Annual changes					
Means	-0.11	+0.04	+0.13	+0.12	-0.35
Standard Dev.	±0.39	±0.29	±0.25	±0.28	0
Refractive state					
Means	-3.70	+1.67	+4.10	+7.46	+10.36
Standard Dev.	±1.79	±0.29	±0.90	±0.95	0
Numbers of eyes	13	22	13	9	1

TABLE 36

Estimated Changes in Refraction per annum related to initial state of Refraction for age group 9 to <12 years

Initial Refractive State	Estimated annual Changes in Refraction - in dioptres
+12.0	+0.19
+9.0	+0.14
+6.0	+0.09
+3.0	+0.05
+1.0	+0.01
-1.0	-0.02
-3.0	-0.05
-6.0	-0.10
-9.0	-0.15
-12.0	-0.19

low coefficients of correlation found for each three yearly group up to nine years of age (-0.038, -0.0287, 0.0193 respectively). The correlation coefficient for the age group nine up to twelve years, although also low, is rather higher than for the other groups, it being 0.1951. Although the standard error shows that this finding could be the result of sampling errors, the regression equation was calculated in order to illustrate the relationship indicated by this level of correlation. The regression coefficient of +0.0159 indicates the change in refraction per annum that can be expected to occur for each dioptre of ametropia present at any stage. It can be seen from table 36 that the estimated annual refractive changes for this age group are very small for all levels of ametropia.

Initial refractive state related to final refractive state

6.13 The incidence of myopia, emmetropia and hypermetropia at the final examination was found to be almost identical to that recorded initially (Table 37). The patterns of refractive change on the other hand, have already been shown to differ between age groups (6.6); such differences, however, are clearly insufficient to result in any significant shift in the proportions of myopes, emmetropes and hypermetropes, except perhaps in the nine to twelve year age group.

In contrast, a very definite difference was found in the levels of ametropia present at the initial and final examinations. For the purpose of this group of analyses, the final examination was taken as the last occasion on which each child was examined, the results from any intermediate examinations being excluded.

TABLE 37

Distribution of Refractive States at Initial and Final Examinations

Analysis by refractive states and (three year) age groups at initial examination - per cent

A - Initial Refractive State

Refractive state	Age in years Birth - <3	3 - <6	6 - <9	9 - <12
Emmetropia	0	0	0.4	0
Hypermetropia	96.9	96.1	93.4	77.6
Myopia	3.1	3.9	6.2	22.4

B - Final Refractive State

Refractive state	Age in years Birth - <3	3 - <6	6 - <9	9 - <12
Emmetropia	0	0	0	0
Hypermetropia	96.3	96.5	95.2	81.6
Myopia	3.7	3.5	4.8	18.4
Numbers of eyes	108	339	145	38

Only data, therefore, from the original non-expanded sample was utilised (6.1): 632 eyes out of a total of 634 were involved; (one eye was excluded through injury and one through omission of relevant data). The chi-square test shows that for both initial age groups - birth up to six years, and six up to twelve years, the differences between the actual levels of ametropia (6.9) are highly significant ($p = <0.001$) (Table 38).

The intervals between initial and final examinations varied widely - from one to six years: the relationships between initial and final ages is shown in appendix A.4. Such variations make it impossible to predict with any accuracy the final levels of refraction. Nevertheless, it is clear that within this variable span, a very definite relationship exists.

The means and standard deviations of the initial and final refractive states for each age group clearly show the trends occurring in the development of refraction. (Table 39). The age groups concerned in both cases represent the age at the time of the first examination; the children involved in the various groups for analysis of initial examination have been retained in these same groups for the final analysis, even though their ages may no longer fall within these groupings. By comparing the initial and the final means for each age group in this way, a longitudinal measure is provided of the shift in refraction occurring within the same children. The shift is undoubtedly most marked for the youngest age group. In contrast, refraction is most stable between six and twelve years of age: this, of course, does not mean that individuals do

TABLE 38

Chi-square analyses of Final Ametropia related to Initial Ametropia for each six year age group *

Analysis by ametropic groups:-

(a) myopia

(b) hypermetropia +0.01 to +3.00 D

(c) +3.01 to +6.00 D

(d) +6.01 to +9.00 D

(e) >+9.00 D

at initial and final examinations

	Age group in years:	
	Birth to <6	6 to <12
χ^2	942.653	505.155
d.f.	16	16
n	447	184
p	<0.001	<0.001

* Ages are based upon those found at the initial examination

TABLE 39

Means and Standard Deviations of Initial and Final Refractive states

Analysis by age at first examination and means and standard deviation of refractive states in dioptres

Refractive state - dioptres	Age in years			
	Birth to <3	3 to <6	6 to <9	9 to <12
	Initial examination			
Mean	+3.83	+4.00	+4.02	+2.55
Standard Deviation	±2.24	±2.75	±3.08	±3.62
	Final examination			
Mean	+4.80	+4.39	+3.83	+2.77
Standard Deviation	±2.47	±2.94	±3.18	±3.87
Numbers of eyes	108	339	145	38

not change markedly at this time of life; what it does suggest is that individual changes in a particular direction tend to be offset by changes occurring in other eyes in the opposite direction.

The correlation between initial and subsequent level of ametropia is, as one might expect, extremely high for each of the age groups involved. It is, nevertheless, lowest for the youngest and highest for the eldest age group. The correlation coefficients are as follows:-

	Age in years			
	Birth to <3	3 to <6	6 to <9	9 to <12
Correlation Coefficient	0.8800	0.9411	0.9747	0.9808

Whilst these results indicate that the younger the child, the less predictable will be the final refractive state, it is clear that final ametropia is closely related to its initial level irrespective of the age group involved.

Initial changes related to final changes in refraction

6.14 It has already been shown that refraction is more likely to alter markedly in the first three years of life than in later years (6.7). The question arises, however, as to whether any relationship exists, for each child, between early developments and those which follow; do changes in refraction occurring between the first and second examinations differ in type from those found from the second and third, or third and fourth examinations? Since a minimum of three examinations must have been carried out in order to provide the requisite data, children on whom only two examinations had been completed were excluded. This left 206 cases for analysis. Duplicity factors were avoided by comparing the alteration in refraction taking place between the first and second examinations with that occurring between the penultimate and final examinations; intermediate changes were disregarded.

Refractive changes were simply classified into three categories indicating direction of change only:

(a) no change

(b) increased positive

(c) decreased positive.

Analysis was carried out by relating final direction to initial direction of change in each of the cases involved.

Comparisons between males and females on this basis, revealed no significant differences for any of the groupings. Using the chi square test, the probability that these differences had arisen by chance was found to be high for both age groups - birth up to six and six up to twelve ($p = <0.5 >0.3$) Males and females were, therefore, grouped together and analysed as a whole (Table 40). Final changes in each of the four age groups (three yearly) are distributed fairly widely, indicating little direct relationship with the previous changes involved. The chi-square results show that the relationship between initial and final change in refraction is not significant (Table 41).

TABLE 40

Final changes in ocular refraction related to initial changes in refraction

Analysis by direction of initial and final changes in refraction for each three year age group from birth to less than twelve years - per cent

Final Refractive Change	Initial Refractive Changes: No change	Increased Positive	Decreased Positive
	Age: Birth to <3 years		
No change	33.3	48.5	0
Increased positive	44.4	36.4	75.0
Decreased positive	22.2	15.2	25.0
Numbers of eyes	9	33	4
	Age : 3 to <6 years		
No change	43.3	37.9	33.3
Increased positive	53.3	40.2	33.3
Decreased positive	3.3	21.8	33.3
Numbers of eyes	30	87	9

TABLE 40 (Continued)

Final Refractive Change	Initial Refractive Changes: No change	Increased Positive	Decreased Positive
	Age : 6 to <9 years		
No change	71.4	71.4	33.3
Increased positive	0	0	16.7
Decreased positive	28.6	28.6	50.0
Numbers of eyes	7	7	12
	Age : 9 to <12 years		
No change	60.0	33.3	0
Increased positive	20.0	33.3	0
Decreased positive	20.0	33.3	0
Numbers of eyes	5	3	0

TABLE 41

Chi-square analyses of Final Change related to Initial Change in Ocular Refraction for each six year age group

Analysis by initial and final directions of change:

(a) no change

(b) increased positive

(c) decreased positive

	Age group in years	
	Birth to <6	6 to <12
χ^2	5.769	2.959
d.f.	4	4
n	172	34
p	<0.3>0.2	<0.7>0.5

Relationship between patterns of ocular change in right and left eyes

6.15 The manner in which the two eyes behave in relation to each other, with regard to refractive changes, is extremely important. By studying such behaviour, it may be possible to exclude certain factors as determinants of changes in refraction. Should the results show, for example, that both eyes always exhibit the same direction and degree of change, then the level of ametropia could be eliminated since it is known that the refractive state of the right eye can differ markedly from that of the left. The patterns of behaviour of each pair of eyes were, therefore, examined. For this purpose, changes were graded according to their degree of similarity, or dissimilarity, as follows:-

(a) both no change

(b) both change, same direction, equal degree

(c) both change, same direction, unequal degree

(d) one increased positive, other no change

(e) one decreased positive, other no change

(f) both change - opposite directions

From table 42 it can be seen that in the majority of cases, right and left behave dissimilarly and in a small proportion of cases, even change in opposite directions. (The chi-square test shows the six yearly distributions to be highly significant; $\chi^2 = 31.24$, d.f. = 5, n = 890, p = <0.001). The most frequently occurring pattern for all ages, except between eight and nine , is one eye showing change in a myopic direction (decreased positive) and one eye remaining stationary. From birth up to nine years of age, the proportion of cases displaying equal ocular changes - that is the stationary and equal change groups combined - tends to increase. The percentage trend for the three yearly groupings up to twelve years of age is shown below:

	Age in years			
	Birth to <3	3 to <6	6 to <9	9 to <12
Equal changes (Nil - equal change)	26.0	43.1	48.3	37.9

As has already been found (6.7: 6.11) the trend is reversed between nine and twelve years of age, although it must be borne in mind that the numbers involved in this group are relatively small.

What is clear is that each eye can behave differently, if not independently, from the other; indeed, it is more likely to be out of phase with its partner than in phase. It is obvious from these results, that age is certainly not the sole factor involved in the refractive changes taking place.

TABLE 42

Relationship between changes in ocular refraction in right and left eyes

Analysis by relationships and yearly age groups - per cent

	Age in years - less than											
	1	2	3	4	5	6	7	8	9	10	11	12
(a) Both no change	0	5.0	11.5	24.8	24.1	28.4	34.8	31.8	43.3	16.7	37.5	22.2
(b) Both change equally	0	15.0	18.4	15.2	15.7	21.6	13.0	11.4	13.3	8.3	12.5	22.2
(c) Both change unequally	0	5.0	4.6	1.4	8.4	9.5	8.7	13.6	16.7	25.0	0	11.1
(d) One increased positive/other no change	0	10.0	16.1	7.6	6.0	8.1	6.5	0	6.7	0	12.5	11.1
(e) One decreased positive/other no change	100.0	55.0	49.4	49.7	44.6	32.4	37.0	43.2	20.0	41.7	37.5	22.2
(f) Both change opposite directions	0	10.0	0	1.4	1.2	0	0	0	0	8.3	0	11.1
Numbers of eyes	2	20	44	73	83	74	46	44	30	12	8	9

Summary point (6.1 - 6.15)

6.16

1. The characteristics of the sample have been described and the effect of expanding the sample analysed. The distributions of males and females within both the original and expanded groups have been shown to be similar (6.1 - 6.3).

Males and females were found to differ little in their pattern and degree of refractive changes associated with age. The small differences that do occur can be explained by the earlier development of girls compared to boys, below the age of five (6.5).

Analysis of the sample as a whole, irrespective of sex, revealed instances of no change, increased positive, and decreased positive occurring at early yearly age groups, from one up to twelve years. Results show that the most pronounced changes in refraction take place in the period from birth to three years of age, and that these are mostly in the direction of increasing hypermetropia (or decreasing myopia). The proportion of cases showing stationary refractions increases with age, particularly after three years; this is associated with a decline in the incidence of increasing hypermetropia. A reversal in this trend was recorded during the period nine to twelve years of age (6.7).

The correlation between age and refractive change was low for each three year group from birth up to twelve years. The regression coefficients have been calculated and the estimated age related changes in refraction presented (6.7). Sampling errors have been shown to be a possible factor for all age groups except the three to six year olds.

2. Analysis of refractive change related to the initial refractive state, revealed little difference between the sexes, except for those children up to six years of age with refractions ranging from +3.01 to +6.00 D. The trend, during the period involved, indicates that girls are rather more advanced than boys and that maturity is probably the factor involved in these differences.

Grouping males and females together revealed that the lowest degrees of hypermetropia - +0.01 to +3.00 D - are most likely to show an increase in hypermetropia and that this occurs in the first three or four years of life. Children in this age group with higher degrees of hypermetropia, show a greater tendency to remain stationary or shift towards myopia than in the lower groups, although the majority still display hypermetropic increases The older the child, the more likely the refraction will remain stationary or show a myopic shift, irrespective of the level of hypermetropia. Myopic eyes behaved similarly to hypermetropic eyes. The reversal in trend in the nine to twelve year age group was again found (6.11).

The rates of annual change for all hypermetropic eyes were found to decrease with age. Reductions in hypermetropia occurred less frequently than increases. Myopic eyes exhibited similar patterns of change. The correlation between change and refractive state was very low for all age groups (6.12).

3. The correlation between final and initial refractive states was high, becoming higher with age (6.13). Final changes in refraction, on the other hand, bear little resemblance to initial changes (6.14).

4. Analysis of refractive development of the two eyes has shown that each eye is more likely to be out of phase with its partner than in phase. This finding confirms that age cannot be the sole factor involved in the changes in refraction that take place (6.15).

Refractive changes related to strabismic characteristics

Characteristics of sample

6.17 Over 80 per cent of the children included in this study had convergent strabismus, whilst less than 10 per cent were non-strabismic. The distribution of the various strabismic states is as follows:

Non-strabismic	7.4%
Convergent:	
Unilateral (RCCS/LCCS)	80.3%
Alternating/Intermittent (ACCS/ICCS)	10.5%
Divergent:	
Unilateral (RCDS/LCDS)	1.3%
Alternating/Intermittent (ACDS/ICDS)	0.4%

Intermittent strabismus was grouped with alternating strabismus since its incidence was very low, and both types have similar visual characteristics - i.e. good visual acuity in both eyes. All strabismic cases were concomitant in nature, non-comitant cases having been previously excluded (5.11)

For the purposes of this study, each eye was classified according to one of the following groupings:

(a) Nil strabismus - non-strabismic subjects

(b) Fixating eyes - RCCS/LCCS

(c) Strabismic eyes - RCCS/LCCS

(d) Fixating eyes - RCDS/LCDS

(e) Strabismic eyes - RCDS/LCDS

(f) Alternating/Intermittent Convergent

(g) Alternating/Intermittent Divergent.

Since the children involved were being treated for the strabismus itself this classification is based on the strabismic condition present prior to the commencement of the treatment.

From this classification, three major groups were formed with a view to analysing whether changes in refraction are related to strabismic type. The fixating eyes from unilateral convergent and divergent cases were grouped with eyes from non-strabismic subjects to form a non-strabismic group. The alternating and intermittent cases - convergent and divergent - comprised the alternating group, whilst the strabismic eyes from the unilateral cases formed the unilateral group;

(i) Nil group: Comprising Nil in either eye
Nil in right eye (LCCS/LCDS)
Nil in left eye (RCCS/RCDS)

(ii) Alternating/Intermittent group :
Comprising Both eyes alternating and intermittent convergent or divergent cases

(iii) Unilateral group :
Comprising Unilateral R (RCCS/RCDS)
Unilateral L (LCCS/LCDS)

The percentage distribution within each three year age group is shown in table 43.

In order to determine the effect of combining the eyes of non-strabismic subjects with the non-strabismic eyes of unilateral cases, the patterns of refractive changes have been analysed for these two groups separately (table 44). Although the distribution is clearly not identical, the chi-square test shows that combination of the two samples into a single "nil" group has not significantly changed the characteristics of the "non-strabismic" unilateral group. The chi-square results for the unilateral and the combined groups are almost identical:

TABLE 43

Distribution of strabismic and non-strabismic eyes within each three year age group

Analysis by strabismic groupings:-

(a) nil

(b) alternating/intermittent

(c) unilateral

and age groups (three yearly) from birth to twelve years - percentage distribution.

Strabismic Groups	Age in years			
	Birth to <3	3 - <6	6 -<9	9 - <12
Nil	40.5	49.7	47.9	58.6
Alternating/ intermittent	21.4	8.3	11.6	6.9
Unilateral	38.2	42.0	40.5	34.5
Numbers of eyes	131	459	242	58

TABLE 44

Changes in refraction related to non-strabismic eyes

Analysis by refractive change and age for non-strabismic eyes in subjects with:

(a) nil strabismus

(b) unilateral strabismus

Percentage distribution

	Age in years			
	Birth to <3	3 - <6	6 - <9	9 - <12
	A - Nil Strabismus (Nil in either eye)			
No change	100	26.7	23.5	28.6
Increased positive	0	46.7	35.3	28.6
Decreased positive	0	26.7	41.2	42.9
Numbers of eyes	2	30	17	14
	B - Unilateral Strabismus (Fixating eyes)			
No change	22.0	42.27	56.25	44.44
Increased positive	72.0	46.91	13.54	44.44
Decreased positive	6.0	10.82	30.21	11.11
Numbers of eyes	50	194	96	18

Unilateral		Combined 'nil' group	
χ^2	= 59.26	χ^2	= 54.67
d.f.	= 6	d.f.	= 6
n	= 358	n	= 430
p	= <0.001	p	= <0.001

The various degrees of ametropia have been examined for each strabismic group and, where appropriate, broken down into fixating and non-fixating eyes. The distribution for the group as a whole, irrespective of age, and sex, is shown in table 45. From this it can be seen that in cases of unilateral convergent strabismus, the non-strabismic eye tends to have a lower degree of hypermetropia than the strabismic eye. Analysis solely of this group of eyes confirms this finding (table 46); this is especially marked for the hypermetropic refractions.

Sex differences

6.18 Refractive changes for males and females did not differ significantly in any of the three strabismic groups, irrespective of the age group involved. The greatest differences occurred in the 'nil' strabismic group up to six years of age, although the chi-square test showed that the probability of these occurring by chance was <0.10>0.05 and, therefore, still not significant. Consequently males and females were grouped together.

Overall changes

6.19 Similar patterns of refractive change occurred in each of the three strabismic groups. Up to six years of age the shift towards hypermetropia was again the dominant change, its incidence being highest during the first three years of life (table 47). The tendency for the proportions of stationary

TABLE 45

Initial refractive state related to strabismic and non-strabismic eyes

A : Analysis by initial refractive state in dioptres and type of strabismus present, for all ages, from birth to over twelve years - percentage distribution

Strabismic state	≥-9.01	-8.01 to-9.00	-7.01 to-8.00	-6.01 to-7.00	-5.01 to-6.00	-4.01 to-5.00	-3.01 to-4.00	-2.01 to-3.00	-1.01 to-2.00	-0.01 to-1.00	Emmetropia	+0.01 to+1.00	+1.01 to+2.00	+2.01 to+3.00	+3.01 to+4.00	+4.01 to+5.00	+5.01 to+6.00	+6.01 to+7.00	+7.01 to+8.00	+8.01 to+9.00	≥ +9.01
Nil strabismus	0	16.7	25.0	100	100	0	75.0	80.0	53.8	42.9	0	6.5	7.1	4.1	2.8	2.1	4.5	3.4	9.8	0	20.7
Fixating eye RCCS or LCCS	0	16.7	25.0	0	0	0	0	0	15.4	28.6	100	51.6	44.0	43.2	51.4	39.6	36.6	37.1	43.9	33.3	27.6
Strabismic eye RCCS or LCCS	0	16.7	25.0	0	0	33.3	0	200	15.4	14.3	0	25.8	26.2	37.7	36.8	45.8	50.0	51.7	36.6	66.7	44.8
Fixating eye RCDS or LCDS	0	0	0	0	0	33.3	0	0	0	14.3	0	6.5	2.4	0	0	0	0	0	0	0	0
Strabismic eye RCDS or LCDS	0	0	0	0	0	33.3	25.0	0	0	0	0	3.2	3.6	0	0	0	0	0	0	0	0
ACCS or ICCS	0	50.0	25.0	0	0	0	0	0	0	0	0	6.5	16.7	15.1	9.0	12.5	8.9	6.7	7.3	0	6.9
ACDS or ICDS	0	0	0	0	0	0	0	0	15.4	0	0	0	0	0	0	0	0	1.1	2.4	0	0
Numbers of eyes	0	6	4	1	7	3	4	5	13	7	1	31	84	146	144	144	112	89	41	21	29

TABLE 46 (Continuation of Table 45)

B : Analysis by initial refractive state and unilateral convergent strabismus for all ages - per cent

Strabismic state	Initial refractive state - dioptres																				
	≥-9.01	-8.01 to -9.00	-7.01 to -8.00	-6.01 to -7.00	-5.01 to -6.00	-4.01 to -5.00	-3.01 to -4.00	-2.01 to -3.00	-1.01 to -2.00	-0.01 to -1.00	Emmetropia	+0.01 to +1.00	+1.01 to +2.00	+2.01 to +3.00	+3.01 to +4.00	+4.01 to +5.00	+5.01 to +6.00	+6.01 to +7.00	+7.01 to +8.00	+8.01 to +9.00	≥+9.01
Fixating eyes RCCS/LCCS	0	50.0	50.0	0	0	0	0	0	50.0	66.7	100	66.7	62.7	53.4	58.3	46.3	42.3	41.8	54.5	33.3	38.1
Strabismic eyes RCCS/LCCS	0	50.0	50.0	0	0	100	0	100	50.0	33.3	0	33.3	37.3	46.6	41.7	53.7	57.7	58.2	44.5	66.7	61.9
Numbers of eyes	0	2	2	0	0	1	0	0	4	3	1	24	59	118	127	123	97	79	33	21	21

TABLE 47

Changes in ocular refraction related to strabismic state of each eye

Analysis by changes in refraction and strabismic groups - Nil : Alternating/Intermittent : Unilateral : for each three year age group from birth up to twelve years - percentage distribution

Changes in Refraction	Strabismic groups Nil	Alternating/ Intermittent	Unilateral
		Age : Birth to <3 years	
No change	24.5	17.9	16.0
Increased positive	66.0	67.9	74.0
Decreased positive	7.5	14.3	10.0
Numbers of eyes	53	28	50
		Age : 3 - <6 years	
No change	39.9	31.6	36.3
Increased positive	46.5	52.6	51.3
Decreased positive	13.6	15.8	12.4
Numbers of eyes	228	38	193

TABLE 47 (Continued)

Changes in Refraction	Strabismic groups Nil	Alternating/ Intermittent	Unilateral
Age : 6 - <9 years			
No change	50.4	42.9	46.9
Increased positive	16.5	42.9	21.4
Decreased positive	33.0	14.3	31.6
Numbers of eyes	115	28	98
Age : 9 - <12 years			
No change	35.3	100.0	30.0
Increased positive	38.2	0	45.0
Decreased positive	26.5	0	25.0
Numbers of eyes	34	4	20

refractions to increase with age, is characteristic of all the groups.

As with previous analyses, the trend is reversed in all cases, during the period nine to twelve years of age. The shift towards myopia (decreasing hypermetropia) is most marked between six and nine years of age. This was, however, found to be less pronounced in cases of alternating or intermittent strabismus than in unilateral and non-strabismic groupings.

The chi-square test confirms that the difference between the gross developments of the three strabismic groups is not significant, (birth - <6 years $\rho = <0.50 >0.30$, 6 to <12 years $\rho = <0.20 >0.10$).

The ranges of annual changes are very similar in the nil, alternating and unilateral groups. (appendix A.5). This is especially pronounced between the ages of three and six, the means and standard deviations for this period being almost identical (table 48).

These results do *not* signify that refractive changes are related to the type of strabismus present. If strabismus is divided simply into unilateral and alternating/intermittent groups then the evidence clearly shows that the difference in pattern of change is not significant (appendix A.5). It should be noted, however, that the two groups are markedly different in size, the unilateral cases being by far the largest. Further analysis, breaking down each group into its convergent and divergent components, was not possible since the overwhelming majority of cases were convergent (6.17).

TABLE 48

Means and standard deviations of annual changes in ocular refraction related to strabismic state of each eye

Analysis by annual changes in ocular refraction and strabismic groups:

(a) Nil
(b) Alternating/Inter mittent
(c) Unilateral

for each three year age group from birth up to twelve years

Changes in refraction -dioptres	Nil	Alternating/ Intermittent	Unilateral
		Strabismic groups	
	Age : Birth to <3 years		
Mean	+0.54	+0.24	+0.49
Standard deviation	±0.58	±0.83	±0.65
Numbers of eyes	53	28	50
	Age : 3 to <6 years		
Mean	+0.18	+0.25	+0.23
Standard deviation	±0.56	±0.46	±0.48
Numbers of eyes	228	38	193

TABLE 48 (Continued)

Changes in refraction -dioptres	Strabismic groups		
	Nil	Alternating/ Intermittent	Unilateral
	Age : 6 to <9 years		
Mean	-0.08	+0.17	-0.05
Standard deviation	±0.44	±0.40	±0.37
Numbers of eyes	115	28	98
	Age : 9 to <12 years		
Mean	0	0	+0.10
Standard deviation	±0.33	0	±0.36
Numbers of eyes	34	4	20

Refractive changes related to angle of strabismus

Characteristics of sample

6.20 The angle of strabismus is known to vary from subject to subject, irrespective of the type of strabismus present. It may, therefore, be related to alterations in ocular refraction, even though the *type* of strabismus has been shown to be a non-causative factor.

The strabismic angle is not necessarily constant for any individual. The children involved were receiving treatment designed to reduce this angle and as a result variations occurred even between refractive examinations. The angle therefore recorded for this analysis was that found by the Hospital Orthoptic Department at the commencement of treatment.

Of the 413 subjects with strabismus, the angle of deviation had not been recorded in fourteen instances. (This was due mainly to omission of data in the patient's records). This left a total of 399 cases, or 798 eyes, for analysis. The angles were initially divided into five groups:

(a) $\leq 5^{o}$

(b) $6 - 10^{o}$

(c) $11 - 20^{o}$

(d) $21 - 30^{o}$

(e) $31 - 40^{o}$

No cases above 40^{o} were recorded.

It was found necessary to reduce the number of divisions for some analyses, in particular the chi-square tests. Consequently, two groups were adopted in such cases:

(a) $1 - 20^{o}$

(b) $21 - 40^{o}$

The distribution within each three year age group can be seen in table 49, together with their means and standard deviations.

Further breakdown on the basis of the strabismic state of each eye was not carried out since nothing has been found to suggest that refractive changes are related to the type of strabismus present (6.19). Fixating eyes in unilateral strabismus cases have, therefore, been classified as part of the same angle group as the strabismic eye.

Sex differences

6.21 The differences found in the patterns of refractive change in males and females were not significant for either of the angle groupings, irrespective of age. Although the largest differences occurred amongst children less than six years of age with angles falling between 1 and 20 degrees, the probability of these findings occurring by chance was still high. ($\chi^2 = 5.636$, d.f.=2, n = 256 $p = <0.05>0.01$).

Overall developments

6.22 The changes in refraction have been analysed for the two groups of strabismic angle, 1 - 20°, 21 - 40°, to show their direction (table 50) as well as the level of such changes (Appendix A.6). What is clearly shown is that refractive developments during the first six years of life are almost identical for the two angle groups, and, therefore, unrelated to strabismic angle. This is confirmed by the chi-square results which show the differences to be insignificant ($p = 0.20$, table 51).

TABLE 49

A : Distribution of angles of strabismus within each three year age group from birth up to twelve years - per cent

Strabismic angle groups in degrees	Age in years Birth to <3	3 to <6	6 to<9	9 - <12
1 - 20°	37.4	51.6	60.9	70.0
21 - 40°	62.6	49.4	39.1	30.0
Numbers of eyes	123	415	220	40

B : Means and standard deviations of strabismic angles within angle groupings for each three year age group - degrees

Strabismic angle groups in degrees	Age in years Birth to <3	3 to <6	6 to <9	9 - <12
1 - 20°	19 ±3.4	17 ±4.8	18 ±4.9	19 ±2.6
21 - 40°	34 ±5.8	33 ±4.6	32 ±3.7	38 ±3.7

TABLE 50

Changes in refraction related to angle of strabismus

Analysis by changes in ocular refraction and strabismic angle for each three year age group from birth to twelve years - percentage distribution

Changes in refraction	Angle of strabismus - degrees $1 - 20^{o}$	$21 - 40^{o}$
	Age : Birth to <3	
No change	19.57	16.88
Increased positive	78.26	70.13
Decreased positive	2.17	12.99
Numbers of eyes	46	77
	Age : 3 to <6	
No change	39.52	36.59
Increased positive	50.00	49.76
Decreased positive	10.48	13.66
Numbers of eyes	210	205

TABLE 50 (Continued)

Changes in refraction	Angle of strabismus - degrees 1 - 20°	21 - 40°
	Age : 6 to <9	
No change	57.46	40.70
Increased positive	24.63	15.12
Decreased positive	17.91	44.19
Numbers of eyes	134	86
	Age : 9 to <12	
No change	50.00	25.00
Increased positive	32.14	58.33
Decreased positive	17.86	16.67
Numbers of eyes	28	12

TABLE 51

Chi-square analyses of changes in ocular refraction related to strabismic angle for each six year age group

Analysis by annual refractive changes and angle of strabismus grouped:

(a) 1 - 20°

(b) 21 - 40°

	Age group in years	
	Birth to <6	6 to <12
χ^2	8.528	20.39
d.f.	6	5 *
n	558	268
ρ	0.20	<0.01 >0.001

* numbers available necessitated combining groups of annual changes thus reducing the degrees of freedom

Analysis of refractive changes on a three year basis demonstrates that the period, three up to six years of age, is one in which the effect of angle is negligible and certainly less than in any other period. The respective means, and standard deviations, are almost identical for this age group (table 52). The results for the preceeding period, birth up to three years, on the other hand, indicate that at this time of life, the smaller the angle, the higher the level of change per annum. It should, however, be noted that the difference in means - +0.64 D compared to +0.34 D - arises from a small number of cases exhibiting a large degree of decreasing hypermetropia (four eyes with changes exceeding -1.41 D). The distribution of changes, otherwise, is similar for the two groups of angles (appendix A.6).

The differences in patterns of change for the subsequent three year periods are quite marked. Between six and nine years, the smaller the angle the greater the incidence of a shift towards hypermetropia. In contrast, between nine and twelve years of age, the position is reversed; the smaller the angle the lower the incidence. The chi-square test shows that these differences are significant, the probability that they occurred by chance being between 0.01 and 0.001 (table 51).

Up to nine years of age both groups of angles display the same clear trend: a decline in the incidence of increasing hypermetropia with an associated rise in the proportions of both stationary refractions and decreasing hypermetropia. Between nine and twelve years, this trend is reversed in both angle groups, the proportions of stationary refractions declining whilst the incidence of increasing hypermetropia rises.

TABLE 52

Means and standard deviations of annual changes in ocular refraction within strabismic angle groups for each three year age group

Analysis by annual refractive changes, in dioptres, and angle of strabismus, in degrees

Annual changes in ocular refraction - dioptres	Angle of strabismus in degrees	
	1 - 20°	21 - 40°
	Age : Birth to <3 years	
Mean	+0.64	+0.34
Standard deviation	±0.54	±0.82
Numbers of eyes	46	77
	Age : 3 to <6 years	
Mean	+0.24	+0.21
Standard deviation	±0.48	±0.44
Numbers of eyes	210	205

TABLE 52 (Continued)

Annual changes in ocular refraction - dioptres	Angle of strabismus in degrees	
	$1 - 20^{\circ}$	$21 - 40^{\circ}$
	Age: 6 to <9 years	
Mean	+0.04	-0.16
Standard deviation	±0.32	±0.48
Numbers of eyes	134	86
	Age: 9 to <12 years	
Mean	+0.02	+0.19
Standard deviation	±0.29	±0.28
Numbers of eyes	28	12

The correlation coefficients shown below are low for each age group, but especially so for the two youngest groups:-

	Age in years			
	Birth to <3	3 - <6	6 -<9	9 to <12
Correlation Coefficients	- 0.1040	-0.0071	-0.2041	-0.3034
Numbers of eyes	123	415	220	40

This indicates that up to the age of six, changes in refraction are not associated with strabismic angle.

The standard error shows that the correlation findings for two eldest groups are unlikely to have arisen as a result of sampling errors: the probability of these findings having occurred by chance being <0.01 >0.001 for those children aged six up to nine, and <0.05 >0.01 for those aged nine to twelve. The regression coefficient, however, indicates that even for the most significant group - the six to nine year olds, the relationship between angle and refractive change is very weak, the regression factor being -0.01 D for each degree of strabismic angle. The estimated changes in refraction related to angle of strabismus for each of the age groups is shown in table 53.

These results do not suggest that strabismic angle on its own has a significant role in determining the nature of the changes in refraction that take place.

Refractive change and ametropic correction

Characteristics of sample

6.23 The extent to which the ametropia is corrected by spectacles varies according to a number of inter-related factors. In this study these factors are mostly associated with the type of strabismus. In some cases the refractive error is corrected fully, whilst in others it is undercorrected or even overcorrected. The variation,

TABLE 53

Estimated changes in refraction per annum related to angle of strabismus for each three year age group from birth up to twelve years

Angle of strabismus - degrees	Estimated change in refraction - dioptres	Regression Coefficient
	Age : Birth to <3 years	
0	+0.70	-0.0077
5	+0.66	
10	+0.62	
20	+0.54	
40	+0.39	
	Age : 3 to <6 years	
0	+0.22	+0.0003
5	+0.23	
10	+0.23	
20	+0.23	
40	+0.24	

TABLE 53 (Continued)

Angle of strabismus -degrees	Estimated change in refraction -dioptres	Regression coefficient
	Age: 6 to <9 years.	
0	+0.19	-0.01
5	+0.14	
10	+0.09	
20	-0.01	
40	-0.21	
	Age: 9 to <12 years	
0	-0.17	+0.0099
5	-0.12	
10	-0.07	
20	+0.03	
40	+0.23	

however, is principally in the direction of an hypermetropic undercorrection rather than overcorrection. The effect of varying the level of ametropic correction can, therefore, be studied.

Of the total cases, approximately 60 per cent were fully corrected. Of the remainder roughly half were undercorrected by +0.25 D or +0.50 D and half by +0.75 D to over +2.50 D. The cases were grouped together into three divisions:

(a) full correction

(b) under correction $\leq$ +0.50 D

(c) under correction $\geq$ +0.75 D

The distribution within age groups is shown in table 54. The average degree of undercorrection falls between +0.29 and +0.37 D for the lower group, and +1.19 and +1.46 D for the higher group (table 55).

Sex differences

6.24 Analysis of sex differences in the patterns of refractive change showed these to be insignificant for both undercorrected groups, irrespective of age. The only significant differences to be found were in fully corrected children up to six years of age (χ^2 = 10.411, d.f. = 2, n = 373, ρ = <0.01 >0.005). By breaking down the age group into yearly intervals the major differences can be seen to occur in the fifth year of life (ρ = <0.001 - table 56). The disparity lies between the proportions of cases remaining stationary and those shifting in an hypermetropic direction, the females displaying the higher incidence of stationary refractions. It is difficult to interpret such differences since in the preceding as well as the subsequent

TABLE 54

Correction of ametropia within age groups

Analysis by level of spectacle worn and three year age groups up to twelve years - per cent

Ametropic correction	Age groups in years Birth - <3	3 - <6	6 -<9	9 - <12
Full correction	68.7	61.7	49.2	62.1
$\leq$+0.50 D under correction	15.3	23.1	31.0	22.4
$\geq$+0.75 D under correction	16.0	15.3	19.8	15.5
Numbers of eyes	131	459	242	58

TABLE 55

Means and standard deviations of undercorrection of ametropia

Analysis by degree of ametropic undercorrection - grouped (a) $\leq$+0.50 D (b) $\geq$+0.75 D - and three year age groups from birth up to twelve years - Means and standard deviations in dioptres

Ametropic undercorrection in dioptres	Age in years: Birth - <3	3 - <6	6 - <9	9 - <12
	Undercorrection $\leq$+0.50 D			
Mean	+0.30	+0.29	+0.37	+0.37
Standard deviation	±0.10	±0.10	±0.13	±0.13
Numbers of eyes	20	106	75	13
	Undercorrection $\geq$+0.75 D			
Mean	+1.19	+1.46	+1.27	+1.44
Standard deviation	±0.50	±0.97	±0.68	±0.50
Numbers of eyes	21	70	48	9

TABLE 56

Changes in ocular refraction related to full correction of ametropia amongst males and females

Analysis by sex and changes in refraction in cases with full ametropia correction for each yearly age group up to six years - percentage distribution

Changes in refraction	Age in years - less than 1	2	3	4	5	6
MALES						
No change	0	14.3	16.7	34.1	16.1	40.6
Increased positive	0	71.4	80.6	51.0	71.0	56.3
Decreased positive	0	14.3	2.8	4.9	12.9	3.1
Numbers of eyes	0	14	36	41	62	32
FEMALES						
No change	0	33.3	38.7	26.9	52.8	37.2
Increased positive	0	55.6	58.1	69.2	30.2	53.5
Decreased positive	0	11.1	3.2	3.8	17.0	9.3
Numbers of eyes	0	9	31	52	53	43
Significance p (χ^2)	-	<0.70 >0.50	<0.20 >0.10	<0.80 >0.70	<0.001	<0.70 >0.50

years of life, the results are reversed, with males displaying marginally the higher incidence. It is questionable whether this difference is of consequence; nevertheless it should be borne in mind that female growth rates have been found to be higher than males up to the fifth year. Maturity factors cannot, therefore, be excluded.

Overall variations

6.25 Changes in refraction in the three correction groups were compared within each separate three year age span (table 57). During the first three years of life, undercorrected cases show a lower proportion of stationary refractions than those fully corrected. The results do suggest that the higher the level of undercorrection the lower the incidence of stationary refractions; 25.6 per cent stationary for the fully corrected group compared with 10.0 and 4.8 per cent for the $\leq$+0.50 D and $\geq$+0.75 D groups respectively. In contrast, fully corrected cases displayed a lower incidence of decreasing hypermetropia than those under-corrected, although the two undercorrected groups were almost identical in incidence; the percentages being 5.6, 20.0 and 19.0 respectively. The incidence of increasing hypermetropia differed little between the three groups, being approximately 70 per cent.

Apart from these gross differences, changes per annum were fairly similarly distributed with cases of >+1.40 D occurring in all three groups. (appendix A.7). Taking the pattern of changes overall, no clear trend stands out, except perhaps for stationary refractions. This is borne out by the means of the annual changes, which are almost identical for the fully

TABLE 57

Changes in refraction related to ametropic correction

Analysis by changes in ocular refraction and ametropic correction for each three year age group from birth to twelve years - percentage distribution

Changes in refraction	Ametropic correction Full correction	$\leq$+0.50 D Under correction	$\geq$+0.75 D Under-correction
	Age: Birth - <3 years		
No change	25.6	10.0	4.8
Increased positive	68.9	70.0	76.2
Decreased positive	5.6	20.0	19.0
Numbers of eyes	90	20	21
	Age : 3 - <6 years		
No change	33.6	44.3	44.3
Increased positive	57.2	40.6	28.6
Decreased positive	9.2	15.1	27.1
Numbers of eyes	283	106	70

TABLE 57 (Continued)

Changes in refraction	Ametropic correction: Full correction	$\leq$+0.50 D Under correction	$\geq$+0.75 D Under-correction
	Age: 6 - <9 years		
No change	46.6	44.0	58.3
Increased positive	27.1	17.3	14.6
Decreased positive	26.3	38.7	27.1
Numbers of eyes	118	75	48
	Age : 9 - <12 years		
No change	36.1	46.2	33.3
Increased positive	38.9	30.8	44.4
Decreased positive	25.0	23.1	22.2
Numbers of eyes	36	13	9

corrected and $\geq$+0.75 D undercorrected groups; the standard deviations, however, do differ (table 58).

For the age group, three up to six years, the percentage of stationary refractions was greater for eyes undercorrected than for those fully corrected. The main differences, however, occurred amongst those cases in which the refraction altered. The incidence of increasing hypermetropia was highest for fully corrected eyes and lowest for undercorrected eyes, the greater the degree of undercorrection, the lower the incidence. The converse was found to be true for decreasing hypermetropia, the incidence being lowest for fully corrected and highest for undercorrected cases.

The differences in the patterns and levels of annual refractive change for the three 'correction' groups are more pronounced for this age span than for the period up to three years of age. This is illustrated by the means of these changes which show that associated with undercorrection of ametropia, there is a tendency for the shift towards hypermetropia to decline, the mean changes per annum being +0.30 D, +0.13 D and -0.11 D for the fully corrected and undercorrected groups respectively (appendix A.7, table 58).

Chi-square analysis of the results for the first six years of life shows the relationship between annual changes in refraction and ametropic correction to be highly significant, the probability of these results occurring by chance being less than 0.001 (χ^2=41.122, d.f. = 12, n = 590).

The correlation coefficient, however, covering the first three years of life, is very low (-0.063) indicating that refractive changes during this period are not dependent upon the extent to which the ametropia is corrected. In contrast, the correlation

TABLE 58

Means and standard deviations of annual changes in ocular refraction related to ametropic correction

Analysis by annual refractive changes and level of ametropic correction in dioptres for each three year age group.

Annual changes in ocular refraction - dioptres	Ametropic correction		
	Full correction	≤+0.50 D Under correction	≥+0.75 D Under correction
	Age : Birth - <3 years		
Mean	+0.48	+0.16	+0.46
Standard deviation	+0.53	±1.15	±0.91
Numbers of eyes	90	20	21
	Age : 3 - <6 years		
Mean	+0.30	+0.13	-0.11
Standard deviation	±0.45	±0.46	±0.71
Numbers of eyes	283	106	70
	Age : 6 - <9 years		
Mean	+0.002	-0.13	-0.05
Standard deviation	±0.42	±0.48	±0.32
Numbers of eyes	119	75	48
	Age : 9 - <12 years		
Mean	+0.04	-0.003	+0.04
Standard deviation	±0.33	±0.18	±0.41
Numbers of eyes	36	13	9

for the following three years - up to the age of six - is much higher, the coefficient being -0.3044. Calculation of the standard error shows this finding to be highly significant (ρ = <0.001), and not one that is likely to have arisen through errors in sampling. The result indicates that the greater the degree of hypermetropic undercorrection, the smaller the degree of hypermetropic increase. The estimated refractive changes have been calculated and are shown in table 59). Care must be taken, however, in predicting the effect of the level of correction since the standard error of estimate is ±0.50 D. This shows that within the 95 per cent confidence limits, changes in refraction may vary over a range of two dioptres.

During the period from six up to nine years of age, the patterns of refractive change were similar for all three groups. The main difference observed was in the incidence of increasing hypermetropia, the higher the degree of undercorrection, the lower the proportion of cases showing a shift towards hypermetropia. Annual changes differed little in their distributions within the correction groups, the means and standard deviations being very similar.

Changes in refraction between nine and twelve years of age differed only marginally, with no clear trends between the three groups. The means of changes per annum were found to be almost identical.

Taking the six year period up to twelve years of age as a whole, the chi-square test shows that the relationship between annual changes in refraction and level of ametropic correction is not significant (χ^2 = 15.387, d.f. = 12, n = 300, ρ = <0.30 >0.20).

TABLE 59

Estimated changes in ocular refraction per annum related to ametropic correction for the period from three up to six years of age

Degree of ametropic undercorrection - dioptres	Estimated change in refraction - dioptres	Regression Co-efficient	Standard Error of estimate
Nil	+0.27	-0.2499	±0.50
+0.25	+0.21		
+0.50	+0.14		
+0.75	+0.08		
+1.00	+0.02		
+1.50	-0.11		
+2.00	-0.23		
+3.00	-0.48		

The correlation coefficients for the periods six up to nine years, and nine up to twelve years of age were found to be very low indeed, -0.0072 and -0.0343 respectively, indicating that refractive change at this period of life is not related at all to the level of ametropic correction.

Changes in refraction related to surgical intervention

6.26 The treatment of strabismus can be classified broadly into two categories - non-surgical and surgical. Non-surgical methods range from orthoptic treatment to the correction of ametropia by optical means. Similarly, surgery can vary from a single operation on one eye only, to a series of operations over a period of time on one eye or on both eyes. In many cases both forms of treatment are carried out alongside each other.

For the majority of children, surgery is carried out during a formative period of their lives. It is a relatively drastic form of treatment which could, conceivably, influence the refractive development of the eye. Certain questions, therefore, arise. For example, when surgery has been performed, do refractive changes differ from those occurring when treatment has been entirely non-surgical? Is the number of operations a factor? Do the patterns of change resulting from surgery in both eyes differ from those found when only one eye has been involved? And in the latter case, are changes in the non-operated eye similar or dissimilar to those in the operated eye?

Characteristics of sample

Surgery was carried out on just over half the total number of cases (table 60). Since individual eyes were being studied, each eye was placed into one of seven categories, indicating the degree of surgery involved and the period in which it had been undertaken:

TABLE 60

Distribution of surgical intervention

within three year age groups - per cent

(890 eyes)

Surgical intervention	Age groups in years: Birth to <3	3 - <6	6 - <9	9 - <12	All ages
Nil on both eyes	43.5	45.3	47.9	58.6	46.6
Nil on one eye only	14.5	17.4	17.4	13.8	16.7
Surgery on one eye only	14.5	17.4	17.4	13.8	16.7
Surgery on both eyes	27.5	19.8	17.4	13.8	19.9
Numbers of eyes	131	459	242	58	890

1. No surgery on either eye
2. No surgery in interval since previous refractive examination, but surgery previously on right eye only
3. No surgery in interval since previous refractive examination, but surgery previously on left eye only
4. No surgery in interval since previous refractive examination, but surgery previously on both eyes
5. Surgery in interval on right eye only
6. Surgery in interval on left eye only
7. Surgery either:

   in interval on both eyes, or

   in interval on one eye and previously on the other.

No account was taken of the specific type of surgery carried out, since this would have required a much larger sample than the one available.

From these seven categories, four groups were formed:-

(a) Nil on both eyes: this covered solely category 1

(b) Nil on one eye only (left or right):
this involvedhalf the eyes in categories 2, 3, 5 and 6.

(c) Surgery on one eye only (right or left):
this involved the remaining half of categories 2, 3, 5 and 6.

(d) Surgery on both eyes:
this involved all the eyes in categories 4 and 7.

Analysis of treatment based on these four groups shows that up to twelve years of age, approximately half the children had never had surgical treatment (table 60). In those cases where surgery had been carried out the incidence of surgical intervention on both eyes declined with age, - from 27.5 per cent in children initially under the age of three, to 13.8 per cent in the nine to twelve year olds. In contrast, the incidence of monocular surgery in the younger group was only 14.5 per cent. This indicates that the earlier strabismus develops, the greater the likelihood that treatment will involve surgery on both eyes. No other clear trends are to be found, and from the age of three onwards no predisposition is shown to one surgical grouping or another.

Sex differences

6.27 Each of the four surgical groupings were analysed separately to ascertain whether the respective patterns of refractive change differ between the sexes. Only in the non-surgical group (a) were significant differences found, these being confined to children within the age group birth to six ($\chi^2 = 12.383$, d.f. = 2, n = 265, $p = <0.01 >0.001$). Further analysis shows that of the six years involved, major differences occurred solely in the fifth; the incidence of stationary refractions being much higher amongst females than males, with the shift towards hypermetropia much lower (table 61). Both male and female developments during the fifth year of life are rather anomalous compared to those occurring in the fourth and sixth years. Up to the fifth year the shift towards hypermetropia tends to decline whilst the proportions of stationary refractions rise. In the fifth year this trend is accentuated in females, whereas in males it is reversed. Further examination of the fourth year patterns of change shows these also to be slightly atypical, particularly for females. If the results for the fourth and fifth years are combined, the resultant pattern fits in with that found in the preceding and subsequent years. The differences between the

TABLE 61

Changes in refraction in non-surgical cases

(Group a), amongst males and females

Analysis by changes in refraction and yearly age groups up to six years - percentage distribution

Changes in refraction	Age in years <1	<2	<3	<4	<5	<6
			MALES			
No change	0	0	33.3	32.4	14.3	39.5
Increased positive	0	66.7	66.7	52.9	71.4	39.5
Decreased positive	100.0	33.3	0	14.7	14.3	21.1
Numbers of eyes	2	12	12	34	42	38
			FEMALES			
No change	0	28.6	41.2	37.5	61.8	47.2
Increased positive	0	64.3	47.1	54.2	23.5	33.3
Decreased positive	0	7.1	11.8	8.3	14.7	19.4
Numbers of eyes	0	14	17	24	34	36

sexes over this combined period are still significant, females quite clearly displaying the higher incidence of stationary refractions. In view of the general trend towards stationary refractions at this time of life, these results suggest that in those cases where surgery has not been carried out, refractive developments in females are more advanced than in males.

These differences were not found in the surgical groups. It appears, therefore, that surgery carried out in the first six years of life might have an equalising effect upon the refractive development of the sexes. It must not be forgotten, however, that other factors, such as ametropic correction, may be involved. Analysis of refractive changes related to correction of ametropia has already indicated that differences between the sexes may be found amongst the four to five year olds where ametropia is fully corrected. (6.24). This raises an important question. Is there a tendency for those having had surgery to be undercorrected and those having had no surgery to be fully corrected? Table 62 shows the relationship between the correction of ametropia and surgical intervention for children in their fourth and fifth years of life. In both non-surgical and surgical cases ametropia was more frequently fully corrected than undercorrected. These findings do not suggest that there is a connection between these two factors; this is confirmed by the chi-square results. (χ^2 = 0.9872, d.f. = 1, ρ = <0.7 >0.5). Surgery may, therefore, be a factor affecting the relationship between the sexes, but the evidence must be regarded as rather tenuous.

TABLE 62

Correction of ametropia related to surgical and non-surgical cases in the fourth and fifth years of life

Analysis by full correction or undercorrection of ametropia and surgical or non-surgical intervention - numbers of eyes

	No surgery	Surgery
Full correction	93	94
Undercorrection	55	70
Totals:	148	164

Overall variations

6.28 The patterns of refractive change in surgical and non-surgical cases differ to a greater extent in the first three years of life than in any other period, up to twelve years of age (table 63). The incidence of stationary refractions was lowest when surgery had been carried out on both eyes and highest when treatment had been entirely non-surgical. The reverse was true of increasing hypermetropia.

When both eyes had been subjected to surgery, changes in refraction were found to be significantly different from those occurring where neither eye had been involved. (χ^2 = 7.1661, d.f. = 2, n = 93, ρ = <0.05 >0.02). This suggests that surgery on both eyes *does affect* refractive development by increasing the chance of change. In contrast, where surgery had been performed on one eye only, the changes in both operated and non-operated eyes were almost identical. It is not clear whether this is the result of the surgery itself, or whether this would have occurred in any case. Earlier findings, however, have shown that changes in the two eyes are more likely to be unequal than equal (6.15). This suggests that monocular surgery does have *some* effect upon refractive development, although there is no evidence to indicate whether one eye or both eyes are involved.

Table 63 shows that where surgery has been confined to one eye only, the changes in refraction are distributed differently from those in the completely non-surgical group. Although this difference is small and not statistically significant, it does lend support to the view that monocular surgery may affect the course of refractive development. It is important, however,

TABLE 63

Changes in refraction related to surgical intervention

Analysis by changes in refraction and nature of surgical intervention for each three year age group - percentage distribution.

Changes in refraction	Surgical intervention: Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both eyes
	Age: Birth - <3 years			
No change	26.3	15.8	15.8	13.9
Increased positive	57.9	73.7	78.9	83.3
Decreased positive	15.8	10.5	5.3	2.8
Numbers of eyes	57	19	19	36
	Age: 3 - <6 years			
No change	38.0	42.5	37.5	33.0
Increased positive	46.2	50.0	56.3	48.4
Decreased positive	15.9	7.5	6.3	18.7
Numbers of eyes	208	80	80	91
	Age: 6 - <9 years			
No change	55.7	52.4	42.9	28.6
Increased positive	22.6	9.5	23.8	28.6
Decreased positive	21.7	38.1	33.3	42.9
Numbers of eyes	115	42	42	42
	Age: 9 - <12 years			
No change	38.2	25.0	37.5	50.0
Increased positive	38.2	50.0	37.5	25.0
Decreased positive	23.5	25.0	25.0	25.0
Numbers of eyes	34	8	8	8

to recognise that surgery is performed on eyes having non-uniform characteristics. Since these characteristics often determine the nature of the surgical approach, it is conceivable that they may account, at least in part, for the differences in refractive development occurring at this time of life.

The range of annual changes, up to the age of three, was similar for both non-surgical and surgical groups (Appendix A.8). Changes exceeding ±1.40 D occurred in all groups, except where surgery had been performed on both eyes, when the maximum shift towards myopia did not exceed -0.60 D. Although the actual distributions differed, most increases in hypermetropia (decreases in myopia) fell between +0.21 and +1.00 D irrespective of the surgical grouping involved. The means of the refractive changes - all representing a shift in the direction of hypermetropia - are lowest where neither eye had had surgery, and highest where surgery was carried out on both (table 64). The means and standard deviations for the other two groups are almost identical, thus confirming that when monocular surgery has been performed refractive changes in the two eyes are unlikely to differ from each other.

The results for the three years up to the age of six, contrast markedly with those for the first three years of life. Almost identical patterns of change were found in the two groups - surgical and non-surgical - involving both eyes (table 63). This arose mainly as a result of stationary refractions increasing in incidence, with the shift towards hypermetropia decreasing, particularly where surgery was involved. The shift towards myopia also increased, but only for the surgical group. Where surgery was confined to one eye, the changes were almost identical

TABLE 64

Means and standard deviations of annual changes in ocular refraction related to surgical intervention

Analysis by annual refractive changes in dioptres and nature of surgical intervention for each three year age group

Changes in ocular refraction - dioptres	Surgical intervention: Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both eyes
	Age : Birth - <3 years			
Mean	+0.34	+0.47	+0.48	+0.60
Standard deviation	±0.73	±0.75	±0.70	±0.50
Numbers of eyes	57	19	19	36
	Age : 3 - <6 years			
Mean	+0.17	+0.26	+0.29	+0.17
Standard deviation	±0.61	±0.42	±0.45	±0.42
Numbers of eyes	208	80	80	91
	Age : 6 - <9 years			
Mean	-0.004	-0.16	-0.05	-0.06
Standard deviation	±0.45	±0.35	±0.42	±0.48
Numbers of eyes	115	42	42	42
	Age : 9 - <12 years			
Mean	+0.02	+0.05	+0.11	0.00
Standard deviation	±0.35	±0.35	±0.38	±0.18
Numbers of eyes	34	8	8	8

with those in the non-operated eye. Here again, the proportions of stationary refractions have risen, whilst the shift towards hypermetropia has fallen.

Large increases in hypermetropia (or reductions in myopia) - >+0.40 D per annum, occurred in all groups except where both eyes were subjected to surgery. Changes of over -1.40 D were, however, found only in the non-surgical group. The distributions of changes per annum were, otherwise, similar; this is illustrated by the means and standard deviations (table 64). The means for the two extreme groups - nil on either eye, and surgery on both eyes - are identical, with those for the surgery one eye, nil one eye groups, almost identical. The difference between the four means is small.

Taking the first six years as a whole, the refractive changes in the four surgical groups do not differ significantly. ($\chi^2 = 23.492$, d.f. = 18, $n = 590$, $p = <0.2 >0.1$). Even the differences found between the four groups in the first three years are not statistically significant.

Children aged between six and nine, whose treatment had been entirely non-surgical, showed a lower incidence of declining hypermetropia (i.e. shift towards myopia) than those who had operations , whether on one eye or on both (table 63). For the first time, differences arose between right and left eyes where surgery had been confined to only one eye: increases in hypermetropia were much lower in incidence in non-operated eyes than in operated eyes, whilst the proportions of stationary refractions were higher.

Taking the four groups overall, the incidence of stationary refractions appears to be related to the level of surgery; the greater the degree of surgery the lower the proportion of stationary refractions. Where surgery had been carried out on both eyes only 28.6 per cent showed no change compared to 55.7 per cent where the treatment was entirely non-surgical. This incidence of 28.6 per cent represents a fall from that in the preceding three years when 33.0 per cent were stationary in the same surgical group. In contrast the proportionsof stationary refractions rose for the three other groups (table 63).

Annual changes were distributed fairly similarly within the four groups. The means in all cases were low.

Changes in refraction in the following three years - up to the age of twelve, seem to bear little relationship to the level of surgical intervention. These findings, however, are based on small numbers. In comparison with the previous period, the range of changes per annum dropped considerably for all groups, the means being very low. The differences between groups do not indicate that refractive change is related to surgery during this period of life.

The chi-square result for the whole six year period up to the age of twelve, shows that the annual changes in the four groups studied do not differ significantly (χ^2 = 21.8, d.f. = 18, n = 300, $p = <0.3>0.2$)

There is no clear indication from the overall findings that surgery affects the course of the refractive development of the eye. In general the results are not statistically significant, this being particularly evident between the ages of six and twelve. One cannot, however, ignore the trends found in the first three years of life. These show that increasing hypermetropia arises more frequently,and stationary refractions occur less frequently, in surgical cases than in non-surgical cases. In addition the results obtained for the period six to nine years of age, do seem to indicate that the more surgery that is carried out, the less likely that the refractive state will remain unchanged. It is not clear whether these differences arise as a result of the surgery itself or as a result of other factors such as those which led to the original surgical intervention. Nevertheless, the fact that these small differences exist is notable.

There is no evidence to suggest that as a result of surgery on one eye only, refractive developments in that eye will differ from those in the non-operated eye. The evidence, in fact, indicates that the changes tend to be very similar. Whether this arises because surgery on one eye produces a refractive change either in one or in both eyes, or because it has no effect on either, is not clear. It is, of course, possible that each eye has a dampening effect upon its partner, the non-operated eye reducing the effect that surgery would have produced on its own.

Summary Point (6.17 - 6.28)

6.29

1. The characteristics of the strabismus present in the sample have been analysed, revealing the majority to be convergent. The distribution of the various degrees of ametropia has also been examined (6.17)

Three groups of subjects have been formed for the purpose of the analysis:

(i) nil group - comprising those cases without strabismus as well as the non-strabismic fixating eyes in unilateral strabismus

(ii) alternating/intermittent group

(iii) unilateral group.

The refractive changes within each of these groups have been compared. No significant sex differences were found (6.18).

The nature of the annual refractive changes occurring have been shown to be very similar for all three groups, especially during the period between three and six years of age. There is nothing to suggest that refractive changes are related to the type of strabismus present (6.19).

2. The angle of strabismus has been examined in order to determine its effect upon changes in refraction, two groups of angles being formed for this purpose:

$1 - 20^\circ$

$21 - 40^\circ$

The patterns of change were similar for both males and females, the greatest differences occurring for those children between birth and six years with angles less than 21, but even these were not significant (6.21).

Analysis of annual changes during the first six years of life indicates that these are almost identical for both angle groups. Correlation between angle and refractive change is very low. (6.22)

The differences in pattern for the two groups during the subsequent periods are more pronounced. Between six and nine years, the results indicate that the smaller the angle the greater the tendency for a shift towards hypermetropia; the position is reversed between nine and twelve years of age. Whilst the correlation coefficients are higher than for the younger groups, the regression coefficient shows the estimated refractive change to be minimal for each degree of strabismic angle. These results do not indicate that strabismic angle plays a significant part on its own as a determinant of refractive change. (6.22)

3. Of the total cases being studied, approximately 60 per cent have been shown to have their refractive error fully corrected, whilst roughly 20 per cent were undercorrected $\leq$+0.50 D and the remainder undercorrected between +0.75 D and over +2.50 D. The effect of ametropic correction upon refractive change has, therefore, been studied (6.23).

Analysis of sex differences revealed a marked disparity in the patterns of change in the fifth year of life, where the full correction was being worn, females displaying a higher incidence of stationary refractions and a lower incidence of hypermetropic increases than males. The pattern of changes in the preceding and subsequent years was found to be reversed, if only marginally. Whether this is associated with difference in growth rates found at this period is, therefore, uncertain (6.24).

Annual changes in refraction during the first three years of life do not appear to be affected by the type of ametropic correction being worn. This is borne out by the correlation coefficient which is very low (-0.063). During the period three up to six years of age, the findings indicate that correction is a much more important factor. These show that the greater the degree of hypermetropic undercorrection, the smaller the hypermetropic increase. Care, however, must be taken in predicting changes since the standard error of estimate is ±0.50 D. In contrast refractive changes between six and twelve years of age bear little relationship to the ametropic correction being worn. (6.25).

4. Just under half the children involved in this study had never had surgical treatment. Of the remainder, the incidence of surgical intervention on both eyes declines with age. The degree of surgery, otherwise, does not appear to be related to age (6.26).

Sex differences in refractive development were found solely amongst those children whose treatment had been entirely non-surgical, and whose ages fell between birth and six. These differences were confined mainly to the fifth year of life; females displayed the higher incidence of stationary refractions, indicating that they are, refractively, rather more advanced than males at this stage. No differences were found in the surgical groups; this suggests that surgery at this time of life tends to eliminate developmental disparity between the sexes. The evidence, however, is rather inconclusive (6.27).

The relationship between surgery and refractive change is closest in the first three years of life. The results show that the greater the degree of surgical intervention, the greater the likelihood of refractive change, this being mainly in an hypermetropic direction. Where surgery has been confined to one eye only, refractive changes in both eyes are almost identical. These changes differ slightly from those in the entirely non-surgical group. Nevertheless, the overall differences, taking all the surgical and non-surgical groups together, are not statistically significant (6.28).

The patterns of refractive change above three years of age are similar for all the groups involved. The exception to this occurs in the six to nine year period when the incidence of stationary refractions tends to decline with an increase in surgery.

Although the results generally are not statistically significant, the differences found up to the age of three, do indicate that, at this stage, the more surgery the lower the chance that the refractive state will remain unchanged. Whether this is due solely to the surgery is not clear. There is no evidence to suggest that surgery on one eye will result in a difference in the refractive developments of the two eyes (6.28).

Ocular astigmatism and its relationship with age

6.30 Ocular refraction has, up till now, been expressed solely in terms of mean sphere (5.13). Analysis of refractive developments have, therefore, been based on mean sphere changes. No account has been taken of the role of astigmatism in the field of refractive development, except inasmuch as it forms a component of the mean sphere. Astigmatism has, nevertheless, been analysed separately, with a view to investigating its behaviour with age, its role as a determinant of refractive changes in general, the relationship between initial levels of astigmatism and subsequent astigmatic changes, and the effect of strabismic treatment on astigmatism.

Characteristics of sample

Children were classified as astigmatic if the spectacle refraction revealed astigmatism of 0.25 D or more. Cases with less than 0.25 D were, therefore, regarded as non-astigmatic. For the purposes of identification astigmatism found at the first of each pair of examinations is referred to as 'initial' astigmatism. Throughout this study minus cylinders have been used to measure initial astigmatism and subsequent changes. All astigmatic values have been converted from spectacle to ocular astigmatism.

Although astigmatism ranged from nil to over 5.0 D, only in just over 19.0 per cent of all cases did it exceed 2.00 D (Tables 65 and 66). Consequently the number of groups used to classify ocular astigmatism was limited to four:

Nil

0.21 * - 1.00 D

1.01 - 2.00 D

>2.00 D

(*0.21 D is equivalent to 0.25 D spectacle astigmatism for myopia of -8.75 D, i.e. the highest degree of myopia found in this sample)

TABLE 65

Distribution of ocular astigmatism within three yearly age groups - per cent

Ocular astigmatism in dioptres	Birth to <3	3 - <6	6 - <9	9 - <12	All ages
	Age in years				
Nil	12.2	11.5	12.0	5.2	11.3
0.21 - 1.00 *	46.6	48.8	31.5	32.8	42.7
1.01 - 2.00	29.8	24.8	29.5	25.9	27.0
>2.00	11.5	14.8	27.0	36.2	19.1
Numbers of eyes	131	459	242	58	890

* The distribution of spectacle astigmatism of 0.25D within these four age groups was 18.3, 16.8, 14.5 and 10.3 per cent respectively

TABLE 66

Means and standard deviations of astigmatism within astigmatic groups

Analysis by initial ocular astigmatism in dioptres and three year age groups

Ocular astigmatism in dioptres	Age in years: Birth to <3	3 - <6	6 - <9	9 - <12
0.21 - 1.00	0.51	0.52	0.50	0.53
	±0.23	±0.22	±0.24	±0.23
Numbers of eyes	61	224	76	19
1.01 - 2.00	1.41	1.38	1.42	1.47
	±0.29	±0.29	±0.29	±0.28
Numbers of eyes	39	114	71	15
> 2.00	2.91	2.75	3.16	4.05
	±0.78	±0.64	±1.01	±1.47
Numbers of eyes	15	68	66	21

The distribution of astigmatism within age groups, which is similar for males and females, suggests that astigmatic levels in strabismic children are in some way related to age. (Table 65 Appendix A.9.) Although the chi-square test shows the results to be highly significant (χ^2 = 45.044, d.f. = 12, n = 890, ρ = <0.001), it does not indicate the nature of the relationship. The results demonstrate that the higher levels of astigmatism tend to be found in the older rather than the younger children. This analysis represents a cross-sectional approach in which astigmatic states in different children have been compared. These findings may, therefore, differ considerably from the longitudinal results in which astigmatic changes in individual children have been analysed.

Changes in ocular astigmatism and age

6.31 Changes in spectacle astigmatism of less than 0.50 D were considered to fall within the limits of experimental error and have consequently been classified as nil. For the sake of uniformity, however, astigmatic changes have been converted to changes in ocular astigmatism in view of the fact that all the previous results have been expressed in terms of ocular rather than spectacle refraction. Since the intervals between examinations varied so widely, total changes were converted to changes per annum. These were classified according to their direction and degree as follows:

>-1.00 D
-0.51 to -1.00 D
-0.01 to -0.50 D
Nil
+0.01 to +0.50 D
+0.51 to +1.00 D
>+1.00 D

The sign indicates an increase or decrease in astigmatism and not plus or minus cylinder notation. Maximum annual changes were -0.79 D and +2.17 D. In two cases, changes of +1.59 D and -0.53 D were recorded over a period of seven months; this equates to annual changes of +2.72 D and -0.91 D respectively, assuming that the same rate of change is maintained over the full year.

Sex differences

6.32 The changes in astigmatism for males and females did not differ significantly in either of the six year groups up to the age of twelve

Overall variations

6.33 Analysis of the results as a whole shows that throughout the period from birth until twelve, astigmatism in the majority of eyes remains unchanged, the incidence being lowest in the first three years, increasing thereafter (Table 67). In these three years astigmatism tends to increase rather than decrease. This tendency drops considerably during the following period up to the age of six, although astigmatism still increases rather than decreases.

Breakdown of the changes into their annual components (Table 68), shows that not only does the incidence of increasing astigmatism exceed that of decreasing astigmatism, but the level of increases also tends to be higher. The higher annual levels - >0.50 D - occur more frequently below the age of three than above.

The probability that these findings occurred by chance is low - between 0.01 and 0.001 ($\chi^2 = 45.955$, d.f. = 24, n = 891). Nevertheless, the correlation between astigmatic changes and age

TABLE 67

Changes in ocular astigmatism related to age

Analysis by direction of change and three year age groups - percentage distribution

Changes in ocular astigmatism	Age in years			
	Birth - <3	3 - <6	6 - <9	9 - <12
No change	57.3	71.0	68.9	82.8
Increase	35.1	22.7	24.1	6.9
Decrease	7.6	6.3	7.1	10.3
Numbers of eyes	131	459	241	58

TABLE 68

Annual changes in ocular astigmatism related to age

Analysis of changes in astigmatism in dioptres and three year age groups from birth up to twelve - percentage distribution

Annual changes in ocular astigmatism - in dioptres	Age in years Birth - <3	3 - <6	6 - <9	9 - <12
>-1.00	0	0	0	0
-0.51 to -1.00	3.1	0.4	0.8	0
-0.01 to -0.50	4.6	5.9	6.2	10.3
0	57.3	71.0	68.9	82.8
+0.01 to +0.50	14.5	14.2	14.1	6.9
+0.51 to +1.00	16.8	7.2	8.7	0
>+1.00	3.8	1.3	1.2	0
Nos. of eyes	131	459	241	58

is low, the correlation coefficient being -0.1636. Although this result is highly significant from a sampling standpoint, it does not indicate a clinically significant relationship between age and changes in astigmatism. The regression equation in fact demonstrates that between the ages of one and two, astigmatism could be expected to increase by +0.18 D, this increase diminishing each year by 0.02 D so that by the age of ten the estimated change is zero.

Although these results for the twelve years as a whole indicate that age and changes in astigmatism are associated, it is clear from the correlation coefficient, that their relationship is rather tenuous. The most significant changes are likely to occur during the critical first three years of life. Even during this period, astigmatism tends to remain stationary rather than change, this tendency increasing with age.

Astigmatism and its relationship with changes in refraction

6.34 Astigmatism is present, in some degree, in the majority of eyes: 88.7 per cent of the children included in this study were astigmatic when first examined. It is important, therefore, that its role in these overall refractive developments of the eye should be investigated.

As a result of the mean sphere method of analysing refractive changes that has been used in this study, astigmatism is an interdependent rather than an independent component of the values given for refractive changes in general. Despite this, it is still worthwhile examining the relationship between initial levels of astigmatism and subsequent overall refractive changes, providing that the interdependent nature of astigmatism is always borne in mind when interpreting the results.

Sex differences

6.35 Relating mean sphere changes in refraction to the level of astigmatism at the initial examination, no significant sex differences were found. The chi-square test shows that the differences that did arise, were more significant for the first six years than the subsequent six, but in no instances did the probability fall below 0.10.

Overall changes

6.36 Up to the age of three, the pattern of refractive change in non-astigmatic eyes differed markedly from those in astigmatic eyes. The incidence of stationary refractions was much lower when astigmatism was absent than when it was present, whereas the incidence of decreasing hypermetropia was much greater (Table 69). The range of changes per annum during this period was similar for all groups, except that the proportions of extreme change - >±1.40 D - are larger in non-astigmatic than in astigmatic cases (Appendix A.10).This difference can be seen from the means and standard deviations (Table 70).

In contrast the patterns of refractive change from the age of three until twelve,bear little relationship with the degree of astigmatism present at the initial examination. The ranges of annual refractive change, which are similar for all the astigmatic groups, tend to contract with age.

The chi-square results for the two six year groupings - birth up to six, and six up to twelve, show that differences in refractive changes between the four astigmatic groups could easily have arisen by chance and are, therefore, not significant. (Birth - <6: $\chi^2 = 13.146$, d.f. = 18, n = 590, ρ = <0.80 >0.70: 6 to <12: $\chi^2 = 17.153$, d.f. = 18, n = 300, ρ = <0.70 >0.50).

TABLE 69

Changes in refraction related to initial astigmatic state

Analysis by changes in refraction and initial level of ocular astigmatism in dioptres, for each three year age group from birth to twelve - percentage distribution

Changes in refraction	Nil	Ocular astigmatism - dioptres 0.21-1.01	1.01-2.00	>2.00
		Age: Birth - <3 years		
No change	6.3	21.3	17.9	33.3
Increased positive	62.5	70.5	76.9	60.0
Decreased positive	31.3	8.2	5.1	6.7
Nos. of eyes	16	61	39	15
		Age: 3 - <6 years		
No change	35.8	38.8	38.6	33.8
Increased positive	49.1	51.8	45.6	45.6
Decreased positive	15.1	9.4	15.8	20.6
Nos. of eyes	53	224	114	68
		Age 6 - <9 years		
No change	37.9	50.0	46.5	52.3
Increased positive	37.9	18.4	25.4	13.8
Decreased positive	24.1	31.6	28.2	33.8
Nos. of eyes	29	76	71	65
		Age 9 - <12 years		
No change	33.3	31.6	53.3	33.3
Increased positive	33.3	42.1	33.3	38.1
Decreased positive	33.3	26.3	13.3	28.6
Nos. of eyes	3	19	15	21

TABLE 70

Means and standard deviations of annual changes in ocular refraction related to initial astigmatic state

Analysis by annual refractive changes in dioptres and initial level of ocular astigmatism for each three year age group

Changes in ocular refraction-dioptres	Ocular astigmatism - dioptres			
	Nil	0.21-1.00	1.01-2.00	>2.00
		Age: Birth - <3 years		
Mean	+0.20	+0.41	+0.58	+0.35
Standard deviation	±1.24	±0.61	±0.69	±0.46
Nos.of eyes	16	61	39	15
		Age: 3 - <6 years		
Mean	+0.25	+0.24	+0.13	+0.14
Standard deviation	±0.42	±0.53	±0.51	±0.57
Nos. of eyes	53	224	114	68
		Age: 6 - <9 years		
Mean	+0.05	-0.07	-0.01	-0.11
Standard deviation	±0.53	±0.41	±0.45	±0.34
Nos. of eyes	29	76	71	65
		Age: 9 - <12 years		
Mean	-0.11	+0.06	+0.11	-0.03
Standard deviation	±0.26	±0.32	±0.28	±0.33
Nos. of eyes	3	19	15	21

Although the correlation coefficient for the first three years of life is higher than for any other period, it is still extremely low (0.0836). The results clearly indicate that the level of astigmatism does not play a significant part in determining the subsequent refractive development of the eye.

Changes in ocular astigmatism related to initial astigmatic state

6.37 It is well known that astigmatism undergoes changes both with respect to power and to principal meridians. What is not known is whether such changes are related to any specific factors, particularly in strabismic children. The role of astigmatism as a determinant of astigmatic changes has, therefore, been investigated. Attention at this stage has been confined to the changes in power. Axis changes will be discussed later.

Sex differences

6.38 Astigmatic changes were similar in males and females except where astigmatism fell between 1.01 and 2.00 D, these differences being confined to children aged between six and twelve. The chi-square test for this age group as a whole demonstrates that the probability of these differences arising by chance is small - ρ = <0.01 >0.005 (χ^2 = 9.568, d.f. = 2, n = 86). Analysis of the differences in each of the six years, however, revealed a somewhat confused and inconclusive picture. In none of them was it possible to identify a clear cut significant difference, mainly owing to the small numbers of cases involved (Table 71). No useful conclusions can, therefore, be drawn.

TABLE 71

Changes in astigmatism related to initial astigmatism between 1.01 and 2.00 D in males and females

Analysis by changes in astigmatism and yearly age groups from 6 up to 12 years

Changes in astigmatism	Age in years: <7	<8	<9	<10	<11	<12	All ages 6 - <12
MALES							
No change	53.3	53.8	88.9	83.3	100.0	0	65.2
Increase	46.7	46.2	11.1	16.7	0	0	32.6
Decrease	0	0	0	0	0	100.0	2.2
Nos.of eyes	15	13	9	6	2	1	46
FEMALES							
No change	53.8	70.0	100.0	50.0	100.0	100.0	75.0
Increase	23.1	10.0	0	0	0	0	10.0
Decrease	23.1	20.0	0	50.0	0	0	15.0
Nos. of eyes	13	10	11	2	1	3	40

Overall changes in astigmatism

6.39 The outstanding feature in each of the astigmatic groups is the high proportion of cases in which the level of astigmatism remains unchanged, irrespective of age. Between 50.0 and 85.0 per cent of all cases were found to be stationary (Table 72). The proportions are, on the whole, lowest during the first three years of life, but even here the level does not fall below 50.0 per cent.

Up to the age of three, changes in all levels of astigmatism tended to be increases rather than decreases. The incidence of astigmatic decreases, however, was considerably higher where astigmatism exceeded 2.0 D than for any other level. This suggests that the higher the astigmatism, the greater the chance that a subsequent reduction will occur.

The relationship between degree of astigmatism and subsequent annual change does not appear to be very close. Whilst increases exceeding 1.00 D were recorded in all groups, reductions did not exceed 1.00 D in *any* group, either during this period or during subsequent periods (Appendix A.11). Nevertheless, annual changes in the majority of cases fell between ±1.00 D. All the means represent an increase in astigmatism. Predictably, the mean for the non-astigmatic group was highest since changes in this group can only be in one direction, i.e. increases. Apart from this, the means were similar (Table 73).

After the age of three, there is an increasing tendency for astigmatism, whatever its level, to remain stationary. This is especially pronounced for the three to six year olds. The children who show the least tendency of all to change, are those with astigmatism between 0.01 and 1.00 D. (This was also the case below the age of three). Annual increases tend to be smaller

TABLE 72

Changes in astigmatism related to initial astigmatic state

Analysis by changes in astigmatism and initial level of ocular astigmatism in dioptres for each three year age group from birth to twelve - percentage distribution

Changes in astigmatism	Ocular astigmatism - dioptres			
	Nil	0.21-1.00	1.01-2.00	>2.00
		Age: Birth - <3 years		
No change	50.0	62.3	53.8	53.3
Increased astigmatism	50.0	31.1	38.5	26.7
Decreased astigmatism	0	6.6	7.7	20.0
Nos. of eyes	16	61	39	15
		Age: 3 - <6 years		
No change	67.9	77.7	62.3	66.2
Increased astigmatism	32.1	18.3	26.3	23.5
Decreased astigmatism	0	4.0	11.4	10.3
Nos. of eyes	53	224	114	68
		Age: 6 - <9 years		
No change	75.9	72.4	67.6	63.1
Increased astigmatism	24.1	23.7	25.4	23.1
Decreased astigmatism	0	3.9	7.0	13.8
Nos. of eyes	29	76	71	65
		Age: 9 - <12 years		
No change	66.7	84.2	80.0	85.7
Increased astigmatism	33.3	10.5	6.7	0
Decreased astigmatism	0	5.3	13.3	14.3
Nos. of eyes	3	19	15	21

TABLE 73

Means and standard deviations of annual changes in ocular astigmatism related to initial astigmatic state

Analysis by annual changes in astigmatism and initial level of ocular astigmatism in dioptres for each three year age group

Changes in ocular astigmatism - dioptres	Ocular astigmatism - dioptres Nil	0.21-1.00	1.01-2.00	>2.00
		Age: Birth - <3 years		
Mean	+0.48	+0.12	+0.20	+0.17
Standard deviation	±0.74	±0.30	±0.44	±0.52
Nos. of eyes	16	61	39	15
		Age: 3 - <6 years		
Mean	+0.14	+0.07	+0.10	+0.12
Standard deviation	±0.34	±0.24	±0.29	±0.36
Nos. of eyes	53	224	114	68
		Age: 6 - <9 years		
Mean	+0.09	+0.08	+0.12	+0.04
Standard deviation	±0.19	±0.22	±0.31	±0.29
Nos. of eyes	29	76	71	65
		Age: 9 - <12 years		
Mean	+0.05	+0.02	+0.02	-0.03
Standard deviation	±0.06	±0.12	±0.12	±0.08
Nos. of eyes	3	19	15	21

than in the previous period, falling between +0.01 and +0.50 D rather than +1.00 D. The means are also generally lower.

Analysis of these changes solely in terms of their direction, indicates that during the years from birth up to six, the distribution within the four astigmatic groups is highly significant and very unlikely to have arisen by chance. (χ^2 = 23.332, d.f. = 6, n = 590, p = <0.001). The results, however, when analysed quantitatively on the basis of dioptic change per annum, are rather less significant, with a probability of only 0.05. The correlation coefficients on the other hand, are not significant at all, being very low indeed; for the periods birth up to three, and three up to six, the coefficients are -0.0717 and +0.0453 respectively. Although astigmatic changes during the first six years are clearly associated with astigmatic levels (χ^2), the correlation coefficients show that the level of astigmatic change is not directly related to the degree of astigmatism present.

Between the ages of six and nine, astigmatic changes are distributed similarly in each of the four astigmatic groups. The overall pattern differs little from that found in the previous age group, with changes showing no clear relationship with the degree of astigmatism. Increases still predominate over decreases, the majority falling between +0.01 and +0.50 D. Astigmatism, however, still remains stationary in the majority of cases. The means are predictably very low all round.

The results for the nine to twelve year olds are similar to those found in the younger children. The only notable difference is a reduction in the level of change, all annual changes falling between ±0.01 and ±0.50 D.

The patterns of change in the four astigmatic groups are very similar throughout the six years up to the age of twelve. The chi-square test shows that the differences during the whole of this period could have arisen by chance. ($\chi^2 = 9.506$, d.f = 6, n = 300, $\rho = <0.20 >0.10$). The correlation coefficient, however, demonstrates that annual change and initial degree of astigmatism are more closely related in the final three years (up to twelve) than in the preceding three years. Despite this, the coefficients are low in both cases: (r = -0.096 and -0.2082). In view of the differences between these two periods, the estimated annual changes in astigmatism have been calculated for the final three years (Table 74). This shows that the changes per annum are likely to be very small indeed, irrespective of the initial level of astigmatism involved. The estimates indicate that astigmatism of 1.00 D would increase by +0.01 D whilst astigmatism of 6.00 D would decrease by only -0.06 D. These findings demonstrate that the relationship is meaningless from a clinical point of view. Care, in any case, must be taken in interpreting these results since the standard error of the correlation coefficient shows that his particular value of -0.2083 could have arisen as a result of sampling errors.

this

The results clearly indicate that astigmatic changes are not determined by the level of astigmatism present at any time. Undoubtedly, the period in which changes are most likely to occur is between birth and three, but these are not particularly related to the degree of astigmatism. It is clear that up to the age of twelve, astigmatism is remarkably stable in a very high proportion of cases, irrespective of astigmatic level.

TABLE 74

Estimated annual changes in ocular astigmatism related to initial level of ocular astigmatism from nine until twelve years of age

Initial level of ocular astigmatism -in dioptres	Estimated annual astigmatic change - in dioptres	Regression coefficient
Nil	+0.02	-0.0122
0.50	+0.01	
1.00	+0.01	
1.50	Nil	
2.00	-0.01	
3.00	-0.02	
4.00	-0.03	
5.00	-0.04	
6.00	-0.06	

Summary Point (6.30 - 6.39)

6.40

1. Ocular astigmatism has been analysed separately in order to establish its behaviour and its role in terms of refractive development. The astigmatic characteristics of the children in this study have been described. Cross-sectional analysis of astigmatic levels and age indicates that the higher levels are more closely associated with older rather than younger children. The distribution for males and females was similar (6.30).

2. Changes in astigmatism were similar for both sexes. In the majority of cases astigmatism remains stationary, the incidence generally increasing with age. Changes occur most frequently in the first three years of life when astigmatism tends to increase rather than decrease. This tendency declines with age. Astigmatic increases also tend to be higher in degree than corresponding decreases, whilst the level of change declines with age. The correlation between annual astigmatic changes and age is, nevertheless, low throughout the period from birth until twelve. The relationship between these two factors is, therefore, shown to be rather tenuous (6.31 - 6.33).

3. The relationship between initial levels of astigmatism and mean sphere changes in refraction has been examined. No sex differences were found. Up to the age of three, the incidence of stationary refractions was lower in non-astigmatic eyes than in astigmatic eyes, whereas the incidence of decreasing hypermetropia was much greater. After the age of three, refractive

changes were similar for all levels of astigmatism. The correlation between these two factors is very low indeed (<0.1) irrespective of the age groups involved. There is nothing to indicate that astigmatic levels have a significant role as determinants of refractive development (6.34 - 6.36).

4. Dioptric changes in ocular astigmatism have been analysed in relation to initial levels of astigmatism. Significant sex differences were confined to those children with astigmatism between 1.01 and 2.00 D, whose ages ranged from six up to twelve. Owing to the small numbers involved, no useful conclusions could be drawn (6.38).

Astigmatism remained unchanged in the majority of cases, irrespective of the initial level. In the first three years, it was found that the higher the astigmatism, the greater the incidence of astigmatic decreases. The most stable astigmatic group up to the age of six is 0.01 - 1.00 D. Between six and twelve years of age the patterns of astigmatic change in all astigmatic groups were similar.

The correlation between astigmatic levels and annual changes in astigmatism was low for all the three year periods studied; at no time did it approach a clinically significant level. The findings indicate that astigmatic changes are not determined by the degree of astigmatism (6.39).

Ocular astigmatism related to strabismic state

6.41 Astigmatism has been shown to vary considerably from child to child (6.30). It is also known that the type of strabismus similarly varies. These two factors have, therefore, been examined in order to ascertain whether they are related in any way.

Strabismus has been classified on the same basis as that used for analysis of refractive state (6.17), the cases being divided into these groups according to the strabismic state of each eye - (a) nil, (b) alternating/intermittent, (c) unilateral. Ocular astigmatism has been grouped as in previous analyses (6.30).

Sex differences

6.42 Significant sex differences were found solely in the strabismic (non-fixating) eyes of unilateral cases, these differences being confined to children aged between six and twelve. Approximately 14.0 per cent of males were non-astigmatic whilst the incidence in females was zero (Table 75). The number of eyes in each year, however, is relatively small, indicating that these findings must be interpreted with caution. In fact, it is only when the results for the whole of the six years are analysed together, that the differences reach a marginally significant level ($\chi^2 = 9.510$, d.f. = 3, n = 118, $\rho = <0.05>0.02$).

Overall distribution - cross-sectional analysis

6.43 Astigmatism ranged from nil to over 2.00 D in each of the three strabismic groups. The sole exception occurred in the alternating/intermittent group during the period between nine and twelve; only four cases, however were involved (Table 76).

TABLE 75

Distribution of initial astigmatic state amongst males and females with unilateral strabismus

Analysis by initial level of ocular astigmatism, unilateral strabismus and sex within yearly age groups from six up to twelve - percentage distribution

Ocular astigmatism in dioptres	Age in years 6 -<7	- <8	- <9	- <10	- <11	- <12	All ages 6-<12
MALES							
Nil	11.8	18.2	20.0	12.5	0	0	14.5
0.21 - 1.00	29.4	22.7	30.0	0	66.7	0	24.2
1.01 - 2.00	35.3	27.3	30.0	37.5	33.3	0	30.6
>2.00	23.5	31.8	20.0	50.0	0	100.0	30.6
Nos. of eyes	17	22	10	8	3	2	62
FEMALES							
Nil	0	0	0	0	0	0	0
0.21 - 1.00	33.3	40.0	33.3	0	100.0	0	35.1
1.01 - 2.00	23.8	20.0	33.3	100.0	0	33.3	26.3
>2.00	42.9	40.0	33.3	0	0	66.7	38.6
Nos. of eyes	21	15	15	1	2	3	57

TABLE 76

Ocular astigmatism related to strabismic state

Analysis by initial levels of ocular astigmatism and strabismic state of each eye, within three year groups up to twelve - percentage distribution

Ocular astigmatism in dioptres	Strabismic groups: Nil	Alternating/Intermittent	Unilateral
	Age: Birth - <3 years		
Nil	13.2	14.3	10.0
0.21 - 1.00	47.2	50.0	44.0
1.01 - 2.00	28.3	25.0	34.0
>2.00	11.3	10.7	12.0
Nos.of eyes	53	28	50
	Age: 3 - <6 years		
Nil	13.2	13.2	9.3
0.21 - 1.00	53.1	31.6	47.2
1.01 - 2.00	22.8	47.4	22.8
>2.00	11.0	7.9	20.7
Nos. of eyes	228	38	193
	Age: 6 - <9 years		
Nil	12.1	28.6	7.1
0.21 - 1.00	35.3	21.4	29.6
1.01 - 2.00	26.7	46.4	27.6
>2.00	25.9	3.6	35.7
Nos. of eyes	116	28	98
	Age: 9 - <12 years		
Nil	5.9	0	5.0
0.21 - 1.00	35.3	50.0	25.0
1.01 - 2.00	20.6	50.0	30.0
>2.00	38.2	0	40.0
Nos. of eyes	34	4	20

Up to three years of age, the distribution of astigmatism differed little from one strabismic group to another, the majority of cases falling between 0.21 and 1.00 D. The pattern in the subsequent three years - up to the age of six, was similar, except that among alternating/intermittent cases the mode fell between 1.01 and 2.00. The chi-square test shows the differences in distribution over the whole of the six year period to be just significant (χ^2 = 15.047, d.f. = 6, n = 590, ρ = 0.02).

In the six years up to the age of twelve, the higher levels of astigmatism increase in incidence in both unilateral and non-strabismic groups. In contrast, the alternating/intermittent group shows a pronounced increase in the incidence of non-astigmatic cases up to the age of nine. The results for the subsequent three years are based on only four eyes, and, therefore, must be regarded as of doubtful significance. The findings for the whole of the six years - up to the age of twelve, are highly significant (χ^2= 23.173, d.f.= 6, n = 300, ρ = <0.001).

The results show that astigmatic levels in the non-strabismic and unilateral groups are very similar. It has already been pointed out that the non-strabismic group largely comprises the fixating eyes of unilateral cases (6.17). It can, therefore, be seen that in cases of unilateral strabismus, astigmatic levels in both eyes (fixating and non-fixating), are likely to be similar. The results also indicate that astigmatism tends to be higher in unilateral cases of strabismus than in alternating cases, particularly above the age of six. It should be recognised, however, that these findings are the outcome of a cross-sectional, and not a longitudinal analysis. The differences between one age group and another are based upon comparisons of the astigmatic state in different children and *not* upon a follow-up of individual changes in astigmatism.

Changes in astigmatism related to strabismic state

6.44 It has already been pointed out that the previous analysis of astigmatism and strabismus was cross-sectional in nature and, therefore, reflects the static state of astigmatism in different children at certain points in time. The relationship between changes in astigmatism and strabismic state has still to be examined.

Sex differences

6.45 Changes in astigmatism in boys and girls were very similar, irrespective of the strabismic state or of the age group involved. The greatest differences occurred in the non-strabismic group up to six years of age, and the alternating group aged between six and twelve. In neither case, however, were these findings significant ($p = <0.30 >0.20$).

Overall astigmatic changes

6.46 Changes in astigmatism in the first three years of life occur more frequently in children with alternating and intermittent strabismus than in those with unilateral strabismus (Table 76A) Nevertheless, astigmatism remains stationary in a high proportion of cases in all the strabismic groups. Its incidence tends to rise with age, particularly in alternating cases.

Up to the age of three, increases in astigmatism are not only far more common than astigmatic decreases - the ratio being not less than 3 : 1, they also tend to be larger (Table 76A Appendix A.12). Annual changes within the strabismic groups are fairly similarly distributed. It can be seen that

TABLE 76 A

Changes in astigmatism related to strabismic state

Analysis by changes in astigmatism and strabismic state of each eye, within three year age groups, up to twelve - percentage distribution

Changes in astigmatism	Strabismic groups: Nil	Alternating/Intermittent	Unilateral
Age: Birth - <3 years			
No change	67.9	42.9	54.0
Increased astigmatism	26.4	42.9	40.0
Decreased astigmatism	5.7	14.3	6.0
Nos. of eyes	53	28	50
Age: 3 - <6 years			
No change	71.9	68.4	70.5
Increased astigmatism	21.5	23.7	23.8
Decreased astigmatism	6.6	7.9	5.7
Nos. of eyes	228	38	193
Age: 6 - <9 years			
No change	66.1	85.7	67.3
Increased astigmatism	29.6	7.1	22.4
Decreased astigmatism	4.3	7.1	10.2
Nos. of eyes	115	28	98
Age: 9 - <12 years			
No change	88.2	100.0	70.0
Increased astigmatism	5.9	0	10.0
Decreased astigmatism	5.9	0	20.0
Nos. of eyes	34	4	20

astigmatism changes more frequently and to a greater extent during this period than at any other time, irrespective of the strabismic state involved.

The patterns of change, between the ages of three and six, were almost identical in each of the strabismic groups (Table 76 A). Annual changes were generally lower than those found previously (Appendix A.12).

In the three years up to the age of nine the incidence of stationary astigmatism in alternating cases reached 85.7 per cent, compared to 68.4 per cent in the preceding period. In contrast the incidence in both non-strabismic and unilateral groups fell slightly, the patterns of change in these two groups being almost identical. In the final three years, i.e. up to twelve, the proportion of stationary cases increased still further. The numbers involved in this group, however, were very small; sampling errors may, therefore, be associated with this finding.

The chi-square test shows that up to the age of six, the patterns of astigmatic change are not associated with strabismic state (χ^2 = 5.726, d.f. = 4, n = 590, ρ = <0.30 >0.20). In the following six years, however, the incidence of stationary astigmatism in alternating and intermittent strabismus is greater than in unilateral strabismus, the differences being just significant (χ^2= 9.957, d.f = 4, n = 300, ρ = <0.05 >0.02). Despite these findings, there is little to suggest that changes in astigmatism are directly related to the type of strabismus present.

Changes in ocular astigmatism related to surgical intervention

6.47 It has already been shown that surgical intervention during the first few years after birth may have some effect upon refractive development in general (6.28). It is conceivable, that alterations in the astigmatic state of the eye may occur following strabismic surgery. It is known that contraction, as well as relaxation, of the extra-ocular muscles can have an effect upon the shape of the globe. The possibility, therefore, exists that surgery may also affect the shape of the eye, as a result of which astigmatic changes may arise.

Surgery was classified, for the purposes of this analysis, on the same basis as that used previously (6.26). This resulted in four separate groups: (a) nil on both eyes, (b) nil on one eye only, (c) surgery on one eye only, (d) surgery on both eyes.

Sex differences

6.48 Where surgery had been carried out, whether on one eye or on both, the patterns of astigmatic change amongst males and females in operated and non-operated eyes, did not differ significantly irrespective of the age group involved. Only in those cases where neither eye had been subjected to surgery were significant differences found, these being confined to the first six years of life (Table 77). The chi-square test for this six year period taken as a whole shows that these findings are very unlikely to have occurred by chance ($p = <0.025 >0.02$)

Analysis on a yearly basis reveals that differences are greatest in the fifth year, when changes in astigmatism occur more frequently amongst females than males. Previous results have demonstrated that astigmatism at this time of life shows an increasing tendency to remain stationary (6.33). This finding, therefore, suggests that males may be more developed, with regard to astigmatism, than females. Examination of the patterns of changes in each year, however, shows that the relative incidences of stationary astigmatism vary from year to year,

TABLE 77

Changes in astigmatism in non-surgical cases amongst males and females

Analysis by changes in astigmatism and yearly age groups up to six - percentage distribution

Changes in astigmatism	Age in years: <1	<2	<3	<4	<5	<6
			MALES			
No change	0	41.7	91.7	76.5	88.1	76.3
Increase	100.0	50.0	0	20.6	7.1	10.5
Decrease	0	8.3	8.3	2.9	4.8	13.2
Nos. of eyes	2	12	12	34	42	38
			FEMALES			
No change	0	78.6	55.6	58.3	71.4	82.9
Increase	0	21.4	33.3	41.7	28.6	14.3
Decrease	0	0	11.1	0	0	2.9
Nos. of eyes	0	14	18	24	35	35

the highest levels occurring as follows:

2nd year	females
3rd year	males
4th year	males
5th year	males
6th year	females.

It is difficult to draw any useful conclusions from this rather confused picture. Further study of these children is obviously needed before these differences can be explained.

Overall changes in astigmatism

6.49 Surgery has a greater effect upon astigmatism in the first three years of life than in any other period up to the age of twelve. The incidence of astigmatic changes in operated eyes is considerably higher than in non-operated eyes, with increases predominating over decreases irrespective of the type of treatment being carried out (Table 78). The patterns of change in the two non-operated groups are very similar to each other, with astigmatism remaining unchanged in a relatively high proportion of cases. In contrast, where surgery has been carried out on one eye alone, the astigmatic pattern in the non-operated eye differs markedly from that found in the operated eye. This suggests that surgery does affect the course of astigmatic developments during this period of life.

In the following three years - up to the age of six, the incidence of astigmatic changes declines markedly in surgical cases, especially where only one eye has been involved. As a result, the patterns of change, in the non-surgical and surgical groups were no longer dissimilar as in the previous period, but almost identical.

TABLE 78

Changes in astigmatism related to surgical intervention

Analysis of changes in astigmatism and nature of surgical intervention for each three year age group - percentage distribution.

Changes in astigmatism	Surgical intervention: Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both eyes
Age: Birth to <3 years				
No change	63.2	68.4	36.8	52.8
Increased astigmatism	29.8	26.3	57.9	36.1
Decreased astigmatism	7.0	5.3	5.3	11.1
Nos. of eyes	57	19	19	36
Age: 3 - <6 years				
No change	76.9	66.3	67.5	64.8
Increased astigmatism	18.8	22.5	26.3	28.6
Decreased astigmatism	4.3	11.3	6.3	6.6
Nos. of eyes	208	80	80	91
Age: 6 - <9 years				
No change	70.4	73.8	61.9	66.7
Increased astigmatism	25.2	19.0	23.8	26.2
Decreased astigmatism	4.3	7.1	14.3	7.1
Nos. of eyes	115	42	42	42
Age: 9 - <12 years				
No change	97.1	75.0	50.0	62.5
Increased astigmatism	2.9	12.5	25.0	0
Decreased astigmatism	0	12.5	25.0	37.5
Nos. of eyes	34	8	8	8

In the six years up to the age of twelve, astigmatic changes once again tended to occur more frequently in operated than in non-operated eyes. This was especially pronounced in the final three years although it should be noted that relatively small numbers were involved during this period.

The range of annual changes differs little from one surgical group to another throughout the period of the study. There is, however, a tendency in all groups for the level of change to decrease with age (Appendix A.13).

The differences between the four surgical groups, are slightly more significant when direction of change is analysed. Despite this the chi-square test demonstrates that astigmatic change is not closely associated with surgery:

Birth - <6: $\chi^2 = 11.513$, d.f. = 6, n = 590, ρ = <0.10 >0.05

6 - <12: $\chi^2 = 11.544$, d.f. = 6, n = 300, ρ = <0.10 >0.05

Even the differences found during the first three years are not statistically significant.

These analyses indicate that surgery does not affect the astigmatic development of the eye. Nevertheless, changes in astigmatism did occur more frequently in operated than in non-operated eyes, particularly between birth and the age of three. Whilst the evidence is far from conclusive, the results do seem to suggest that astigmatic change may, in some way, be connected with surgery.

Summary point (6.43 - 6.49)

6.50

1. The relationship between ocular astigmatism and strabismic state of each eye has been examined. Marginally significant sex differences were found solely in the strabismic (non-fixating) eyes of unilateral cases, these differences being confined to children aged between six and twelve (6.42).

The distribution of astigmatism differed little between strabismic groups, except that above the age of six the higher levels of astigmatism were associated with unilateral strabismus rather than alternating strabismus. The results also show that astigmatic levels in fixating and non-fixating eyes are unlikely to differ to any great extent. Attention, however, is drawn to the fact that these findings are the outcome of a cross-sectional and not a longitudinal analysis (6.43).

2. Changes in astigmatism have been investigated in relation to strabismic state, thus providing a longitudinal analysis of these two factors. No significant sex differences were found for any of the strabismic groups (6.45).

Astigmatism remains stationary in a high proportion of cases in each of the strabismic groups, the incidence tending to rise with age. Up to the age of three, changes occur most frequently in alternating and intermittent cases. Increasing astigmatism is more common than decreasing astigmatism in all groups, whilst the range of changes per annum is similar. Between the ages of three and six, the patterns of change in the three groups were almost identical. The level of annual changes is generally lower than that found previously. The incidence of stationary astigmatism in alternating cases continues to rise during the six years up to the age of twelve.

It has been shown that the overall results do *not* suggest that any definite relationship exists between astigmatic changes and strabismic state - at least when analysed on the basis used in this study (6.46).

3. Attention has been drawn to the possibility that surgery upon the extra-ocular muscles could conceivably affect the shape of the globe, thus producing changes in astigmatism (6.47). Astigmatic changes have, therefore, been analysed in relation to surgical intervention.

Significant sex differences were found only in those cases where neither eye had been subjected to surgery, the differences being confined to the first six years of life. The data when analysed on a yearly basis was found to be rather inconclusive (6.48)

The effect of surgery is most pronounced in the first three years of life. The incidence of astigmatic changes in operated eyes is considerably higher than in non-operated eyes. This suggests that surgery does affect the course of astigmatic developments during this period. In the following three years however, the patterns of changes in all groups were almost identical. Between the ages of six and twelve, eyes subjected to surgery once again show a greater tendency to exhibit astigmatic changes than non-operated eyes although the differences were rather less than in the first three years. The range of annual changes was similar for all groups, whilst the level declined with age.

The statistical analyses indicate that surgery and astigmatic changes are not related. Nevertheless, the results do seem to suggest that astigmatic changes may, in some way, be connected with surgery. The evidence, however, is inconclusive (6.49).

Changes in the axis of astigmatism in relation to age

Characteristics of sample

6.51 Changes in astigmatism have so far been examined on the basis of dioptric alterations alone. Astigmatism, however, involves two components - dioptric power and axis (principal meridian). Both are important elements of refraction. Axis behaviour has, therefore, been investigated with the aim of determining its relationship with other variables such as age, level of astigmatism, strabismic state and treatment.

Changes in axis were analysed on the basis of the shift between one examination and the next. Alterations of less than 10° were classified as nil: 77.4 per cent of the total sample fell into this category. Axis changes in the remaining 21.5 per cent fell between 10 and 30°, 1.0 per cent between 35 and 55°, with one solitary case of 80°. In none of the cases involving alterations of $>30^{\circ}$ did the level of astigmatism exceed 0.50 D. In view of the small number involved, all axis changes have been grouped together and not quantified. The analysis is, therefore, based on two groupings only: (a) no change, covering nil - $<10^{\circ}$, (b) axis change, covering $\geq 10^{\circ}$. Consequently the results represent total changes between examinations carried out over widely varying intervals, and *not* changes per annum.

Axis changes and age

6.52 The principal meridians in astigmatism tend to remain unchanged throughout the period studied, i.e. from birth up to twelve (table 79). The incidence of changes did not exceed 30 per cent in any group. Axis changes, nevertheless, occurred rather more frequently, and the range of changes was rather higher, below the age of six than above. (Tables 79 and 80). These

TABLE 79

Changes in the axis of astigmatism related to age

Analysis by change in axis of astigmatism in degrees and three yearly age groups from birth up to twelve - percentage distribution

Changes in axis - degrees	Age in years: Birth - <3	3 - <6	6 - <9	9 - <12	All ages
Nil (0 - <10)	71.8	74.1	85.8	81.0	77.4
≥ 10	28.2	25.9	14.2	19.0	22.6
Nos. of eyes	131	459	240	58	888

TABLE 80

Means and standard deviations of changes in axis of astigmatism related to age

Analysis by change in axis of astigmatism in degrees and three yearly age groups from birth to twelve

Changes in axis -degrees	Age in years: Birth - <3	3 - <6	6 - <9	9 - <12
Mean	5	5	2	3
Standard deviation	±9.3	±10.4	±5.5	±6.4
Nos. of eyes	131	459	240	58

differences were shown to be highly significant, the likelihood that they had arisen by chance being very small ($\chi^2 = 15.4664$, d.f. = 3, n = 888, $p = <0.005 >0.001$). The results demonstrate that age and changes in axis are related. They clearly indicate that the younger the child the more likely that such changes will occur. Although the pattern of events in the first six years differs significantly from that in the subsequent six, it must be remembered that in the majority of cases the axis remains stationary irrespective of age.

Changes in axis related to initial astigmatism

6.53 Ocular astigmatism has been classified according to the value found at the first of each pair of examinations - i.e. initial astigmatism, and grouped as in the previous analyses - (a) Nil, (b) 0.01 - 1.00 D, (c) 1.01 - 2.00 D, (d) >2.00 D (6.30). The non-astigmatic group, however, has been excluded from the analysis since, by its very nature, it cannot be subject to changes in axis.

Sex differences

6.54 The distribution of axis changes in males and females were almost identical in all the astigmatic groups, the differences being insignificant. This applied to both six year age groups.

Overall changes in axis

6.55 The predominating feature in all the astigmatic groups (excluding the non-astigmatic cases) is the tendency for astigmatism to remain stationary between examinations (Table 81). This is characteristic of all the age groups involved (i.e. from birth to twelve), the lowest incidence being 63.2 per cent. Up to the age of three, the ratio of stationary to changing

TABLE 81

Axis changes in astigmatism related to initial astigmatic state

Analysis by changes in axis in degrees and initial level of ocular astigmatism in dioptres for each three year age group - percentage distribution

Changes in axis - degrees	Ocular astigmatism - dioptres Nil	0.01-1.00	1.01-2.00	>2.00
		Age: Birth - <3 years		
Nil (0 - <10)	100.0	67.2	69.2	66.7
≥10	0	32.8	30.8	33.3
Nos of eyes	16	61	39	15
		Age: 3 - <6 years		
Nil (0 - <10)	100.0	66.5	74.6	77.9
≥10	0	33.5	25.4	22.1
Nos. of eyes	53	224	114	68
		Age: 6 - <9 years		
Nil (0 - <10)	100.0	77.6	81.4	95.4
≥10	0	22.4	18.6	4.6
Nos. of eyes	29	76	70	65
		Age: 9 - <12 years		
Nil (0 - <10)	100.0	63.2	73.3	100.0
≥10	0	36.8	26.7	0
Nos. of eyes	3	19	15	21

axes is approximately 2 : 1, irrespective of the level of astigmatism present. Where changes in axis occur, they tend to be rather larger and more widely spread when astigmatism is less than 1.00 D than when it exceeds 1.00 D (Table 82). The changes in the two highest groups, however, are almost identical. This does not suggest that axis changes at this age are closely related to the degree of initial astigmatism.

Between three and six years of age the higher the initial astigmatic level, the lower the incidence of change in axis. Although the differences between the three groups of astigmatism are not particularly large, the trend is clear. It becomes increasingly pronounced in the subsequent age groups, six to nine and nine to twelve (Table 81). The means and standard deviations underline these trends (Table 82).

The differences between these astigmatic groups are clearly not significant up to the age of six (χ^2 = 3.636, d.f. = 2, n = 521, ρ = 0.30). In contrast, the differences during the following six years - up to twelve, are highly significant (χ^2 = 16.317, d.f. = 2, n = 266, ρ = <0.001). Whilst correlation between changes in axis and degree of astigmatism is never very high, it does increase with age. This is illustrated by the correlation coefficients for each three year age group up to twelve:

	Age groups in years			
	Birth - <3	3 - <6	6 - <9	9 - <12
Correlation Coefficients	-0.0335	-0.0830	-0.1121	-0.2744

TABLE 82

Means and Standard Deviations of changes in axis related to initial astigmatic state

Analysis by changes in axis of astigmatism in degrees and initial level of ocular astigmatism in dioptres, for each three year age group.

Changes in axis of astigmatism - degrees	Ocular astigmatism - in dioptres			
	Nil	0.01-1.00	1.00-2.00	>2.00
		Age: Birth - <3 years		
Mean	0	7	4	4
Standard deviation	0	±11.9	±5.8	±6.1
Nos of eyes	16	61	39	15
		Age: 3 - <6 years		
Mean	0	7	4	3
Standard deviation	0	±13.2	±7.2	±6.0
Nos of eyes	53	224	114	68
		Age: 6 - <9 years		
Mean	0	3	3	1
Standard deviation	0	±6.7	±5.8	±3.6
Nos of eyes	29	76	71	65
		Age: 9 - <12 years		
Mean	0	6	3	0
Standard deviation	0	±8.8	±6.0	0
Nos of eyes	3	19	15	21

By calculating the regression coefficient it is possible to estimate the changes in axis likely to arise for different levels of astigmatism. In this way the nature of the relationship represented by these degrees of correlation can be seen. The relationship in the first six years is clearly very weak, although it is far from strong in the following six years. The estimates for the period between the ages of six and nine show that the axis is likely to change by approximately 2.5° when the initial astigmatic level is 0.50 D, but by only 0.2° for astigmatism of 5.00 D (Table 83). From nine until twelve the axis will change by approximately 5° when astigmatism is only 0.50 D, dropping by 1° for each 1.0 D rise in astigmatism so that at 5.0 D, the estimated change will be approximately nil. The standard error of estimate for this age group is $\pm 6.2^{\circ}$; therefore in 95 per cent of cases, the changes occurring may lie within $\pm 12^{\circ}$ of the estimated value. It is obvious that extreme care must be exercised in making predictions of changes in axis from these results.

What these results show is that the higher the level of initial astigmatism, the less likely that the axis will change between examinations. This relationship increases with age, although it is not very pronounced in any of the age groups covered by this study. Predictions clearly cannot be made with any degree of certainty and this is underlined by the standard error of estimate already found.

TABLE 83

Estimated changes in axis between examinations related to initial level of ocular astigmatism

Analysis by axis changes between examination in degrees and initial level of ocular astigmatism in dioptres for age groups 6 - <9 and 9 - <12

Ocular astigmatism -dioptres	Estimate changes in axis - degrees	Regression coefficient
	Age group : 6 - <9 years	
0.50	2.5	-0.493
1.00	2.2	
1.50	2.0	
2.00	1.7	
3.00	1.2	
4.00	0.7	
5.00	0.2	
	Age group : 9 - <12 years	
0.50	4.5	-0.960
1.00	4.0	
1.50	3.5	
2.00	3.0	
3.00	2.1.	
4.00	1.1	
5.00	0.1	

Changes in axis related to changes in astigmatism

6.56. Since level of astigmatism as well as axis are subject to change, both have been examined to see if they are related in any way.

Astigmatism has been classified according to whether it changed or remained stationary between examinations, and these two groups compared with axis changes classified on the same basis. The distribution within each of the age groups does not suggest that changes in astigmatism are accompanied by changes in axis, or that stationary axes are associated with stationary astigmatism (Table 84). Only between the ages of six and nine do axis and astigmatic changes appear to be related in any way, but even here, the results, although marginally significant (ρ = <0.05 >0.02 Table 85), are far from conclusive.

Changes in axis related to strabismic state

6.57 Although it has already been shown that no definite association exists between the strabismic groups analysed in this study and changes in ocular astigmatism (6.46), this does not exclude the possibility that changes in axis may be related to the strabismic state of each eye.

Sex differences

6.58 Axis changes in males were similar to those in females irrespective of strabismic groups or of age. The greatest differences occurred in children under six who had alternating or intermittent strabismus, but even in this case, they were not statistically significant (χ^2 = 2.67, d.f. = 1, n = 66 ρ = <0.20 >0.10)

TABLE 84

Changes in axis related to changes in astigmatism

Analysis by axis changes and astigmatic changes for each three year age group - percentage distribution

	Stationary astigmatism	Changes in astigmatism
	Age: Birth - <3 years	
Stationary axis	71.4	73.2
Changes in axis	28.9	26.8
Nos. of cases	76	56
	Age: 3 - <6 years	
Stationary axis	74.7	72.4
Changes in axis	25.3	27.6
Nos. of cases	324	134
	Age: 6 - <9 years	
Stationary axis	89.1	78.7
Changes in axis	10.9	21.3
Nos. of cases	165	75
	Age: 9 - <12 years	
Stationary axis	81.3	80.0
Changes in axis	18.8	20.0
Nos. of cases	48	10

TABLE 85

Chi-square analyses of axis changes related to changes in the level of astigmatism

	Age groups in years:			
	Birth - <3	3 - <6	6 - <9	9 - <12
χ^2	0.1367	0.2613	4.6076	0.0082
d.f.	1	1	1	1
n	132	458	240	58
ρ	<0.95>0.90	<0.70>0.50	<0.05>0.02	<0.95>0.90

Overall changes

6.59 Changes in axis up to the age of three, occurred more frequently in alternating and intermittent cases than in the unilateral and non-strabismic groups. (Table 86). The patterns of change in the latter two groups were very similar to each other, not only during these three years, but right up to the age of twelve.

Between the ages of three and six, axis changes in unilateral cases declined in incidence compared to the first three years. As a result almost identical patterns of change were found in all three groups. This decline continues up to the age of twelve.

Although the differences in the three strabismic groups are slightly greater between the ages of six and twelve than in the earlier period, in neither case are they statistically significant.

There is nothing to suggest from these results, that changes in axis bear any relationship to the type of strabismus present. Nevertheless, it has been shown that fixating and non-fixating eyes in unilateral strabismus tend to display the same behaviour patterns with respect to the axis of astigmatism.

Changes in axis related to surgical intervention

6.60 Of all forms of strabismic treatment, surgery is the one most likely to produce changes in the position of the principal meridians of the eye. Whether this in fact happens is not known. The relationship between strabismic treatment and axis behaviour has, therefore, been examined. For the purposes of this analysis, surgery was again classified on the same basis as that used previously: (a) nil on both eyes

TABLE 86

Axis changes in astigmatism related to strabismic state

Analysis by axis changes in degrees and strabismic state of each eye within three yearly age groups from birth up to twelve

Changes in axis - degrees	Strabismic groups Nil	Alternating/Intermittent	Unilateral
		Age: Birth - <3 years	
Nil (0 -<10)	71.7	64.3	76.0
≥ 10	28.3	35.7	24.0
Nos. of eyes	53	28	50
		Age: 3 - <6 years	
Nil (0 - <10)	72.8	76.3	75.1
≥ 10	27.2	23.7	24.9
Nos. of eyes	228	38	193
		Age: 6 - <9 years	
Nil (0 - <10)	85.1	92.9	84.7
≥ 10	14.9	7.1	15.3
Nos. of eyes	114	28	98
		Age: 9 - <12 years	
Nil (0 - <10)	79.4	100.0	80.0
≥ 10	20.6	0	20.0
Nos. of eyes	34	4	20

(b) nil on one eye only, (c) surgery on one eye only, (d) surgery on both eyes (6.26).

Sex differences

6.61 Axis changes in boys and girls differed only marginally. The differences were perhaps slightly greater where treatment had been entirely non-surgical than in other cases, but these were still far from being statistically significant.

Overall variations

6.62 Below the age of three, comparable patterns of change were found where, on one hand, surgery had involved both eyes, and on the other, treatment had been entirely non-surgical. (Table 87). The incidence of change in these two groups was considerably higher than when surgery had been confined to one eye only. Nevertheless, in all groups the axis remained stationary in more than two-thirds of the cases involved.

In the three years up to the age of six the incidences of change in all four surgical groups were relatively uniform. This remained the position until the age of nine. In each case, however, changes occurred less frequently than in the previous period, there being an increasing tendency for the principal meridians to remain stationary between examinations.

In the final three years, i.e. up to the age of twelve, the trend in three of the four groups, was reversed, with the incidence of stationary axes declining. The exception occurred in the non-surgical group, where treatment on both eyes has been confined to orthoptics. Extreme caution must be exercised in drawing conclusions for this period, since the findings, which are based on relatively small numbers, could clearly have resulted from sampling errors.

The results are not statistically significant either for the first six or for the latter six years covered by this study. There is nothing to suggest that any connection exists between surgery and subsequent changes in axis.

TABLE 87

Axis changes in astigmatism related to surgical intervention

Analysis by axis changes in degrees and surgical intervention on each eye within three year age groups from birth up to twelve

Changes in axis - degrees	Surgical groups: Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both eyes
	Age: Birth - <3 years			
Nil (0 - <10)	66.7	78.9	84.2	69.4
≥ 10	33.7	21.1	15.8	30.6
Nos. of eyes	57	19	19	36
	Age: 3 - <6 years			
Nil (0 - <10)	77.4	73.8	70.0	70.3
≥ 10	22.6	26.3	30.0	29.7
Nos. of eyes	208	80	80	91
	Age: 6 - <9 years			
Nil (0 - <10)	86.8	88.1	83.3	83.3
≥ 10	13.2	11.9	16.7	16.7
Nos. of eyes	114	42	42	42
	Age: 9 - <12 years			
Nil (0 - <10)	88.2	75.0	62.5	75.0
≥ 10	11.8	25.0	37.5	25.0
Nos. of eyes	34	8	8	8

Summary Point (6.51 - 6.62)

6.63.

1. The distribution of changes in the axis of astigmatism has been described and the method of presentation discussed. The results have been presented on the basis of total changes between examinations and not changes per annum (6.51). Analysis of axis behaviour in relation to age indicates that changes occur more frequently and are rather larger below the age of six than above, although in the majority of cases the axis remains stationary irrespective of age (6.52).

2. Axis changes have been compared to initial levels of ocular astigmatism. No significant sex differences were found (6.54). Axis changes up to the age of three do not appear to be related to astigmatic level. The results, however, indicate that during the period from three until twelve, the higher the level of initial astigmatism, the less likely the axis will change between examinations. This relationship, although not very pronounced in any age group, does tend to become closer with age. The findings for the six years up to the age of twelve are highly significant. The correlation coefficients, whilst increasing with age, are nevertheless low for all groups. Changes in axis cannot be regarded as being directly related with the level of ocular astigmatism (6.55).

3. Comparison of changes in axis with changes in astigmatism does not suggest that these two factors are related to each other in any way (6.56).

4. The relationship between strabismic state and axis changes has been examined. Once again, no significant sex differences were found (6.58). There is nothing to suggest from the overall results, that changes in axis bear any relationship to the strabismic

state of any eye (6.59).

5. The effect of surgery on the position of the principal meridians of the eye has been investigated. Only marginal differences were found in its effect on boys and girls (6.61). Axis behaviour, generally, in the four surgical groups did not differ significantly for either of the six year periods studied. This indicates that there is no connection between surgery and subsequent changes in axis (6.62).

Anisometropia related to age

Characteristics of sample

6.64 Anisometropia is defined as a condition wherein the total refractions of the two eyes are unequal. Although this is a universally accepted definition, there is considerable divergence of opinion as to the exact degree of inequality that should be regarded as clinically significant. It has already been shown that some authorities consider the threshold of anisometropia to lie between 2.00 and 3.00 D, whilst others state that differences of 0.25 D are significant (3.33). In these circumstances, the minimum differences, rather than the maximum, have been taken to represent anisometropia. For the purposes of this study, therefore, anisometropia has been classified as a difference in the mean sphere spectacle refraction of 0.25 D or more. Consequently, the results of this investigation can be compared with those of other studies, simply by adjusting the threshold values, as and when necessary.

Since anisometropia is a measure of the relationship of the refractive state of the two eyes, it is clear that the data must represent the findings from pairs of eyes rather than individual eyes. The total number of cases available for analysis was therefore 445, compared to 891 in the previous analyses. Measurements were taken at the first and the second of each pair of examinations, and the findings defined as 'initial' and 'subsequent' anisometropia respectively.

Distribution of anisometropia and sex differences

6.65 The range of anisometropia in the sample was very wide. Differences in ocular refraction as high as 8.38 D and 8.52 D were recorded at initial and subsequent examinations respectively. The majority of cases, however, fell far below this level, with only 15 per cent of the total exceeding 1.50 D. Anisometropic cases in excess of 1.50 D have, therefore, all been grouped together; those below 1.50 D have been divided into half dioptric groups, whilst non-anisometropic cases have been classified separately, thus making a total of five categories as follows:

(a) Nil

(b) 0.25 - 0.50 D

(c) 0.51 - 1.00 D

(d) 1.01 - 1.50 D

(e) >1.50 D

No significant differences could be found in the male-female distributions of anisometropia within these five groups, either before or after the age of six.

Age distribution - cross-sectional analysis

6.66 Over 75 per cent of children under the age of three either were non-anisometropic or had anisometropia not exceeding 1.00 D. The distribution in the three groups involved was almost identical (Table 88). From three years of age onwards, the incidence of non-anisometropic cases declined, with the majority of children exhibiting differences in ocular refraction ranging from 0.25 to 0.50 D. In over 50 per cent of each age group, anisometropia did not exceed 1.00 D.

Apart from the decline in the proportions of isometropic cases with age, no clear trends are to be seen. The means, however, indicate that the level of anisometropia does increase with age, although it should be noted that this is accompanied by an increase in the spread, as shown by the standard deviations (Table 89). The higher levels of anisometropia - above 1.50 D - clearly tend to be found later in life rather than earlier (Tables 88 and 90).

TABLE 88

Initial anisometropia related to age

Analysis by anisometropia at 'initial' examination in dioptres and three year age groups - percentage distribution

Anisometropia	Age in years:				
in dioptres	Birth - <3	3 - <6	6 - <9	9 - <12	All ages
Nil	26.2	12.2	13.2	3.4	13.9
0.25 - 0.50	27.7	40.9	36.4	48.3	38.2
0.51 - 1.50	24.6	24.8	16.5	17.2	22.0
1.01 - 1.50	7.7	10.0	14.9	0	10.3
>1.50	13.8	12.2	19.0	31.0	15.5
Nos. of cases	65	230	121	29	445

TABLE 89

Means and Standard Deviations of initial and subsequent anisometropia related to age

Analysis by anisometropia at initial and subsequent examinations in dioptres and three year age groups

Anisometropia in dioptres	Age in years: Birth - <3	3 - <6	6 - <9	9 - <12
Initial mean	0.58	0.71	0.91	1.38
Subsequent mean	0.58	0.61	0.94	1.26
Initial standard deviation	±0.65	±0.90	±1.07	±1.86
Subsequent standard deviation	±0.64	±1.02	±1.14	±1.66
Numbers of cases	65	230	121	29

TABLE 90

Means and standard deviations of initial and subsequent anisometropia related to initial anisometropic groups for each three year age group

Anisometropia -dioptres	Initial anisometropic groups - dioptres Nil	0.25-0.50	0.51-1.00	1.01-1.50	>1.50
		Age: Birth - <3 years			
Initial mean	0	0.18	0.68	1.18	1.93
Subsequent mean	0.25	0.19	0.66	1.10	1.56
Initial standard deviation	0	±0.08	±0.16	±0.15	±0.21
Subsequent st. deviation	±0.25	±0.28	±0.50	±0.18	±0.75
Nos. of cases	17	18	16	5	9
		Age: 3 - <6 years			
Initial mean	0	0.27	0.68	1.24	2.53
Subsequent mean	0.27	0.15	0.49	1.15	2.33
Initial standard deviation	0	±0.11	±0.16	±0.14	±1.37
Subsequent st. deviation	±0.54	±0.43	±0.38	±0.62	±1.70
Nos. of cases	28	94	57	23	28

TABLE 90 (Continued)

Anisometropia - dioptres	Initial anisometropic groups - dioptres Nil	0.25-0.50	0.51-1.00	1.01-1.50	>1.50
		Age: 6 - <9 years			
Initial mean	0	0.27	0.73	1.21	2.71
Subsequent mean	0.15	0.32	0.73	1.21	2.60
Initial standard deviation	0	±0.12	±0.17	±0.13	±1.15
Subsequent st. deviation	±0.18	±0.54	±0.49	±0.38	±1.38
Nos. of cases	16	44	20	18	23
		Age: 9 - <12 years			
Initial mean	0	0.26	0.67	0	3.68
Subsequent mean	0.13	0.26	0.89	0	3.16
Initial standard deviation	0	±0.12	±0.14	0	±1.83
Subsequent st. deviation	0	±0.21	±0.84	0	±1.74
Nos. of cases	1	14	5	0	9

The means of this group rise from 1.93 D in the first three years to 3.68 D in the period between nine and twelve.

The chi-square test shows that age (based on three year intervals) and degree of anisometropia are associated, it being extremely unlikely that the differences in the distribution of anisometropia within the four age groups could have arisen by chance (χ^2 = 29.05, d.f. = 12, ρ = <0.005 >0.001). Despite this, the correlation coefficient is only 0.1756. This does not indicate that anisometropia and age are closely related, although it does show that anisometropia tends, if anything, to increase with age. It must, however, be borne in mind that these findings are based on a cross-sectional analysis, in which anisometropic levels in different children have been compared. Individual patterns of change may, therefore, differ considerably from the trends indicated here.

Changes in anisometropia related to age

Characteristics of sample

6.67 Changes in anisometropia were initially classified simply according to the direction in which the changes had occurred: i.e. no change, increase or decrease. On further investigation however a few cases were found where, although anisometropia had remained unchanged, the relative refractive state of the two eyes had been reversed: the eye which previously had the lower refractive error now presented the higher degree of ametropia, but despite this, the differences between the two eyes was identical to that found earlier. Similar reversed cases were discovered in the other two groups, but here the overall effect was either an increase or a decrease in the level of anisometropia. Anisometropic changes were, therefore, finally classified according to whether they were non-reversed or reversed, as follows:

(a) no change

(b) increase

(c) decrease

(d) reversed no change

(e) reversed increase

(f) reversed decrease

One child sustained an ocular injury during the course of the study as a result of which the total number of cases below the age of twelve was reduced to 444.

Anisometropic changes - age distribution

6.68 Analysis of anisometropic changes related to age shows that anisometropia remains stationary in approximately only 20 per cent of cases, irrespective of the age group involved (Table 91). In the remainder, changes are fairly evenly divided into increases and decreases. Reversals occur at all ages, although they form only a very small proportion of the total in each group. There are no clear differences in the general patterns of change between one age group and another.

Anisometropic changes related to initial anisometropia

Sex differences

6.69 The patterns of anisometropic change in males were similar to those in females in each of the five groups of initial anisometropia. The differences that were present were not statistically significant, either below or above the age of six.

Overall anisometropic developments

6.70 Throughout the twelve years covered by this study, anisometropia tends either to increase or to decrease rather than remain stationary, irrespective of the initial level involved (Table 92). Although the patterns of anisometropic change vary between one

TABLE 91

Changes in anisometropia related to age

Analysis by direction of anisometropic change and age groups (three yearly) - percentage distribution

Changes in anisometropia	Birth - <3	3 - <6	6 - <9	9 - <12	All ages
No change	18.5	17.8	20.0	13.8	18.2
Increase	44.6	33.9	39.2	37.9	37.1
Decrease	30.6	35.7	33.3	41.4	34.6
Reversed: No change	0	3.0	3.3	3.4	2.9
Reversed: Increase	4.6	5.2	4.2	0	4.5
Reversed: Decrease	1.5	4.3	0	3.4	2.7
Nos. of cases	65	230	120	29	444

TABLE 92

Changes in anisometropia related to initial anisometropia

Analysis by direction of change and initial level of anisometropia within each three year age group - percentage distribution

Changes in anisometropia	Initial anisometropia - dioptres Nil	0.25-0.50	0.51-1.00	1.01-1.50	>1.50
		Age: Birth - <3 years			
No change	17.6	33.3	6.3	20.0	11.1
Increase	82.4	27.8	37.5	20.0	44.4
Decrease	0	27.8	50.0	60.0	44.4
Reversed: No change	0	0	0	0	0
Reversed: Increase	0	11.1	0	0	0
Reversed: Decrease	0	0	6.3	0	0
Nos. of cases	17	18	16	5	9
		Age: 3 - <6 years			
No change	46.4	13.8	15.8	26.1	0
Increase	53.6	34.0	24.6	34.8	35.7
Decrease	0	26.6	54.4	34.8	64.3
Reversed: No change	0	6.4	1.8	0	0
Reversed: Increase	0	11.7	0	0	0
Reversed: Decrease	0	7.4	3.5	4.3	0
Nos. of cases	28	94	57	23	28

TABLE 92 (Continued)

Changes in anisometropia	Nil	0.25-0.50	0.51-1.00	1.01-1.50	>1.50
		Age: 6 - <9 years			
No change	43.8	7.0	25.0	27.8	17.4
Increase	56.3	41.9	40.0	27.8	30.4
Decrease	0	32.6	30.0	44.4	52.2
Reversed: No change	0	9.3	0	0	0
Reversed: Increase	0	9.3	5.0	0	0
Reversed: Decrease	0	0	0	0	0
Nos. of cases	16	43	20	18	23
		Age: 9 - <12 years			
No change	0	28.6	0	0	0
Increase	100.0	42.9	60.0	0	11.1
Decrease	0	21.4	20.0	0	88.9
Reversed: No change	0	7.1	0	0	0
Reversed: Increase	0	0	0	0	0
Reversed: Decrease	0	0	20.0	0	0
Nos. of cases	1	14	5	0	9

anisometropic group and another, their relationship is poorly defined. There is, perhaps, a tendency during the first six years for anisometropia above 0.50 D to decrease rather than increase, with the reverse being true up to 0.50 D. This is still present after the age of six, except that the dividing line occurs at 1.00 D. From three until nine years of age, non-anisometropic cases are characterised by a greater tendency to remain unchanged than any other group. Nevertheless, the incidence is still less than 50 per cent.

Reversed changes, although forming a relatively small proportion of the total, occur rather more frequently when the level of anisometropia is low than when it is high. This is to be expected since the 'reversed' group of changes involve larger dioptric alterations between the two eyes than their non-reversed counterparts; for example, where anisometropia remains unchanged but the relative refractive states of the two eyes have been reversed, a dioptric change of twice the original degree of anisometropia has in fact taken place. In contrast, the change in the 'non-reversed' case has been zero.

The chi-square test shows that the differences between the anisometropic groups are highly significant, particularly those for the period up to the age of six (table 93A). Combining the reversed groups with their non-reversed counterparts does not affect the result from a statistical point of view (Table 93B). Reversed changes, however, can be regarded as overshoots of straight, non-reversed, decreases, since the direction of change in both cases is initially the same, i.e. an anisometropic reduction. Analysis on this basis, however, does not materially affect the statistical significance of the results (Table 93C).

Although the patterns of anisometropic change are clearly

TABLE 93

Chi-square analyses of changes in anisometropia related to initial degree of anisometropia

	Age groups in years: Birth - <6	6 - <12
	A : Reversed and Non-reversed changes	
χ^2	83.22	43.23
d.f.	20	20
p	<0.001	<0.005 >0.001
	B : Reversed changes combined with non-reversed changes	
χ^2	52.08	23.13
d.f.	8	8
p	<0.001	<0.005 >0.001
	C : All reversed changes combined with non-reversed changes	
χ^2	44.72	22.18
d.f	8	8
p	<0.001	<0.005 >0.001
Nos.	295	149

related to the degree of anisometropia present, the nature of this relationship is rather obscure. The overall findings do indicate that anisometropia in the majority of cases tends to change rather than remain stationary. Where changes do occur, the lower levels of anisometropia seem to display a greater tendency to increase than decrease. The reverse appears to be true of the higher levels, with the cross-over point slightly lower in children under the age of six (0.50 D), than in those over six (1.00 D).

Subsequent anisometropia related to initial anisometropia

6.71 In order to assess the relationship between the degree of anisometropia at one examination and the next, 'initial' and 'subsequent' levels of anisometropia were compared.

No significant sex differences were found in any of the initial anisometropic groups. This applied to all the children involved, whether below or above the age of six.

Subsequent and initial levels of anisometropia were found to be very closely correlated in each of the three year age groups up to the age of twelve. The correlation coefficient increased with age, from 0.7331 in the first three years, to 0.9682 in the final three years (i.e. nine to twelve):

	Age in years: Birth - <3	3 - <6	6 - <9	9 - <12
Correlation coefficient r	0.7331	0.8658	0.9230	0.9682
Nos. of eyes	65	230	120	29

These findings show that the younger the child, the less predictable the subsequent level of anisometropia will be. This is confirmed by the regression coefficient which is lower for the first three years than for any other period (Table 94). It is clear that subsequent levels of anisometropia are likely to be very close to the previous level, particularly after the age of three. This is underlined by the estimated anisometropia values (Table 94). In making predictions, however, the standard errors of the estimate must be taken into account. These show that in 95 per cent of cases, real values may deviate by as much as ±1.00 D from these estimates. It must also be borne in mind that since the intervals between examinations varied considerably, a time scale cannot be applied to the estimates. Care must obviously be exercised in drawing conclusions from these findings.

Changes in anisometropia related to surgical intervention

6.72 The aim of treatment in cases of strabismus is to eliminate, or at least reduce, the angle of deviation. It is possible that such treatment may affect the relative refractive development of the two eyes. The relationship of anisometropic changes to surgical and non-surgical forms of treatment has, therefore, been investigated.

In view of the fact that the behaviour of pairs of eyes, rather than individual eyes, was being studied, treatment was simply classified into two groups - surgical and non-surgical. The surgical group constituted those cases on which surgery has been carried out at any time, whether on one eye or on both.

As with the previous anisometropic analyses in this study, the patterns of changes were similar for males and females, regardless of treatment and age.

TABLE 94

Estimated subsequent level of anisometropia related to initial anisometropic level

Initial anisometropia - dioptres	Estimated subsequent anisometropia - dioptres	Regression coefficient	Standard error of estimate - dioptres
	Age: Birth -<3 years		
0.50	0.53	0.7135	±0.43
1.00	0.88		
2.00	1.60		
3.00	2.31		
4.00	3.02		
5.00	3.74		
	Age: 3 - <6 years		
0.50	0.41	0.9763	±0.51
1.00	0.90		
2.00	1.87		
3.00	2.85		
4.00	3.82		
5.00	4.80		
	Age: 6 - <9 years		
0.50	0.53	0.9826	±0.44
1.00	1.02		
2.00	2.01		
3.00	2.99		
4.00	3.97		
5.00	4.95		
	Age: 9 - <12 years		
0.50	0.50	0.8633	±0.42
1.00	0.93		
2.00	1.79		
3.00	2.66		
4.00	3.52		
5.00	4.38		

Overall changes

6.73 Throughout the period from birth up to the age of nine, anisometropia remained stationary in approximately the same proportions of surgical and non-surgical cases (Table 95). During the first three years overall changes in anisometropia were distributed similarly in both groups. This contrasts with the patterns of change found during the nine years up to the age of twelve, when anisometropia increased more often in surgical than non-surgical cases, with the reverse being true of reductions in anisometropia.

Although 'reversed' changes were not very common at any time, in the first three years of life they occurred most frequently following surgery, with a gradual shift towards the non-surgical cases in the subsequent years.

The differences between the two groups is never very pronounced at any age. Statistically (χ^2) these differences are not significant, least of all during the first three years. As previously found (6.68), analysis either by combining reversed changes with their non reversed counterparts, or by treating them all as straight decreases does not materially affect the distribution or the statistical significance of the results. The youngest group is possibly an exception to this inasmuch as combination of the reversed changes in this way, reduces the significance still further, such that the probability of these changes occurring by chance is approximately 0.98 as opposed to $<0.70 >0.50$.

These findings clearly show that changes in anisometropia are similar in surgical and non-surgical forms of treatment. There is a suggestion that after the age of three anisometropia is more likely to increase than decrease following surgery.

There is, however, nothing to suggest from a statistical point of view that surgery affects the relative refractive states of the two eyes any more than other forms of treatment.

TABLE 95

Changes in anisometropia related to strabismic treatment

Analysis by direction of anisometropic change and surgical and non-surgical treatment for each three year age group - percentage distribution

Anisometropic change	Age:Birth -<3 years		Age: 3 - <6 years		Age: 6 - <9 years		Age: 9 - <12 years	
	Surgical	Non-surgical	Surgical	Non-surgical	Surgical	Non-surgical	Surgical	Non-surgical
No change	17.9	18.9	18.3	17.5	19.3	20.6	11.8	16.7
Increase	50.0	40.5	29.8	37.3	31.6	46.0	23.5	58.3
Decrease	32.1	29.7	42.3	30.2	42.1	25.4	52.9	25.0
Reversed: No change	0	0	1.0	4.8	5.3	1.6	5.9	0
Reversed: Increase	0	8.1	4.8	5.6	1.8	6.3	0	0
Reversed: Decrease	0	2.7	3.8	4.8	0	0	5.9	0
Nos. of eyes	28	37	104	126	57	63	17	12

Summary Point (6.64 - 6.73)

6.74

1. The anisometropic characteristics of the sample have been described. Anisometropia ranged from 0.25 D to just over 8.00 D although in the majority of cases (85 per cent) it did not exceed 1.50 D. The male-female distributions did not differ significantly irrespective of the age group involved (6.64 - 6.65)

2. Cross-sectional analysis of anisometropic levels within age groups, indicates that anisometropia tends, if anything, to increase with age. The correlation coefficient of 0.1756, however, shows that these two factors are not closely related (6.66).

3. Analysis of anisometropic changes shows that in a small number of cases, reversal of the relative refractive states of the two eyes occurs, as a result of which the highest level of refraction is found in the eye which previously had the lowest (6.67). Anisometropia generally tends to change rather than remain stationary. There is, however, little to suggest that anisometropic patterns of change are related to age (6.68).

4. The relationship between anisometropic changes and initial levels of anisometropia has been examined. No significant sex differences were found (6.69). All levels of anisometropia tend either to increase or to decrease rather than remain stationary. This applies to all age groups. In the first six years, anisometropia above 0.50 D shows a tendency to decrease rather than increase whilst below 0.50 D the reverse is true. Above the age of six the pattern is the same except that the dividing line occurs at 1.00 D. Reversed changes tend to occur more frequently when anisometropia is low rather than high.

The results for both periods, above and below the age of six, are highly significant. This shows that anisometropic changes are related to anisometropic level, although the relationship is rather obscure. It is clear that anisometropia is more likely to change than remain stationary, and that the lower levels tend to increase rather than decrease, with the reverse being true of the higher levels (6.70).

5. Comparison of subsequent and initial levels of anisometropia shows that they are very closely related for both males and females, there being no significant differences between the two. Correlation coefficients are high for all age groups, increasing from 0.7331 in the first three years, to 0.9682 in the final three. This suggests that the younger the child, the less predictable the subsequent level will be. It is clear that subsequent levels are likely to be very close to the previous level, particularly after the age of three. The standard error for these values, however, is relatively large and care must, therefore, be exercised in making predictions (6.71).

6. The effect of surgery on anisometropic development has been studied. The patterns of change in males and females did not differ significantly, regardless of treatment or of age (6.72). During the first three years, changes in anisometropia were similar in incidence in surgical and non-surgical cases. In contrast, however, between the ages of three and twelve, anisometropia displayed a tendency to increase rather than decrease, following surgery. Reversed changes were associated with surgery up to the age of three, but became increasingly associated with the non-surgical cases in subsequent years. The results overall are not statistically significant. This suggests that surgical intervention does not affect the level of anisometropia any more than other forms of treatment (6.73).

7. RESULTS APPLIED TO ORIGINAL HYPOTHESES

7.1. The background to the hypotheses has already been described in section 4. Some of these hypotheses were postulated in an attempt to explain certain phenomena which had been observed in strabismic children between one examination and another over a number of years. Others emerged from clinical impressions, or in some cases simply from conjecture; such hypotheses are, therefore, empirically rather than scientifically based. Consequently, it may not always be feasible to investigate a particular theory.

After processing the available data, it was found possible to test all but four of the original hypotheses. The results are presented here; they inevitably overlap the ground covered in section 6. As previously pointed out (4.48), all the hypotheses are related to the strabismic child. Where possible, the relationships between males and females have been investigated with respect to each individual hypothesis and the findings presented accordingly.

7.2.

I. Refractive changes in children alter in character as age increases:

The greatest changes occurred in the first three years of life, these being primarily in the direction of increasing hypermetropia or decreasing myopia. The proportion of stationary refractions increased with age, associated with a decline in the incidence of hypermetropic increases, this trend being reversed in the three years from nine to twelve.

The correlation between age and *annual* changes in refraction was low for all the three year age groups, although it was shown that, except for the three to six year olds, these findings could have arisen as a result of sampling errors.

The patterns of change in males and females suggest that up to the age of six refractive development in girls may be rather more advanced than in boys. These differences were not maintained which suggests that they are related to maturity factors.

It is clear that refractive changes do alter in character with age, although the data indicates that age is unlikely to be the sole factor involved (6.1 - 6.8).

2. <u>The initial refractive state determines the subsequent type and degree of refractive change, and, therefore, the final refractive state.</u>

The results show that the lowest degrees of hypermetropia - +0.01 to +3.00 D - are most likely to increase, particularly in the first three years of life. The higher degrees show a greater tendency to remain stationary or shift towards myopia, although increasing hypermetropia still predominates in all refractive groups. The older the child the more likely that the refractive state will remain stationary or shift in a myopic direction, irrespective of the degree of hypermetropia. This trend was reversed between the ages of nine and twelve. Myopic eyes behaved similarly. Annual changes tend to decrease with age for all refractive groups, although the correlation coefficient was found to be very low, irrespective of age. In contrast, the final refractive state was very closely correlated with the initial state, the coefficient increasing with age.

Significant sex differences were found only in those children with hypermetropia between +3.01 and 6.00 D who were less than six years old. The results again indicate that girls are rather more advanced, refractively, than boys. The evidence seems to suggest that refractive differences at this age may be related to sex differences in height velocity which occurs in the first four years of life. Maturity factors are almost certainly implicated.

Although final refractive state is very closely related to initial refractive state, the results do not suggest that initial state determines subsequent changes in refraction, although during the first three years of life these two factors are more closely associated than at any other period. (6.9 - 6.13).

3. Refractive changes continue in the same direction as age increases; that is, final change is in the same direction as initial change.

Final changes in refraction show no particular tendency to continue in the same direction as previous changes. This applies to both males and females (6.14).

4. Refractive changes in right and left eyes are dissimilar, but become equalised with age.

Analysis of refractive development demonstrated that refractive changes in right and left eyes do differ, each eye being more likely to be out of phase with its partner than in phase. There is, however, nothing to suggest that changes become equalised with age. This finding confirms that age cannot be the sole factor involved in refractive changes (6.15).

5. Refractive changes in children with strabismus differ from those without strabismus.

Only 7.4 per cent of the children involved in this study were non-strabismic. This hypothesis could not, therefore, be tested owing to the nature of the sample.

6. Refractive changes in the strabismic eye differ from those in the fixating eye.

Refractive changes were similar in fixating and non-fixating eyes, irrespective of age. The greatest differences were found during the first three years, but even these were not statistically significant. Increases in hypermetropia predominated during this period, the incidence thereafter declining until the age of nine, when the trend was reversed. It is clear that in unilateral strabismus, refractive changes in the strabismic eye do not materially differ from those in the non-strabismic eye. These findings apply equally to both males and females. The results, therefore, do not support this hypothesis (6.17 - 6.19).

7. Refractive changes are related to the type of strabismus present.

The patterns of refractive change in unilateral strabismus did not significantly differ from those in alternating strabismus. Comparison, however, was complicated by the difference in size of the two groups. Further analysis was not possible, since the overwhelming majority of cases were convergent. The evidence available, therefore, does not suggest that refractive changes are related to the type of strabismus present (6.19).

8. Initial refractive error in strabismic cases determines the refractive change to a greater extent than the error in non-strabismic cases.

It was not possible to test this hypothesis owing to the fact that only 7.4 per cent of the cases were non-strabismic.

9. Refractive changes are related to the angle of strabismus.

Up to the age of six, annual changes in refraction were almost identical for the two groups of strabismic angle analysed (1 - 20°, 21 - 40°). For the period from six until nine the results indicate that the smaller the angle, the greater the tendency for hypermetropia to increase (or myopia to decrease). The reverse is true for the following three years. The correlation coefficients, although higher than for the younger groups, are nevertheless low. The findings were similar for males and females.

These results generally do not support the theory that refractive changes are related to the angle of strabismus, although they are suggestive of a partial involvement after the age of six (6.20 - 6.22).

10. Refractive changes are determined by the extent to which the refractive error is fully corrected or under corrected.

During the three years up to the age of six, ametropic correction and refractive change were more closely related than at any other time. The results for this period demonstrate that the greater the degree of hypermetropic under-correction, the smaller the hypermetropic increase. It was shown, however, that predictions based on these results must be interpreted with caution as the standard error of the estimate is ±0.50 D.

Refractive changes at other times bear little relationship to the ametropic correction worn.

Sex differences were recorded in those cases where ametropia was fully corrected, these being confined to the first six years. The differences, which were greatest in the fifth year, indicate that females may be rather more developed than males at this stage, although the data is far from conclusive, with conflicting results for the fourth and sixth years.

It can be seen that ametropic correction may be a determinant factor in refractive changes, but only between the ages of three and six (6.23 - 6.25).

II. Surgical intervention influences the type and degree of refractive change.

The relationship between surgical intervention and refractive change is closest in the first three years of life. The results show that changes in refraction, in particular hypermetropic increases, arise more often in surgical than in non-surgical cases. It is not clear whether these differences arise as a result of the surgery itself or as a result of the factors which necessitated surgical intervention originally. These differences were not found from the age of three onwards.

Sex differences were found where treatment had been entirely non-surgical, these being mainly confined to the fifth year of life. The findings indicate that in the absence of surgery, females are more advanced refractively than males at this stage.

The results support the hypothesis that surgical intervention does have some effect upon the patterns of refractive change, (the greater the degree of surgical intervention, the greater the incidence and degree of change). This applies, however, only in the first three years of life. Whether this is a causal relationship is another question (6.26 - 6.28).

12. The larger the initial refractive error, the greater the effect of surgery upon refractive change.

The sample available was too small to support the number of divisions necessary for such a complex analysis. Consequently this hypothesis was not investigated.

13. Surgery on one eye only affects both eyes equally in relation to refractive changes.

The evidence strongly supports this hypothesis. Where surgery had been carried out on one eye only, the refractive changes in both operated and non-operated eyes were almost identical, especially up to the age of three. Whether this arises directly as a result of this type of surgery or whether this would have occurred in the absence of such treatment is not clear (6.28). Evidence has, however, already been produced to show that refractive changes in right and left eyes are generally out of phase with each other (6.15). This does, therefore, suggest that surgery is the determinant factor here.

14. The level of astigmatism is related to age.

Cross-sectional analysis of the distribution of astigmatism indicates that the higher levels of astigmatism tend to be found in older rather than younger children. This applies equally to males and females (6.30)

Changes in astigmatism occur most frequently in the first three years, when there is a tendency for increases to exceed decreases both in incidence and in degree. These tendencies decline with age. The correlation between age and annual astigmatic change is, nevertheless, low throughout the twelve years covered by the study. These findings apply to males and females almost equally.

The results show that the level of astigmatism is not directly related to age, although both analyses - cross-sectional and longitudinal - indicate that there is a tendency for astigmatism to increase with age, particularly in the early years (6.30 - 6.33).

15. Initial degree of astigmatism is related to the degree of spherical error.

Analysis of refractive state has, in this study, been based upon the mean sphere and not the straight sphere. Since the mean sphere is derived from the astigmatic as well as the spherical error, the degree of astigmatism is not independent of the mean sphere. Consequently this hypothesis could not be tested.

16. Initial astigmatism determines the type and degree of overall refractive change.

Up to the age of three the incidence of stationary refractive state was found to be lowest in non-astigmatic eyes whilst the incidence of decreasing hypermetropia was highest. These differences between astigmatic and non-astigmatic eyes were limited to this age group and applied solely to direction of change. The correlation between annual changes in refraction and astigmatic levels was very low indeed, irrespective of age. No sex differences were found.

There is nothing to suggest that initial astigmatism has a significant role as a determinant of refractive development, except perhaps in the first three years although the evidence is far from conclusive. The results, therefore, do not support this hypothesis.

17. Initial astigmatism determines the subsequent type and degree of astigmatic change.

The results clearly show that astigmatic changes occur independently of the initial level of astigmatism, irrespective of age and that such changes are not determined by the degree of astigmatism present. There is an indication that, up to the age of three, the higher the level of astigmatism the greater the tendency for astigmatism to decrease.

Significant sex differences were found in children with astigmatism between 1.01 and 2.00 D whose ages ranged from six up to twelve, but owing to the small numbers involved, no useful conclusions could be drawn (6.38 - 6.39).

18. Strabismic eyes have a greater degree of astigmatism than non-strabismic eyes.

The data here is inconclusive. Cross-sectional analysis of the distribution of astigmatism indicates that above the age of six, astigmatism tends to be higher in unilateral strabismus than in alternating strabismus. Sex differences were found solely in the non-fixating eyes of children with unilateral strabismus, who were aged between six and twelve. Conclusions, however, could not be drawn owing to the small numbers involved (6.41 - 6.43).

19. Astigmatic changes are greater in strabismic eyes than in non-strabismic eyes.

Astigmatism remained stationary in a high proportion of cases for all strabismic groups, the incidence tending to increase with age. The results indicate that between birth and three years, astigmatism is more likely to change in alternating cases than in unilateral cases, whereas between the ages of six and nine, the reverse is true. In unilateral strabismus, the patterns of astigmatic change in fixating and non-fixating eyes were almost identical for all ages. Annual changes were generally similar for all strabismic groups, the levels of change tending to decline with age. These findings applied almost equally to males and females.

The results indicate that astigmatic changes in strabismic and non-strabismic eyes are likely to be similar. The evidence, therefore, does not support the hypothesis.

20. Changes in astigmatism are greater in cases of surgical intervention than in non-surgical cases.

The effect of surgery is most pronounced in the first three years of life, the incidence of astigmatic changes in operated eyes being considerably higher than in non-operated eyes. In particular, where surgery had been confined to one eye only, the differences between the non-operated and operated eyes were very pronounced indeed. The range of annual changes, on the other hand,was similar for all groups.

These differences were not found in the subsequent three years - i.e. up to six. Between six and twelve, however, the tendency was again present for operated eyes to exhibit astigmatic changes more often than non-operated eyes.

Significant sex differences, confined to the first six years, were found in those cases in which neither eye had been subjected to surgery. The data, however, was rather inconclusive.

Although from a statistical point of view, astigmatic changes do not appear to be related to the type of treatment, the results do seem to suggest that changes in astigmatism occur more frequently in operated eyes than in non-operated eyes, particularly up to the age of three (6.47 - 6.49).

21. Axis changes in astigmatism are related to age.

Analysis of axis behaviour demonstrated that age and axis changes are related; that changes occur more frequently, and are rather larger in extent, below the age of six than above, although in the majority of cases the axis remains stationary, irrespective of age. The results strongly support the hypothesis (6.51 - 6.52).

22. Axis changes in astigmatism are related to the initial degree of astigmatism.

No association between axis changes and astigmatic level could be found in the first three years of life. Subsequently - up to the age of twelve - the higher degrees of astigmatism displayed the lowest incidences of change in meridian. This relationship increased with age, although it was not pronounced in any age group. Males and females presented the same characteristics.

The results indicate that changes in axis are only marginally related to the degree of astigmatism. The data must be regarded as inconclusive (6.53 - 6.55).

23. Axis changes in astigmatism are related to dioptric changes in astigmatism.

The results do not support this statement. The analysis does not indicate that changes in axis are related to changes in astigmatism in any way (6.56).

24. Axis changes in astigmatism are greater in strabismic eyes than in non-strabismic eyes.

The patterns of axis behaviour were generally similar for all eyes irrespective of strabismic state, especially with respect to the strabismic and non-strabismic eyes in unilateral strabismus. This applied to both males and females.

The results clearly do not support the hypothesis (6.57 - 6.59).

25. Axis changes in surgical cases are greater than in non-surgical cases.

Up to the age of three, comparable patterns of axis changes were found where, on one hand, surgery had involved both eyes, and on the other, treatment had been entirely non-surgical. The incidence of change in these two groups was considerably higher than when surgery had been confined to one eye only, although in all groups, over two-thirds of the cases remained stationary. In the subsequent age groups, these differences were only marginal. Similar findings were recorded for males and females.

The results indicate that axis changes are not connected with surgical intervention. The hypothesis is, therefore, not supported (6.60 - 6.62).

26. Anisometropia decreases with age.

Cross-sectional analysis of the distribution of anisometropia indicates that anisometropia tends to increase with age, although the correlation coefficient shows that the relationship is not close. The distributions for males and females are similar.

Longitudinal analysis demonstrated that anisometropic levels remain stationary in approximately 20 per cent of cases, irrespective of age, with the remainder fairly evenly divided into increases and decreases. The results, therefore, do not support the hypothesis that anisometropia decreases with age; if anything, they indicate the opposite (6.64 - 6.68).

27. Changes in anisometropia are determined by the initial level of anisometropia.

Up to the age of six, anisometropia above 0.50 D displayed a tendency to decrease rather than increase, with the reverse being true of anisometropia up to 0.50 D. This tendency was still present in the final six years - up to twelve, except that the dividing line occurs at 1.00 D. These findings applied to both males and females alike.

The results are statistically highly significant, indicating that the lower levels are more likely to increase than decrease, the reverse being true of the higher levels.

Subsequent and initial levels of anisometropia were very closely correlated. The correlation coefficients increased with age, from 0.7331 in the first three years, to 0.9682 in the final three (up to the age of twelve).

It is clear from this data that the degree of anisometropia is a determinant of subsequent changes in anisometropia (6.69 - 6.71).

28. Changes in anisometropia are related to surgical intervention.

Changes in anisometropia in the first three years of life were very similar for both surgical and non-surgical forms of treatment. From the age of three until twelve, anisometropia displayed a tendency following surgery to increase rather than decrease. The differences, however, were not statistically significant. The evidence indicates that surgical intervention does not affect the level of anisometropia any more than other forms of treatment (6.72 - 6.73).

29. Patterns of refractive behaviour are related to sex.

The results do not generally support this statement. In the majority of cases, refractive development in males and females was found to be almost identical. Where differences were recorded (6.5, 6.10, 6.24, 6.27, 6.38, 6.42, 6.48) these were not universal, but confined to one period, mainly the first six years of life, the differences being greatest in the fourth and fifth years. The results indicate that at this period, girls may be more advanced, refractively, than boys. The fact that in no instances were the differences maintained over the whole twelve years suggests that they are associated with factors of maturity.

8. DISCUSSION AND CONCLUSIONS

8.1. This study has shown that refractive changes in strabismic children may occur in any direction and are not confined to reductions in hypermetropia. The results clearly demonstrate that increasing hypermetropia, or decreasing myopia, is a common feature of refractive development in such children, especially in the first three years of life. The results also show that refraction remains stationary in a relatively high proportion of cases, even in these first three years, its incidence increasing with age, whilst the shift towards hypermetropia declines. The shift away from hypermetropia, on the other hand, was found to be rather erratic, increasing in some years, decreasing in others. Over the whole of the twelve year period, however, the incidence increases. These findings applied equally to myopia and hypermetropia, although the numbers of myopic cases were too small for any definite conclusions concerning myopia to be drawn.

8.2 The most significant refractive development took place in the first three years of life. Changes in refraction not only occurred more frequently, but tended to be larger than in any other period. These changes were also more closely related to other factors, such as the level of ametropia; for example, the lower levels of hypermetropia (i.e. $\leq +3.00$ D) displayed a greater tendency to increase than the higher levels ($> +3.00$ D). Treatment likewise seems to be an associated factor; refractive changes occurring more often in surgical cases than in non-surgical cases.

Changes in astigmatism were more prominent below the age of three than above, astigmatism tending to increase rather than decrease. Similarly, the effect of strabismic surgery was greatest during this period, the incidence of astigmatic changes in operated eyes being considerably higher than in non-operated eyes. Changes in axis were also more common below the age of six than above.

There can be little doubt about the importance of these first three years. It can be seen that it is not only a period in which rapid and marked ocular growth takes place, but a period in which environmental factors, such as surgery, may affect the pattern of normal refractive development.

During the three years up to the age of six the rate of growth slows down considerably. This is a gradual process, the rates of deceleration almost certainly varying from child to child. Although refractive changes are not as marked as in the previous period, they are, nevertheless, extremely important. The incidence of increasing hypermetropia remains high, whilst axis changes are greater and occur more frequently than in older children.

The relationship between spectacle correction and refractive development was found to be closer between the ages of three and six than at any other time. The results demonstrate that the greater the degree of hypermetropic undercorrection, the smaller the hypermetropic increase. This suggests that refractive development may be susceptible to environmental influence during this period.

8.3 Refractive development in males and females was generally almost identical. Some differences were found but these were mainly confined to the fourth and fifth year of life, the results indicating that females tend to be more developed, refractively, than males at this age. These differences were not maintained - by the sixth and seventh years they were no longer present; this suggests that they are associated with maturity factors. Studies of height velocity in children have shown that during the first four years of life the rate of growth in females is also greater than in males (Tanner et al 1966, Deming et al 1963). Sex differences in ocular growth may, therefore, be directly associated with sex differences in body growth.

8.4 Analyses involving changes in mean sphere indicate that between the ages of nine and ten, the patterns of refractive development alter in character, with the shift towards hypermetropia increasing in incidence; this contrasts with the previous six years in which it had been declining. Whether this is characteristic of this particular period of life, or simply an artefact associated with sampling errors or examination methods, is another question. Certainly the numbers involved in the three years from nine until twelve were relatively small and obviously care must be exercised in interpreting the results for this reason. In addition, there was a marked reduction in the use of atropine as a cycloplegic agent during this period, it being replaced by homatropine or cyclopentolate (5.2). These two agents are, if anything, less effective than atropine. It is, consequently, more likely that their use would result in an apparent decline in the incidence of hypermetropic increases rather the reverse. It therefore seems highly improbable that this was a causative factor. One other possibility, however, does arise. This period - nine to twelve - approximates to the stage at which adolescence begins; it is well known that during adolescence a spurt in bodily growth occurs (Tanner et al 1966). It is possible, therefore, that the change in pattern of refractive development which was observed, may be associated with adolescence. Quite clearly, however, further work is required before any conclusions can be drawn concerning the significance of these findings.

8.5 The major differences between the results of this study and those which have been restricted to non-strabismic children, lie in the proportion of cases exhibiting increases in hypermetropia. In the majority of studies, these increases either have been completely disregarded, or their incidence has been reported as being very low, and, therefore, insignificant in terms of refractive development. Sorsby, Benjamin & Sheridan (1961) in their follow-up study of normal children, take no account at all of increasing hypermetropia as a possible pattern of refractive development, although the results do show that hypermetropic increases did occur in 10.6 per cent of the 386 cases involved. In a supplementary report, however, covering the same group of children, reference is made to the 'paradoxical' increases in hypermetropia (decreasing myopia) which were found in 11.8 per cent of the sample. (The sample size in this case was only 68). (Sorsby & Leary 1970). This compares with an overall incidence of 44.1 per cent in this study and 55 per cent in Vorisek's strabismic study (Vorisek 1935).

The question is: How do these differences arise? It is of course possible that they are associated with the range of ages in the various studies. The youngest children in this study were less than one year old, compared to three years in Sorsby's study. Nevertheless, this cannot be the only explanation since the incidences of increasing hypermetropia from the age of three onwards still differ considerably.

It is almost certain that the major cause lies in the nature of the two samples, one being strabismic, the other non-strabismic. There is no doubt that refractive development in these two groups differs markedly. Refractive changes in normal, non-strabismic children are characterised by a shift away from hypermetropia, towards emmetropia and myopia. Strabismic children, in contrast, are characterised by a shift towards hypermetropia, away from myopia and emmetropia, especially in the early years. The differences are greatest below the age of six, although it must be remembered that no data for the first three years is available in Sorsby's study.

It has been shown that the shift towards hypermetropia was most marked in the first three years of life. Since this coincides with the period in which strabismus most frequently becomes manifest, certain related questions are raised: Does increasing hypermetropia indicate a predisposition to strabismus? Do increases in hypermetropia occur before strabismus becomes manifest? Should increases in hypermetropia be regarded as a premonitary symptom, indicative of the possibility of strabismus developing?

These questions can only be answered by comparing refractive developments in non-strabismic and strabismic children, commencing at birth. The problem lies in obtaining sufficient numbers of non-strabismic infants who will eventually develop strabismus: an extremely large sample is required in order to provide the numbers necessary to enable comparisons to be made. Although such a study has yet to be undertaken the results of this present study and those of Sorsby et al (1961, 1970) do provide sufficient evidence to suggest that the shift towards hypermetropia and the development of strabismus are related. This, of course, does not mean that in the absence of increasing hypermetropia the possibility of strabismus can be excluded, since the results have shown that decreases in hypermetropia and stationary refractions *are* found in strabismic children, even during the first three years. Should a direct relationship eventually be shown to exist, then it might prove possible to predict the development of strabismus on the basis of the type of refractive changes taking place. The possibility would, therefore, also arise of actually preventing the strabismus appearing in certain cases rather than simply attempting a cure. Such a situation would, of course, necessitate *all* children being examined and followed-up as a matter of routine in the early years after birth.

8.6 Although measurement of the components of refraction did not fall within the scope of this study, it is worthwhile considering the mechanism involved in hypermetropic increases. Refractive changes of this type could arise in a number of ways:

(a) corneal and lenticular powers decreasing more rapidly than the rate of axial elongation

(b) corneal and lenticular powers decreasing in the absence of axial elongation

(c) refractive power remaining stationary whilst axial length decreases

(d) both refractive power and axial length decreasing.

Sorsby et al in 1961 stated that "Changes in refraction are ... determined by axial elongation", and arise as a result of compensatory changes in the cornea and lens, the more inadequate the compensation the greater the change. Compensation involves refractive power decreasing as axial length increases, the shift towards myopia occurring as a result of compensation lagging behind elongation. Full compensation would, therefore, result in a static refraction.

If this in fact represents the only mechanism by which the refractive changes can occur, then certainly the first two explanations of hypermetropic increases - i.e. (a) and (b) are inadmissable. If, however, it is accepted that compensation can lag behind axial elongation, then surely there is no reason why elongation may not be overcompensated by excessive reductions in the powers of the cornea and lens? This could occur, either through flattening of the radii of curvature, or as a result of a reduction in the refractive indices, although this seems the least likely explanation since the indices tend to increase with age rather than decrease. Bearing in mind that changes in power are not geared exactly to axial elongation, there seems to be no reason why these changes should not continue once elongation has ceased. The results of Sorsby & Leary (1970) in fact demonstrate that such cases almost certainly do occur. They point out that"...similar increases in refraction * could be accompanied by marked differences in axial elongation. The possibility that axial elongation during school life may be slight or actually suppressed is suggested by some cases".
(* Increases in refraction mean myopic increases or hypermetropic decreases). It therefore seems perfectly possible that refractive power may either decrease more rapidly than the rate

of axial elongation, or may even decrease whilst axial length remains stationary.

Is it conceivable that axial length can decrease? Although cases have been recorded in which axial length decreased in childhood, the generally accepted view has been that such changes are not possible and must, therefore, be the result of experimental error in measurement. In the longitudinal study of Sorsby et al (1961) 51 cases out of a total of 440 exhibited a shortening of axial length. They were all excluded on the basis of experimental error. In a supplementary report of the same study, Sorsby & Leary (1970) again reported that cases had been found in which axial length decreased between visits. The majority of these cases occurred in the age group of fourteen and over. This they observed "...raises the question whether at fourteen and subsequently there does in fact occur, in some cases at any rate, an actual shortening of the eye". They state, however, that such findings when seen in children under the age of fourteen "...are probably experimental errors...." The basis for such an assumption is very obscure, for if such changes are accepted from the age of fourteen onwards, there seems to be no reason to assume, in the absence of evidence to the contrary, that they cannot occur at any age.

Axial elongation has almost become synonymous with growth of the eye, mainly because axial length was, until the advent of radiological and ultrasonic methods, the only dimension that could be calculated. Consequently, in the majority of refractive studies, attention has been directed towards changes in axial length to the exclusion of the other diameters.

Certainly it is generally considered to be the most important factor in the refractive development of the eye.

Ocular growth tends to be regarded as having certain characteristics in common with skeletal growth. Just as it is inconceivable that physiological changes could involve a decrease in height during childhood, so it has become accepted that a decrease in axial length is impossible. There is, however, increasing evidence to suggest that this assumption may not be true.

Van Alphen (1961) pointed out that ocular growth involves the eye as a whole, the globe expanding in all directions but not necessarily at the same rate (3.45). There is, therefore, no reason why, for example, the vertical meridians should not increase more rapidly than the anterior-posterior axis, or even increase in the absence of axial elongation. The analysis of Weymouth and Hirsch (1950), based upon three separate studies, in fact shows that the various diameters do not grow at the same rate. Tanner's (1963) work confirmed this finding (3.46). Consequently, the eye may change shape at the same time as growing larger. The globe is a flexible, rather than a rigid, structure; it is possible, therefore, that an increase in one meridian may be accompanied by, or may even cause, a shortening of another. If axial length decreased as the result of such a process, then, unless compensatory increases in corneal and lenticular powers occurred, the outcome would be an increase in hypermetropia or a decrease in myopia.

8.7 Hypermetropic increases have been found in many previous studies (section 3). In the overwhelming majority of cases they have been regarded as experimental errors associated either with relaxation of accommodation or with the method of measurement. There seems little doubt, however, that increases in hypermetropia, or decreases in myopia, do occur and that they are part of the normal pattern of refractive growth. They probably occur in far higher proportions of the 'normal' population than has so far been shown, since it seems almost certain that a significant proportion of the cases excluded in the past on the basis of experimental error were hypermetropic increases.

If hypermetropic increases are accepted as normal, then reductions in myopia must also be accepted as normal and not simply the result of myopic 'cures', or treatment aimed to eliminate myopia. It is clear that myopia, like hypermetropia, may either increase, decrease, or remain stationary. There is no reason to regard changes in non-pathological myopia as any more alarming than changes in hypermetropia. The confusion that has surrounded myopia for so long stems from the failure to clearly and adequately define simple myopia and pathological myopia as two completely separate clinical entities.

8.8 These results clearly indicate that the concept of emmetropization is outdated. It is impossible to accept that increasing hypermetropia or, indeed, increasing myopia, represents such a process. This supports the view of Sorsby and Leary (1970) that "to designate .... ocular change as 'emmetropization' is hardly warranted ...." Doubts, however, are also raised as to the validity of the concept expressed by Sorsby & Leary that "the compensatory mechanism inherent in the reduction of the powers of the cornea and lens ... is geared to the axial elongation". The evidence in fact suggests that refractive changes are not determined in this way.

8.9 The results of this study have emphasised the need for further work in this field. It is obvious that many problems and questions remain unresolved. There is an outstanding need for further longitudinal studies from birth up to, and beyond, puberty. The importance of the first six years of life has been underlined by these findings and it is clear that a large scale controlled study is required to enable ocular developments occurring in each year of life to be investigated. Such a study should ideally involve measurements of all the components of refraction, including all the diameters, not only axial length, so that hypermetropic changes can be more fully explained than has up till now been the case.

It is obvious that developments in the strabismic child differ from those in the non-strabismic child. It is important that the nature of these developments should be understood. Further studies involving these children are essential since the results of such studies may have a bearing on the treatment and management of the child with strabismus. There is a need to compare strabismic and non-strabismic results in order to establish exactly how they do differ, particularly in the first three years of life. There is also a need to establish whether infants who display increases in hypermetropia, show a greater tendency to develop strabismus than infants who do not exhibit this characteristic. A controlled study involving both groups of children is, therefore, required and this should be regarded as a priority.

This study has shown that refractive development in the first six years may be affected by environmental factors, such as strabismic treatment and spectacle correction. There is increasing evidence to suggest that ocular growth is not solely genetically determined, but is also influenced by environmental factors. The work of Goldschmidt (1968) and Sorsby et al (1970) supports this view. The data at present, however, is insufficient for any firm conclusions to be drawn. Further research is obviously needed in this direction.

APPENDIX 'A'

TABLES OF BASIC DATA

APPENDIX A.I

Distribution of males and females within original and expanded samples

Analysis by sex and yearly age groups - percentage distribution

Sex	Age in years - less than 1	2	3	4	5	6	7	8	9	10	11	12	13	Total Nos
						Original sample								
Males	0.65	7.79	9.09	20.78	20.13	15.58	6.49	9.09	3.90	2.60	2.60	1.30	0	151
Females	0.60	4.22	11.45	18.67	19.28	13.25	10.24	7.83	7.83	1.21	2.41	2.41	0.60	166
						Expanded sample								
Males	0.44	4.85	10.13	16.30	18.5	16.30	9.69	10.57	5.29	3.97	2.20	1.76	0	454
Females	0.46	4.11	9.36	16.21	18.72	16.89	10.96	9.13	8.68	1.37	1.37	2.28	0.46	438

APPENDIX A.2

Annual changes in ocular refraction related to age

Analysis by annual changes in refraction and three year age group from birth up to twelve - percentage distribution

Annual changes in refraction - dioptres	Age at initial examination - in years			
	Birth - <3	3 - <6	6 - <9	9 - <12
Over -1.40	3.5	1.7	0.4	0
-1.21 to -1.40	0	0.7	0.8	0
-1.01 to -1.20	0.8	0.4	2.1	0
-0.81 to -1.00	0.8	0.9	2.5	1.7
-0.61 to -0.80	0	0.9	2.9	0
-0.41 to -0.60	4.6	2.2	7.9	8.6
-0.21 to -0.40	0.8	4.6	10.0	10.3
-0.01 to -0.20	0	2.0	3.7	3.5
0	19.9	37.7	48.1	37.9
+0.01 to +0.20	3.1	2.2	1.7	12.1
+0.21 to +0.40	11.5	13.9	7.1	12.1
+0.41 to +0.60	9.2	15.0	6.6	8.6
+0.61 to +0.80	17.6	7.2	2.5	5.2
+0.81 to +1.00	14.5	5.7	2.9	0
+1.01 to +1.20	4.6	2.6	0.8	0
+1.21 to +1.40	4.6	1.3	0	0
Over +1.40	5.3	1.1	0	0
Nos. of eyes	131	459	241	58

APPENDIX A.3.

Annual changes in ocular refraction related to initial refractive state

Analysis by annual changes in refraction and refractive state in dioptres for each three year age group from birth up to twelve years - percentage distribution

Age: Birth - <3 years

Annual changes in refraction - dioptres	Refractive state in dioptres: Myopia	+0.01 to +3.00 D	+3.01 to +6.00 D	+6.01 to +9.00 D	>+9.00 D
Over -1.40	0	0	4.3	5.9	0
-1.21 to -1.40	0	0	0	0	0
-1.01 to -1.20	0	0	1.5	0	0
-0.81 to -1.00	0	0	1.5	0	0
-0.61 to -0.80	0	0	0	0	0
-0.41 to -0.60	0	5.4	5.8	0	0
-0.21 to -0.40	0	2.7	0	0	0
-0.01 to -0.20	0	0	0	0	0
0	100.0	8.1	18.8	35.3	0
+0.01 to +0.20	0	8.1	0	5.9	0
+0.21 to +0.40	0	13.5	11.6	11.8	0
+0.41 to +0.60	0	10.8	8.7	5.9	25.0
+0.61 to +0.80	0	21.6	21.7	0	0
+0.81 to +1.00	0	13.5	13.0	23.5	25.0
+1.01 to +1.20	0	0	5.8	0	50.0
+1.21 to +1.40	0	8.1	4.3	0	0
Over +1.40	0	8.1	2.9	11.8	0
Nos. of eyes	4	37	69	17	4

APPENDIX A.3(Continued)

Age: 3 - <6 years

Annual changes in refraction - dioptres	Refractive state in dioptres				
	Myopia	+0.01 to +3.00 D	+3.01 to +6.00 D	+6.01 to +9.00 D	>+9.00 D
over -1.40	16.7	0	0	1.3	25.0
-1.21 to -1.40	11.1	0	0.5	0	0
-1.01 to -1.20	0	0	0.9	0	0
-0.81 to -1.00	0	0.8	0.9	1.3	0
-0.61 to -0.80	0	0	1.3	0	6.3
-0.41 to -0.60	22.2	0.8	0.9	4.0	0
-0.21 to -0.40	0	4.8	4.9	4.0	6.3
-0.01 to -0.20	0	1.6	0.9	6.6	0
0	5.6	40.5	37.2	43.4	31.3
+0.01 to +0.20	0	4.8	1.3	1.3	0
+0.21 to +0.40	5.6	15.1	14.4	14.5	6.3
+0.41 to +0.60	0	13.5	18.8	9.2	18.8
+0.61 to +0.80	22.2	8.7	7.6	1.3	0
+0.81 to +1.00	16.7	5.6	4.0	7.9	6.3
+1.01 to +1.20	0	2.4	2.7	3.9	0
+1.21 to +1.40	0	0	2.7	0	0
Over +1.40	0	1.6	0.9	1.3	0
Nos. of eyes	18	126	223	76	16

APPENDIX A.3 (Continued)

Age: 6 - <9 years

Annual changes in refraction - dioptres	Refractive state in dioptres Myopia	+0.01 to +3.00 D	+3.01 to +6.00 D	+6.01 to +9.00 D	>+9.00 D
Over -1.40	0	0	0	2.0	0
-1.21 to -1.40	0	0	2.2	0	0
-1.01 to -1.20	0	1.3	3.2	2.0	0
-0.81 to -1.00	0	6.6	1.1	0	0
-0.61 to -0.80	7.1	2.6	2.2	2.0	0
-0.41 to -0.60	7.1	10.5	6.5	6.1	12.5
-0.21 to -0.40	0	9.2	15.1	6.1	0
-0.01 to -0.20	0	2.6	6.5	2.0	0
0	50.0	44.7	45.2	53.1	87.5
+0.01 to +0.20	7.1	1.3	2.2	0	0
+0.21 to +0.40	7.1	9.2	7.5	4.1	0
+0.41 to +0.60	7.1	5.3	5.4	12.2	0
+0.61 to +0.80	14.3	2.6	0	4.1	0
+0.81 to +1.00	0	3.9	2.2	4.1	0
+1.01 to +1.20	0	0	1.1	2.0	0
+1.21 to +1.40	0	0	0	0	0
Over +1.40	0	0	0	0	0
Nos. of eyes	14	76	93	49	8

APPENDIX A.3(Continued)

Age: 9 - <12 years

Annual changes in refraction - dioptres	Refractive state in dioptres				
	Myopia	+0.01 to +3.00 D	+3.01 to +6.00 D	+6.01 to +9.00 D	>+9.00 D
Over -1.40	0	0	0	0	0
-1.21 to -1.40	0	0	0	0	0
-1.01 to -1.20	0	0	0	0	0
-0.81 to -1.00	0	4.6	0	0	0
-0.61 to -0.80	0	0	0	0	0
-0.41 to -0.60	30.8	4.6	0	0	0
-0.21 to -0.40	23.1	0	7.7	11.1	100.0
-0.01 to -0.20	0	4.6	0	11.1	0
0	7.7	50.0	53.8	33.3	0
+0.01 to +0.20	7.7	22.7	0	11.1	0
+0.21 to +0.40	23.1	4.6	7.7	22.2	0
+0.41 to +0.60	0	4.6	30.8	0	0
+0.61 to +0.80	7.7	4.6	0	11.1	0
+0.81 to +1.00	0	0	0	0	0
+1.01 to +1.20	0	0	0	0	0
+1.21 to +1.40	0	0	0	0	0
Over +1.40	0	0	0	0	0
Nos. of eyes	13	22	13	9	1

APPENDIX A.4

Final ages related to initial ages

Analysis by age in years at final examination and age in years at initial examination - percentage distribution

Final age in years	Initial age in years - less than 1	2	3	4	5	6	7	8	9	10	11	12	13
1 -<2	0	0	0	0	0	0	0	0	0	0	0	0	0
-<3	0	22.2	0	0	0	0	0	0	0	0	0	0	0
-<4	100.0	27.8	23.5	0	0	0	0	0	0	0	0	0	0
-<5	0	16.7	20.6	15.7	1.7	0	0	0	0	0	0	0	0
-<6	0	16.7	17.6	26.8	25.9	4.2	0	0	0	0	0	0	0
-<7	0	11.1	29.4	24.4	22.4	31.2	3.7	0	0	0	0	0	0
-<8	0	5.6	8.8	26.8	19.0	22.9	29.6	0	0	0	0	0	0
-<9	0	0	0	4.7	22.4	20.8	37.0	25.9	0	0	0	0	0
-<10	0	0	0	1.6	8.6	12.5	18.5	33.3	37.8	0	0	0	0
-<11	0	0	0	0	0	8.3	11.1	14.8	27.0	0	0	0	0
-<12	0	0	0	0	0	0	0	18.5	13.5	57.1	33.3	0	0
-<13	0	0	0	0	0	0	0	3.7	10.8	0	16.7	16.7	0
-<14	0	0	0	0	0	0	0	3.7	10.8	42.9	50.0	33.3	0
-<15	0	0	0	0	0	0	0	0	0	0	0	16.7	100.0
-<16	0	0	0	0	0	0	0	0	0	0	0	33.3	0
Nos. of eyes	4	36	68	127	116	96	54	54	37	14	12	12	2

APPENDIX A.5

Annual changes in ocular refraction related to strabismic state of each eye

Analysis by annual changes and strabismic groups -

(a) Nil (b) Alternating/Intermittent (c) Unilateral -

for each three year age group from birth up to over twelve years - percentage distribution.

Annual changes in refraction - dioptres	Age: Birth to <3 years Strabismic groups Nil	Alternating/Intermittent	Unilateral
Over -1.40	0	10.71	2.00
-1.21 to -1.40	0	0	0
-1.01 to -1.20	0	0	2.00
-0.81 to -1.00	0	3.57	0
-0.61 to -0.80	0	0	0
-0.41 to -0.60	5.66	0	6.00
-0.21 to -0.40	1.88	0	0
-0.01 to -0.20	0	0	0
0	24.5	17.9	16.00
+0.01 to +0.20	1.88	3.57	4.00
+0.21 to +0.40	11.32	10.71	12.00
+0.41 to +0.60	5.66	17.86	8.00
+0.61 to +0.80	15.09	17.86	20.00
+0.81 to +1.00	15.09	10.71	16.00
+1.01 to +1.20	3.77	3.57	6.00
+1.21 to +1.40	9.43	0	2.00
Over +1.40	5.66	3.57	6.00
Numbers of eyes	53	28	50

APPENDIX A.5(Continued)

Age : 3 to <6 years

Annual changes in refraction - dioptres	Strabismic groups Nil	Alternating/Intermittent	Unilateral
Over -1.40	3.07	0	0.52
-1.21 to -1.40	0.88	0	0.52
-1.01 to -1.20	0.44	0	0.52
-0.81 to -1.00	0.44	2.63	1.04
-0.61 to -0.80	0.44	0	1.55
-0.41 to -0.60	2.19	0	2.59
-0.21 to -0.40	4.82	5.26	4.15
-0.01 to -0.20	1.32	7.89	1.55
0	39.9	31.60	36.3
+0.01 to +0.20	0.88	5.26	3.11
+0.21 to +0.40	14.91	10.53	13.47
+0.41 to +0.60	13.16	21.05	16.06
+0.61 to +0.80	7.02	10.53	6.74
+0.81 to +1.00	5.70	0	6.74
+1.01 to +1.20	3.07	0	2.59
+1.21 to +1.40	0.44	2.63	2.07
Over +1.40	1.32	2.63	0.52
Numbers of eyes	228	38	193

APPENDIX A.5(Continued)

Age : 6 to <9 years

Annual changes in refraction - dioptres	Strabismic groups Nil	Alternating/Intermittent	Unilateral
Over -1.40	0	0	1.02
-1.21 to -1.40	0.87	0	1.02
-1.01 to -1.20	2.61	0	2.04
-0.81 to -1.00	3.48	0	2.04
-0.61 to -0.80	5.22	3.57	0
-0.41 to -0.60	5.22	3.57	12.24
-0.21 to -0.40	10.43	7.14	10.20
-0.01 to -0.20	5.22	0	3.06
0	50.4	42.9	46.9
+0.01 to +0.20	1.74	5.26	2.04
+0.21 to +0.40	1.74	10.53	11.22
+0.41 to +0.60	6.96	21.05	4.08
+0.61 to +0.80	1.74	10.53	2.04
+0.81 to +1.00	2.61	0	2.04
+1.01 to +1.20	1.74	0	0
+1.21 to +1.40	0	2.63	0
Over +1.40	0	2.63	0
Numbers of eyes	115	28	98

Age : 9 to <12 years

Annual changes in refraction - dioptres	Strabismic groups Nil	Alternating/Intermittent	Unilateral
Over -1.40	0	0	0
-1.21 to -1.40	0	0	0
-1.01 to -1.20	0	0	0
-0.81 to -1.00	2.94	0	0
-0.61 to -0.80	0	0	0
-0.41 to -0.60	8.82	0	10.00
-0.21 to -0.40	11.76	0	10.00
-0.01 to -0.20	2.94	0	5.00
0	35.3	100	30.00
+0.01 to +0.20	17.65	0	5.00
+0.21 to +0.40	8.82	0	20.00
+0.41 to +0.60	8.82	0	10.00
+0.61 to +0.80	2.94	0	10.00
+0.81 to +1.00	0	0	0
+1.01 to +1.20	0	0	0
+1.21 to +1.40	0	0	0
Over +1.40	0	0	0
Numbers of eyes	34	4	20

APPENDIX A.6

Annual changes in ocular refraction related to angle of strabismus

Analysis by changes in refraction in dioptres and angle of strabismus in degrees, for each three year age group from birth up to twelve years - percentage distribution

Annual changes in refraction - dioptres	Age Birth to <3 years	
	Angle of strabismus in degrees	
	1 - 20°	21 - 40°
Over -1.40	0	5.19
-1.21 to -1.40	0	0
-1.01 to -1.20	0	0
-0.81 to -1.00	0	1.30
-0.61 to -0.80	0	0
-0.41 to -0.60	2.17	5.19
-0.21 to -0.40	0	1.30
-0.01 to -0.20	0	0
0	19.57	16.88
+0.01 to +0.20	2.17	3.90
+0.21 to +0.40	15.22	10.39
+0.41 to +0.60	8.70	10.39
+0.61 to +0.80	17.39	18.18
+0.81 to +1.00	15.22	14.29
+1.01 to +1.20	2.17	6.49
+1.21 to +1.40	10.87	1.30
Over +1.40	6.57	5.19
Numbers of eyes	46	77

APPENDIX A.6 (Continued)

Age: 3 to <6 years

Annual changes in refraction - dioptres	Angle of strabismus in degrees 1 - 20°	21 - 40°
Over -1.40	0	0.49
-1.21 to -1.40	1.43	0
-1.01 to -1.20	0	0.98
-0.81 to -1.00	0.95	0.98
-0.61 to -0.80	0.95	0.98
-0.41 to -0.60	3.33	0.98
-0.21 to -0.40	3,33	5.85
-0.01 to -0.20	0.48	3.41
0	39.52	36.59
+0.01 to +0.20	0.95	3.41
+0.21 to +0.40	15.71	14.15
+0.41 to +0.60	15.23	14.63
+0.61 to +0.80	5.24	9.27
+0.81 to +1.00	5.71	4.88
+1.01 to +1.20	2.86	2.44
+1.21 to +1.40	2.38	0.49
Over +1.40	1.90	0.49
Numbers of eyes	210	205

APPENDIX A.6 (Continued)

Age : 6 to <9 years

Annual changes in refraction - dioptres	Angle of strabismus in degrees	
	$1 - 20^{o}$	$21 - 40^{o}$
Over -1.40	0	1.16
-1.21 to -1.40	0.75	1.16
-1.01 to -1.20	0.75	3.49
-0.81 to -1.00	0	3.49
-0.61 to -0.80	0.75	4.65
-0.41 to -0.60	5.22	10.47
-0.21 to -0.40	6.72	16.28
-0.01 to -0.20	3.73	3.49
0	57.46	40.70
+0.01 to +0.20	2.24	0
+0.21 to +0.40	8.96	4.65
+0.41 to +0.60	7.46	5.81
+0.61 to +0.80	4.48	0
+0.81 to +1.00	1.49	4.65
+1.01 to +1.20	0	0
+1.21 to +1.40	0	0
Over +1.40	0	0
Numbers of eyes	134	86

APPENDIX A.6 (Continued)

Age : 9 to <12 years

Annual changes in refraction - dioptres	Angle of strabismus in degrees	
	$1 - 20^{o}$	$21 - 40^{o}$
Over -1.40	0	0
-1.21 to -1.40	0	0
-1.01 to -1.20	0	0
-0.81 to -1.00	0	0
-0.61 to -0.80	0	0
-0.41 to -0.60	10.71	0
-0.21 to -0.40	7.14	8.33
-0.01 to -0.20	0	8.33
0	50.00	25.00
+0.01 to +0.20	10.71	16.67
+0.21 to +0.40	10.71	8.33
+0.41 to +0.60	7.14	25.00
+0.61 to +0.80	3.57	8.33
+0.81 to +1.00	0	0
+1.01 to +1.20	0	0
+1.21 to +1.40	0	0
Over +1.40	0	0
Numbers of eyes	28	12

APPENDIX A.7

Annual changes in ocular refraction related to ametropic correction

Analysis by changes in refraction in dioptres and level of ametropic correction for each three year age group birth up to twelve years - percentage distribution

Age : Birth to <3 years

Annual changes in refraction - dioptres	Ametropic correction: Full correction	≤+0.50 D undercorrection	≥+0.75 D undercorrection
Over -1.40	0	15.0	4.8
-1.21 to -1.40	0	0	0
-1.01 to -1.20	1.1	0	0
-0.81 to -1.00	0	5.0	0
-0.61 to -0.80	0	0	0
-0.41 to -0.60	4.4	0	9.5
-0.21 to -0.40	0	0	4.8
-0.01 to -0.20	0	0	0
0	25.6	10.0	4.8
+0.01 to +0.20	3.3	0	4.8
+0.21 to +0.40	14.4	5.0	4.8
+0.41 to +0.60	8.9	10.0	9.5
+0.61 to +0.80	13.3	30.0	23.8
+0.81 to +1.00	16.7	10.0	9.5
+1.01 to +1.20	3.3	10.0	4.8
+1.21 to +1.40	4.4	0	9.5
Over +1.40	4.4	5.0	9.5
Numbers of eyes	90	20	21

APPENDIX A.7 (Continued)

Age: 3 - <6 years

Annual changes in refraction - dioptres	Ametropic correction Full correction	≤+0.50 D undercorrection	≥+0.75 D undercorrection
Over -1.40	0	0.9	10.1
-1.21 to -1.40	0.7	0.9	0
-1.01 to -1.20	0.4	0	1.5
-0.81 to -1.00	0.7	0.9	1.5
-0.61 to -0.80	0	0.9	4.3
-0.41 to -0.60	2.1	2.8	1.5
-0.21 to -0.40	4.2	5.7	4.3
-0.01 to -0.20	1.1	2.8	4.3
0	33.6	44.3	44.9
+0.01 to +0.20	2.8	0.9	1.4
+0.21 to +0.40	15.9	12.3	8.7
+0.41 to +0.60	16.6	15.1	8.7
+0.61 to +0.80	9.2	5.7	1.5
+0.81 to +1.00	6.4	2.8	7.2
+1.01 to +1.20	2.8	3.8	0
+1.21 to +1.40	2.1	0	0
Over +1.40	1.4	0	0
Numbers of eyes	283	106	70

APPENDIX A.7 (Continued)

Age: 6 to <9 years

Annual changes in refraction - dioptres	Ametropic correction: Full correction	≤+0.50 D undercorrection	≥+0.75 D undercorrection
Over -1.40	0	1.3	0
-1.21 to -1.40	1.7	0	0
-1.01 to -1.20	1.7	2.7	2.1
-0.81 to -1.00	1.7	5.3	0
-0.61 to -0.80	1.7	5.3	2.1
-0.41 to -0.60	7.6	6.7	10.4
-0.21 to -0.40	5.9	14.7	12.5
-0.01 to -0.20	5.9	2.7	0
0	46.6	44.0	58.3
+0.01 to +0.20	1.7	2.7	0
+0.21 to +0.40	9.3	4.0	6.3
+0.41 to +0.60	8.5	5.3	4.2
+0.61 to +0.80	3.4	1.3	2.1
+0.81 to +1.00	4.2	1.3	2.1
+1.01 to +1.20	0	2.7	0
+1.21 to +1.40	0	0	0
Over +1.40	0	0	0
Numbers of eyes	118	75	48

APPENDIX A.7 (Continued)

Age: 9 - <12 years

Annual changes in refraction - dioptres	Ametropic correction Full correction	≤+0.50 D undercorrection	≥+0.75 D undercorrection
Over 1.40	0	0	0
-1.21 to -1.40	0	0	0
-1.01 to -1.20	0	0	0
-0.81 to -1.00	0	0	11.1
-0.61 to -0.80	0	0	0
-0.41 to -0.60	13.9	0	0
-0.21 to -0.40	8.3	15.4	11.1
-0.01 to -0.20	2.8	7.7	0
0	36.1	46.2	33.3
+0.01 to +0.20	11.1	15.4	11.1
+0.21 to +0.40	8.3	15.4	22.2
+0.41 to +0.60	13.9	0	0
+0.61 to +0.80	5.6	0	11.1
+0.81 to +1.00	0	0	0
+1.01 to +1.20	0	0	0
+1.21 to +1.40	0	0	0
Over +1.40	0	0	0
Numbers of eyes	36	13	9

APPENDIX A.8

Annual changes in ocular refraction related to surgical intervention

Analysis by changes in refraction in dioptres and extent of surgical intervention for each three year age group from birth to twelve years - percentage distribution

Age : Birth - <3 years

Annual changes in refraction - dioptres	Surgical intervention Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both eyes
Over -1.40	3.5	5.3	5.3	0
-1.21 to -1.40	0	0	0	0
-1.01 to -1.20	1.8	0	0	0
-0.81 to -1.00	1.8	0	0	0
-0.61 to -0.80	0	0	0	0
-0.41 to -0.60	7.0	5.3	0	2.8
-0.21 to -0.40	1.8	0	0	0
-0.01 to -0.20	0	0	0	0
0	26.3	15.8	15.8	13.9
+0.01 to +0.20	0	0	0	11.1
+0.21 to +0.40	7.0	15.8	26.3	8.3
+0.41 to +0.60	12.3	10.5	5.3	5.6
+0.61 to +0.80	10.5	10.5	21.1	30.6
+0.81 to +1.00	14.0	21.1	10.5	13.9
+1.01 to +1.20	7.0	5.3	5.3	0
+1.21 to +1.40	1.8	5.3	5.3	8.3
Over +1.40	5.3	5.3	5.3	5.6
Numbers of eyes	57	19	19	36

APPENDIX A.8 (Continued)

Age : 3 - <6 years

Annual changes in refraction -dioptres	Surgical intervention			
	Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both eyes
Over -1.40	3.8	0	0	0
-1.21 to -1.40	1.4	0	0	0
-1.01 to -1.20	0	0	1.3	1.1
-0.81 to -1.00	1.0	1.3	0	1.1
-0.61 to -0.80	0.5	0	1.3	2.2
-0.41 to -0.60	1.9	1.3	2.5	3.3
-0.21 to -0.40	5.3	5.0	0	6.6
-0.01 to -0.20	1.9	0	1.3	4.4
0	38.0	42.5	37.5	33.0
+0.01 to +0.20	1.9	0	6.3	1.1
+0.21 to +0.40	10.6	21.3	15.0	14.3
+0.41 to +0.60	15.4	7.5	12.5	23.1
+0.61 to +0.80	5.8	11.3	10.0	4.4
+0.81 to +1.00	6.7	3.8	7.5	3.3
+1.01 to +1.20	2.4	5.0	2.5	1.1
+1.21 to +1.40	1.9	0	1.3	1.1
Over +1.40	1.4	1.3	1.3	0
Numbers of eyes	208	80	80	91

APPENDIX A.8 (Continued)

Age : 6 - <9 years

Annual changes in refraction - dioptres	Surgical intervention			
	Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both eyes
Over -1.40	0.9	0	0	0
-1.21 to -1.40	0.9	0	2.4	0
-1.01 to -1.20	2.6	4.8	0	0
-0.81 to -1.00	1.7	0	2.4	7.1
-0.61 to -0.80	2.6	7.1	2.4	0
-0.41 to -0.60	3.5	4.8	11.9	19.0
-0.21 to -0.40	5.2	19.0	7.1	16.7
-0.01 to -0.20	4.3	2.4	7.1	0
0	55.7	52.4	42.9	28.6
+0.01 to +0.20	1.7	2.4	2.4	0
+0.21 to +0.40	5.2	2.4	14.3	9.5
+0.41 to +0.60	7.8	4.8	0	11.9
+0.61 to +0.80	4.3	0	2.4	0
+0.81 to +1.00	1.7	0	4.8	7.1
+1.01 to +1.20	1.7	0	0	0
+1.21 to +1.40	0	0	0	0
Over +1.40	0	0	0	0
Numbers of eyes	115	42	42	42

APPENDIX A.8 (Continued)

Age : 9 - <12 years

Annual changes in refraction - dioptres	Nil on both eyes	Surgical intervention Nil on one eye only	Surgery on one eye only	Surgery on both eyes
Over -1.40	0	0	0	0
-1.21 to -1.40	0	0	0	0
-1.01 to -1.20	0	0	0	0
-0.81 to -1.00	2.9	0	0	0
-0.61 to -0.80	0	0	0	0
-0.41 to -0.60	8.8	12.5	12.5	0
-0.21 to -0.40	11.8	12.5	0	12.5
-0.01 to -0.20	0	0	12.5	12.5
0	38.2	25.0	37.5	50.0
+0.01 to +0.20	11.8	25.0	0	12.5
+0.21 to +0.40	14.7	0	12.5	12.5
+0.41 to +0.60	5.9	25.0	12.5	0
+0.61 to +0.80	5.9	0	12.5	0
+0.81 to +1.00	0	0	0	0
+1.01 to +1.20	0	0	0	0
+1.21 to +1.40	0	0	0	0
Over +1.40	0	0	0	0
Numbers of eyes	34	8	8	8

APPENDIX A.9

Distribution of ocular astigmatism within yearly age groups - per cent

Ocular astigmatism in dioptres	Age in years <1	<2	<3	<4	<5	<6	<7	<8	<9	<10	<11	<12
Nil	50.0	17.5	54.0	10.3	13.3	10.8	13.0	14.8	6.5	8.3	6.3	0
0.21 - 1.00	50.0	30.0	21.8	50.3	47.0	49.3	31.5	27.3	37.1	16.7	50.0	38.9
1.01 - 2.00	0	50.0	16.1	26.9	21.7	26.4	30.4	26.1	32.3	33.3	18.8	22.2
Over 2.00	0	2.5	8.0	12.4	18.1	13.5	25.0	31.8	24.2	41.7	25.0	38.9
Numbers of eyes	4	40	87	145	166	148	92	88	62	24	16	18

APPENDIX A.10

Annual changes in ocular refraction related to initial astigmatic state

Analysis by changes in refraction in dioptres and initial ocular astigmatism for each three year age group from birth to twelve - percentage distribution

Age: Birth - <3

Annual changes in refraction - dioptres	Ocular astigmatism - dioptres			
	Nil	0.21-1.00	1.01-2.00	>2.00
Over -1.40	12.5	1.6	2.6	0
-1.21 to -1.40	0	0	0	0
-1.01 to -1.20	0	1.6	0	0
-0.81 to -1.00	6.3	0	0	0
-0.61 to -0.80	0	0	0	0
-0.41 to -0.60	6.3	4.9	2.6	6.7
-0.21 to -0.40	6.3	0	0	0
-0.01 to -0.20	0	0	0	0
0	6.3	21.3	17.9	33.3
+0.01 to +0.20	0	4.9	2.6	0
+0.21 to +0.40	18.8	11.5	2.6	26.7
+0.41 to +0.60	6.3	13.1	7.7	0
+0.61 to +0.80	6.3	23.0	12.8	20.0
+0.81 to +1.00	6.3	6.6	33.3	6.7
+1.01 to +1.20	0	1.6	12.8	0
+1.21 to +1.40	6.3	8.2	0	0
Over +1.40	18.8	1.6	5.1	6.7
Nos. of eyes	16	61	39	15

APPENDIX A.10 (Continued)

Age: 3 - <6 years

Annual changes in refraction -dioptres	Ocular astigmatism - dioptres Nil	0.21-1.00	1.01-2.00	>2.00
Over -1.40	0	2.2	0.9	2.9
-1.21 to -1.40	0	0.4	1.8	0
-1.01 to -1.20	0	0	0.9	1.5
-0.81 to -1.00	0	0.9	1.8	0
-0.61 to -0.80	1.9	0	0.9	2.9
-0.41 to -0.60	1.9	1.3	2.6	4.4
-0.21 to -0.40	7.5	3.6	5.3	4.4
-0.01 to -0.20	3.8	0.9	1.8	4.4
0	35.8	38.8	38.6	33.8
+0.01 to +0.20	0	2.2	2.6	2.9
+0.21 to +0.40	9.4	15.2	15.8	10.3
+0.41 to +0.60	20.8	14.3	13.2	16.2
+0.61 to +0.80	5.7	8.9	6.1	4.4
+0.81 to +1.00	9.4	4.9	4.4	7.4
+1.01 to +1.20	3.8	2.7	2.6	1.5
+1.21 to +1.40	0	1.3	0.9	2.9
Over +1.40	0	2.2	0	0
Nos. of eyes	53	224	114	68

APPENDIX A.10 (Continued)

Age: 6 - <9 years

Annual changes in refraction - dioptres	Ocular astigmatism - dioptres Nil	0.21-1.00	1.01-2.00	>2.00
Over -1.40	0	1.3	0	0
-1.21 to -1.40	3.5	0	1.4	0
-1.01 to -1.20	3.5	1.3	2.8	1.5
-0.81 to -1.00	3.5	1.3	2.8	3.1
-0.61 to -0.80	3.5	2.6	4.2	1.5
-0.41 to -0.60	3.5	9.2	1.4	15.4
-0.21 to -0.40	3.5	10.5	12.7	9.2
-0.01 to -0.20	3.5	5.3	2.8	3.1
0	37.9	50.0	46.5	52.3
+0.01 to +0.20	3.5	1.31	0	3.1
+0.21 to +0.40	6.9	7.9	5.6	7.7
+0.41 to +0.60	10.3	5.3	11.3	1.5
+0.61 to +0.80	6.9	2.6	2.8	0
+0.81 to +1.00	10.3	1.3	4.2	0
+1.01 to +1.20	0	0	1.4	1.5
+1.21 to +1.40	0	0	0	0
Over +1.40	0	0	0	0
Nos. of eyes	29	76	71	65

APPENDIX A.10 (Continued)

Age: 9 - <12 years

Annual changes in refraction - dioptres	Ocular astigmatism - dioptres Nil	0.21-1.00	1.01-2.00	>2.00
Over -1.40	0	0	0	0
-1.21 to -1.40	0	0	0	0
-1.01 to -1.20	0	0	0	0
-0.81 to -1.00	0	0	0	4.8
-0.61 to -0.80	0	0	0	0
-0.41 to -0.60	33.3	10.5	0	9.5
-0.21 to -0.40	0	10.5	6.7	14.3
-0.01 to -0.20	0	5.3	6.7	0
0	33.3	31.6	53.3	33.3
+0.01 to +0.20	33.3	5.3	6.7	19.1
+0.21 to +0.40	0	21.1	6.7	9.5
+0.41 to +0.60	0	10.5	6.7	9.5
+0.61 to +0.80	0	5.3	13.3	0
+0.81 to +1.00	0	0	0	0
*1.01 to +1.20	0	0	0	0
+1.21 to +1.40	0	0	0	0
Over +1.40	0	0	0	0
Nos. of eyes	3	19	15	21

APPENDIX A.11

Annual changes in ocular astigmatism related to initial astigmatic state

Analysis by changes in astigmatism and initial level of ocular astigmatism in dioptres for each three year age group from birth up to twelve - percentage distribution

Annual changes in ocular astigmatism - dioptres	Age: Birth - <3 years			
	Ocular astigmatism - dioptres			
	Nil	0.21-1.00	1.01-2.00	>2.00
>-1.00	0	0	0	0
-0.51 to -1.00	0	1.6	5.1	6.7
-0.01 to -0.50	0	4.9	2.6	13.3
0	50.0	62.3	53.8	53.3
+0.01 to +0.50	12.5	18.0	12.8	6.7
+0.51 to +1.00	25.0	11.5	23.1	13.3
>+1.00	12.5	1.6	2.6	6.7
Nos. of eyes	16	61	39	15

APPENDIX A.11 (Continued)

Age: 3 - <6 years

Annual changes in ocular astigmatism - dioptres	Ocular astigmatism - dioptres Nil	0.21-1.00	1.01-2.00	>2.00
>-1.00	0	0	0	0
-0.51 to -1.00	0	0	0.9	1.5
-0.01 to -0.50	0	4.0	10.5	8.8
0	67.9	77.7	62.3	66.2
+0.01 to +0.50	24.5	11.6	16.7	10.3
+0.51 to +1.00	5.7	5.8	8.8	10.3
>+1.00	1.9	0.9	0.9	2.9
Nos. of eyes	53	224	114	68

Age: 6 - <9 years

Annual changes in ocular astigmatism - dioptres	Ocular astigmatism - dioptres Nil	0.21-1.00	1.01-2.00	>2.00
>-1.00	0	0	0	0
-0.51 to -1.00	0	0	0	3.1
-0.01 to -0.50	0	3.9	7.0	10.8
0	75.9	72.4	67.6	63.1
+0.01 to +0.50	20.7	14.5	11.3	13.8
+0.51 to +1.00	3.4	9.2	11.3	7.7
>+1.00	0	0	2.8	1.5
Nos. of eyes	16	76	71	65

APPENDIX A.11 (Continued)

Age: 9 - <12 years

Annual changes in ocular astigmatism - dioptres	Ocular astigmatism - dioptres			
	Nil	0.21-1.00	1.01-2.00	>2.00
>-1.00	0	0	0	0
-0.51 to -1.00	0	0	0	0
-0.01 to -0.50	0	5.3	13.3	14.3
0	66.7	84.2	80.0	85.7
+0.01 to +0.50	33.3	10.5	6.7	0
+0.51 to +1.00	0	0	0	0
>+1.00	0	0	0	0
Nos. of eyes	3	19	15	21

APPENDIX A.12

Annual changes in ocular astigmatism related to strabismic state

Analysis by changes in astigmatism in dioptres and strabismic state of each eye within separate three year age groups, from birth up to twelve - percentage distribution.

Annual changes in ocular astigmatism - dioptres	Strabismic groups: Nil	Alternating/Intermittent	Unilateral
		Age: Birth - <3 years	
>-1.00	0	0	0
-0.51 to -1.00	1.9	10.7	0
-0.01 to -0.50	3.8	3.6	6.0
0	67.9	42.9	54.0
+0.01 to +0.50	11.3	28.6	10.0
+0.51 to +1.00	13.2	7.1	26.0
>+1.00	1.9	7.1	4.0
Nos. of eyes	53	28	50
		Age: 3 - <6 years	
>-1.00	0	0	0
-0.51 to -1.00	0.9	0	0
-0.01 to -0.50	5.7	7.9	5.7
0	71.9	68.4	70.5
+0.01 to +0.50	12.7	23.7	14.0
+0.51 to +1.00	7.5	0	8.3
>+1.00	1.3	0	1.6
Nos. of eyes	228	38	193

APPENDIX A.12 (Continued)

Annual changes in ocular astigmatism - dioptres	Strabismic groups: Nil	Alternating/Intermittent	Unilateral
	Age: 6 - <9 years		
>-1.00	0	0	0
-0.51 to -1.00	0.9	0	1.0
-0.01 to -0.50	3.5	7.1	9.2
0	66.1	85.7	67.3
+0.01 to +0.50	17.4	0	14.3
+0.51 to +1.00	10.4	3.6	8.2
>+1.00	1.7	3.6	0
Nos. of eyes	115	28	98
	Age: 9 - <12 years		
>-1.00	0	0	0
-0.51 to -1.00	0	0	0
-0.01 to -0.50	5.9	0	20.0
0	88.2	100.0	70.0
+0.01 to +0.50	5.9	0	10.0
+0.51 to +1.00	0	0	0
>+1.00	0	0	0
Nos. of eyes	34	4	20

APPENDIX A.13

Annual changes in ocular astigmatism related to surgical intervention

Analysis by annual astigmatic changes in dioptres and nature of surgical intervention for each three year age group - percentage distribution

Annual changes in ocular astigmatism - dioptres	Surgical intervention: Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both
Age: Birth - <3 years				
>- 1.00	0	0	0	0
-0.51 to -1.00	5.3	0	0	2.8
-0.01 to -0.50	1.8	5.3	5.3	8.3
0	63.2	68.4	36.8	52.8
+0.01 to +0.50	7.0	15.8	26.3	19.4
+0.51 to +1.00	17.5	10.5	26.3	13.9
>+1.00	5.3	0	5.3	2.8
Nos. of eyes	57	19	19	36
Age: 3 - <6 years				
>-1.00	0	0	0	0
-0.51 to -1.00	0	1.3	0	1.1
-0.01 to -0.50	4.3	10.0	6.3	5.5
0	76.9	66.3	67.5	64.8
+0.01 to +0.50	11.5	15.0	16.3	17.6
+0.51 to +1.00	7.2	6.3	7.5	7.7
>+1.00	0	1.3	2.5	3.3
Nos. of eyes	208	80	80	36

APPENDIX A.13 (Continued)

Annual changes in ocular astigmatism - dioptres	Surgical intervention			
	Nil on both eyes	Nil on one eye only	Surgery on one eye only	Surgery on both
	Age: 6 - <9 years			
>-1.00	0	0	0	0
-0.51 to -1.00	0.9	0	2.4	0
-0.01 to -0.50	3.5	7.1	11.9	7.1
0	70.4	73.8	61.9	66.7
+0.01 to +0.50	13.0	11.9	14.3	19.0
+0.51 to +1.00	11.3	7.1	7.1	4.8
>+1.00	0.9	0	2.4	2.4
Nos. of eyes	115	42	42	42
	Age: 9 - <12 years			
>-1.00	0	0	0	0
-0.51 to -1.00	0	0	0	0
-0.01 to -0.50	0	12.5	25.0	37.5
0	97.1	75.0	50.0	62.5
+0.01 to +0.50	2.9	12.5	25.0	0
+0.51 to +1.00	0	0	0	0
>+1.00	0	0	0	0
Nos. of eyes	34	8	8	8

APPENDIX 'B'

DATA PROCESSING

The preparation of data for the final computer analyses is described in this appendix. The results of each examination were initially recorded on the appropriate hospital record cards, the relevant data being subsequently transferred to specially prepared data sheets (figure B1). These findings were then coded for manual analysis using the Paramount Kendrew punched card, described in section 5.14 (figure B2) The volume of data that required processing, however, exceeded the capacity of this system. The data were, therefore, recoded on the basis of the eighty column punched card (figure B3). The results for each eye were entered on separate cards, each card carrying the data for one examination and its follow-up.

The coding system was originally designed for manual analysis, but was later adapted for computer processing. Consequently it was a compromise. Details of the final coding are as follows: entries in columns 1 - 20 represent common data, columns 21 - 42 specifically refer to the results of the 'initial' examination, whilst columns 43 - 77 refer to the respective follow-up investigation.

Sex - direct coding, M or F	column 1
Data sheet entry number - exact details entered	columns 2 - 5
Computer identification	columns 6 - 9
Hospital record number - exact numbers entered	columns 10 - 13
Right or left eyes - direct coding R or L	column 14

FIGURE B.1. - Sample Data Sheet (one quarter original size)

SEX INITIALS NUMBER	D.O.B.	1ST EXAM METHOD	RETINOSCOPY RESULTS WORKING 50cm	Rx GIVEN	ABNORMALITIES	2nd EXAM METHOD	RETINOSCOPY RESULTS	Rx GIVEN	3rd EXAM METHOD	RETINOSCOPY RESULTS	Rx GIVEN	4th EXAM METHOD	RETINOSCOPY RESULTS	Rx GIVEN	TREATMENT
F LB 78260	23 10 52 [illegible]	24 1 59 Atrop	+9.00 170 +10.75 9.1; +3.00 +10.25 6.82	+6.25/1.25 170; +6.25/1.75 10	CDS 15 [illegible]	+3 C.8 21 1 60 Atrop	+9.25 175 +10.75 7.53; +8.75 +10.50 7.1	+5.75/1.50 175; +5.50/1.75 [illegible]							O D
M WW 74[illegible]	23 5 50	5 3 59 Atrop	+2.50 5 +4.00 +2.25; +2.25 75 +7.25 +1.35	-0.75/1.25 5; +2.50/7.50 175	LDS	17 C 13 15 11 61 HRC	+2.50 5 +4.25 0.44; +2.00 +6.50 -1.56	-1.50/-1.00 [illegible]; +3.75/3.75 75	-0.19 0.37 18 12 65 Cyclo	+2.50 +3.50 0.25; +3.00 175 -7.00 +2.34	+0.75/7.50 10; +3.75/7.00 175	?			26 3 57 LER [illegible] L.R [illegible]; 7 1 57 RER [illegible]; 1 4 60 RIR [illegible]
F AK 74[illegible]	5 2 57	1 7 59 Atrop	-0.50 120 +0.50 -2.91; -2.25 120 +0.50 -3.71	-2.00/1.00 180; -2.00/2.75 130	LC.V [illegible] in CF	14 9 60 Atrop	-0.50 150 +0.50 -2.91; -2.50 +0.50 -3.82	-2.50/1.00 130; -2.50/3.00 180	0.81 0.32 1 10 62 Cyclo	Plano 30 +2.50 -1.22; -1.00 175 +2.00 -1.94	-1.00/2.50 30; -1.25/3.00 175	-1.36 -1.1 3 9 63 Cyclo	-2.00 32 +1.00 -2.89; -2.50 127 +1.00 -3.12	-1.00/3.00 21; -1.00/3.50 167	[illegible]
F MC 7[illegible]	19 6 51	2 5 60 HRC	+3.25 170 +5.50 1.67; +1.50 +6.50 1.33	+2.00/1.75 170; +3.00/4.75 [illegible]	LDCS	-0.21 -0.23 31 1 62 HRC	+2.50 175 +5.25 1.16; +0.50 15 +6.00 0.58	+2.75/2.5 175; +3.50/3.00 15							22 3 58 [illegible] LMR [illegible]; 2 12 60 RER [illegible] RIR [illegible]
F SR [illegible]	4 5 59	26 4 63 Atrop	-0.75 170 -1.25 -0.92; -1.75 25 -0.25 -3.84	-2.25/1.5 5; -3.25/1.25 25	LDS	-2.29 [illegible] 23 3 64 Myd	-1.75 180 +0.50 -3.02; -2.75 -1.00 -3.71	-2.00/1.75 5; -3.00/1.50 [illegible]		[illegible] value of [illegible]					O D
M DC [illegible]	2 10 57		Congenital Buphthalmos												
F JS 71[illegible]	2 7 57	5 5 60 Atrop	+0.75 +2.50 -1.15; +1.25 +2.25 -1.23	-0.50/1.75 12; -0.75/1.00 152	Div. [illegible]	Nil [illegible] 26 9 63 Atrop	Plano 15 +3.00 -1.46; +1.00 +2.00 -1.43	-0.25/3.00 15; -1.00/1.00 160							2 5 61 RER [illegible] RIR [illegible]
F AW 7[illegible]	17 8 57	7 10 60 Atrop	+5.75 +5.50 2.7; +6.00 +5.75 2.96	+2.50 DS; +2.75 DS	LCCS. +40 +23	[illegible] 6 4 62 Atrop	+5.75 +6.50 3.23; +5.75 +6.25 3.09	+3.25/1.50 170; +3.25/0.50 10	28 6 63 Atrop	+6.00 +6.75 3.29; +6.75 +6.75 3.9	+3.75/0.75 180; +3.25 DS				20 5 61 RER [illegible] MR [illegible]
F AB 176[illegible]	4 10 54	20 11 57 Atrop	+8.75 +10.00; +8.75 5 +10.50	+6.50/1.25 180; +7.00/1.75 5	Esophoria +19 +3	16 5 60 HRC	+9.00 +10.00 7.2; +9.00 +10.75 6.8	+5.50/1.00 90; +5.50/1.75 105	[illegible] 2 5 63 Myd	+8.50 10 +10.00 7.25; +8.00 +10.50 7.26	+7.00/1.75 10; +7.50/2.50 175				O D
F PMW 76[illegible]	23 6 54	2 1 59 HRC	+4.00 1.27; +4.5 1.78	+1.50 DS; +2.00 DS	Esophoria +10 +15 +8	[illegible] 60 HRC	+5.25 +5.25 2.56; +5.25 +5.25 2.56	No change	[illegible] 26 5 61 Nil	+4.25 2.3; +4.25 2.3	+1.75; +1.75	[illegible] 8 11 62 Nil	+4.75 2.56; +4.75 2.83	No change	+7 60 [illegible]
" "	[illegible]	[illegible] 9 12 63	+4.00 2.04; +4.75 2.83	+1.50 DS; +1.75 DS											
M PT 76[illegible]	20 1 55	18 12 57 HRC	+5.50 10 +5.75 2.96; +5.50 +5.25 60 2.7	+3.00/0.25 10; +2.75/0.25 60	R [illegible] Con. [illegible] +18 +10 [illegible]	Nil 0.41 8 1 61 HRC	+5.50 10 +6.25 3.23; +5.75 15 +6.00	+3.25/0.75 10; +3.00/0.25 15	[illegible] 1 11 63 Myd	+6.50 4.17; +6.50 4.17	+3.50 DS; +3.00 DS				[illegible] RIR [illegible]
F CM 73[illegible]	19 8 54	14 10 59 Atrop	+2.00 +3.00 -0.49; -8.00 5 -5.50 -8.87	Plano/1.00 175; -8.50/2.50 5	Esophoria -7 +3	0.80 [illegible] 12 11 60 Atrop	+3.00 +3.75 0.38; -7.25 -4.50 -2.14	+0.75/0.75 [illegible]; -7.50/2.75 [illegible]							O D
F AG 7[illegible]	12 4 53	17 4 59 Atrop	+8.25 30 +9.00 5.94; +8.75 180 +9.50 6.53	+6.00/0.75 30; +6.50/0.75 180	LCCS +15 +6	[illegible] 21 6 63 Myd	+7.25 15 +8.00 5.40; +6.50 175 +7.50 4.71	+5.00/1.00 20; +4.25/1.00 175							O D
F JAE [illegible]	4 9 54	15 4 59 Atrop	+8.75 20 +9.50 6.53; +7.25 15 +8.00 4.95	+6.50/0.75 20; +5.00/0.75 175	RCCS +8 [illegible]	7 2 62 HRC	+8.25 +9.25 6.39; +7.00 5 +8.25 5.12	+6.50/1.00 5; +5.50/1.00 5							Nil O D
M CB 73[illegible]	2 54	17 4 59 HRC	+7.25 +7.25 4.71; +4.75 +4.75 2.04	+5.00 DS; +2.00 DS	RCCS +26 +15	0.51 Nil 17 3 61 Atrop	+3.50 +8.25; +5.25 +5.25 2.30	+5.50/0.25 115; +2.25	[illegible] 1 12 61 Cyclo	+8.50 +8.00 115 [illegible]; +5.50 +5.25 115 2.06	+5.75/0.25 [illegible]; +2.25 DS				O D
F PB [illegible]	5 6 59	1 3 63 Myd	+7.75 +7.75; -8.00 120 +9.25	+4.50 DS; +6.00/0.75 180	LCCS +25 +15	Nil -1.63 7 2 64 Myd	+7.50 +7.50 5.26; +7.00 +7.75 5.33	+3.50 DS; +3.00/0.75 [illegible]							O D
M CA 6[illegible]	12 6 55	29 3 58 Atrop	+9.00 6.38; +9.00 6.38	+5.50; +5.50	RCCS +30 +5	[illegible] 15 6 62 Atrop	+8.00 +9.25 5.96; +8.00 10 +9.00 5.83	+6.25/-1.25 [illegible]; +5.75/-1.00 10	[illegible] 15 11 63 Atrop	+7.75 +9.00 5.68; +7.50 +8.50 5.26	+6.00/-1.25 [illegible]; +5.50/-1.00 5				O D

FIGURE B.2 - Paramount Kendrew Punched Card

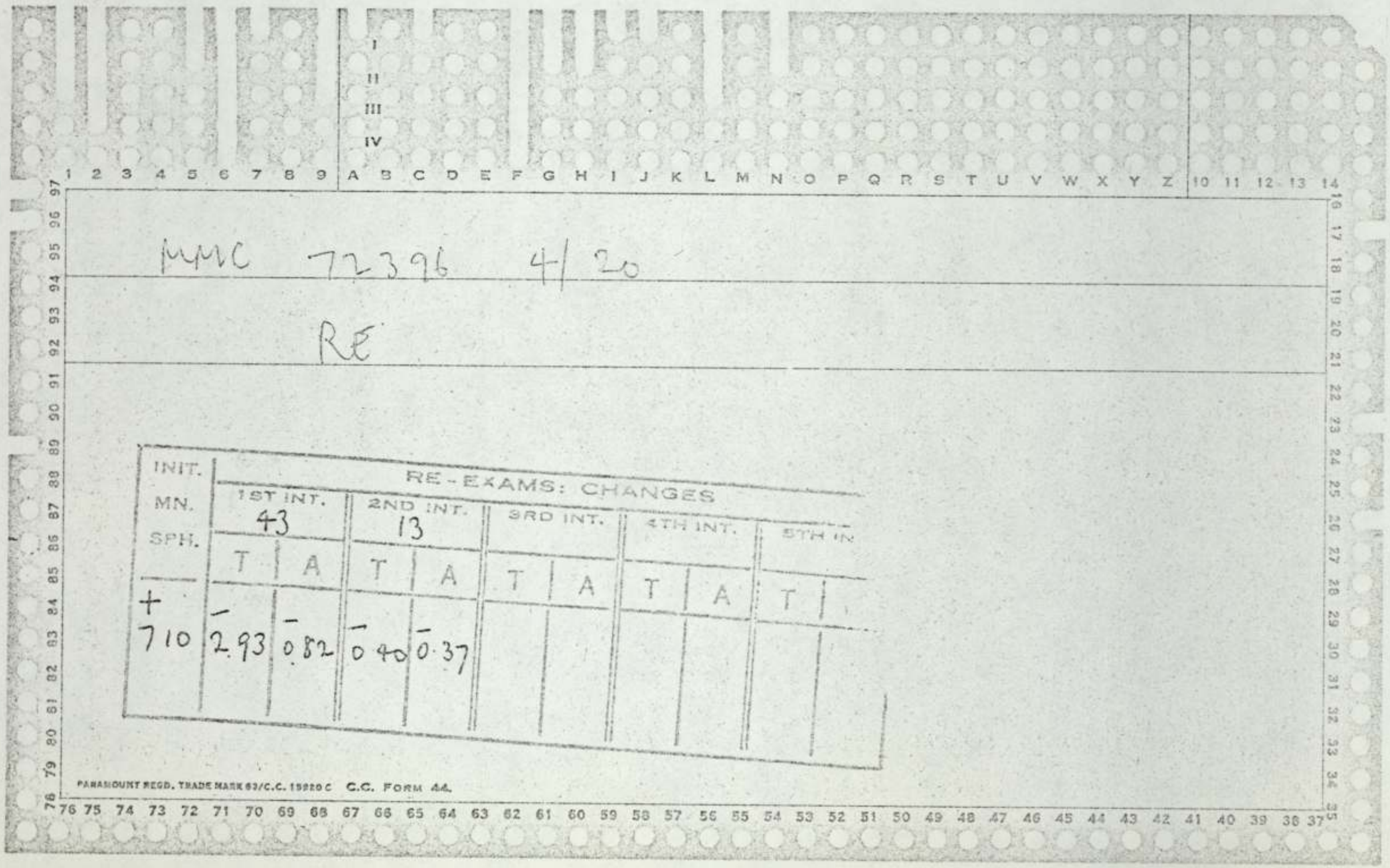
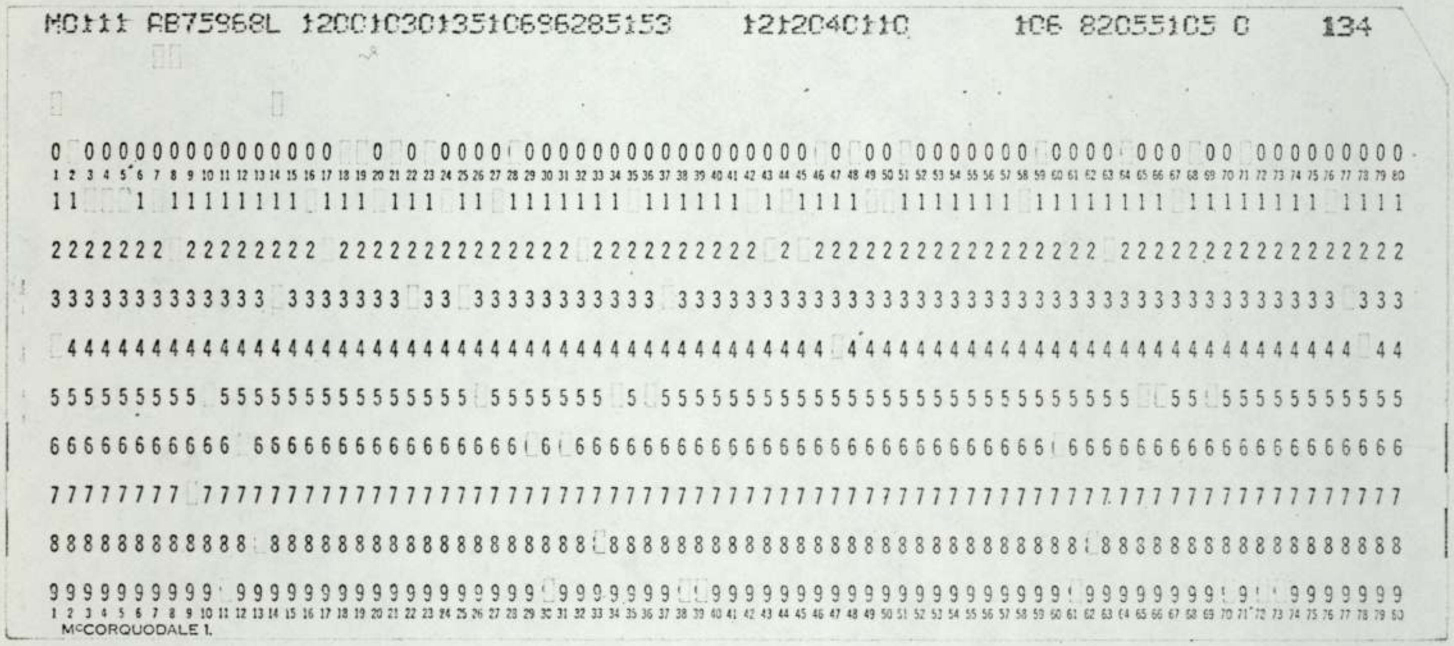


FIGURE B.3. - 80 column punched card



Strabismic state - coded as follows:

Nil	0	
R.C.C.S.	1	
L.C.C.S.	2	
A.C.C.S.	3	
I.C.C.S.	4	
R.C.D.S.	5	
L.C.D.S.	6	
A.C.D.S.	7	
I.C.D.S.	8	
Vertical strabismus	9	column 16

Angle of strabismus - coded as follows:

5°	0	
$6 - 10^{\circ}$	1	
$11 - 20^{\circ}$	2	
$21 - 30^{\circ}$	3	
$31 - 40^{\circ}$	4	column 17

Heterophoria - coded as follows:

Nil	0	
Esophoria	1	
Exophoria	2	
Hyperphoria	3	column 18

Other conditions - coded as follows:

Nil	0	
Vertical/horizontal	1	
Amblyopia only	2	column 19

Treatment - coded as follows:

Nil	0	
Surgery and orthoptics	1	
Orthoptics only	2	
Surgery and orthoptics prior to first examination	3	column 20 (see also col. 78)

Age at first visit in years and months	columns 21 - 24
Number of examinations carried out during the period of the study - exact number entered	column 25
Number of years followed up- exact number entered	column 26

Initial mean sphere ocular refraction - actual values entered except column 27 coded:

Emmetropia	0	
Hypermetropia	1	
Myopia	2	columns 27 - 31

Ocular astigmatism - actual values entered, except nil coded as 9 and entered in column 32	columns 32 - 34
Anisometropia at initial examination - actual values entered, except nil coded as 9 and entered in column 35	columns 35 - 37
Examiner - initial examination	column 38
Level of spectacle correction: the exact degree of ametropic under-correction entered, with the following exceptions: Over plussed one eye — Coded 7 Nil prescribed — Coded 8 Full correction — Coded 9	columns 39 - 41
Method of examination coded according to the cycloplegic used: Nil — 0 Atropine — 1 Cyclopentolate — 2 Homatropine — 3	column 42
Follow-up examination number - exact number entered i.e. 2 - 5	column 43
Interval in months since previous examination - exact values entered	columns 44 & 45
Age in years and months at follow-up exam.	columns 46 - 49
Surgery prior to examination in preceding interval: Coded Nil 0 Surgery 1	column 50 (See also column 78)
Direction of mean sphere refractive change - coded Nil 0 Increased positive 1 Decreased positive 2	column 51
Total change in mean sphere - exact values entered	columns 52 - 54
Annual change in mean sphere ocular refraction - exact values entered	columns 55 - 57
Resultant mean sphere ocular refraction - exact values entered except column 58 coded Emmetropia 0 Hypermetropia 1 Myopia 2	columns 58 - 62

Effect of refractive change on level of anisometropia, coded:

Nil	0	
Increase	1	
Decrease	2	column 63

Resultant degree of anisometropia - exact values entered — columns 64 - 66

Changes in ocular astigmatism - coded:

No change	0	
Increase	1	
Decrease	2	column 67

Degree of change in ocular astigmatism - exact values entered — columns 68 - 70

Changes in axis - coded:

Nil - $<10^o$	0	
10^o	1	
11 - 20^o	2	
21 - 30^o	3	
31 - 40^o	4	
41 - 50^o	5	
51 - 60^o	6	
61 - 70^o	7	
71 - 80^o	8	column 71

Examiner - follow-up examination — column 72

Level of spectacle correction - exact values entered with the following exceptions:

Over-plussed on one eye	7	
Nil prescribed	8	
Full correction	9	columns 73 - 75

Method of follow-up examination coded according to the cycloplegics used:

Nil	0	
Atropine	1	
Cyclopentolate	2	
Homatropine	3	column 76

Relationship between the mean sphere refractive changes in both eyes - coded:

Both no change	0
Both change same direction equal amounts	1
Both change same direction unequal amounts	2
One changes plus, other no change	3
One changes minus, other no change	4
Both change, opposite direction	5

column 77

Surgery - coded as follows:

Nil at any time previously	0	
Nil in interval, but surgery previously on right eye	1	
Nil in interval, but surgery previously on left eye	2	
Nil in interval, but surgery previously on both eyes	3	
Surgery in interval on right	4	
Surgery in interval on left	5	
Surgery in interval on both, or interval on one and previously on the other	6	column 78

The data were finally processed on the Science Research Council's Atlas Computer at Chilton, using the Multiple Variate Counter program, initially developed by Andrew Colin of the University of London Institute of Computer Science (Singh 1968). This facilitated preparation of the tables required as well as much of the statistical analyses, such as the chi-square tests, and correlations (Pearson product moment correlation), which have been carried out.

REFERENCES

ADELSTEIN, A.M. and SCULLY, J. (1967). Epidemiological aspects of squint. Br. med. J. 3, 334 - 338.

AIRY, G.B. (1827). On a peculiar defect in the eye and a mode of correcting it. Trans. Camb. phil. Soc. 267 - 271.

ANON. (1962). Ocular astigmatism - a historical sketch. Optician. 144, 549 - 553.

AWERBACH, M.I. (1900). The dioptrics of refraction (in Russian). Thesis, Moscow. Cited by Sorsby 1934.

BALABANOV, V.I. (1967). Correction of myopia in schoolchildren. Vest. Oftal. 80, 84 - 85.

BALDWIN, W.R. (1964). The relationship between axial length of the eye and certain other anthropometric measurements of myopes. Am. J. Optom. 41 - 9, 513 - 522.

BALDWIN, W.R. (1967). Clinical research and procedures in refraction. Synopsis of the Refractive state of the eye. A Symposium. Am. Acad. Optom. Series Vol. 5. 39 - 59. Burgess Publishing Co. Minneapolis.

BALL, J.M. (1919). Modern ophthalmology. Philadelphia, Davis. Ed. 4. p. 728. Cited by Cook and Glasscock 1951.

BARRIE, S. (1922). The incidence of squint at various ages. Trans. ophthal. Soc. U.K. 42, 273 - 277.

BEDROSSIAN, R.H. (1964). The effect of atropine on progressive myopia. Paper presented at the First International Conference on Myopia, New York City. (Unpublished). Cited by F. A. Young 1965.

BLUM, H., PETERS, H.B., BETTMAN, J.W. (1959). Vision screening for elementary schools - the Orinda study. Berkeley, Calif. Univ. of California Press.

BOTHMAN, L. (1932). Refraction changes in the eyes of children under 6 years of age. Archs. Ophthal. 7, 294 - 296.

BRICKLEY, P.M., and OGLE, K.N. (1953). Residual accommodation under homatropine cocaine cycloplegia. Am. J. Ophthal. 36, 649.

BRISSIMIS, N. (1965). The myopical development during adolescence (Greek with Eng. Summary). Am. Ophthal (Athens) 2, 110 - 116.

BROWN, C.H. (1902). The Opticians Manual - Vol 2. Keystone, Philadelphia.

BROWN, E.V. and KRONFELD, P.C. (1930). The refraction curve in the U.S.A. with special reference to the changes in the first two decades. Proc. XIII. Int. Congr. Ophthal. I, 87 (Amsterdam).

BROWN, E.V.L. (1936). Apparent increase in hyperopia up to age of nine years. Am. J. Ophthal. 19, 1106.

BROWN, E.V.L. (1938). Net average yearly changes in refraction of atropinized eyes from birth to beyond middle life. Archs.Ophthal. 19 - 5, 719 - 734.

BROWN, E.V.L. (1942). Use - abuse theory of changes in refraction versus biologic theory. Archs. Ophthal. 28 - 5. 845 - 850.

BROWN, E.V.L. (1950). A comparison of the refraction of strabismic eyes with that of non-strabismic eyes from birth to the 25th year. Conc. Ophthal. 2, 751 - 756.

BUTLER, T.H. (1922). Changes in refraction. Trans. ophthal. Soc. U.K. 42, 293 - 301.

CAVICCHI, L. and SARAUX, H. (1965). L'evolution des myopies benignes de l'enfant Cliniq. ophtal. 6, 4 - 13.

CIOCCO, A. (1938). Changes in the types of visual refractive errors in children. A statistical study. Public Health Reports 53. 35. 1571 - 1578. (Reprint 1980). U.S. Government Printing Office, Washington.

CLARKE, E. (1924). Treatment of convergent concomitant strabismus. Trans. ophthal. Soc. U.K. 44, 260 - 263.

COHN, H. (1886). The hygiene of the eye in schools: an English translation edited by W. P. Turnbull. Simpkin Marshall & Co. London. Cited by W. N. Suter.

COOK, R.C. and GLASSCOCK, R.E. (1951). Refractive and ocular findings in the newborn. Am. J. Ophthal. 34, 1407 - 1413.

CRONE, R.A. and VELZEBOER, C.M.J. (1956). Statistics on strabismus in the Amsterdam youth. Archs. Ophthal. 55, 455 - 470.

CURTIN, B.J. (1963). The pathogenesis of congenital myopia; a study of 66 cases. Archs. Ophthal. 69 (2), 166 - 173.

CURTIN, B.J. (1967). Refractive anomalies of the eye p. 57. U.S. Department of Health, Education and Welfare. National Institute of Neurological Diseases and Blindness, Bethesda, Maryland. Monograph No. 5.

DELLER, J.F.P., O'CONNOR, A.D., and SORSBY, A. (1947). X-ray measurement of diameters of the living eye. Proc. R. Soc. London. Ser. B. 134, 456 - 467.

DEMING, J. and WASHBURN, A.H. (1963). Application of the Jenss curve to the observed pattern of growth during the first eight years of life in forty boys and forty girls. Hum. Biol. 35, 484. Cited by Tanner, Whitehouse & Takaishi 1966

DOBROMYSLOV, A.N. (1957). Oftal. Zh. 3, 134. Cited by Litvinova et al 1964.

DONDERS, F.C. (1899). An essay on the nature and the consequences of anomalies of refraction. Edited by C. A. Oliver. P. Blakiston's Son & Co. Philadelphia.

DONDERS, F.C. (1864). On the anomalies of accommodation and refraction of the eye. The New Sydenham Society, London.

DORRINGTON. (1900) Refraction and how to refract. Raphael, Wheway & Redfern Ltd.

DOWNING, A.H. (1945). Ocular defects in sixty thousand selectees. Archs. Ophthal, 33, 137 - 143.

DUKE-ELDER, W. STEWART. (1930). An investigation of the effect upon the eyes of occupations involving close work. Br. J. Ophthal. 14, 609 - 620.

DUKE-ELDER, W. STEWART. (1949). Textbook of Ophthalmology. Vol. 4. Henry Kimpton, London.

DUKE-ELDER. W. STEWART. (1970). System of ophthalmology. Vol. 5. Ophthalmic Optics and Refraction. Henry Kimpton, London.

EAMES, T.H. (1964). The effect of anisometropia on reading achievement. Am. J. Optom. 41, 700 - 702.

ELLETT, E.C. (1926). Refractive changes. J. Am. med. Ass. 87, 1453.

ERISMANN, F. (1882). Handbuch der hygiene und der gewerbekrankheiten. M von Pettenkofer, H. W. von Ziemssen. Cited by W. N. Suter.

FANTL, E.W.and PERLSTEIN, M.A. (1967). Refractive errors in cerebral palsy, their relationships to the causes of brain damage. Am. J. Ophthal. 63 - 4, 857 - 863.

FICK, A.E. (1908). Diseases of the eye and ophthalmoscopy. J. K. King and Son, Manchester.

FRANCESCHETTI, A., and LUYCKZ, J. (1967). Study of the emmetropization effect of the lens by the method of ultrasound echography. (French). Annls. Oculist. 200. 177 - 190.

FRANCIS, J.L. (1961). Some measurements on myopic eyes. Trans. International Ophthalmic Optical Congress.

FRANCIS, J.L. (1963). Myopia. Optician. 145, 529.

FRANDSEN, A.D. (1960) Occurrence of squint - a clinical statistical study on the prevalence of squint and associated signs in different groups and ages of the Danish population. Acta. ophthal. Suppl. 62. Munksgard, Copenhagen.

FUCHS, E. (1924). Textbook of ophthalmology. Philadelphia, Lippincott. Ed. 8, p. 187 - 194. Cited by Cook & Glasscock 1951.

GARDINER, P.A. (1954). The relation of myopia to growth. Lancet. 266, 476 - 479.

GARDINER, P.A. (1955). Physical growth and the progress of myopia. Lancet. 269 (2), 952 - 953.

GARDINER, P.A. (1956). Observations on the food habits of myopic children. Bri. med. J. II, 699 - 700.

GARDINER, P. (1963). Refractive errors and cerebral palsy. Visual Disorders & Cerebral Palsy. Little Club Clinics in Developmental Medicine No. 9. National Spastics Society Medical Education and Information Unit. William Heinmann Medical Bks.Ltd. London.

GERNET, H. (1964). Achsenlange und refraktion lebender augen von neugeborenen. Albrecht v. Graefes. Arch. Ophthal. 166, 530 - 536. Abstract in Ophthal. Lit. Lond. 1964. 148.

GERNET, H., and OLBRICH, E. (1968). L'exces de la combe de refraction de l'oeil humain et ses causes. Bull. Soc. belge Ophtal. 149, 423 - 432. 4.

GILES, G.H. (1950). The distribution of visual defects. Br. J. physiol. Optics. 7 (4), 3 - 32.

GOLDSCHMIDT, E. (1969). Refraction in the newborn. Acta ophthal. 47 - 3, 570 - 578.

GOLDSCHMIDT, E. (1968). On the aetiology of myopia. Acta ophthal. Supplementum 98.

GOSTIN, S.B. (1964). Prophylactic management of myopia. Paper presented at the First International Conference on Myopia. New York City. (Unpublished). Cited by F. A. Young 1965.

GOULD, G.M., and PYLE, W.L. (1905). Diseases of the eye. Blakiston's Son & Co. Philadelphia.

GRAHAM, M.V., and GRAY, O.P. (1963). Refraction of premature babies' eyes. Brit. med. J. I, 1452 - 1454.

GRIGNOLD, A., and RIVARA, A. (1968). Observations biometriques sur l'oeil des enfants nés à terme et prématures au cours de la première année. Annls. Oculist. 201. 817 - 826.

GULLSTRAND, A. (1909). Appendices. Handbuch der Physiologischen Optik. Erster Band. H. von Helmholtz.

HARTRIDGE, G. (1896). Refraction of the eye. J & A Churchill. London.

HEATH, G.G. (1967). Discussion of papers. Synopsis of the refractive state of the eye - a symposium. Am. Acad. Optom. Series Vol. 5. p. 91 - 92. Burgess Publishing Co. Minneapolis.

HELMHOLTZ, H. von. (1909). Handbuch der Physiologischen Optik. Erster Band. Verlag von Leopold Voss, Hamburg and Leipzig. Translated and edited by J. P. C. Southall, Dover Publications Inc. New York. 1962. p. 358 - 382.

HERM, R.J. (1965). Refraction of children. Int. Ophthal. Clin. 5, 413 - 422.

HERRNHEISSER, J. (1892). Die refraktionsentwicklung des menschlichen auges. Z. Heilk. 13, 348. Cited by Cook and Glasscock.

HIGGINS, C. (1903). A manual of ophthalmic practice. H. K. Lewis, London. p. 64.

HILL, A.B. (1961). Principles of medical statistics. The Lancet, London. 7th edition.

HIRSCH, M.J. and WEYMOUTH, F.W. (1947). Notes on ametropia - a further analysis of Stenström's data. Am. J. Optom. 24 (12), 601 - 608.

HIRSCH, M.J. (1952). The changes in refraction between the ages of 5 and 14 - theoretical & practical considerations. Am. J. Optom. 29 - 9. 445 - 459.

HIRSCH, M.J. (1953). Sex differences in the incidence of various grades of myopia. Am. J. Optom. 30 (3), 135 - 138.

HIRSCH, M.J. (1955). The Ojai longitudinal study of refractive state. Am. J. Optom. 32, 3. 162 - 165.

HIRSCH, B.J. (1961). A longitudinal study of refractive state of children, during the first six years of school - a preliminary report of the Ojai study. Am. J. Optom. 38, 10. 564 - 571.

HIRSCH, M.J. (1962). Relationship between refraction on entering school and rate of change during the first six years of school - an interim report from the Ojai Longitudinal Study. Am. J. Optom. 39, 2. 51 - 59.

HIRSCH, M.J. (1963). Changes in astigmatism during the first eight years at school - an interim report from the Ojai Longitudinal Study. Am. J. Optom. 40, 3. 127 - 132.

HIRSCH, M.J. (1964 a) Predictability of refraction at age 14 on the basis of testing at age 6 - interim report from the Ojai Longitudinal Study. Am. J. Optom. 41 - 10. 467 - 573.

HIRSCH, M.J. (1964 b) The Longitudinal Study of Refraction. Am. J. Optom. 41, 3. 137 - 141.

HIRSCH, M.J. (1964 c) The refraction of children. Vision of children - an optometric symposium. Ed. M. J. Hirsch and R. E. Wick, 145 - 172. Hammond, Hammond & Co. Ltd. London.

HIRSCH, M.J. (1964). Refraction of children. Am. J. Optom. 41 - 7, 395 - 399.

HIRSCH, M.J. (1965). The prevention and/or cure of myopia. Am. J. Optom. 42, 6, 327 - 336.

HIRSCH M.J. Ed. (1967). Synopsis of the refractive state of the eye: a symposium. American Acad. of Optometry. Series Vol. 5. Burgess Publishing Co. Minneapolis.

HIRSCH, M.J. (1967). Anisometropia: a preliminary report of the Ojai Longitudinal Study. Am. J. Optom. 44, 9. 581 - 585.

HIRSCH, M.J. and DITMARS, D.L. (1969). Refraction of young myopes and their parents - a reanalysis. Am.J. Optom. 46. 1. 30 - 32.

HOLLOWAY, T.B. (1926). Discussion on paper by E. C. Ellett on Refractive Changes read before section on ophthalmology at seventy seventh annual session of the Americal Medical Association Dallas Texas. J. Am. med. Ass. 87, 18. 1458 - 1459.

HOLMES SPICER, W.T. (1897). Nettleship's diseases of the eye. J. & A. Churchill, London.

HONG, S.K., KIM, S.D., and LEE, J.W. (1967). Refraction in schoolchildren. J. Korean Ophthal. Soc. 8, 7 - 10. Abstract in Ophthal. Lit. Lond. 1968 21, 5.

HORI, M. (1964). Analysis of accommodation in myopia - three studies on myopic conditions in children and youths. J. clin. Ophthal, Tokyo. 18, 307 - 314.

HORWICH, H. (1964). Anisometropia amblyopia. Am. orthopt. J. 14, 99 - 104.

JACKSON, C.R.S. (1964). Hypermetropic anisometropia. Br. orthop. J. 21, 106 - 110.

JACKSON, E. (1918). Common changes in regular astigmia and their causes. Trans. Sect. Ophthal. Am. med. Ass. 88 - 103.

JACKSON, E. (1920). Changes in refraction with age. Am. J. Ophthal. 3 (3), 228 - 230.

JACKSON, E. (1928) Changes in the refraction of the eye. Trans. Am. Acad. Ophthal. Oto-lar. 33, 26 - 37.

JACKSON, E. (1931). Norms of refraction. Trans. Sect. Ophthal. Am. med. Ass. 174 - 190.

JACKSON, E. (1931). The control of myopia. Am. J. Ophthal. 14, 719 - 725.

JACKSON, E. (1932). Changes in ocular refraction. Bull. Am. Coll. Surg. 16, 50 - 54.

JACKSON, E. (1933). Changes in astigmatism. Am. J. Ophthal. 16, 967.

JULER, H.E. (1904). Ophthalmic Science and Practice. Smith Elder & Co. London.

KANEFUJI, M. (1953). Correlation among refractive factors. Acta Soc. ophthal. jap. 57, 85 - Abstract in Ophth. Lit.Lond. 1953. 7, 37.

KÄSTNER. (1755). Vollständinger Lehrbegriff der Optik. Altenburg. Cited by Duke-Elder, Textbook of Ophthalmology Vol. IV. H. Kimpton, London. 1949.

KAZAS, I.I. (1913). Vest. Oftal, Kiev. II. 829.
Cited by A. F. Korablev 1964.

KEINER, E.C.J.F. (1968). The early treatment of strabismus convergens. Ophthalmologica, Basel. 156, 20-24.

KELLMER PRINGLE, M.L., BUTLER, N.R., and DAVIE, R. (1966) 11,000 seven year olds. First report of the National Child Development Study (1958 Cohort). Longmans Green and Co.Ltd. London.

KIMURA, T. (1965). Developmental change of the optical components in twins. Acta Soc. ophthal. jap. 69. 963 - 969.

KORABLEV, A.F. (1964). On the question of the alteration of clinical refraction in children. Oftal. Zh. (2), 83 - 87.

KRONFELD, P.C. and DEVNEY, C. (1930). The frequency of astigmatism. Archs. Ophthal. 4. 873 - 884.

KUBIŠTOVÁ, V. (1968). Contribution to the genesis of anisometropia (in Czech.) Cs. oftal. 24. 263 - 265. 4. Abstract in Ophthal. Lit. Lond. 1968. 22, 3. 2313.

KULAKOVSKAYA, T.S. and PILMAN, N.I. (1968). Optical correction and progressive myopia (in Russian). Vest. Oftal, 81. 88 - 89. 5. Abstract in Ophthal. Lit. Lond. 1969. 22. 5. 4699.

LAWSON, G. (1877). Diseases and injuries of the eye. Henry Renshaw, London.

LEARY, G.A. (1970). The reconciliation of genetically determined myopia with environmentally induced myopia. Am. J. Optom 47. 9. 702 - 709.

LEBENSOHN, J.E. (1960). Donders and astigmatism. Am. J. Ophthal 49. 1053 - 1056.

LITVINOVA, M.P., VOLOKITENKO, A.E., and PIKALOVA, L.D. (1964) Refraction and binocular vision in children under school age. Oftal. Zh. 2. 87 - 91.

LOBASOV, N.I. (1912). Vest. Oftal, Kiev. 6. 413.
Cited by A. F. Korablev 1964.

LONDON COUNTY COUNCIL ANNUAL REPORT OF THE COUNCIL (1930). Vol. V (No. 2874) p. 8.

LONDON COUNTY COUNCIL ANNUAL REPORT OF THE COUNCIL (1931). Vol. V (No. 2927) p. 9.

LONDON COUNTY COUNCIL ANNUAL REPORT OF THE COUNCIL (1932). Vol. V. (No. 2986) p. 8.

LONDON COUNTY COUNCIL ANNUAL REPORT OF THE COUNCIL (1933). Vol. V. (No. 3072) p.7.

LONGMORE, T. (1888). Illustrated Optical Manual. Longmans, Green & Co. London.

LOSEV, N.A. (1968). A brief statistical analysis of the ocular refraction development in schoolchildren of the Zhloba district (In Russian). Vest. Oftal, 81. 84 - 86.

LUDLAM, W.M., WITTENBERG, S., and ROSENTHAL, J. (1965). Measurements of the ocular dioptric elements utilizing photographic methods. Part I. Errors analysis of Sorsby's photographic ophthalmophakometry. Am. J. Optom. 42. 394 - 416.

LUYCKZ, J. (1966). Mesure des composantes optiques de l'oeil du nouveau - né par échographie ultrasonique. Archs. Ophthal. Rev. gen. Ophthal. 26 - 2. 159 - 170

LYLE, T.K. (1950), Worth and Chavasses Squint. Bailliere, Tindall & Cox, London. 8th edition. 254 - 255.

McILROY, J.H. (1928). London County Council Annual Report of the Council 1928. 3 (2), 86 - 87.

McILROY, J. (1932). Investigation into the incidence and progress of myopia in children. London County Council Annual Report of the Council 1932. 4 (3). (No. 3013) 40 - 53.

MACKENZIE, W. (1840). A practical treatise on the diseases of the eye. Longman Orme Brown Green & Longmans, London. 3rd edition. p.789 - 795.

McLAREN, D.S. (1963). Malnutrition and the eye. Academic Press New York and London. p. 310.

NcNEIL, N.L. (1955). Patterns of visual defects in children. Br. J. Ophthal. 39. 688 - 701.

McVAIL, E.M. (1929). London County Council Annual Report of the Council. 1929. 3 (2), 109 - 110.

McVAIL, E.M. (1932). London County Council Annual Report of the Council. 3 (2). (No. 2977). 34 - 35

McVAIL, E.M. (1933). London County Council Annual Report of the Council 1933. 3. (2). (No. 3054). 89 - 90.

MARIN-AMAT, M. (1956). Les variations physiologiques de la combine de la cornée pendant la vie. Leur importance et transcendance dans la réfraction oculaire. Bull. Soc. belge Ophthal. 113, 251 - 293.

MARRON, J. (1940). Cycloplegia and mydriasis by use of atropine scopolamine and homatropine - paradrine. Archs. Ophthal. 23. 340-350.

MATSUO, C. (1965). Studies on spectacles correcting corneal astigmatism for the prevention of progress in myopia. Report 2. on the variation in corneal astigmatism. Acta Soc. ophthal. jap. 69. 145 - 154.

MAUTHNER, L. (1876). Vorlesungen ueber die Optischen Fehler des Auges. Wilhelm, Braumuller, Wien.

MAZEPA, G.M. (1967). Results of a thorough examination of the eye in infants in Saratov (in Russian). Oftal. Zh. 22. 151 - 154.2.

MEHRA, K.S., KHARE, B.B., and VAITHILINGAM, E. (1965). Refraction in full term babies. Br. J. Ophthal. 49. 276 - 277.

MILES, P.W. (1962). Should the myopic child wear glasses all the time? Am. J. Ophthal. 53. 866- 867.

MILLER; F.J.W., COURT, S.D.M., WALTON, W.S., and KNOX, E.G. (1960). Growing up in Newcastle upon Tyne. Oxford University Press, London.

MITCHELL, D.W.A. (1959). The use of drugs in refraction. British Optical Association, London. 2nd Ed.

MIZINA, A.V. (1967). The effect of optical correction on the progress of myopia. Vest. Oftal. 80. 81 - 82.

MOLNAR, L. (1967). Über die Vererbung des Schielens. Klin. Mbl. Augenheilk. 150. 557 - 568. Abstract in Ophthal. Lit. Lond. 21.1.

MOLNAR, L. (1970). Changes of refraction during life. The stabilisation of the eyeball (in German). Klin. Mbl. Augenheilk. 156. 3. 326 - 339. Abstract in Ophthal. Lit. Lond. 24. 1. 212.

MORAX, V. (1907). Précis d'Ophtalmologie. Masson et Cie Paris.

MORGAN, A.L. and PASHBY, T.J. (1950). Refraction in children. Trans. Can. ophthal. Soc. p. 109.

MORGAN, M.W. (1960). The change in ametropia with age. Can. J. Optom. 22 (4). 83 - 88.

MORGAN, M.W. (1967). Discussion of papers. p. 99. Synopsis of the Refractive state of the eye, - a symposium. Am. Acad. Optom. Series. Vol. 5. Burgess Publishing Co. Minneapolis.

MORRA, M. (1967). Evoluzione della miopia nel bambino (contributo clinico). Boll. Oculist. 46. 783 - 796. Abstract in Ophthal. Lit. Lond. 1969. 21. 6. 5831.

de MÛELENAERE, H.(1970) Les ametropies. Bull. Soc. belge Ophtal. 154

NAKAJIMA, A. (196). The heritability estimates of the optical components of the eye and their mutual relationships of a new method of measurement on twins - proceedings of the second International Congress of Human Genetics, Rome, Instituto G. Mendel, p 280. Abstract Am. J. Ophthal. 1968.

NAKAJIMA, A. (1968. Refractive elements of the eye as metric traits. (Japanese with Eng. summary). Acta Soc. ophthal. jap. 72. 2059-2082.

NORDENSON, E. (1883). Recherches ophtalmométriques sur l'astigmatisme de la cornée chez des escoliers de 7 à 20 ans. Annls. Oculist. 89. 110.

NORDLÖW, W. (1951). Spontaneous changes in refraction and angle of squint together with the state of retinal correspondence and visual acuity in concomitant convergent strabismus during the years of growth. Acta. ophthal. 29. 383 - 421.

NORRIS, W.F. and OLIVER, C.A. (1894). A textbook of ophthalmology. Y. J. Pentland. Edinburgh & London.

OGIELSKA, E,, CZEREK-JAGUCZANSKA, H., PACYNSKA. (1967). The problem of refractive anomalies in school children and students (In Polish). Klin, oczna. 37. 721 - 728.

OTSUKA, J. (1968). Supplementary studies on the genesis and treatment of myopia (In Japanese with Eng. Summary). Acta. Soc. ophthal. jap. 72. 2012 - 2058.

OTSUKA, J. (1969). Can Dr. Chikashi Sato insist that acquired myopia is caused only by close work? (In Japanese with English summary). Rinsho Ganka 23. 395 - 398.

PACYNSKA, J., OGIELSKA, E., CZEREK-JAGUCZANSKA, H. (1968). Studies on the development of errors of refraction in schoolchildren. Acta. med. pol. Vars. 9. 149 - 161.

PENDSE, G.S., DAN DE KAR, V.M., BHAVE, L.S. (1951). Preliminary note on study of the refractive state with special reference to myopia. Archs. Ophthal. 45 (2). 168.

PILMAN, N.I. (1959). Functional treatment of collaborating squint in children (In Russian). Ukranian Medical Publishing House. Cited by Litvinova et al 1964.

RANDALL, B.A. (1885). The refraction of the human eye; a critical study of the statistics obtained by the examination of the refractions, especially among schoolchildren. Am. J. med. Sci. 89. 123 - 152.

RANDALL, B.A. (1888-1890). Can hypermetropia be healthfully outgrown? Trans. Am. ophthal. Soc. 657. Cited by E. Jackson Bull. Amer. Coll. Surg. 1932. p. 51.

REFRACTIVE ANOMALIES OF THE EYE. (1967). U.S. Department of Health, Education and Welfare. National Institute of Neurological Diseases & Blindness, Bethesda, Maryland. Monograph No. 5.

REICH. (1883). Albrecht v. Graefes Arch. Ophthal. 29. 2. 303. Cited by W. N. Suter.

ROBB, R.M., and PETERSEN, R.A. (1968). Cycloplegic refractions in children. J. Ped. Ophthal. 5. 110 - 114.

ROSS, J.S. (1952). The National Health Service in Great Britain. Oxford University Press, London.

RUETE, C. G. Th. (1855). Lehrbuch der Ophthalmologie fur Aerzte und Studirende. Druck und Verlag von Friedrich Vieweg und Sohn - Braunschweig, Erster Band. p. 234.

RUSKELL, G.L. (1967). Some aspects of vision in infants. Br. orthop. J. 24. 25 - 31.

SANTONASTASO, A. (1930). La Refrazione oculare nei primi Anni di Vita. Annali Ottal. Clin, ocul. 58. 852 - 885. Abstract in Br. J. Ophthal. 16. p 48. 1932.

SATO, T. (1965). Discussion on myopia in Japan. Trans. ophthal. Soc. N.Z. 17. 109 - 115.

SATO. T. (1968). So-called school myopia with emphasis on its causes and preventative measures. (Japanese with Eng. Summary). Acta. Soc. ophthal. jap. 72. 1981 - 2011.

SAVOLYUK, M.M. (1968) Optical correction and progressive myopia. Vest. Oftal. 81. 82 - 83.

SCHOLZ, D. (1967). Ergebenisse von vorsorgeuntersuchingen an 12,000 vierjährigen in West Berlin. Bundesgesundheitsblatt 10. 373 - 379. Abstract in Ophthal. Lit. Lond. 21. 6. 6702. 1969.

SCHNABEL, I., and HERRNHEISER, I. (1895). Ueber staphyloma posticum, conus and myopie. Z. Heilk. 16. I. Cited by A. Sorsby 1934.

de SCHWEINITZ, G.E.. (1921) Diseases of the eye. Philadelphia, Saunders, Ed. 3. p. 128 - 134. Cited by Cook & Glasscock 1951.

SICHEL. (1845). Des lunettes et des états pathologiques consécutifs a leur usage irrationnel. Annls. Oculist Vol. XIII. pp. 5, 49, 109, 169. Vol. XIV. pp.14, 193. Bruxelles.

SINGH, G. (1968). A Manual of the Multiple Variate Counter. University of London Atlas Computing Services, London.

SLATAPER, F.J. (1950). Age norms of refraction and vision. Archs. Ophthal. 43. 3. 466 - 481.

SMEE, A. (1854). The eye in health and disease. Longman & Co. London. 2nd. ed. p. 33.

SMITH, R. (1738). A compleat system of opticks. Vol. II. 1738. p. 2 authors remarks.

SNYDACKER, D. (1964). Strabismus. J. Am. med. Ass. 190. 693 - 694.

SOOD, N.N. and GUPTA, S. (1966). Refractive changes in malnourished children. Orient. A. Ophthal. 4. 264 - 269.

SORSBY, A. (1932). School myopia. Br. J. Ophthal. 16 (4). 217 - 222.

SORSBY, A. (1933). Normal refraction of infants and its bearing on development of myopia. London County Council Annual Report of the Council 1933.4. Pt. 3 (No. 3089). 55 - 59.

SORSBY, A. (1934). The pre-myopic state; its bearing on the incidence of myopia. Trans. ophthal. Soc. U.K. 54. 459 - 467.

SORSBY, A. (1940). The problem of myopia. Modern trends in ophthalmology. Ed. by R. Ridley & A. Sorsby. Chap. 24. Butterworth & Co. Ltd. London.

SORSBY, A. and SHERIDAN, M. (1953). Changes in the refractive power of the cornea during growth; observations on the rabbit. Br. J. Ophthal, 37(9),555 - 557.

SORSBY, A., SHERIDAN, M., MOORES, N., HAYTHORNE, J. (1955). Hyoscine cycloplegia in children. Lancet II. 214 - 216.

SORSBY, A., BENJAMIN, B., DAVEY, J.B., SHERIDAN, M., TANNER, J.M. (1957). Emmetropia and its aberrations. Spec. Rep. Ser. med. Res. Coun., Lond. No. 293. H.M. Stationery Office.

SORSBY, A., and SHERIDAN, M. (1960). The eye at birth - measurement of the principal diameters in 48 cadavers. J. Anat. 94. 193.

SORSBY, A., SHERIDAN, M., LEARY, G.A., BENJAMIN, B. (1960). Vision, visual acuity and ocular refraction of young men. Br. med. J. May 7th. 1394 - 1398.

SORSBY, A., BENJAMIN, B., SHERIDAN, M. (1961). Refraction and its components during the growth of the eye from the age of three. Spec. Rep. Ser. med. Res. Coun., London. No. 301. H.M. Stationery Office.

SORSBY, A., BENJAMIN, B., and SHERIDAN, M. (1961). Unpublished data of study on refraction and its components during the growth of the eye from the age of three. National Institute for Medical Research Library, London.

SORSBY, A., LEARY, G.A., and RICHARDS, M.J. (1962 a) Correlation ametropia and component ametropia. Vision Res. 2. 309 - 313.

SORSBY, A., LEARY, G.A., and RICHARDS, M.J. (1962 b) The optical components in anisometropia. Vision Res. 2. 43 - 51.

SORSBY, A., SHERIDAN, M., and LEARY, G.A. (1962). Refraction and its components in twins. Spec. Rep. Ser. med. Res. Coun., London. No. 303. H.M. Stationery Office.

SORSBY, A. (1964). The nature of spherical refractive errors. Modern Ophthalmology ed. A. Sorsby, Butterworth, London. Vol. 3.

SORSBY, A., and FRASER, G.R. (1964). Statistical note on the components of ocular refraction in twins. J. Med. Genet. I. 47.

SORSBY, A., LEARY, G.A., and FRASER, G.R. (1966). Family studies on ocular refraction and its components. J. Med. Genet. 3. 269 - 273.

SORSBY, A., and LEARY, G.A. (1970). A longitudinal study of refraction and its components during growth. Spec. Rep. Ser. med. Res. Coun., Lond. No. 309. Suppl. to No. 301. H.M. Stationery Office.

SORSBY, A. (1970). Ophthalmic Genetics. Butterworths. 2nd ed. London.

SORSBY, A. (1970). Transmission of refractive errors within Eskimo families- letter to Editor. Am. J. Optom. 47. 3. 244 - 246.

SOURASKY, A. (1928). Race, sex and environment in the development of myopia. Br. J. Ophthal. 12. 197.

SOURASKY, A. (1928). The growth of the eye and the development of myopia: a study during the school period. Br. J. Ophthal. 12. 625-644.

STEIGER, A. (1913). Die entstchung der Sphärischen Refraktionen des menschlichen auges. Verlag von S. Karger. Berlin.

STENSTRÖM, S. (1946). Untersuchungen über die variation und kovariation der optischen elemente des menschlichen auges. Acta ophthal. Suppl. 26.

STENSTRÖM, S. (1948). Investigation of the variation and the correlation of the optical elements of human eyes. Am. J. Optom. 25. 218 - (Translation by D. Woolf).

STENSTRÖM, S. (1948). Variations and correlations of the optical components of the eye. Modern Trends in Ophthalmology Vol. 2 chap. 9. Ed. by A. Sorsby. Butterworth & Co. London.

STONE, J., and LEARY, G. (1957). Changes in refraction during growth; the significance of changes in corneal power as observed in the rabbit. Brit. J. physiol. optics. 14. 90 - 94.

STRAUB, M. (1901). Die normale refraktion des menschlichen auges. Zeitschr. f. Physiol. d. Sinnersorg. XXV. S.78. Cited by Helmholtz, Handbuch der Physiologischen Optik, Erster Band 1909 p.358 - 382, translated by J. P. C. Southall, Dover Publications New York. 1962.

STRAUB, M. (1909). Über die Ätiologie der Brechungsanomalien des auges und den ursprung der emmetropie. Albrecht v Graefes Arch. Ophthal. LXX. I. S. 130. Cited by Helmholtz, H. von. Handbuch der Physiologischen Optik. Erster Band. p. 358 - 382. Translated and edited by James P. C. Southall, Dover Publications, New York. 1962.

STRAUB, M. (1918-19). La part de l'hérédité et de l'étude dans le développement de la myopie. Archs. Ophthal., Paris. 36. 68.

SUTER, W.N. (1903) The refraction and motility of the eye. Lea Brothers & Co. New York.

SWANZY, H.R. (1900). A handbook of the diseases of the eye and their treatment. H. K. Lewis, London.

TANNER, J.M. (1963). Rozwój w okresie pokwitania. PZWL Warszawa. Cited by Pacynska et al 1968.

TANNER, J.M., WHITEHOUSE, R.H., TAKAISHI, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British Children. 1965. Archs. Dis. Childh. 41. 454 - 471. 613 - 635.

THOMPSON, E. (1924). Some considerations regarding the aetiology, the incidence and the course of concomitant convergent strabismus which have a bearing upon its treatment. Trans. ophth. Soc. U.K. 44. 238 - 252.

TOKORO, T., and KABE, S. (1964). Relationship between changes in the ocular refraction and refractive components and development of the myopia. Acta Soc. ophthal. jap. 68. 1240 - 1253.

TOKORO, T., and KABE, S. (1965). Treatment of the myopia and changes in optical components. Report 2 . Full or under correction of myopia by glasses. Acta Soc. ophthal. jap. 69. 140 - 144.

TOKORO, T., NAKAO, H., and OTSUKA, M. (1967). Progress of myopia and changes of refractive components - 6 cases followed up for five years. Acta. Soc. ophthal. jap. 71. 30 - 38.

TOKORO, T., and SUZUKI, K. (1968). Significance of changes of refractive components in the development of myopia during seven years.(Japanese with Eng. Summary). Acta. Soc. ophthal. jap. 72. 1472 - 1477. (Also Jap. J. Ophthal. 13. 27 - 34. 1969).

TOMAS, J.G. (1965). Consideraciones en Torno a la refraccion del recien nacido. Archos. Soc. oftal. hisp - am. 25. 666 - 675.

TRON, E.J. (1929). Variations statistische untersuchungen über refraktion. Albrecht v. Graefes Arch. Ophthal. 122. 1. Cited by A. Sorsby 1932.

TRON, E.J. (1931). Albrecht v. Gaefes Arch. Ophthal. 124. 454 - Cited by A. Sorsby 1932.

TRON, E.J., (1940). The optical elements of the refractive power of the eye. Modern Trends in Ophthalmology ed. by F. Ridley and A. Sorsby. chap. 23. Butterworth & Co. Ltd. London.

TSCHERNING. M. (1904). Physiologic optics, translated by C. Werland. The Keystone. Philadelphia.

TSVETKOV, V.L. (1970). Pediatric ophthalmology in the U.S.S.R. J. Ped. Ophthal. 7. 4. 238 - 246.

UTKIN, V.F. (1966). Ocular refraction in children and prophylactic measures for abnormalities. Vest. Oftal. 79. 2. 69 - 72.

VAN ALPHEN, G. (1961). On emmetropia and ametropia. Supplementum Ophthalmologica. Basel. 142.

VAN ALPHEN, G. (1967). Refractive anomalies of the eye. U.S. Department of Health, Education and Welfare. National Institute of Neurological Diseases and Blindness. Bethesda, Maryland, Monograph No. 5. 29 - 31.

VORISEK, E.A. (1935). Changes in refraction with convergent strabismus. Am. J. Ophthal. 18. 820 - 826.

WAARDENBURG, P.J. (1954). Squint and heredity. Documenta ophth. 7 - 8. 422 - 494.

WALTON, W.G. Jr. (1950). Refractive changes in the eye over a period of years. Am. J. Optom. 27 (6) 267 - 286.

WANSPA, S., and LIMPAPHAYOM, P. (1965). Vision in school-children in Thailand. Trans. ophthal. soc. N.Z. 17. 106 - 109.

WARE, J. (1813). Observations relative to the near and distant sight of different persons. Phil. Trans. R. Soc. 31 - 50.

WEALE, R.A. (1963). The aging eye. H.K.Lewis, London.

WELLS, W.C. (1811). Observations and experiments on vision. Phil. Trans. R. Soc. 378 - 391

WEYMOUTH, F.W., and HIRSCH, M.W. (1950). Relative growth of the eye. Am. J. Optom. 27 (7). 317 - 328.

WIBAUT, F. (1925). Ueber die emmetropisation und den ursprung der sphärischen refraktionsanomalien. Albrecht v. Graefes Arch. Ophthal. 116. 596. Cited by Cook & Glasscock 1951.

WOLD, K.C. (1949). Hereditary myopia. Archs. Ophthal. 42. 225 - 237.

WOODRUFF, M.E. (1969). Ocular refractive trends in the human eye up to six years of age. PhD thesis, Indiana University, USA.

YAMANAKA, T. (1963). Correlation between tonus of ciliary muscle and astigmatism of cornea (anterior surface). Acta. Soc. ophthal. jap. 67. 475 - 483.

YOUNG, F.A., BEATTIE, R.J., NEWBY, F.J. and SWINDAL, M.T. (1954). The Pullman Study. A Visual survey of Pullman school children. Am. J. Optom. 31. 111 - 121. 192 - 203.

YOUNG, F.A. (1955). An evaluation of the biological and nearwork concepts of myopia development. Am. J. Optom. 32. 7. 354 - 366.

YOUNG, F.A. (1961). The effect of restricted visual space on the primate eye. Am. J. Ophthal. 52. 799 - 806.

YOUNG, F.A. (1965 a). The aetiology of myopia. Optom. wkly. 56. 17 - 24.

YOUNG, F.A. (1965 b). Effect of atropine on the development of myopia in monkeys. Am. J. Optom. 42 (8). 439 - 449.

YOUNG. F.A. (1967 a). Refractive anomalies of the eye. U.S. Department of Health, Education and Welfare. National Institute of Neurological Diseases and Blindness, Bethesda, Maryland. Monograph No. 5. p. 34 - 35.

YOUNG, F.A. (1967 b). Animal experimentation and research on refractive state. Synopsis of the Refractive State of the Eye: A symposium. Am. Acad. Optom. Series. Vol. 5. 26 - 38. Burgess Publishing Co. Minneapolis.

YOUNG, F.A. (1968). The development of simple myopia. Eye, Ear, Nose, Throat, Mon. 47. 171 - 174.

YOUNG, F.A., BALDWIN, W.A., LEARY, G.A., WEST, D.C., BOX, R.A., HARRIS, E., and JOHNSON, C. (1969). The transmission of refractive errors within Eskimo families. Am , J. Optom. 46. 676 - 685.

YOUNG, F.A. (1970). Transmission of refractive errors within Eskimo families - letter to Editor. Am. J. Optom. 47. 3. 246 - 249.

YOUNG, T. (1801). On the mechanism of the eye - The Bakerian Lecture. Phil. Trans. R. Soc. 23 -

ZEEMAN, W.P.C. (1911). Linsenmessungen und emmetropisation. Albrecht v. Graefes Arch. Ophthal. 78. 93. Cited by A. Sorsby 1934.

ZENTMAYER, W. (1911) Changes occurring in the refraction of corrected ametropic eyes. J. Am. med. Ass. 57. 470 - 474.

ZENTMAYER, W. (1923). Changes occurring in refraction of ametropic eyes. Trans. Stud. Coll. Physns. Philad. 45. 376 - 379.