A STUDY OF OCULAR REFRACTION IN WESTERN NEWFOUNDLAND

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by

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ABSTRACT

Myopia is a debilitating condition that, in extreme cases, can cause blindness. For over 100 years, investigators have argued its etiology, with the hereditary and environmental schools polarized to the extreme. It was felt that a study of a population which had been exposed to two types of near work environments and which was fairly stable in composition would further elucidate the relative influences of these factors on refraction.

The population of three communities in Western Newfoundland was studied. These communities had been relatively isolated until about 1956, and had not had formal compulsory education until 1948. Subjects were examined optometrically and psychologically to investigate previously reported associations of ocular refraction with near work, personality and body build. Familial resemblances for refraction and near work were also examined.

The study took place as part of a larger health survey undertaken by the Faculty of Medicine at Memorial University of Newfoundland. Nine hundred and seventy-one subjects, or 80% of the target population were examined.

This study addressed directly refraction, near work, education, heredity, personality and body build, to investigate previously reported associations of these variables. A literature review is presented for each of these reported associations, followed by results of the inves-

tigation.

The findings were that females were more myopic than males and achieved myopia earlier than the males in this population. Those under 30 years of age had more negative mean refraction than those over 30. Those who started school in 1948 were 30 years of age at the time of the study (1974). Those who did substantial near work at work or at leisure had more negative refractions. Near work showed substantial correlation with refraction after adjustment for other influencing variables, at all ages. The parallel fit of mean near work, in hours, to mean refraction by five year age intervals over essentially the entire life span was striking.

The number of persons in this population with uncorrected refractive errors was very high compared to the United States population. This represents a serious public health problem.

It was found that the correlation of first degree relatives for refraction was on the order of .20 to .25, and could have been inflated by familial similarities in near work patterns.

Contrary to previous claims, no association was found for refraction and personality or body build.

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INTRODUCTION

Myopia, or nearsightedness, is that refractive condition of the eye in which distant vision is blurred. This defect can have serious sequelae. Young (1978c) has shown that the probability of a myope developing a detached retina is much higher than that for a non-myope. Even relatively "mild" myopia can limit vocational choice. Airlines do not accept persons with myopia as pilot trainees, and entry into transport or police forces is also difficult for the myope. Nearsighted professional athletes are rare.

Myopia is a common problem which has been recognized for over two thousand years, but its serious study began in the mid-nineteenth century (Duke-Elder, 1970; Goldschmidt, 1968).

The United States Department of Health, Education and Welfare released a report (1978) in which prevalence of refractive error was one of the items studied. The percentage of those wearing glasses who were myopic rose from 30.2% at age 4 to 5, to 87.2% at age 12 to 17. A report prepared by the Department of Consumer Affairs, Government of Canada (1978), estimates that annual wholesale sales of ophthalmic appliances in Canada total $69,425,634.00. The total expenditure for the consumer is of course even greater.

In the last 20 years, several investigators have reported a dramatic increase in myopia in several countries (Young, 1969; Boniuk, 1973; Morgan, 1973; Sato, 1978). Indeed, Morgan (1973) has referred to this phenomenon as an "epidemic of myopia." If it is the case that the prevalence of myopia is increasing, it is important to determine the etiology of myopia, to attempt to find prophylactic measures of early application, and to find predictive tests to apply to children so that those "at risk" can be treated. The savings in discomfort and dollars would be enormous, and in extreme cases, blindness would be prevented.

The indications of epidemic myopia, which will be described in more detail, come from studies of Eskimos and Amerinds, and of Japanese populations. It would be of interest to know whether they are also found in Caucasian populations that have experienced the same environmental changes as have those populations.

Of the various causes suggested for myopia, most fall into genetic or environmental categories. Duke-Elder (1970) presents an extensive list of the suggested causes with supporting studies. The investigation of both familial and environmental factors affecting refraction in the same population would contribute much information on the question of its control.

It is usually impossible to manipulate environmental variables in a study on a human population. If one could find a human population for which environmental factors suspected to influence refraction had remained unchanged until a known point in time, and then one or more of the variables had changed, it would be possible to study the effects of this change on the refraction of that population.

This thesis describes the distribution of refraction in a population to which modern education was introduced relatively recently, and examines the distribution in as many aspects as possible. The population studied lives in an area of Western Newfoundland that was until recently relatively very isolated. Standardized compulsory education began in 1948, the year Newfoundland entered the Canadian Confederation.

From the time the first settlers arrived to the time of the study in 1974, nine generations had passed. Eighty-five percent of the study population were descendants of John and Mary, the original settlers. The population can therefore be considered relatively homogeneous and stable. Movement into or out of the area was only possible by boat until 1956 when work began on an unpaved road into the area.

This investigation was undertaken as part of the West Coast Health Survey (Marshall, 1975). Nine hundred and seventy-one of the inhabitants aged 5 to 97, representing some 80% of the target population, received an ophthalmic examination. These persons were refracted and given a psychological test, in addition to the complete physical examination done by the medical team of the survey. Data were collected on the occupation, educational level, near work and leisure habits of the subjects. The data were analyzed to investigate:

1) The population distribution of refraction by age and sex;
2) The relationship of near work, education, and leisure activities to refraction;
3) Familial resemblances in refraction and near work;
4) The relationship of refraction to personality and physique.

These variables were studied because of previous investigations indicating their influence on refraction. This study was designed to evaluate simultaneously the influences of the above-mentioned factors in a Caucasian population. From a thorough search of the literature on refraction in populations, it would appear that this study is unique in its scope, for it allows for the investigation of refraction distribution, as affected by education, near work, personality, and family, all measured in the same population.

The Optics of Refraction

TERMS AND CONCEPTS

Refractive status of the eye refers to the relative position of the posterior principal focus of the eye's refractive system in relation to the retina of the eye, while accommodation is at rest, or relaxed, i.e. where the rays of light entering the eye come to a focus after passing through the refractive media of the eye.

If the posterior principal focus (PP) falls on the retina, the eye is said to be emmetropic.

If the PP falls in front of the retina, the eye is said to be myopic.

If the PP falls behind the retina, the eye is said to be hyperopic.

Sharp optical imaging on the retina is dependent on the refractive power of all the optical components, their spacing, and the location of the retina relative to the optical system. In myopia, where the PP falls in front of the retina, the optic axis, or length of the eyeball, is too long. There are unusual cases, to be discussed later, where an eye can be myopic and yet have a normal optic axis.

In hyperopia, the reverse is true.

The major optical components determining refraction are the optic axis and the refractive media of the eye, i.e. the cornea, the aqueous humor, the lens, and the vitreous humor.

Accommodation is the process which alters the total refractive power of the eye, i.e. nearer objects are imaged sharply on the retina through accommodation. When the eye accommodates, the anterior surface of the crystalline lens increases in convexity, as does the posterior

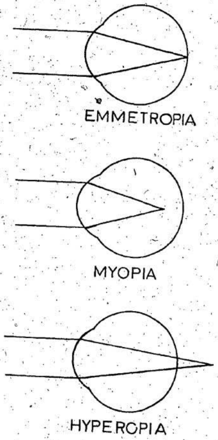

Figure 1. Points of focus for Emmetropia, Myopia, and Hyperopia.

surface, to a lesser degree. The anterior portion of the lens moves forward slightly, while the posterior pole remains nearly fixed. At the same time, the lens thickens while its equatorial diameter decreases. During the act of accommodation, the lens trembles, and the pupil contracts. The ciliary body contracts during accommodation, resulting in a decrease in the diameter of the annulus framed by the ciliary muscle. Paradoxically, the zonules relax during accommodation. When the eye accommodates, the eyes converge, and when the eyes converge, the eyes accommodate.

Accommodation will be treated in more detail later (pp. 21-25)

The Measurement of Ocular Refraction

The refractive state of the eye is measured clinically by retinoscopy. The retinoscope is a hand instrument with a light source that is directed by means of a mirror into the subject's eye. The observer, or refractionist, observes the subject's eye through a peep hole in the center of the mirror. The mirror is moved in different directions so that the shadow of the subject's iris cast on the subject's retina by the light beam can be observed. The shadow, called the "fundus reflex" will move "against" the motion of the mirror, or "with" the mirror's motion, depending upon whether the optic axis of the subject is long or short. If the shadow moves in an against motion, concave lenses are placed in front of the subject's eye until the shadow does not move, that is until "neutralization" has been achieved. Similarly, if the shadow moves with the mirror, convex lenses are placed in front of the subject's eye until neutralization is achieved. In its simplest application, the power of concave or convex lenses at point of neutralization, represents the error of refraction. For technical reasons, +2.00 D. must be subtracted from the end-lens power to account for the observer's distance from the subject (20 inches).* In cases of astigmatism, retinoscopy is more complicated, but the principle is the same.

Retinoscopy is performed with the subject's gaze directed to infinity (20 feet),* called static retinoscopy, and at near (20 inches)* called dynamic retinoscopy. Following this objective procedure, the refraction is refined using the subjective test which requires the subject's cooperation to decide on the final lens power required by the subject for clear vision. This procedure will be described more fully in the Methodology section.

Concave (negative) lenses are used to correct myopia, and Convex (positive) lenses to correct hyperopia. A myopic refraction is sometimes referred to as a negative refraction, and a hyperopic refraction can be called a positive refraction.

The unit of measure describing the power of a lens is called the Dioptre (D.). If the Dioptric power is positive, the lens is convex, and if it is negative, the lens is concave.

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* The use of metric units for acuity and retinoscopy has not been generally established in North America. The equivalents for 20 inches and 20 feet are 50 cms. and 6 m.

Chapter II

EARLIER STUDIES OF REFRACTION

Introduction

Early studies on refraction dealt with two aspects of the question. The first was characterization of the population distributions for refraction, and the second proposed causes for refractive errors, especially myopia. Because of the great interest in myopia, most of the studies in the literature have dealt with this subject, and neglected hyperopia.

In reviewing the early studies, it will be difficult to separate those dealing with distribution, and those dealing with etiology, as in many cases, both aspects are dealt with in the same study.

CAUSES OF REFRACTIVE ERROR

Prior to the investigations into refraction which commenced a little over 100 years ago, the human eye was considered to be made up of various components which had "standard" curves and thicknesses. If these components matched properly, emmetropia was the result.

Any deviation from this was called an "error" of refraction, a term in use even to this day.

Myopia has been recognized since at least the time of Aristotle, but Plempius (1632) was the first to associate the condition with a longer optic axis (cited in Borish,1970). Donders (1864) considered myopia to be an adjustment to the environment; that the eye muscles "squeezed" the eye during convergence, causing the globe to stretch. This theory was accepted at the time by many researchers. A refinement of this theory was proposed by Levinsohn (1925) who worked with primates and introduced the gravitational theory, i.e. close work produced a posture in which the eye hangs down. Gravity pulls on the optic nerve, thus stretching the eye.

Prompted by the work of Donders (1864), Cohn (1867) conducted a study of over 10,000 school children, and proposed the "use-abuse" theory. In his view, constant accommodation at near point led to increased myopia in school children. This theory was strongly supported at the time and has many adherents today.

Because of Cohn's findings (1867), and that of others at the time, illustrating the increase of myopia with increased education (Tscherning, 1882), the hypothesis arose that myopia was due to close work.

There were also those who thought that myopia was an hereditary trait, as did Donders (1864). Although he thought that myopia was caused by the muscles "squeezing" the eyeball, he also postulated that once myopia was acquired, it could be passed on to succeeding generations. Eventually, he supposed, the entire world population would become myopic, and he therefore proposed that drastic measures should be taken to combat this possibility. This led to many meetings by leading researchers and thence to the improvement of lighting in classrooms. Ask (1925) was one of the Scandinavian investigators at the time who attributed a drop in myopia to improved school hygiene.

While the predominant thought at that time was that close work caused an elongation of the eyeball in some way, other factors implicated were: bad nutrition, vitamin deficiencies, calcium deficiences, poor hygiene. Duke-Elder (1970) lists several of these alleged causes of myopia, and their proponents. Some of these early studies will be described where relevant.

The early mechanistic theories gave way to the biological view after the work of Steiger (1913). He appreciated refraction to be a continuum with myopia at one end, and hyperopia at the other, that refraction was distributed normally, just as height, weight, etc. He suggested that there was a wide range of refractive states, which was normally distributed, but that as each ocular component varied normally, there was a compensating mechanism controlling the components that could override any component that varied beyond the norm. In his view, each of the components was primarily inherited, but could be influenced by environmental factors. The compensating mechanism worked in this manner. If, for example in one eye, the cornea was too flat, the axis length would compensate for this anomaly, leading to an emmetropia in that eye. In this view, the optic axis was the component that compensated the most for any other non-normal components. Because, as he thought, all components varied freely, refraction itself must vary freely and follow a Gaussian distribution.

Earlier, Straub (1909) had argued that the ocular components might vary independently in a manner offsetting a longer axis. In studies on distribution of refraction, Wibaut (1926) found however that the distribution curve of refraction was not Gaussian, but that it was skewed to the minus side. Betsch and Scheerer (1929) showed that the curve was not normal, but was leptokurtotic and skewed to the minus side. This has been confirmed by many subsequent studies (Sorsby, 1962; Brown and Kronfeld, 1929; Stenstrom, 1946). Figure 2 taken from Betsch and Scheerer (1929), Sato (1941) and Otsuka (1967) illustrates the typical curve of distribution of refraction.

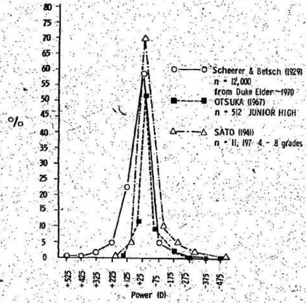

Figure 2. Refractive distribution curves from three studies.

The data of Sato and of Otsuka were superimposed on the display and the axes of Sheerer and Betsch (Duke-Elder, 1970), which were set out in 1 D. intervals in each direction from the modal refraction (+0.25 D.) on the abcissa. The Japanese studies indicate more myopia, and thus proportionately less hyperopia in these frequency distributions. (pp.69-71).

Although most of the early studies were conducted on either clinical material, army recruits, or other pre-selected groups, which would produce unnatural curves by the very nature of the pre-selection, other studies on a broader range of subjects showed similar curves of distribution (Borish, 1970). Coupled with the wide range of materials, there was also a great diversity in experimental techniques used in the studies. However, Sorsby (1966) has pointed out that in spite of these factors, the curves all agree in the most important factors, namely the leptokurtosis and the skewness. In general:

1. The peak of the curve is at or about +0.50 D. and not at plano (0.00 D.).
2. There are more high hyperopes and high myopes than would be expected in a normal distribution.
3. There are more high myopes than high hyperopes, causing the skewness to the minus side.

COMPONENTS OF REFRACTION

It was shown earlier that myopia is caused by the focussing of the PP in front of the retina. This can be caused by a shortened radius of curvature of any one of the refracting surfaces of the eye; a change in the refractive index of any of the media; a decrease in depth of the anterior chamber; or an increase in axial length. That is, myopia can result from variation in any of the ocular components. Because certain of these components are in a constant state of change, it has been impossible to measure all of the components at the same time with any degree of accuracy. However, it has been possible to measure certain components and to measure the refractive error at the same time. The components that have been measured are the radius of the cornea, the length of the optic axis, and anterior chamber depth, while the power of the lens has been computed indirectly from other direct measurements.

After Steiger's (1913) hypothesis, work began on measuring the various optical components which make up the refraction.

Tron (1934) measured corneal curvature, anterior chamber depth, thickness of the lens, anterior and posterior lens radii, power of the cornea, power of the lens, refraction of the eye, and from these direct and indirect measures, he calculated the axial length indirectly. Of these, all but the axial length followed a normal Gaussian distribution. However, Tron found that by removing the values over -6 D. from the data, the axial length curve was also Gaussian. Figure 3 illustrates the distribution of the various components, as shown by Tron (1929), who concluded that the concept of Steiger (1913) was wrong, viz., that refraction was not normally distributed.

Tron also showed that for a given value of any component, there were a variety of possible refractions, i.e. if the eye had a long axis, the other components could compensate for this 'error' in length of axis. Because if those values over -6 D. were removed the axial length curve was also Gaussian, he concluded myopia must be of two types, simple and pathological. However, Titoff (1937) repeated Tron's experiment and found that even if those eyes with posterior pole damage, or those over -6 D. were removed, the axial length curve was still leptokurtotic and skewed to the long side.

There then followed a period of extensive investigation into each of the components by Stenstrom (1946), Sorsby (1966), and van Alphen (1961), inter alios.

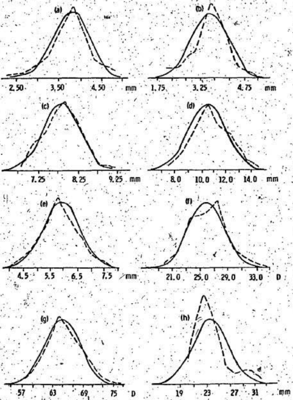

Figure 3. Variability of: a) depth of anterior chamber, b) thickness of lens, c) anterior surface of the lens, d) posterior surface of the lens, e) radius of the cornea, f) refractive power of the lens, g) refractive power of the eye, h) length of the optic axis. (all myopic eyes).

solid line————————normal curve

dotted line------------actual curve

(from Tron, 1929)

Stenstrom (1946) measured 1000 right eyes of 315 females and 685 males using keratometry to measure corneal curvature, and the then new X-Ray technique to measure the axial length. He calculated correlation coefficients between the various elements and found that Tron was correct: all the components followed a Gaussian curve except for axial length. Stenstrom found that Titoff was also correct, that is, that even with conus eyes removed, the distribution for axial length was leptokurtotic and skewed to the long side. Stenstrom also reported some correlation between the components which effected a counter-balancing mechanism or "emmetropisation" of the refraction. In effect, an eye with a long axis would have a flatter cornea to achieve emmetropia. If this were true, there would be more emmetropes than could be seen by chance. He also determined that certain elements contribute more than others to the resultant refraction, with the optic axis being the most important.

Hirsch and Weymouth (1947) confirmed this by reanalyzing Stenstrom's data and concluded using correlations that the axial length contributed twice more than the cornea or lens, and the anterior chamber only 1/10th to the total refraction.

Sorsby et al (1957, 1961, 1962, 1970) used more modern methods (ultrasonography) to measure the components and came to the conclusion that as the eye lengthens, the cornea and lens compensate, bringing about emmetropisation. However, Sorsby (1972) concluded that there were two types of eyes. One type lengthens only slightly in the early years, allowing the other elements to alter themselves with ease and producing an emmetropic or nearly emmetropic eye. The second type of eye enlarges much more. The cornea and lens try to compensate, but they cannot fully negate the longer axis, and these eyes shift towards myopia, or less hyperopia. Sorsby (1972) asserts that the child with this type of eye usually shows rapid growth in childhood.

Sorsby refers to these two types of myopia as "correlation" and "component" types, and Sorsby (1960) showed that the axial length is usually proportional to the degree of refractive error.

In Correlation amtropia, all the components are variable, with most normally distributed, and with the distribution for each of the components showing a wide range of values, whether the ametropia is high or low. Where there is ametropia, it can be due to poor coordination of the components, even though each could fall in the normal range. The components are probably inherited (Goldschmidt, 1968).

Emmetropia is the result of good coordination, with a high correlation of the components. About 20% of all subjects are myopic because of poor coordination of the components. The mechanism is unknown (Sorsby, 1957).

Component ametropia is usually found in high ametropia, i.e. at the extremes of the refraction continuum. This type of ametropia is usually due to the axial length being either shorter or longer than normal, without proper compensation by the other components.

Stenstrom (1946) correlated axial length with corneal curvature and found the value of r to be -0.84 for all refractions, which confirmed that these two variables are the most responsible for refractive error because the values of r for the other components with refraction were less. As the eye lengthens, the cornea becomes correspondingly flatter. In studying these same two variables, Sorsby (1957) found the correlation to be -0.877 for 66 emmetropic eyes. The correlations for myopia and hyperopia, however, were less than those found by Stenstrom (1946), but the number of observations made by Sorsby was much smaller.

Table 1. Correlation coefficients of axial length and corneal curvature for different refractive errors (Sorsby, 1957)

	myopia axis > 25mm	myopia < 25mm	emmetropia	hyperopia
n (eyes)	17	29	66	82
r	-0.680	-0.541	-0.877	-0.517

Sorsby (1957) also found a higher mean corneal power in 42 myopic eyes compared to 107 hyperopic eyes and 90 emmetropic eyes.

Table 2. Mean axial length and mean corneal power for three different refractive states (from Sorsby, 1957)

	myopia	emmetropia	hyperopia
n (eyes)	42	107	90
range	-0.51 D to -4.0 D	0	+0.51 D to +4.0 D
mean ax. length	24.61 mm	23.85 mm	23.47 mm
mean corneal power	44.4 D	43.25 D	42.86 D

A higher corneal power represents a flatter corneal curve, or a longer radius of curvature. From the results presented in Table 2, Sorsby concluded that corneal power is important in refractions between + and -4 D., with a flatter cornea the result in emmetropia and myopia. Because an increase of 1/3 mm of axial length in low refractive error is equal to 1 D. of myopia, to compensate the corneal radius has to increase by 0.19 mm. Therefore if the cornea fails to flatten, or if the axis becomes too long to compensate for the flattened cornea, myopia will be the result.

Stenstrom (1946) determined the correlation coefficient (r) of axial length and refraction to be -0.76. Hirsch and Weymouth (1947) reanalyzed the data and partialled out corneal curvature, resulting in an r of -0.87. Sorsby et al (1957) used the same data, but partialled out corneal power, lens power, and anterior chamber depth, with a resultant r of -0.971. From these partial correlations, it seems that the depth of the chamber is an important determinant of the final refraction. Stenstrom (1946) found the r for anterior chamber depth and axial length to be 0.44, and Sorsby (1957) found this value to be 0.478. However, when van Alphen (1961) reanalyzed Sorsby's data by first removing extreme values (± 8 D.) r fell to 0.29. When he partialled out the corneal power, r became 0.50, indicating again the importance of axial length and corneal power to refraction, while the other components had lesser importance. He demonstrated that high hyperopes have a shallow anterior chamber, while high myopes have a deeper chamber. The deep chamber in myopia was also found by Stenstrom (1946). van Alphen (1961) also found that increased lens power is associated with a shallow anterior chamber, leading to the conclusion that the depth of the anterior chamber is the result of an interaction of corneal curvature and axial length change as well as lens change.

van Alphen (1961) reanalyzed Stenstrom's data (1946) in order to evaluate his hypothesis regarding the origin of refractive errors. At the outset, he pointed out some of the inherent errors in the studies of Stenstrom (1946) and Sorsby (1957). In the former case, Stenstrom had compared variables that had been measured in different dimensions. For instance, axial length had been correlated with corneal power. van Alphen advocated that corneal power should have been converted to corneal radius before comparison with axial length. In both the Stenstrom and Sorsby studies spurious correlations could have arisen. Lens power had not been measured directly by Stenstrom but had been correlated with variables which themselves had contributed to the calculation for lens power. Similarly, Sorsby (1957) had correlated axial length with variables that had contributed to the axial length value.

From his reanalysis of the correlation data; van Alphen (1961) offered an hypothesis for the origin of refractive errors, which will be discussed later. (pp. 27-29).

Comment:

Of the optical components known to affect refraction, axial length is the only one to show a non-Gaussian distribution. Its distribution is peaked and skewed to the long side. Correlation studies by Stenstrom (1946), Sorsby (1957), and van Alphen (1961) demonstrate that axial length, corneal power, anterior chamber depth, and lens power all contribute to the ultimate refraction, but that the first two are relatively more important.

Using the nomenclature of Sorsby (1957), there are two basic types of ametropia, correlation and component. In the former, most of the refractions fall between -4 and +4 D, this range encompassing 90% of refractions. In this range, Sorsby (1957) showed that the cornea and lens adapt to any axial change. This emmetropization is mentioned by Tron (1929), Sorsby (1947), and Hirsch (1952), but the mechanism itself is unknown. Duke-Elder (1970) and Goldschmidt (1968) have both suggested that in this type of ametropia, the distribution of component values is probably determined genetically.

Component ametropia accounts for the more severe but relatively less frequent forms of ametropia. Duke-Elder (1970) asserts that in this type of ametropia, the components can be of abnormal size, usually from genetic cause, and often in association with other manifestations of the deleterious gene.

The study of correlations between ocular components has proven illuminating as regards their interrelationships with each other and with ocular refraction. But, as van Alphen (1961) has pointed out, this work has not done much to explain the origins of refractive errors. Refraction depends to a large extent on the length of the eye, the curve of the cornea, and lens power. One of the major problems is that in no study have all the components been measured simultaneously, nor is it technically possible to do so. The measure of refraction at the same time as the other measures are being made is also important. It has been suggested by van Alphen (1961) and others (Young, 1969; Sato, 1957), that accommodation plays a role in the determination of final refraction. The literature on this association is now examined.

ACCOMMODATION

Helmholtz (translated 1942) said:

> There is no other subject in physiological optics about which so many antagonistic opinions have been entertained as concerning the accommodation of the eye.

Accommodation is that action by the ciliary muscle and the lens which increases the convexity of the lens, principally on the anterior surface.

Helmholtz's theory of accommodation states that the contraction of the ciliary muscle by drawing forward the choroid relaxes the tension of the zonule, and permits the lens by virtue of its elasticity to passively assume a more spherical form, which at the same time produces a corresponding decrease in the equatorial diameter of the lens, the equator receding inwards towards the axis of the eye, kept from coming in contact with the ciliary processes as they advance.

An opposing theory, that of Tscherning (1895), states that the contraction of the ciliary muscle does not relax, but rather tightens the zonule, altering the lens surface from a spherical to a hyperboloid form. This is caused by an active compression by Mueller's ring and not by a passive exercise of the elasticity of the lens.

Of the two, the first theory is the more generally accepted.

The normal eye at rest is focussed at infinity (effectively 20 feet or more). In order to focus an object within infinity, the eye must add to its dioptric power enough power to neutralize the light wave entering the eye from the object and to render the wave as if it was coming from infinity. The distance (from the eye) of the object is the radius of curvature of the light wave when it strikes the eye, and this distance is the focal length of the dioptric power which the eye, by accommodation, must add to itself to focus the object. In the normal eye, accommodation is the reciprocal of the distance for which it is exercised. Thus for an object that is 20 inches from the eye, the eye uses 2 D. of accommodation, and at 10 inches it uses 4 D. In a hyperope, who at infinity uses an amount of accommodation equal to his hyperopia, one must add this amount to the reciprocal of the distance. A 2 D. hyperope fixating at 20 inches uses 2 D. plus his own 2 D. of hyperopia, or a total of 4 D. of accommodation. In the myope of -2 D. whose far point is within infinity, the amount of myopia must be deducted from the reciprocal of the distance. If he fixates at 10 inches, he uses 4 D. (reciprocal of 0.25) minus his 2 D. of myopia, or 2 D. of accommodation.

Neurologically, contraction of the ciliary muscle is caused by action of the parasympathetic of Nerve III, originating in the Eidinger-Westphal nucleus. The fibres relay in the ciliary ganglion. Davson (1972) states that the sympathetic might also play a part in accommodation, and adjustments effected through interplay of the two systems. Atkinson (1944) describes the innervation as being primarily of the sympathetic. In his view, the accommodative reflex is initiated by a blurred retinal stimulus, but the mechanism of this reflex is as yet unclear, as Davson (1972) also states. Atkinson states without experimental evidence that the retinally initiated impulse is carried via the optic tract to the occipital cortex. There it is transferred to the 4th ventricle, relayed to the motor oculi, by which it is carried to the ciliary ganglion, and delivered to the ciliary neurons of the sympathetic, and thence to the ciliary muscle, causing contraction.

Little is known of the contribution of accommodation to efficiency or control of vision and visual perception, let alone its contribution to image focussing in the eye. The human visual system uses two effector systems in its action, the convergence system, which allow the two eyes to center on an object in space, and a focussing system that provides discrimination and clarity of image. This second system, highly complex and adjustable, allows the visual center of the brain to achieve clear vision.

It is known that accommodation and convergence are linked (Davson, 1972). It is also known that the ciliary muscle consists of three types of fibers, longitudinal, meridional and circular, and that this ciliary body allows the crystalline lens to expand or diminish in size. It has also been observed that the eyes are in constant saccadic motion, and that the lens oscillates during accommodation, signifying that focussing is being constantly checked. The retinal locus for the initiation of the signal is however unknown, and as stated above, the neurological mechanism is not completely understood (Davson, 1972).

Haynes et al (1965) have shown that the neonate has a "locked in" focus at 19 cm, which achieves adult flexibility by the age of four months. The adult at about age 40 begins to lose this flexibility (presbyopia). The components influencing accommodation and convergence are in constant interplay, and change with any fine alteration in signal or change in the eye. Because infants as young as two weeks seem to be able to focus, Fantz (1961) has proposed that the focussing mechanism might be "prewired."

Aside from the mutually antagonistic parasympathetic and sympathetic systems involved in accommodation, there have been studies suggesting voluntary control of focussing. Westheimer (1957) demonstrated increases in excess of 1 D. of accommodation in states of anger, and the mere thought of 'near' or 'far' concepts produce shifts of up to 0.50 D.

Regarding the fibers of the ciliary muscle, there have been conflicting reports. Wolff (1948) quoting Fuchs, states that the circular fibers only appear after age 5, while Mann (1928) reported that they are seen in a 6 month old fetus. Adler (1959) states that these fibers are poorly developed in myopes and well developed in hyperopes, thus implying that the circular fibers are important in accommodation, and also indicating a use-disuse function in ametropia. Adel (1966) reported that the circular fibers provided about 40% of the total Amplitude of accommodation, accounting for the first 3 D. of accommodation. Amplitude of accommodation is defined as the greatest amount of dioptric power that can be added to the static eye by the maximum ciliary effort. Adel also found however, that sustained accommodation is effected by the longtitudinal portion of the ciliary body which pulls the choroid forward, causing the axial shift in myopia, an essential point in the van Alphen (1961) theory discussed later (pp. 27-29). The diminution of the amplitude of accommodation with age has been noted and has been attributed (Duke Elder, 1970) to changes in the lens or in the ciliary muscle.

Otsuka (1968) reported on several experiments by himself, Tokoro, and Imagura in Japan, which found an increase in ciliary muscle tonus to be correlated with lengthening of the optic axis and myopic increase in 45 subjects ranging in age from 7 to 15 over a period of 3 to 5 years. Otsuka found that the ciliary muscle is innervated mainly by the parasympathetic while the sympathetic innervated the ciliary wall.

STUDIES ON ARTIFICIAL MANIPULATION OF ACCOMMODATION

Atropine

Atropine is a cycloplegic drug used to inactivate accommodation. During the 16th century, atropine was used for cosmetic purposes, to enlarge the female pupil, hence the term "belladonna" (Michaels, 1975). The drug has been used by several investigators in an attempt to reduce or reverse myopia, on the premise that accommodation causes myopia, and therefore if the accommodation could be relaxed, myopia would disappear.

Young's studies (1965, 1966, 1975) on the effect of atropine on myopia in monkeys seem to confirm that accommodation plays an important role in the development of myopia. He confined his monkeys into a restricted visual space and after myopia had developed, he instilled atropine to eliminate any further accommodation, while the animals still maintained convergence. After 1½ months of atropine instillation, no further myopia was observed, compared to controls in which it continued to develop.

Bedrossian (1964) used atropine on humans in order to control myopia by suppressing accommodation. He concluded that atropine instilled on a daily basis in children with progressive myopia significantly retarded the progress of the myopia, when compared to the control eye which was not treated. In some patients, the treated eye actually showed a decrease of myopia.

Sato (1957) performed a study using atropine on 1000 Japanese children and found a great change towards increased plus in hyperopes and emmetropes, and also in myopes that were between 0 and -1 D. The changes started within 4 days of start of treatment, and Sato postulated that weak myopia is caused by a hypertonicity of the ciliary muscle.

Neither Young nor Bedrossian reported a change to plus. The initial myopia in Bedrossian's material was not reported, so it is possible that his subjects had more than 1 D. of myopia at the start of the experiment. Sato reported that after cessation of atropine treatment, the original state of refraction was regained within 40 days.

Bifocals to Modify Accomodation

Kelly (1975) demonstrated the arrest of myopia in 68% of subjects over 2 years, using bifocals, and Oakley and Young (1975) reported that the use of bifocal lenses in a study on 544 children caused a lower rate of myopic progression (from 0.50 D. to 0.05 D. per year), again showing the effect of accommodation on myopia. Since the use of plus lenses relaxes the accommodation at near, and in a bifocal lens the lower segment is more convex than the upper segment, the effect of the bifocal on accommodation is explained. The lower segment of the bifocal lens is more convex than the upper segment, and plus lens power relaxes accommodation.

HYPOTHESES ON ACCOMMODATION AND REFRACTION

Young (1975) speculated that myopia develops in two stages. The first stage is a continuous state of accommodation that is not relaxed, when the young child is doing near work. When the child then shifts his gaze to distance, he is unable to relax the accommodation as a result of long hours at near work which have upset the normal response characteristics of the ciliary muscle. This leads, according to Young, to an increase in axial length. Sato (1944) also demonstrated this continuous state of accommodation with near work.

On the other hand, Baldwin (1965), using cycloplegic and non-cycloplegic refraction with the retinoscope, and subjective refraction procedures, concluded that over-accommodation does not cause myopia. He found that accommodation did not change with an increase in myopia, nor did the accommodative-convergence ratio. He claimed that the lens and the axial length were the main contributors, but did not explain how these two components became the causal agents.

In the earlier discussion regarding the investigations on the optical components, reference was made to the work of van Alphen (1961). He had pointed out that refraction could be expressed as a linear function of the optical components or as a simple function of the total refractive power and axial length. These functions, however, revealed no information about the underlying mechanism that determined the ultimate refraction. His theory was developed from comparisons of the simple correlations between the five components, namely, refraction, axial length, chamber depth, corneal power, and lens power.

Using factor analysis, he proposed that there were two independent factors, factor S related to corneal power and axial length, and factor P related to axial length, lens power, and chamber depth. Factor S indicated that larger eyes have flatter corneas and that this trend is independent of refraction, an idea that had been expressed by Steiger (1913), but largely ignored. Factor P indicates a deeper anterior chamber and a flatter lens in larger eyes.

Contraction of the ciliary muscle leads to increased tension in any part of the choroid during accommodation, and pressure in the supra-choroidal space decreases. The parasympathetic system causes ciliary contraction, causing the choroid to move forward, reducing pressure in the supra-choroidal space, leading to an increased scleral pressure. When the accommodation is relaxed, the opposite occurs, i.e. the tension on the choroid decreases. If tension on the choroid increases, there could be an increase of intra-ocular pressure during accommodation. The intra-ocular pressure is important in the determination of refraction. Eyes of different size have similar shape, with the underlying size of the eye resulting from growth and stretch factors. Growth is genetic, and stretch depends on the intra-ocular pressure and the elasticity of the sclera and rigid coats of the eyeball. In other words, refraction has no relationship with the eye size.

A third factor, R, determines the refraction and expresses the interrelationship between P and S. This factor R is mediated by the higher cortical and sub-cortical centers.

When the increase in axial length is accompanied by an increase in corneal power, the result is myopia. The small hyperopic eye with the flat cornea, shallow chamber, and round lens is the opposite to the ovoid myopic eye with the curved cornea, deep chamber, and flat lens.

According to this model, psychological factors and stress are involved in the final determination of the refraction.

There are two types of near work, according to van Alphen. There is the sustained near work, or reading, that is involved in deep thinking and learning, and there is the near work or reading that is not involved nearly as much with thinking, such as reading for pleasure, knitting, sewing, etc. It is his contention that the former type of near work leads to more stress on the visual system, with different innervation via the parasympathetic on the ciliary muscle, leading to the described choroidal tension, lengthening the axis, and thus causing myopia.

The possibility that the optical elements are inherited as suggested by Sorsby (1957), does not mean that refractive errors are inherited. van Alphen says that if the refraction of the eye is ultimately determined by cortical and sub-cortical regulation of the optic axis, then the whole question of the etiology of refraction is basically related to the inheritance of psychological and autonomic traits.

However, van Alphen does not place enough emphasis on the environmental aspect of the near work phenomenon as he described it. This question of the effect of near work, which has received so much attention in the past (Cohn, 1867, etc.) will be examined in light of van Alphen's exposition (1961), in a later section of results of this investigation in Western Newfoundland.

In addition, there are certain studies which bear directly on this question. Earlier, Stenstrom (1946) reported that there was a correlation of 0.65 between the anterior-posterior axis of the eye and the transverse diameter, indicating that as the eye enlarges, it does so in all directions, which would be the case in a sphere suffering increased pressure from within.

If, as was suggested by van Alphen (1961), an increase in tension on the choroid and decrease in the pressure in the choroidal space occurs, an increase in the intra-ocular pressure during accommodation is to be expected. Coleman and Young (1962) did demonstrate a reduced anterior chamber pressure during accommodation, with an increased pressure in the vitreous. Reduced anterior chamber pressure was also shown by Armaly and Burian (1961, 1962) and by Perkins and Young (1978).

Young (1975) postulated that the increase in vitreous volume could occur in many small steps, depending on the type and amount of accommodation that was taking place over time. He devised a technique for measuring the change in pressure in the vitreous taking place over time in monkeys. He reported that there is an increase in vitreous pressure which is linearly related to the distance of the object being viewed. The lowest pressure occurs when the viewing object is at infinity (20 feet), and conversely, the highest pressure occurs at the near point. Further, the pressure changed with the interest value of the object, with more pressure recorded when the object had more interest for the subject. The pressure change remained relatively constant for as long as an hour and if the fixation distance was changed over a range of one foot to 20 feet, the pressure changed correspondingly.

The work of van Alphen (1961) and Young (1975) in this area seems to support the concept of the importance of near work, and specifically studying, in the determination of refraction. It would seem that near work and refraction may indeed be interrelated as was suggested by Tscherning (1900).

MISCELLANEOUS FACTORS IMPLICATED IN MYOPIA

Factors other than accommodation have variously been proposed as causes of myopia. Duke-Elder (1970) lists those most often cited, and their proponents. This section reviews the more pertinent literature on this subject.

Growth Factors

The notion that height was related to myopia was investigated by Walker (1930) who concluded that height increased more rapidly than weight in myopic children. Other studies relating myopia to height were reported by Dunstan (1934) who reported myopic children to be taller and thinner than non-myopic children of the same age, and by Pendse (1951) who examined 500 unselected school children in India. In none of these studies were other variables investigated, such as socio-economic status, nutrition, , or general health. Some studies, to be discussed later, have reported relationships between health, nutrition and myopia.

Gardiner (1955) reported that children with progressive myopia grew faster than those with stationary myopia. He did not explain the distinction between the two myopias, nor did he examine any other variables. In a study that was concerned with psychological factors in myopia, Schultz (1960) also correlated ponderal index (height/weight^3) with refraction. He found a greater ponderal index for hyperopia compared to myopia.

Neither Sorsby (1961) nor Otsuka (1956) found any significant differences in height between myopes and non-myopes. Goldschmidt (1966) cited studies by Francke (1938) and by Johansen (1950). Francke reported a slight difference in height between myopes and non-myopes, but Table 3 indicates the differences to be marginal. Table 4 represents the data from the Johansen study and indicates that differences do not reach statistical significance.

The best study of the relationships of height and refraction is that of Goldschmidt (1966). He examined the records of 3511 military conscripts, the majority of whom were aged 18-20, subdivided into six groups based on educational level and trade. He found a highly significant difference in height among occupational groups. The myopes were on an average 1.6 cm taller ($p < 0.001$). However, when compared to non-myopes in their own social group, differences were not significant.

Table 3. Body height and refraction (from Goldschmidt, 1966)*

	mean ht. in cm	SD	SE
Myopes	170.4	7.24	0.47
Emmetropes	168.0	6.28	0.49
Hyperopes	167.1	6.91	0.67

*Francke 1938 study

Table 4. Survey of the average values found for body heights of myopic and non-myopic boys between the ages of 12 and 15 (from Goldschmidt, 1966)*

	Ages							
	12		13		14		15	
	non-M.	Myopic	non-M.	Myopic	non-M.	Myopic	non-M.	Myopic
Number	159	10	125	12	120	6	80	15
height (cms) (mean)	151.16	153.25	156.53	158.27	163.07	166.50	169.11	174.52
SD	-6.89	-3.84	-7.52	-7.01	-7.57	-7.64	-6.62	-6.68
Probability	10-20%		40-50%		30%		0.7%	

*Johansen 1950 study

Table 5. Mean heights (in cms) of conscripts by occupational group, and by refractive status (adapted from Goldschmidt, 1966)

Occupational Group	Myopes (a)	Myopes height	non-myopes (n)	non-myopes height
1. Grammar School & undergraduates	152	179.51	252	179.58
2. Business and office	116	178.04	505	177.06
3. Technical engineers	29	175.38	110	178.53
4. Craftsmen	49	177.35	286	176.52
5. Skilled workers	104	176.04	1177	175.57
6. Laborers, seamen	41	175.59	690	174.17
Total	491	177.64	3020	176.03

Goldschmidt concluded that the average height of the myopic conscripts was greater than the average height of the non-myopic conscripts, but this was not so in each of the six occupational groups. The data confirmed that students are taller than laborers, whether this was genetic or environmental, but taking into account the difference in social milieu, better food, better health care, etc., thought it highly probable that the differences were environmentally determined (Goldschmidt, 1966).

Goldschmidt also found, in examining 359 boys and girls aged 13-14, that the average height varied between the different school streams, so that the more academically inclined children were taller than those in the "practical" streams ($p < 0.001$). He notes that height is predominantly determined by heredity, but can also be environmentally determined, as during the past century, the mean height of men in Denmark rose from 165.4 cms to about 176.0 cms.

Goldschmidt therefore concluded that myopes and non-myopes in the same social group were not different in height. Even though in students, there might be a difference in height between social groups, it does not *follow that there is a causal relationship between height and refraction*, but only,

> that a large number of human characteristics, including refraction, are not equally distributed among different social groups.

Alsbirk (1979) found a statistically non-significant association of height and refraction (negative) in a small sample of Greenland Eskimos.

Comments

We may conclude from the Goldschmidt (1966) study that height varies within different social and cultural groups, and also that refraction varies between these groups. It is however not possible to relate the two findings in a *cause and effect manner*. *Height has* increased through time, probably due to better nutrition and improved environments. However, as Goldschmidt (1968) has shown, the incidence of myopia has not increased in Denmark in 80 years, while height has increased. From these results, it cannot be concluded that growth has any causal effect on myopia.

Nutrition and Diet

There have been many reports and studies speculating on the effects of diet and nutrition (or malnutrition) on refraction, the connection being that myopia seems to develop more rapidly during the period of body growth.

Draper (1924) observed that there was less myopia in societies which maintained "traditional" diets, such as Eskimo or certain African or European societies. He implicated the use of commercial bread which lacked proper vitamins. This study reported no data, nor did the study of Laval (1941), who suggested that nutritional deficiency is related to socio-economic status. Because he had noted the same incidence of myopia in clinical outpatients as in private practice, he felt nutrition could not be a factor.

Jackson (1936) examined the effects of protein deficiency on rats. The eyeball enlarged by up to 50%. However, Addis, Poo, and Lew (1936) found that in a similar experiment the eyeballs failed to show any protein loss. McKeehan (1940) and McLaren (1958) studied the effects of protein loss on pigs and rats, and found little effect of severe protein deficiency on either the growth of the globe or the fluid content of the eye. Young et al (1973) examined the effects of diet (protein deficiency) on 20 rhesus monkeys. While growth was affected, refractive error showed no change.

Smith (1951) and Livingston (1946) found more myopia in war prisoners. In Smith's study on 22 POWs, former emmetropes became myopic and low myopes showed a marked increase in myopia.

Skeller (1954) found little myopia in Eastern Greenland and noted that the inhabitants ate a large amount of animal fat, whereas Cass (1973) thought that myopia increased because the Northern Canadian native people went from a low fat to a high fat diet.

Gardiner (1958) found that 91 myopic children showed greater irregularity in growth, earlier maturity, and had less animal protein in their diets. Gardiner (1964) noted that myopic children ate less protein than non-myopic children and found girls refuse protein more than boys. When he administered protein in the form of calcium caseinate to one group of 91 children and compared them to a control group of 346, the change in refraction was statistically significant, the protein group becoming less myopic. Walkinshaw (1964) reported on the control of myopia by diet modification, increasing animal protein and diminishing carbohydrate. His report is mainly anecdotal in nature.

Comment

Although it would seem that nutrition should have an influence on refraction, this has not been convincingly demonstrated. It is possible that nutrition varies with socio-economic status, and Goldschmidt (1966) showed that height varied within social groups (pp.33-34 .). Possibly any difference in refraction between social groups could result in an overall height/refraction relationship, but this would be due to the differences in growth in different social groups due to nutritional differences.

On the other hand, evidence for the influence of accommodation on refraction is more substantive, many studies indicating the modifiability of refraction by accommodative patterns.

Scleral Rigidity:

Imai (1952) studied 101 human eyes in subjects aged 10 to 30 and reported that more myopic eyes had less rigid sclerae. Curtin and Feng (1958) found scleral fibers to be thinner and less abundant in eyes of over -10 D. Castren and Pohjola (1961) studied 216 subjects between the ages of 10 and 40; 149 eyes were more than 1 D. hyperopic, 234 eyes were emmetropic (-0.50 to +1 D.), and 49 eyes were myopic (over -0.50 D.). The average rigidity was highest in hyperopic eyes, but the difference between hyperopic and emmetropic eyes was non-significant. However the rigidity of the myopic eyes was significantly lower compared to the other two groups. In the myopic eyes, the low rigidity persisted, whereas in hyperopic and emmetropic eyes normal values were reached by age 20. They proposed that low ocular rigidity at puberty was a factor in the development of myopia.

These studies indicate that weakness of collagen tissue of the sclera could be associated with myopia, usually in its more severe degrees and that scleral rigidity is decreased in all myopias. Goldstein et al (1971) implicated collagen weakness in myopia and dental caries. Hirsch (1973) also reported similar findings with respect to collagen weakness and myopia, with certain qualifications. Both studies were done on college freshmen, 100 subjects in the Goldstein study, and 42 in the Hirsch study. In neither case was the sex of the subjects given. It was noted that the subjects had a much higher incidence of myopia than normally found in the general population. Hirsch found a positive relationship between degree of myopia and number of caries, while Goldstein did not, but their definitions of "high" myopia differed. Hirsch felt that the data were insufficient to make definite conclusions and suggested further studies on the sociological, ethnic, and other variables which could have been involved.

Endocrinological Correlates

Bothman (1931) found the BMR of 30 young myopes to be below normal, and concluded that hypofunction of the thyroid gland could be involved in myopia. Lindner (1939) postulated that near work was the cause of myopia because the greater metabolic demand of close work produced an abnormal composition of nourishing fluids which softened the sclera.

In a study by De Vries (1950), cited in Baldwin (1964), 1600 Dutch children between the ages of 9 and 12 were studied. Those with enlarged thyroid glands were found to have less myopia, the ratio being 1:4. In a smaller group of older teen-agers, he found a low BMR associated with higher degrees of myopia, similar to findings of Bothman (1931). The De Vries study was conducted in an area where goitre was very common.

Diabetes causes changes in the crystalline lens, and is often associated with a more negative refraction. Scott (1953) observed 150 cases which demonstrated this effect. When the blood sugar level became stable, the refraction reverted to its pre-disease state in all but one or two cases. The mechanisms of these diabetic changes, while extensively investigated (Duke Elder, 1970), are not completely understood, and though interesting, are not pursued further in this thesis.

General Disease and Debility:

Tuberculosis in children was reported to be a causal agent of myopia by Thompson (1919). Various diseases have been reported to cause myopia, traditionally febrile diseases such as measles and scarlet fever. In a study on rabbits, sudden high fever was reported to produce myopia (Maurice and Mushin, 1966).

In a study of 314 school children aged 13 to 17 who had measles between the ages of 5 and 8, Hirsch (1957) reported five times the usual prevalence of -1.00 D. or more.

Toxemia of pregnancy was implicated in refractive change towards myopia by Gardiner and James (1960).

The studies of Goldstein (1971) and Hirsch (1973) mentioned above (p.37) reported the correlation of myopia with dental caries. Goldstein explained that this could be due to the fact that tooth enamel and the eyeball are both of collagenous material.

Comments

It is well established that myopia is a mismatch of the ocular components. Accommodative effort appears to play an important role in the determination of the final refraction. Aside from accommodation, certain investigators have sought to implicate other factors in myopia, such as height, nutrition, general debility, disease, etc. However, for none of these is the evidence as convincing as that for accommodation. From the earliest studies of Cohn (1867) and others, the effects of near work have been mentioned as being important to the determination of refraction. The studies reviewed generally support this early hypothesis. The work of van Alphen (1961) and of Young (1975, 1978a) have added experimental evidence demonstrating that intra-ocular pressure can increase the volume of the eyeball, and not only the optic axis. The reported long eye seen in myopia could reflect an increase in intra-ocular pressure from within the eyeball and not from the exterior, as postulated by Donders (1864). Findings that accommodation is modifiable with drugs or with bifocals, and that this can arrest the progress of myopia, further implicate the effect of accommodation on refractive change, presumably through the effects of accommodation on intra-ocular pressure.

The next chapter describes the population of the present study, and the data collected. Further chapters describe the analysis of this data and the incidence and distribution of refraction in the study population, after which the relations between refraction and accommodative effort, as measured by near work, will be considered.

PART B

Chapter III

INTRODUCTION TO THE PRESENT STUDY

When the Faculty of Medicine at Memorial University began planning to visit three communities in Western Newfoundland to undertake a comprehensive health survey, it became apparent that the population in the area met many requirements of this study. The population was, relatively, isolated both demographically and genetically. The education system had changed dramatically about 25 years before the study (1974). From an epidemiological point of view, the population was ideal for a study of the effects of near work, familial resemblances, education, and leisure activities, as well as personality characteristics, on refraction in a Caucasian population.

THE STUDY POPULATION

As indicated earlier, the first settlers in the area, John and Mary, were the progenitors of the great bulk of the population of the three communities studied. Eighty-five percent of the population claim direct descent from these two people. The three communities are located on the west coast of the Great Northern Peninsula of Newfoundland. They are fishing communities, that is, the bulk of employment has to do with the fishery, with some farming and mining. There are few secondary employers, several small stores, one "hotel," and the three local schools. The distance from the first village to the third is 15 miles, with the second about halfway between the two outer communities. Until 1956, the only access to the area was by small boat, and even today, the road to this area is not completely paved.

According to Census Canada (1971), there were 1190 residents in the three villages between the ages 5 and 97 inclusive. This study was conducted in 1974, so there should have been little change in the population figures.

Table 6 indicates the 1971 population for each community in the studied age range, and the number actually examined, also given as a percentage of the 1971 population. Actually, 971 were examined, but as will be discussed presently, 14 subjects were not included in the data.

Table 6. Actual population (1971), number and percentage of subjects for each community

Community	Population (1971)	Number examined m	%
S	275	224	81
C	515	370	72
P	400	363	80
Total	1190	957	80

Of the 957, 438, or 45.8% were male, and 519, or 54.2% were female. The mean age was 26.7, the median age was 21.24.

Table 7 shows the age and sex distribution of the subjects examined, compared to the numbers resident in 1971, indicating the relatively high completion rate in each age range and for each sex.

Of the 14 subjects not included in the main investigation, 11 had refractions outside + or −6 D. and are reported separately. Three subjects with right eye amblyopia were excluded, as only data for the

Table 7. Populations of the three communities (1971 census), by age interval, and sex, with the number examined (1974), and also expressed as a proportion of the 1971 populations

Community	Age: 5–9		10–14		15–19		20–24		25–34		35–44		45–54		55–64		65–69		70+		Total	%
Sex:	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F		
C. population	50	30	35	35	35	35	25	20	35	30	35	40	30	20	20	15	5	–	10	10	515	
examined																					370	72
P. population	35	25	30	20	20	35	20	40	35	30	25	15	20	10	10	10	–	10	5	5	400	
examined																					363	91
S. population	25	30	25	30	20	30	10	15	15	15	10	10	15	10	5	5	–	–	5	–	275	
examined																					224	81
Total population	110	85	90	85	75	100	55	75	85	75	70	65	65	40	35	30	5	10	20	15	1190	
	195		175		175		130		160		135		105		65		15		35			
Total examined	109	86	76	69	38	70	18	58	56	82	47	57	49	51	31	22	6	12	8	12	957	
	195		145		108		76		138		104		100		53		18		20			
% examined	100	100	84	81	51	70	33	77	66	100	67	88	75	100	89	73	100	100	40	80		
	100		83		62		58		86		77		95		82		100		57			80

right eye were analyzed. Subjects were not visually selected, that is, all tests were administered whether the subjects had a visual problem or not.

METHODOLOGY

All refractions were performed by the investigator. Height and weight were measured by the attending nursing staff, and any pertinent pathological data (other than ocular) were recorded by the physicians on the team as part of a complete physical examination.

Information recorded by the examiner prior to the examination included whether glasses were worn by the subject, and when available, the actual prescription; whether subjects' parents wore glasses, and for what purpose, time spent at near work, watching television, and favorite leisure activities. Also recorded was type of illumination at home and at work.

The examination form is included as Appendix A.

Some months after the study was completed, a second questionnaire (Appendix B) was distributed to each subject, in order to check the accuracy of the responses during the examination. Approximately half the subjects returned the second questionnaire.

Observed or suspected eye pathology was referred to one of the physicians on the team. Several hypertensive fundi were recorded, and a peculiar salt-pepper fundus condition was discovered, almost exclusively confined to one family, which awaits diagnosis. Cases of strabismus, cataract, and pterygium were referred to an ophthalmologist for follow-up.

The methods of objective and subjective determination of refraction are described in Appendix C.

EQUIPMENT

Examination equipment comprised a Welch-Allyn Halogen ophthalmoscope, a Welch-Allyn spot retinoscope, an American Optical Ultramatic refractor mounted on a portable stand, a Bausch and Lomb Keratometer (carefully calibrated each morning with a 7.50 mm steel ball), and a self-illuminated Snellen chart with a Lancaster astigmatic dial.

DATA MANIPULATION

Refractions were converted to vertical ocular refraction using the formula of Sorsby and Leary (Appendix D). This method converts all cylindrical (astigmatic) refraction to spherical form at 90°, allowing the results of the present study to be compared to those of Sorsby et al (1962) and Young et al (1969), the most recent and pertinent studies of population distribution of refraction.

The data were transferred to coding sheets and checked by the investigator to eliminate possible error by an untrained coder. IBM cards, punched from the coding sheets by a trained keypuncher were spot-checked with a random sample of over 100 cards selected to eliminate punching errors. These same cards were then checked against the original examination records by comparing each card to its data sheet using a master printout of all the cards. Distributions of the variables were checked for extreme mispunched information.

EXAMINATION PROCEDURE

In each community, the refractions were performed in a room that was at least 20 feet long, so that the Snellen chart could be placed at

20 feet from the subject. The EPI test, a personality inventory to be described later, was administered in a separate room, with each subject in complete privacy.

The standard optometric examination consisted of:

1) History -- including:

a) any familial eye disease or refractive problem

b) personal eye history, including correction (if worn)

c) ocular injuries

d) eye surgery

e) previous treatment

f) school and/or reading problems, school complaints, etc.

g) scholastic history--last grade attended, any failures, etc.

h) habitual near point distance.

2) Eye test:

a) visual acuity each eye, near and far, with and without correction

b) external examination, lids, conjunctivae, etc.

c) ophthalmoscopy

d) cover test, near and far, versions and rotations

e) Ishihara color vision test

f) eye and hand dominance -- The eye dominance was determined using the thumb and forefinger extended to sight a target

g) static, non-cycloplegic retinoscopy

h) dynamic, non-cycloplegic retinoscopy

i) keratometry, in high astigmatism

j) phorias and ductions

k) subjective, fogging method at far and near.

The results of procedures d, f, i, and j were not included in the data for this study. They are optometric tests used by the examiner to aid in the final determination of the refraction.

This provided the data base for the investigation to be reported in this thesis. Most of the statistical computations were performed by an IBM 370 computer, using the standard SPSS Computer Programmes. Measures of familial resemblance, elaborated on in Chapter 6 were obtained using a battery of programmes developed by M. M. Hindmarsh and J. C. Bear at the University of Newcastle Upon Tyne, modified for use at Memorial University of Newfoundland by G. Burke.

Statistical significance levels are conservative, with two-tailed tests used throughout. Only data for right eye is used, because the refractions of the two eyes are highly correlated. If both eyes are counted, the size of the sample is doubled, and associations inflated in a misleading manner. The data and the statistical procedures will be discussed for each investigation.

Comments

In some cases, problems arose in the gathering of data and information. Young males aged 18 to 25 were busy fishing at the time of the study, and some refused to take time off for the procedures. Possibly one-third of those men did not come to the clinic. Relatively few problems arose due to lack of understanding or lack of cooperation. Extra effort spent on a few persons usually produced a good response in the end. Lack of understanding could have affected some of the EPI tests, but maximum effort was made to aid the subjects without compromising the value of the data. The relatively high completion rate for this study has been shown (Table 7).

Chapter IV

THE POPULATION DISTRIBUTION OF REFRACTION

Introduction

There have been many studies on the distribution of refraction in populations. In the main these studies have involved clinical groups, but studies on military conscripts (Goldschmidt, 1968) and school populations (Hirsch, 1962, 1964) have also been reported. It is difficult to compare such studies. In most studies the populations cannot be considered representative of the general population, and in some instances factors such as age and sex have not been taken into account. In studies of clinical patients (Slataper, 1950; Morgan, 1973) the subjects were visually selected, and the results cannot be generalized.

Studies vary in methodology. For instance, in measuring the refraction, some investigators have used the ophthalmoscope alone (which can only produce an estimate), some have used objective retinoscopy, others have used subjective methods only, and still others have only recorded spectacles habitually worn. In the earlier studies, either the spherical equivalent was reported, or refraction in only one meridian was reported. Some of the later, more complete studies (Sorsby, 1970; Young, 1969) have used the vertical ocular refraction. In the actual refraction procedure, some investigators have used cycloplegia, with different agents being used in different studies, while some investigators have not used drugs at all. In other studies, both methods have been used.

Studies vary in interpretation. In some studies, refractive error is graded in 0.25 D. steps, and in others, in 0.50 D. or even 1.00 D. steps. Myopia has been identified as starting at -0.25 D. and in steps up to 2 D., while in other studies, it is assumed to be any error over 0.01 D. Some have arbitrarily eliminated any error outside ± 5 D., and other have used a 6 D. cut-off.

In the sections to follow, the methods used in each study will be mentioned whenever the information was published. In spite of the great variation in methodology, it will be seen that certain general conclusions are possible regarding the distribution of refraction in various populations.

Early Studies

General Population Studies

The earliest measures of refraction were obtained with the ophthalmoscope. With this device, a beam of light is aimed at the back of the subject's eye, and a battery of lenses placed on a disc that rotates in front of the examiner's peephole brings the retina into focus. The measure of refraction is the power of the lens which achieves this focus. Because this method of estimating refraction is dependent on the examiner's own refraction and accommodation, the results cannot be considered reliable. The technique of retinoscopy is described in Appendix C; once this method became general the results became more consistent.

Because it was considered to be deleterious, most early studies of refraction concentrated on prevalence of myopia. Baldwin (1964) has reviewed the earlier studies and these are summarized in Table 8.

Table 8. Early studies on the incidence of myopia, as cited in Baldwin (1964)

Study	Date	n (subjects)	Material	Age	% myopia	
Ware	1813	1300	military school (privates)		3 subjects over -1 D.	
		127	Oxford University students		32 subjects over -1 D.	
Schumayer	1856	2172	students	8-14	18	
				14-17	35	
von Jaeger	1861	?	orphans	7-14	55	
		?	private school	9-16	80	
Cohn	1866	90000		5-21	24.12	*review of 126 studies. The youngest showed 1% myopia, and the university students showed 80% myopia
Flosshcutz	1874				21	
Seggal	1878				53.81	
Cottard	1880		university students		23.42	
Szokolsky	1848	6300	grade school		0	
		?	university students		12.5	

From Table 9, it can be seen that although there were differences in estimates of incidence, there was a tendency for older subjects and for those with more education to be more myopic. These early studies provided a basis for investigators to implicate school work in myopia (Ask, 1925, see also Chapter 2, pp. 9).

Kempf, Jarman, and Collins (1928) recorded a study on white school children in Washington, D.C. Refraction was recorded in 0.25 D. steps, using the spherical equivalent; the examinations were conducted with cycloplegia. They found in subjects aged 6 to 20, that the incidence of refraction was:

hyperopia	88%
emmetropia	5.1%
myopia	6.9%

Two studies dealing with eye clinic patients were conducted by Betsch (1925) and Clarke (1924). The Betsch study investigated the records of 16,000 patients, and recorded 12.55% were myopic over -1 D. In the Clarke study, 5000 patients were studied, and 19% were myopic, with no criterion for myopia recorded. Walton (1961) examined 1000 patients in a home for the indigent, with an age range of 30 to 100. He found 23.25% to be myopic with 0.25 D. being the criterion for myopia. Sorsby (1960) examined records of 1000 army recruits who had been examined with cycloplegic. Seventy-five percent of the subjects had refractions between plano (0.000) and +2.00 D. Nine percent of the soldiers had myopia of less than -4 D., and 2% were myopic over -4 D. Wixson (1956) examined 250 subjects non-cycloplegically, and recorded 57% hyperopic, and 27% myopic, with no age range noted.

The influence of pre-selection of material is seen from the above studies. Pre-selection implies that those examined have visual problems and so sought visual attention. Those on clinical patients (Walton, Betsch, Clarke, Wixson) report a higher incidence of myopia as compared to other studies. Studies on complete populations would include many persons with no refractive problems, and incidence of refractive error would be lower. It should also be noted, as will be discussed later, that there are geographical differences in distribution of refraction.

Goldschmidt (1968) has extensively investigated the distribution of ocular refraction in the Danish population. He summarizes earlier Danish studies. Table 9 lists the investigators, material, and data. These studies suggest that the incidence of myopia in Denmark is lower than in other parts of Europe and in the United States. Goldschmidt compared his findings on school children and army conscripts with previous studies (Tscherning, 1882; Bjerrum, 1884; Philipsen, 1884) in order to test whether there had been any change in incidence of myopia over the 80 years separating the studies.

Of 9243 Copenhagen school children born in 1948, and examined in 1962, 877, or 9.49% were myopic. Examination was non-cycloplegic, although some of the children were examined cycloplegically after the first examination where clinically desirable. More girls were myopic than boys (6.7% to 5.1%, $p < .001$). The incidence of myopia was comparable to that of earlier studies (Table 9).

The records of 3651 military conscripts, aged 18 to 30 in 1964, revealed that 531, or 14.5% were myopes. Of these, 337, or 9.2% had myopia of -1.5 D. or over. Because Tscherning (1882) considered any refractive error less than -1 D. to be emmetropia, and used 1 D. steps to record refractive error, he effectively starts his myopia category

Table 9. Earlier studies on the incidence of myopia (from Goldschmidt, 1968)

Author	Date	material	age at examination	no. subjects	no. myopes	% myopes
Tscherning	1882	conscripts	18–25	7523	627	8.33
Bjerrum & Philipsen	1884	school children	5–19	1897	171	9.04
Bjerrum	1886	infants	< 14 days	87	3	
Edm. Jensen	1899	inmates of geriartric wards	> 60	647	55	8.50
Bjerrum	1913	patients	< 25	1605	266	16.6
Holm	1925	school children	18–29	199	71	37.[illegible] (no. eyes)
Blegvad	1927	outpatients	?	53000	2643	4.99
Ludsgaard	1927	private patients	?	61968	1547	(myopia over 6 D.)
Knutzon	1941	school children	7–14	ca2000	30	1.6
Johanses	1950	school children	12–15	527	43	8.16
Oster & Jjaegaard	1964	school children	7–17	2229	153	6.90

at -2 D. Goldschmidt considered his -1.50 D. category as being comparable to Tscherning's -2 D. category. In comparing the 9.2% incidence (over -1.5 D.) with the 8.3% incidence of the older study (over -2 D.), Goldschmidt found no great difference. He therefore concluded that the prevalence of myopia had not increased in Denmark between the earlier studies and his own, an interval of 80 years. He noted, however, that the incidence of low myopia had increased, while high myopia (over -6 D.) had decreased from 1.7% in Tscherning's study to 0.6% in his own study ($p < .001$).

Comment

The differences in incidence of myopia in different occupations found in these studies will be discussed in the appropriate section, but these studies (Goldschmidt and the earlier Danish studies) do point to an age and sex difference in refraction, which will be discussed in the section that follows.

Age Distribution of Refraction

Introduction

This section reviews various cross-sectional, and longitudinal studies dealing with age differences in refraction.

Prematures

It has been generally found that premature children are more at risk for any ophthalmic defects (Fledelius, 1976). Not only did Fledelius report that prematures were more prone to exhibit ophthalmic defect, he also found that refractive problems were more prevalent in these children, with the degree and incidence inversely proportional to birth weight. Gleiss and Pau (1952) found that 11 of 23 premature children had myopia of up to -3 D., but that at the age of 8 months, only four children still had any myopia. Castrin (1955) found that prematures were twice as likely to be myopic as hyperopic.

No studies have been reported examining refractive problems associated with birth weight in normal children (full term), and this might be a fruitful area for research.

Studies in the Newborn

Early investigators found a high incidence of hyperopia in the newborn, but more recent investigations indicate a distribution of refraction comparable to that in adults. Table 10 presents data from several studies assembled from Baldwin (1964) and Borish (1970).

The von Jaeger study (1861) and the Santonasto study (1930) both record very high incidence of myopia (Table 10). von Jaeger used the ophthalmoscope to estimate the refraction, and mechanical means to keep the lids open, which could have altered the findings because of pressure on the globe. Santonasto reported that most of the myopes became hyperopic after one year, a phenomenon also reported by Hirsch (1963). Slataper studied clinical patients, and because his practice is almost exclusively confined to strabismus cases (which include more hyperopes than myopes), his findings should be treated with caution.

Cook and Glasscock (1951) examined 1000 eyes in neonates, using atropine sulphate 1% ointment at 4 to 6 hour intervals. They found a larger incidence of myopia than had been reported by the earlier investigators. They reported that:

74.9% had refractions between 0.0 and +12 D., with 50% in the range of +1 D. to +3 D.

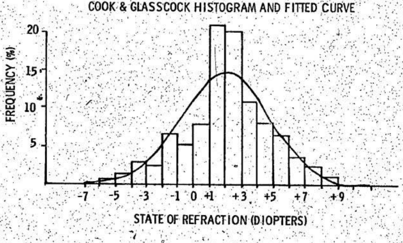

Figure 4. Distribution of refraction in newborn.
(Cook and Glasscock)

Table 10. Some early studies on the incidence of myopia in newborn (from Baldwin, 1964; Borish, 1970)

Author	Date	no.	method of refraction	% myopic	% hyperopic	% emmetropic
von Jaeger	1861	100 eyes	ophthalmoscope	78	17	5
Koenigstein	1881	181	cycloplegia	0	almost all (sic)	few (sic)
von Reuss	1881	154	ophthalmoscope atropine	18	69	14
Schleick	1882	150	atropine	0	53 (4-8 D.) 36 (2-4 D.) 11 (1-2 D.)	0
Bjerrum	1884	63	atropine ½%	0	57 (1.5-9 D)	43
Hortsman	1885	40	atropine 1%	10	70	20
Hortsman	1885	87	atropine 2%	2.5 (-1 D.)	70 (+1 D.)	27.5 (average 4 D)
Herrnheiser	1892	1918 eyes	atropine	0.1	99.9 (1-6 D.)	0
Randall	1885	1534	atropine	8.8	91.2	0
Elschnig	1904			mean refraction +2 D.		
Wibaut	1925			mean refraction +2.6 D		
Santonasto	1930	480 190	non-cycloplegic atropine	75 52	25 48	0 0
Slataper	1949			mean refraction +2.32D		
Cook & Glasscock	1951	1000 eyes	atropine	25.1	74.9	0*
Molnaar	1961			mean refraction +3.2 D		

* Zero percentage emmetropia in this study is due to its derivation from a frequency distribution. (Figure 4).

25.1% were myopes (from 0.0 to -12 D.), while 88% of the myopes ranged from -0.25 D. to -5 D.

Hirsch (1972) used the data of Cook and Glasscock (1951) to calculate the distribution of refraction in the newborn. He found no skewness, such as is found in the adult distributions, but even at the neonate level, there was some leptokurtosis. There were more positive refractions than would be expected in a normal distribution (Figure 4).

In a study on newborn, Goldschmidt (1969) examined 356 children, and found that 24.2% were myopic, similar to the prevalence reported by Cook and Glasscock (1951). Goldschmidt noted that previous investigators had found less myopia than he had, and suggested several possible technical reasons for this. He cited the use of the ophthalmoscope, which could introduce systematic errors in the estimates of refraction based on observer's own refraction, accommodation and bias. The use of this instrument also explains the zero percentage of emmetropia in the early studies. Goldschmidt noted that the relative increase in incidence of myopia in the newborn as seen with the retinoscope could be due to difficulty in refracting infants with this instrument. Cycloplegia could also alter the refractive state. He further suggested that the socioeconomic composition of the population studied could influence findings, as refraction has been shown to vary with socioeconomic status in Denmark (Goldschmidt, 1968).

Figure 5 illustrates the results of the distribution of refraction found in the Goldschmidt (1969) study on the newborn. Skewness is absent, as was found also in the Cook and Glasscock (1951) study, but as in that study, a peak occurs in low hyperopia.

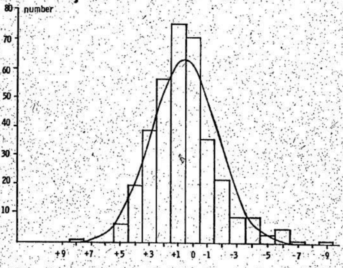

Figure 5. Curve of refractive status in
356 infants. (from Goldschmidt, 1969)

Comments

Recent studies in the newborn have shown that the distribution of refraction has a constitutional basis. This distribution is similar to that found in adults, but is not skewed to the minus side. These observations have only emerged in two studies, that of Cook and Glasscock (1951) and Goldschmidt (1969). From Goldschmidt's remarks, and from the wide diversity between reports on refraction in newborn, it is apparent that studies using more precise measurements are needed.

School Age

Studies relating the distribution of refraction to age have concentrated on the 6 to 18 year age group, probably due to both the convenience of using school samples, and also because of the ongoing controversy about "school myopia." These studies are now reviewed. Comparison of results among them is sometimes impeded by the failure of researchers to state the criteria used to distinguish the ametropias.

Cohn (1867) examined 10,060 school children, using the ophthalmoscope without cycloplegia, and found that if he excluded those with less than -1 D., the incidence of myopia went from 1.4% in the primary grades to 55.8% in the highest grade (age 16). He also examined students in a state school (grades 4-13), and found myopia increased in prevalence from 13.6% in the lowest grade to 41.7% in the highest grade. In a village school study, using atropine this time, he found "more than 80% were between + or -1 D., with only 4 eyes myopic."

Kempf, Jarman, and Collins (1928) found in examining 1001 school children, that the incidence of myopia in the age groups were as follows:

age 6-8	2.1%
age 9-11	5.5%
age 12+	9.1 to 9.5%

Brown and Kronfeld (1929) in a United States study reported the increase of prevalence of myopia in school as follows:

age 6-7	incidence of myopia was	1.4%
age 8-9	it rose to	4.2%
age 10-11	the incidence was	8.5%
age 12-13	the incidence of myopia	9.1%
from age 14 up	it was	9.1%

Tassman (1932) recorded mean spherical refraction of 9000 young clinical patients and found that myopia prevalence increased radically in the 5 to 10 year age interval and also in the 15 to 20 age group. Myopia and hyperopia tend to stabilize in adulthood. This stabilization could be due to senile changes in one or more of the ocular components with increasing age.

Baldwin (1964) cited the longitudinal study of Jaeger (1938), who examined annually 350 female and 150 male subjects from age 10 to 16 in the female group and from age 10 to 18 in the males. The greatest increase in myopia took place around the ages of 10 to 12, as did the most rapid changes in refraction. The rapidity of change lessened at age 13 to 15, and from ages 15 to 18, there was almost no mean change.

Slataper (1950) reported on changes in refraction with age on 35,000 clinical patients. He reported the total change in spherical equivalent cycloplegic refraction from birth to age 7 was +1.617 D. of hyperopia, or +0.231 D. per year. After age 7, there was a shift to myopia of -0.15 D. per year until age 30. From age 31 to 64, Slataper reported a gain of +1.362 D. of presbyopic hyperopia, or +0.04 D. annually. Slataper's subjects were mainly strabismic patients, so his results should be treated with some caution.

McNeill (1955) studied 1066 British school children who were referred to a school clinic and found that the younger age group showed 20% myopia while the older group (ages 13-16) showed 40% with the condition. Sixty percent of those wearing glasses were myopic.

Coleman (1970) examined 3628 school children from kindergarten to grade 6 inclusive using the objective method (retinoscope). He found that myopia becomes predominant in grade 3 (age 9) and commented:

> Myopia begins to appear in grade 2, shows a radical upsurge in grade 3, and by grade 4 is a major problem. This is occurring almost a full year earlier than previous studies indicated.

He also reported more grade repetition amongst hyperopes and astigmats than amongst myopes. By grade 6, one-third of the girls and one-quarter of the boys were myopic.

In the Coleman study, criteria for hyperopia were beyond +1.5 D. and for myopia beyond -0.50 D. Using these limits, the distribution shown in Table 11 resulted:

Table 11. Distributions of refraction from kindergarten to grade 6 in 3628 school children, using spherical equivalent

Grade	Total % myopia	Boys	Girls
K	20.0	15.8	25.0
1	21.3	20.65	22.0
2	20.4	20.77	19.6
3	17.89	18.57	17.2
4	22.67	20.0	25.4
5	26.07	18.7	34.7
6	30.95	25.7	39.1

Table 11 illustrates that in grades kindergarten to grade 3, the incidence of myopia is fairly stable. However in grade 4 (age 10-11) there is indeed an upsurge. This continues in the two subsequent years, with the girls being more myopic than the boys. This will be elaborated upon in the appropriate section.

In a longitudinal study, Hirsch (1964) examined a group of children in Ojai, California, at age 6 and again at age 14. In the 1964 refraction, 383 children remained of the original 1200 subjects. Examination was by retinoscopy, with refraction recorded in both principal meridians, using the equivalent sphere. There were 92 eyes with myopia of -0.50 D. or more, 69 eyes with hyperopia of +1 D. or more, and Hirsch selected 100 eyes from the remaining 605 eyes to represent the emmetropes. He found a highly significant relationship between refraction at age 6 and at age 14.

If a child was myopic at the earlier age, he was also myopic at the later age, if he was hyperopic at the earlier age he remained hyperopic, provided the earlier hyperopia was over +0.50 D. If, on the other hand, the first refraction was between plano and +0.50 D., the child became myopic. As the investigator put it: "the die is cast by age 5." Hirsch concluded that the children are "at risk" before entering school.

This Ojai study illustrates the difficulties that can be encountered in a longitudinal study. Only 32% of the original material reported back at age 14, which alters the representativeness of the material. Fledelius (1976) also commented that because different examiners were used at different stages of the study, including student optometrists, the accuracy of the data could be questioned. Fledelius also notes that Hirsch did not consider the racial and cultural composition of the material, and whether this remained the same in both examinations. In spite of these imperfections, the Hirsch study provides some valuable insight into the changes that take place during the school years.

Baldwin (1964) reported the critical period for change to be from age 7 to 18, where the mean change from birth to adulthood is about 2.50 D. in the direction of myopia. About 15% of the population shows this trend, and this sub-population usually shows a hyperopia of +0.75 D. or less at age 6 (Hirsch, 1964).

Similar in many respects are the findings of the Sorsby group (1933 and on). Sorsby (1933) studied patients in age groups from 3 to 15, with approximately 50 subjects in each age group and in each sex. Cycloplegia was used. From age 3 to 6, the mean spherical equivalent refractions were:

age 3	+2.65 D.
age 4	+2.30 D.
age 5	+2.20 D.
age 6	+1.77 D.

indicating a progressive change to more negative refraction, evident even at age 4.

Both Sorsby (1933) and Hirsch (1952) studied non-visually selected groups of children. Sorsby used cycloplegia, while Hirsch did not. The number of subjects in the Hirsch study was 10,000, and in the Sorsby study was approximately 1100. Both studies indicate a change in mean refraction to more negative values over time, and in both studies the girls showed greater changes in mean refraction.

In an effort similar to his 1933 study, Sorsby et al (1961) examined 1432 nursery and school children with an age range of 3 to 15, comprising

671 males aged 3 to 14, and 761 females aged 3 to 15. Cycloplegia was used. In boys, the mean refraction changed from +2.33 D. at age 3 to +0.93 D. at age 14, in girls, the change was from +2.96 D. at age 3 to +0.64 D. at age 15. This indicates that in both sexes, the refraction changed to more negative values from age 3 to 14 or 15, and that the changes were of a greater magnitude in the females. Sorsby then excluded extreme values from his data (over ±2 D., 43 males and 44 females). The mean vertical refraction in males became +2.2 D. at age 3 and in females +2.7 D. at that age. The ultimate mean refractions for males and females were +1.0 D. and +0.8 D., respectively. The greater change and more myopic refraction in females was again evident (Figure 6).

In a follow-up study, Sorsby (1961) compared 386 subjects. The reduction in positive refraction for males was 1.4 D., and for females was 2.3 D., an even greater spread and range than in the original subjects.

Adult Changes in Refraction

Most authors agree that there is very little change in refraction between the ages of 25 and 45 (Slataper, 1950; Hirsch and Wick, 1960; *Stenstrom*, 1948). After 45, presbyopia influences refractive error. Slataper (1950) cited earlier, reported that from the age of 8 to 30 mean refraction changed a total of -3.327 D. From age 31 to 64, it changed +1.362 D., and from age 65 to 87, the senile changes caused a return to the myopic range of -2.367 D. For all ages, the mean annual decrease in hyperopia was -.142 D., and the mean annual increase in myopia was -0.288 D. Hirsch (1960) showed that adults change to hyperopia from the ages of 45 to 70, and reported the following data for change in median refraction.

Table 12. Average median refraction by 5 year age groups (from Hirsch, 1960)

age	median refraction
45-49	+0.18 D.
50-54	+0.31 D.
55-59	+0.74 D.
60-64	+0.84 D.
65-69	+0.94 D.
70-74	+1.04 D.
75-79	+1.02 D.

This study was of clinical patients, therefore visually selected, and the number of subjects was not reported. The median changed from +0.18 to +1.02, or about 0.9 D., similar to the change reported by Slataper (1950) of 1.00 D. Hirsch referred to this as an increase of real hyperopia, or acquired hyperopia as described by Donders (1964), and Duke-Elder (1949). He notes that the rate of change was more rapid from age 50 to 55. After age 65 to 70, the hyperopic shift is slowed, probably due to senile changes in the media including lens changes, or to lessened ciliary muscle activity.

Comments

Two trends are clearly seen for changes in refraction with age. During the school years, population mean and individual refractions become more negative. Depending on the initial refraction, ultimate refraction will be minus or plus. Refractive state normally remains fairly stable until about age 40 and then starts a change to more positive values, due to what Hirsch (1960) calls acquired hyperopia.

These trends will be evident when population distribution curves for refraction are examined. Mean refraction is on the minus side until ages 40-45, and then becomes positive, increasing until senile changes reverse the trend. In some populations, change in population mean refraction in the middle years is more rapid. This is demonstrated in a later section.

Sex Differences

In the studies reviewed earlier, any sex differences in distribution of refraction were mentioned. Females were found to be more myopic than males.

Cohn (1867) noted an almost equal distribution of refraction for either sex. Goldschmidt (1968) on the other hand, noted that more girls were myopic than boys ($p < .001$) (p.51). Morgan (1958) also found a strong sex difference at ages 13 and 33, and Coleman (1970) found girls became more myopic than boys with the mean spherical change for boys being -0.04 D. and -0.22 D. for girls. Hirsch (1953) studied case records of 2574 males and 2627 females of all ages. When all negative refraction was considered (from plano to -7.00 D.), 63.65% of females were myopic, while 57.54% of males were myopic. If only plano to 5.00 D. was considered, the males showed more myopia, indicating that females had more myopia of a higher degree. Table 13 gives Hirsch's (1953) findings.

Sorsby (1961) also found a greater prevalence of myopia among females, although in his 1933 study he found the mean refraction for males to be more myopic at age 13.

Table 13. Sex differences in various degrees of myopia (from Hirsch, 1953)

refraction	men n	men %	women n	women %
myopia – more than 7.00 D.	7	0.27	12	0.46
-6 to -7 D.	4	0.16	14	0.53
(more than 6 D. of myopia)	11	0.43	26	0.99
-5.01 to -6.00 D.	16	0.62	12	0.46
-4.01 to -5.00 D.	33	1.28	26	0.99
-3.01 to -4.00 D.	54	2.10	45	1.71
-2.01 to -3.00 D.	120	4.66	90	3.42
-1.01 to -2.00	219	8.51	182	6.93
-0.01 to -1.00	640	24.86	574	21.85
0.00 and all + corrections	1481	57.54	1672	63.65
	2574	100.00	2627	100.00

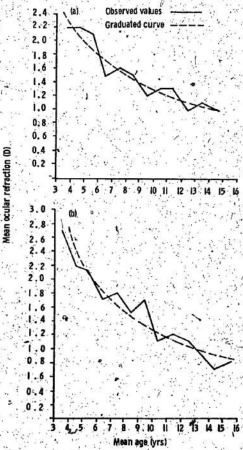

Figure 6. Ocular refraction in relation to age:
(a) boys and RAMC recruits, (b) girls.
(from Sorsby, 1961)

Comment

Studies on sex differences in refraction are in general agreement. Girls start the change to negative refraction earlier than boys. It has been shown by Mechanic (1978) and others, that females seek medical and health care more often than males. For this reason, more females are represented in clinical studies on sex differences with respect to refraction, and the data could be affected by this. On the other hand, the studies on unselected material, i.e. the school children, also showed the same sex effect.

Geographic and Ethnic Studies

Asia

There have been several studies on refractive distribution in Asia. The Japanese have long felt the incidence of myopia in their country to be a serious problem. Sato (1978) reported that Japanese optical laboratories produce nine concave lenses to one convex lens.

Rasmussen (1936) examined 120,000 Chinese clinical patients, and reported that in the 25 cities where they resided, 42% were myopic with an average error of -3 D., and that myopia was common over all classes, presumably meaning literates and illiterates alike.

Pertinent Japanese studies are reviewed in Table 14. It is seen from Table 14 that myopia appears to have increased from 1911 to 1970, with higher degrees of myopia in the higher school grades, and in the older children. The studies comparing pre and post war data presumably were meant to show that during the war, fewer students were at school, and therefore myopia was less frequent, increasing as academic activity resumed. However, change in nutrition could have been a factor, and no

Table 14. Prevalence of myopia as reported in Japanese studies

Author	Date	Year of Study	Prevalence of Myopia	Type of Myopia
Tamura	1932	1911	5%	low myopia
		1932	12%	low myopia
Sato	1957	1914	15% (27,000 students)	
		1947	45% high school	
			70%	
Kitamura & Hagihara	1970	prewar (II)	(unrecorded)	
		postwar	28% primary grades	
			39% junior high	
			50% senior high	
Otsuka	1967	prewar (II)	70%	
		wartime	decrease	
		postwar	70%	

mention is made in any study of the class of society from which each sample was taken, nor of different psychological atmosphere during and after the war. While a trend towards increased myopia is shown with time, the causes cannot be deduced.

Malaysia

Chandran (1972) conducted a study of refractive errors in West Malaysia, comparing 223 Malays to 292 Chinese and 235 South Indians. The subjects were aged from 5 to 65, and were patients in a hospital clinic over a four year period. In comparing his data with Sorsby's (1957) on Caucasians which showed a refractive peak at plano to +2 D., comprising 73.4% of the subjects, his Malaysians peaked at plano to -2 D. at 39.5%.

By race, the Chinese showed a peak at plano at -2 D., 40.3% of subjects; the Malays at plano to -2 D., 39%; and the Indians showed two peaks in their curve, one at +2 D. and one at -2 D. The hyperopic peak was at 34.7% and the myopic peak at 37%.

India

Patel et al (1970) examined 250 babies in India under cycloplegia and reported that 62% were hyperopes and 12% were myopes with a range of 1 to 5 D.

Prakash (1971) examined 730 clinical patients in India up to the age of 15. He reported 65.2% hyperopia and 33.4% myopia. Presumably there were very few emmetropes. Myopia was the most prevalent in the 10 to 15 year age group.

New Zealand-Polynesia

Grosvenor (1970a) compared the refractive error distribution in Polynesian and European children in New Zealand. Static retinoscopy and Visual Acuity tests were done on 973 subjects aged 12 to 19 years. The refractive errors were tabulated in 1 D. intervals. Table 15 presents the findings.

Table 15. Mean refractions, standard deviations and variances in 973 European and Polynesian children in New Zealand (from Grosvenor, (1970a)

	European	Polynesian
mean	+0.18 D.	+0.22 D.
SD	1.02 D.	0.66 D.
variance	1.04 D.	0.44 D.

F test comparing variances significant to 0.01

Table 16 illustrates the frequencies of emmetropia, myopia, and hyperopia in the two groups.

Table 16. Frequencies of the ametropias and emmetropia in 973 European and Polynesian children in New Zealand (from Grosvenor, 1970a)

	European		Polynesian	
	n	%	n	%
hyperopia (+.75 or more)	144	21.1	36	12.4
emmetropia (-.25 to +.50)	437	64.0	221	76.2
myopia (-.50 or over)	102	14.9	33	11.4
	683	100.0	290	100.00

$X^2 = 14.85$; $p < .001$

There was a lower frequency of hyperopia in the Polynesians and a lower frequency of myopia of -1.50 D. or beyond.

Africa

Holm (1937) examined 6000 records of black males, aged 18 to 37 in French Equatorial Africa and found only 1% myopia. Scott (1945) reported the same findings in Gambia amongst a school child population.

Olurin (1973) reported the retinoscopic refraction of 1150 Nigerian subjects. Myopia was the most common error (58.1%), especially under the age of 41. From age 41 to 50 hyperopia accounted for 70.8%. Of the 669 myopes,

78.8% had less than 2 D.

16.4% had from 2 to 5 D.

4.8% were myopic over 5 D.

This population was mostly illiterate. These findings contrast sharply with the earlier studies of Holm and Scott on African subjects.

Comment

The great difference between Olurin's findings and those of the two previous studies is explained by Olurin (1973) as being due to better screening methods in his hospital, and the fact that his material was clinical patients, visually pre-selected. It must be said that this would not explain all of the difference. Some of the diversity may be cultural, or that examination techniques and cut-off points may have been different in the earlier studies. Holm (1937) found not only a 1% prevalence of myopia, but the prevalence for hyperopia was a very low 14%, while he classified 85% of subjects as being "normal," without specifying his refractive criteria. Olurin noted that three studies in other parts of Africa in 1963, 1964, and 1967 showed very similar results to his own.

Russia

In Russia, Maimulov (1971) examined 2034 children ages 5 to 7 and reported 3.3% myopic and 6.7% hyperopic.

Eskimos and Amerinds

Abraham and Volovick (1972) performed non-cycloplegic refractions on almost 4000 students in a Navajo school in the United States, and found more myopia than is usual among Caucasians of similar ages. Sixty percent of the myopes had an error of less than -3.00 D. They also found higher astigmatism than in comparable Caucasian samples but the difference seemed to diminish with age.

In a study on Eskimo children, Young (1969) recorded 58% myopic with virtually no myopia in parents and grandparents. The study was of 508 volunteer subjects divided into family units, and both non-cycloplegic and cycloplegic examinations were performed. Young (1970) in a further report on his Eskimo data noted that the incidence of myopia was much higher than in comparable Caucasian or Japanese studies on similar samples.

Boniuk (1973) reported on the eye status of Indians in the Canadian Arctic. Of 951 clinical patients examined retinoscopically under cycloplegia, myopia ranging from -1 to -5 D. was the most prevalent error. Myopes comprised 32.5% of the population studied. In the 10 to 20 age range, the incidence reached 50%. She termed this an "epidemic of myopia," suggesting that the recent availability of schooling could be a cause, but also implicated diet.

Morgan and Munro (1973) studied 2833 Eskimos and 844 Indians in northern Canada, finding a marked increase of myopia among the young. They said of the distribution curve:

> One expects however to find the curve plateauing, not declining with age. The prevalence should not change appreciably after age 15 if the condition is chronic, non-fatal, and irreversible.

Cass (1973) found that during her 10 years in the Canadian far North there was a changing incidence of myopia by settlement and group. She gives the following data in Table 17:

Table 17. Percentage of myopia by settlement, group: 1958, 1970 (from Cass, 1973) *

		1958	1970
Eskimos	Tuktoyaktuk	2%	23%
	Spence Bay	--	2.2%
Indians	Good Hope	2.2%	6.7%
	Old Crow	0.8%	8.7%

Number of subjects are not given in her report. Table 18 presents the changing incidence of myopia in some schools.

Table 18. The changing incidence of myopia of students in Akaitch Hall, Yellowknife, trade school for older children who have lived for many years in residential schools (from Cass, 1973) *

	1958	1970
Eskimos	6.5%	65%
Indians	13.3%	65.7%
Metis	17.4%	59.5%

*The author did not specify cutoff values for myopia.

Cass speculated the change in diet from high protein/low fat/salt/ carbohydrate to low protein/high fat/carbohydrate/salt might cause these increases.

In a study on 4018 Amerinds in the Canadian North, Woodruff and Samek (1977) reported a difference in refractive distribution between those under 30 and those over 30. The population was drawn in part from the same area as that studied by Morgan (1973). The mean refraction for the total population was -0.49 D., for females -0.57 D., and for males -0.37 D. In comparing their findings with those of Morgan (1973) (Figure 7), they found the peak in Morgan's distribution to be at age 20 and to be much higher than the peak in their study at age 11. Woodruff explains this by virtue of the fact that part of his population was non-visually selected, while Morgan's material was all clinical.

In a study on West Greenland Eskimos, Alsbirk (1979) examined 483 subjects over age 15 non-cycloplegically, using the subjective test only. Refractions were reported in spherical equivalents. These subjects comprised 98% of the local population. The distribution of refraction showed the typical non-Gaussian curve and was skewed to the minus side among subjects over 40 years. The women were found to be more hyperopic than men. Six percent of the males and 4% of the females were myopic over -2 D., while for any degree of myopia, 40.3% of the males and 33.1% of the females were myopic, indicating more myopia in males in this population than in females. In the 15 to 19 year age groups, 28% were myopic, parallelling Morgan's findings. However, Alsbirk found the percentage of myopia across all age groups to be fairly uniform, in contrast to Young (1969) and Morgan (1973).

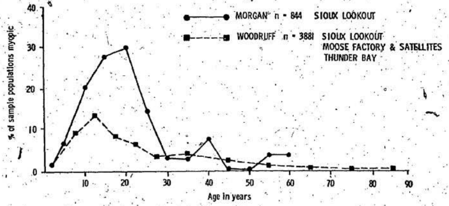

Figure 7. Comparison of the percentage of persons myopic between two samples (Morgan, Woodruff) of Sioux Lookout Amerinds.

Comment

All but one of the preceding studies on Eskimos and Amerinds reported a dramatic increase in myopia in one generation. The various investigators offer several explanations for this "epidemic of myopia." Near work causality is espoused by Young and his associates, Cass implicates diet. Morgan and Boniuk have suggested that schooling and near work could be the cause, while Woodruff et al discount near work and suggest diet and febrile disease as possible causes. A study of a Caucasian population that had been exposed to similar environmental changes would clearly be helpful in interpreting this change. Findings of the present study, described in the next section, can be compared to the studies reviewed above and to the discordant findings of Alsbirk (1978).

Refraction in Jews

Early studies by Nicati (1879), Stephenson (1919), and Gallus (1922) reported myopia to be more prevalent in Jewish children and adults, compared to non-Jews. Kantor (1933) found in comparing 365 Russian Jews to 374 White Russians from Minsk that among compositors, 22.8% of the Jews were myopic, while among non-Jewish compositors 6.1% were myopic. In other occupations, the prevalence of myopia in Jews was 14.75% and 4.93% among non-Jews.

The most extensive studies on this point are those of Sorsby (1928, 1933). In the 5 to 9 year age group, for 170 Jewish children, compared to 315 non-Jewish, the percentage myopic was 9.1% for Jews, and 10.2% for non-Jews. However, in 510 Jews and 892 non-Jews from the ages of 5 to 14, 25.2% of the Jews were myopes compared to 20.2% of the non-Jews.

Evidently, the 10 to 14 year age group showed more myopia in the Jewish children. In his 1933 study on 1659 Jewish males compared to 600 non-Jewish males, he found myopia in 43.2% of Jews, and 21.7% of non-Jews. The age range in this study was also 5 to 14.

Sorsby (1940) reported on a study of 672 unselected non-Jews and 772 Jews aged 4 to 8. Atropine was used in refraction. He noted that on school leaving the myopia is double in Jews compared to the non-Jews.

As he noted, the curve for Jewish children is decidedly flatter, i.e. "the mode of refraction is on a lower hyperopic level, and the whole curve is shifted to the myopic side."

Woodruff and Schmidt (1976) reported on the prevalence of refractive error in 633 pre-schoolers in Ontario, which included 92 Jewish children. The age range for all children was 2½ to 6. The mean refraction of the group of Jewish children was +0.42 D., compared to +0.51 D. for the non-Jewish children. Using the Student t test, the difference was significant at $p < 0.00001$.

Comment

The studies on refraction in Jews do not attempt to account for the difference in distribution compared to non-Jews. The explanation could be cultural, i.e. environmental, or genetic.

It is also to be noted that the studies on the Jews were done on Ashkenazi (Eastern European) Jews, and that no studies have been reported of the distribution of refraction in Sephardi (African and Middle Eastern) Jews. Because of the dispersion of the Jews that has taken place over the past 2000 years, the Jews cannot be considered to be a

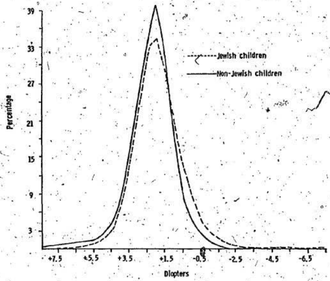

Figure 8. Curve showing the distributions of refraction in Jewish and non-Jewish children. (from Sorsby, 1940)

race, so racial explanations for differences in refraction in Jews must be treated with caution.

Discussion

Studies in India, Malaysia, New Zealand, and Africa show varying distributions of refraction in different groups, but are not informative on possible causes for these differences. Cultural differences could account for the results. Loehlin, Lindzey, and Spuhler (1975) note that visual acuity tests have high reliability, but can be biased against certain peoples. In a subjective eye test, the subject's refraction is validated and refined by his ability to read a certain line on a Snellen chart 20 feet away. If the subject comes from a culture that spends little time discerning objects at that distance, there may be a bias in measuring his refraction. This renders interpretation of geographical and ethnic variation difficult. The results for the Alaskan Eskimo and Canadian Northern peoples are informative. They indicate a sudden appearance of myopia in one generation in areas that had little myopia previously. The next section will offer some evidence for the importance of near work in refraction. The data presented might also aid in interpreting the Japanese studies that associate myopia with more education.

PERSONAL INVESTIGATION I

THE INCIDENCE AND DISTRIBUTION OF REFRACTION

Aims of the Study

The aims of this investigation were to ascertain the distribution of the measures of refraction in the study population, and to examine the influence of age and sex. These descriptive characteristics permit comparison with investigations reported in other populations and provide a basis for determining the amount and degree of myopia detected, and the extent to which the need for corrections have been met.

Method

The raw data from the computer file were the measures of refraction, and the recorded age and sex. The product moment correlation coefficient and the frequency distribution of refraction and cross tabulations with age and sex were obtained by using SPSS programmes.

In studies on the distribution of refraction, arbitrary values have generally been selected to categorize refraction, the cut-off for myopia ranging from -0.01 D. to -2.00 D. Refraction is treated as a continuous variable in this present study and arbitrary categorization is generally avoided. Where required for graphical and statistical comparison with previous studies, any minus refraction is taken to comprise myopia and any positive refraction, hyperopia. This distinction is arbitrary and is of course not based on clinical relevance.

Correlation Between Right and Left Eye Measures

As a first step, the product moment correlation coefficient was calculated between the vertical refraction measures for right and for left eyes. This yielded a value of $r = 0.93578$ ($p < 0.00001$), denoting an almost perfect correspondence between the two measures. On this basis, it was decided that further analysis could be carried out using the vertical refraction (subjective) for right eye only (designated RVERT in tables). By using this single measure, it was possible to count subjects only rather than eyes.

The Distribution of Refraction in the Population

In Figure 9, the distribution of refraction values in the study population is shown graphically. The curve peaks between plano and +0.75 D. and lacks symmetry in that it appears to contain a preponderance of negative values. To test the extent to which it conforms to the normal distribution, expected values were calculated by expansion of the theoretical binomial distribution and compared by chi-square to the observed values as in Table 19.

Table 19. Fit of population distribution of refraction to normal distribution

	+4+6						-4-6
no. observed	14	58	198	344	225	89	29
no. expected	14.9	87.3	235.4	281.8	235.4	87.3	14.9

chi square = 41.16 ($p < 0.001$) for 6 degrees of freedom

This confirmed that the distribution was significantly different from normal and, from inspection, it shows more than expected numbers in the intervals plano to +0.75 D. (leptokurtosis) and -4 to -6 D. (negative skew). These deviations from the normal distribution in the distribution of refraction have been reported by Sato (1957) and by Hirsch (1962) and were discussed previously.

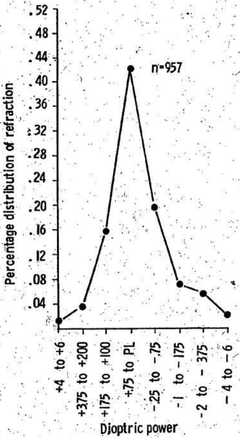

Figure 9. Distribution of refraction for the population in the present study.

Points chosen to facilitate comparison with Figure 2, page 11.

The Effects of Age

Table 20 shows the mean right vertical refractions measured in various age groups and the percentage of myopia occurring at these ages.

For age interval 5-9, the mean refraction is +0.62 D., and by age 15-19, the extreme negative value is reached (-0.924 D.). After age 19, the mean refraction begins to shift towards hyperopia. After age 65-69, the refraction becomes erratic, probably due to both senile changes in the eye, and the very low number of subjects refracted. The single subject, aged 97, had a refraction of -1.[illegible]5 D. due to senile cataract. Slataper (1950) has also noted that refraction in the older age groups becomes less hyperopic or more myopic.

Figure 10 depicts the same data in graphic form and illustrates the rapid shift in the mean refraction after age 15-19.

It is of interest that the transition point at which the population mean refraction becomes positive corresponds approximately to age 30. This is an unexpected finding which will be examined subsequently in more detail.

Sex Differences with Age

Table 21 and Figure 11 present the distribution by age of the refraction measured for the 438 males in this study. In the youngest age group, the mean refraction is +0.635 D., and the lowest mean value is reached in the 20-24 age group. The refractive distribution then becomes more hyperopic, reaching its maximum at age 65-69, at +1.417 D. The highest frequency of myopia is in the 15-19 age group (50%).

Table 22 and Figure 12 present the data for the age distribution of refraction in the 519 females. In the youngest age group the mean

Table 20. Age distribution of RVERT, means, standard deviations, number and percentage, by age group (n=957)

Age group	n	RVERT	SD	no. myopes	% myopes
5-9	195	+0.62	1.026	37	18.97
10-14	145	-0.172	1.251	73	50.34
15-19	108	-0.924	1.472	69	63.88
20-24	76	-0.812	1.619	40	52.63
25-29	85	-0.286	1.722	38	44.71
30-34	53	-0.094	0.935	17	32.07
35-39	49	+0.082	0.967	15	30.61
40-44	55	+0.236	1.409	10	18.18
45-49	52	+0.533	1.477	10	19.23
50-54	48	+0.765	0.894	5	10.42
55-59	25	+0.747	0.706	1	4.0
60-64	28	+1.414	1.595	2	7.14
65-69	18	+1.442	1.445	2	11.11
70-74	10	+1.013	1.94	0	0.0
75-79	5	+0.55	1.771	0	0.0
80-84	2	+1.615	2.312	0	0.0
85-89	2	+0.50	0.707	0	0.0
90+	1	-1.95	0.0	1	100.0
	957			320	33%

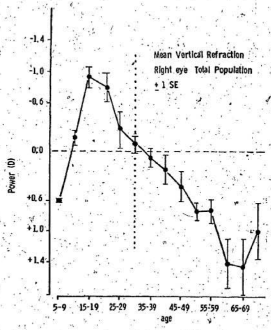

Figure 10. Mean vertical refraction (right eye) for the total population in this present study.

Table 21. Distribution of refraction males (n=438)

Age group	n	RVERT	SD	no. myopes	% myopes
5-9	109	+0.635	0.681	15	13.76
10-14	76	-0.01	1.233	28	36.84
15-19	38	-0.313	0.975	19	50.0
20-24	18	-0.366	1.375	7	38.88
25-29	36	-0.024	1.690	11	30.55
30-34	20	+0.203	0.383	5	25.0
35-39	22	-0.057	1.198	8	36.36
40-44	25	+0.069	1.429	5	20.0
45-49	21	+0.525	1.363	4	19.04
50-54	28	+0.689	1.006	4	14.28
55-59	16	+0.75	0.508	0	0.0
60-64	15	+0.617	0.790	2	13.33
65-69	6	+1.417	0.516	0	0.0
70-74	5	+1.38	1.865	0	0.0
75-79	2	+1.0	0.707	0	0.0
80-84	0	0.0	0.0	0	0.0
85-59	1	0.0	0.0	0	0.0
90+	0	0.0	0.0	0	0.0
	438			108	

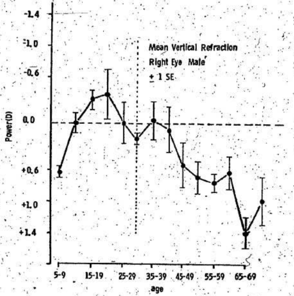

Figure 11. Mean vertical refraction (right eye) for males in this present study.

Table 22. Distribution of refraction females (n=519)

Age group	n	RVERT	SD	no. myopes	% myopes
5-9	86	+0.60	1.347	22	25.88
10-14	69	-0.351	1.254	45	65.22
15-19	70	-1.256	1.592	50	71.42
20-24	58	-0.95	1.674	33	56.89
25-29	49	-0.478	1.738	27	55.16
30-34	33	-0.274	1.116	12	36.36
35-39	27	+0.196	0.734	7	26.92
40-44	30	+0.376	1.401	5	16.66
45-49	31	+0.539	1.571	6	19.35
50-54	20	+0.878	0.718	1	5.0
55-59	9	+0.742	1.006	1	11.11
60-64	13	+2.334	1.813	0	0.0
65-69	12	+1.454	1.762	2	16.66
70-74	5	+0.646	2.157	0	0.0
75-79	3	+0.25	2.385	0	0.0
80-84	2	+1.615	2.312	0	0.0
85-89	1	+1.0	0.0	0	0.0
90+	1	-1.95	0.0	1	100.0
	519			212	

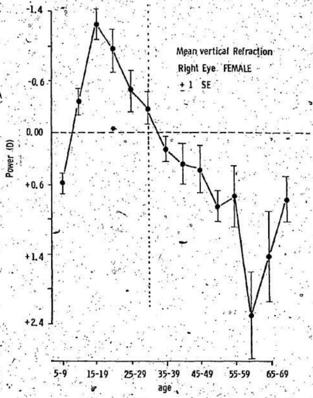

Figure 12. Mean vertical refraction (right eye) for females in this present study.

refraction is +0.60 D., and the lowest value is found in the 15-19 age group (-1.256 D.). The percentage of myopia in the 15-19 age group is 71.42%, almost 50% more than in the males. The maximum hyperopic refraction is +2.34 D., reached at age 60-64.

When the findings for males and females are compared, the mean refraction scores for females (-0.0703, SD = 1.48) was significantly lower than the mean for males (0.2805, SD = 1.015) ($t = 4.137$, $p < 0.001$). It can be seen that the females in this population have a more negative mean refraction than males in the younger age groups, and a more positive refraction than males above ages 35-39. With the exception of age ranges 50-54 and 55-59, the standard deviation of the refraction measures in females is greater for each group than that for males, reflecting the tendency for the range of negative and positive refractions to be greater in females than in males. Also the extreme of negative mean refraction is reached earlier in females (15-19 years) than in males (20-24).

Similar results have been reported by Sorsby et al (1961), Hirsch (1952), Young (1969), and others, and are usually attributed to earlier physical and psychological maturation in females compared to males. Goldschmidt (1968) pointed out that the differences in refractive distribution between males and females have usually been shown only in *children's studies*, and rarely or never in adult studies. He therefore questioned whether there was a difference in refractive status by sex. In the present material in those over 30 years of age the differences between the sexes in the percentages considered to be myopic (17% for males and 19% for females) are marginal.

Comparison with Other Studies

The data for incidence and distribution of refraction in the population studied shows the typical leptokurtosis and skewed curve reported by other investigators. The age and sex differences found in other studies are also seen in this population. However the change in mean refraction from negative to positive values at about age 30 was unexpected and has been reported by Young (1969), Morgan and Munro (1973), and Boniuk (1973), in the Eskimos.

Once a person becomes myopic, he retains that refraction throughout his life (with rare exceptions) until his refraction changes to more positive values at about age 45 to 50. Thus, a distribution curve would show the mean refraction changing to the positive area in the graph at about age 45, and not at age 30 as seen in the present study. A search of the literature has revealed only one study that provides data for mean refraction across all age groups (Young, 1969). It is therefore difficult to compare the distribution curve found in the present study with any other study. To overcome this, data were computed from two studies to provide a basis for comparison with the present findings. The present material is substantially larger than that reported by Young (1969) and Alsbirk (1978), and these studies and the present study are not samples but approach total population studies. The HEW study is a carefully constructed sample representative of the US population. Statistical comparisons were therefore avoided in favor of simple descriptions.

The United States (HEW) Study (1978). The United States Department of Health, Education and Welfare published data from a comprehensive survey of refractive status and other ocular parameters, in a sample of

9263 subjects, representative of the population of the United States. The age range was comparable to that of the present study, viz. 4-74. Table 13 of this report presents data showing the percentage and types of lenses worn by the population, in equivalent spheres. A total of 52.4% of the population was wearing glasses. The study also reported that 21.5% of the population needed correction, and could achieve maximum vision (20/20) if proper correction was provided. This data was treated in the manner described below to allow comparison with the findings of the present study.

The United States study listed, by age groups, the percentage of lenses worn in each category of minus and plus lenses, and also in plano lenses. This percentage was multiplied by the dioptric value, and the products summed and divided by 100 to give the correction in each group. This value is called X. Because 52.4% of the population wore glasses, and because 21.5% of the population could achieve maximum vision if they had glasses, the mean refraction for each age group was calculated to be .524X + .215X.

This calculation assumes that the distribution of correction required in the 21.5% of the population needing glasses was the same as that for persons wearing glasses. The validity of this assumption depends on the reasons why persons in the United States do not have glasses. Extreme refractive errors are probably more likely to be corrected, regardless of personal cost. The distribution of uncorrected refractions might therefore be less extreme than that of corrected refractions, but this should not seriously affect estimates of mean refractive error.

In the United States study it was found that equal numbers of plus and minus lenses were worn. The percentage of persons with minus corrections was reported to increase with age from 30.2% at age 4 to 5, to a maximum of 87.2% at age 12 to 17, then to decrease to include 15.7% of those aged 65 to 74. These values are based on the powers of lenses being worn. From this, the proportion of myopes in the total population was derived using the logic above, and is presented in graphical form below (Figure 14).

The Alsbirk Study (1979). In his study on West Greenland Eskimos (cited earlier), Alsbirk examined 222 adult male and 261 adult female subjects, aged 15 years and up, and reported the mean spherical equivalent refraction by decade. His data were converted to show mean refraction for the total population by decade.

Comparison of Findings from the Four Studies

Figure 13 illustrates the distribution curve of mean refraction in the United States (HEW) study (1978), Young's 1969 study, Alsbirk's 1979 study, and the present investigation.

It will be seen that in both the United States study and the Alsbirk study, the distribution curve becomes positive and stays positive after age 44, while in the Young study and in the present study, the mean refraction becomes positive at an earlier age, viz. age 30.

Figure 14 illustrates the percentage of myopes in different age groups in the four studies. It can be seen that the findings of the present study resemble Young's results much more than Alsbirk's, and those reported in the United States study. The distributions of refraction in the Young study and the present study indicate a great difference in refractive distribution before age 25 to 30 and after this

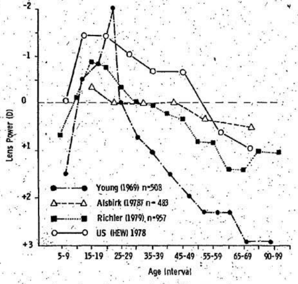

Figure 13. The distribution of refraction in 4 studies.

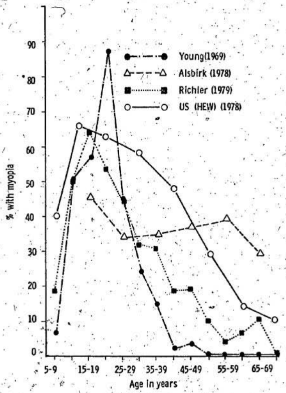

Figure 14. Percentage of myopes in different age groups in 4 studies.

age, while Alsbirk's findings indicate a fairly stable distribution of refraction over all ages. The United States study indicates that the percentage of myopes is greater before age 45, and is more uniform until at least that age.

Evidently, there is some factor or factors operative in the population in this study, and in Young's population that might explain these differences, and this will be discussed further in Chapter 5 on near work.

Comments

The distribution of refraction in the study population resembles that demonstrated in most early studies, being leptokurtotic, and skewed to the minus side. The females exhibit the tendency to negative refractions earlier and to a greater degree than males, but in the older groups exhibit higher positive mean refraction than males.

Compared to the sample of the United States (HEW) study (1978), and Alsbirk's (1979) Greenland Eskimo population, the population studied showed a more rapid change towards positive refraction, with the change occurring at about age 30, rather than over the ages of 45 to 50. In Young's (1969) Alaskan Eskimo study, there is a surge of negative refraction up to about age 25 to 30, and then a rapid change in mean refraction towards more positive (or less negative) values. In Alsbirk's population, the mean refraction was in fact fairly uniform across all age groups.

Previous studies (Hirsch, 1952) have demonstrated a shift towards less negative refractions, or more positive refractions, due to acquired hyperopia, which usually manifests itself at age 45 to 55 (Slataper, 1950; Hirsch, 1952). This was shown in both the United States (HEW) study, and the Alsbirk (1979) study.

Interpretation of the differences among studies in refractive distribution by age is deferred to Chapter 5, on near work.

PREVALENCE OF REFRACTIVE CORRECTIONS

Data were collected regarding the number of subjects that had spectacles, those that did not, and those who had had corrections at one time, but did not wear glasses at the time of the study.

Table 23 presents this information broken down by age group and sex.

It can be seen that more females wear corrections than males in all age groups, 50% vs. 22%. Eighty-six percent of the females but only 45% of the males over age 45 wear corrections, the majority of these corrections are positive lenses. Seventy percent of males have never worn glasses, while 39% of the females have never had glasses.

Table 24 presents the proportion of persons not wearing corrections who had myopia of -1 D. or more at examination. A -1 D. error is equivalent to a visual acuity of 20/50 or less (Duke-Elder, 1970).

Table 25 presents the proportion of persons not wearing corrections who had hyperopia of +1 D. or more, and those who are uncorrected. A +1 D. error would present a subject with difficulty in reading. Duke-Elder (1970) has pointed out that uncorrected errors of hyperopia in young persons can cause eye strain, over-accommodation, and sometimes amblyopia. Borish (1970) noted that errors of as little as +0.75 D. should be corrected for school children.

Table 23. Number and percentage of subjects that now wear glasses, never wore glasses, wore glasses at one time; by age group, and sex

Males

Age	have Rx		never had Rx		had Rx at one time		Total
	n	%	n	%	n	%	
5-15	25	.14	156	.84	4	.02	185
15-30	15	.16	64	.70	13	.14	92
30-45	14	.21	45	.67	8	.12	67
45+	42	.45	40	.43	12	.12	94
all ages	96	.22	305	.70	37	.08	438

Females

Age	have Rx		never had Rx		had Rx at one time		Total
	n	%	n	%	n	%	
5-15	32	.21	116	.75	7	.04	155
15-30	96	.54	55	.31	26	.15	177
30-45	50	.56	24	.27	16	.17	90
45+	83	.86	6	.06	8	.08	97
all ages	261	.50	201	.39	57	.11	519
Total population	.37			.53		.10	957

Table 24. Percentage of those with myopia and with uncorrected myopia of -1 D. or more by age and sex, and those not wearing corrections

Males

Age	n	no. myopic -1 D or more	%	no. not wearing glasses	%	% not wearing glasses of total -1 D or more
5-15	185	12	6.0	4	2.0	33.3
15-30	92	10	11.0	1	1.0	10.0
30-45	67	5	7.0	1	1.0	20.0
45+	94	4	4.0	1	1.0	25.0
all ages	438	31	7.1	7	1.6	22.6

Females

Age	n	no. myopic -1 D or more	%	no. not wearing glasses	%	% not wearing glasses of total -1 D or more
5-15	155	21	14.0	9	6.0	42.8
15-30	177	68	38.0	10	6.0	14.7
30-45	90	15	17.0	6	7.0	40.0
45+	97	6	6.0	1	1.0	16.7
all ages	519	110	21.2	26	5.0	23.6

Table 25. Percentage of those with hyperopia and with uncorrected hyperopia of +1 D. or more, by age and sex, and those uncorrected

Males

Age	n	no. hyperopic +1 D or more	%	no. not wearing glasses	%	% not wearing glasses of total +1 D or more
5-15	185	52	28	47	25	90
15-30	92	5	5	3	3	60
30-45	67	8	12	7	10	88
45+	94	31	33	15	16	48
all ages	438	96	22	72	16	75

Females

Age	n	no. hyperopic +1 D or more	%	no. not wearing glasses	%	% not wearing glasses of total +1 D or more
5-15	155	42	27	31	20	74
15-30	177	15	8	2	1	13
30-45	90	13	14	1	1	8
45+	97	50	52	2	2	4
all ages	519	120	23	36	7	30

Table 24 indicates that the females are more myopic than the males, as shown earlier. The percentage of myopes uncorrected is higher in the females, except in the oldest age group. It was shown in Table 23 that in the total population, and for all refractive errors, the females corrected their refractive errors more often than the males. In those who are myopic by -1 D. or more, the males and females show approximately the same percentage of uncorrected errors. However, by age groups, the females under 45 are not corrected as often as the males. In the youngest age group (5-15), 33.3% of the males, and 42.8% of the females are not wearing glasses.

Table 25 reveals that more males than females are uncorrected hyperopes in all age groups. The hyperope can have very good visual acuity at distance without correction, but needs correction for near vision. The males are predominantly outdoor people in this area, fishermen, farmers, etc. The females spend their time indoors, with housework, sewing, etc. It is therefore not surprising that females wear hyperopic corrections much more often than males. In the youngest age group, 90% of the males and 74% of the females are uncorrected.

Table 26 presents data of those in all age groups who are corrected for myopia and hyperopia, by sex, and the percentage for each age group.

It can be seen that females wear glasses more often than males when they have ametropias. An average of 52.2% of myopic females are corrected compared to 31.8% of myopic males, with the greatest differences occurring in those over age 15. Among the hyperopes, 56.3% of females compared to only 19.1% of males are corrected. A likely explanation for this has been indicated above.

Table 26. Proportion of those wearing corrections for myopia and hyperopia, by age and sex

Males

Age	n	myopes no.	myopes %	myopes no. corrected	myopes %	hyperopes no.	hyperopes %	hyperopes no. corrected	hyperopes %
5-15	185	46	24.9	15	32.6	113	61.1	8	7.0
15-30	92	38	41.3	12	31.6	28	30.4	3	10.7
30-45	67	17	25.4	7	41.1	37	55.2	5	13.5
45+	94	9	9.6	6	66.7	78	82.9	33	42.3
all ages	438	110	25.1	35	31.8	256	58.4	49	19.1

Females

Age	n	myopes no.	myopes %	myopes no. corrected	myopes %	hyperopes no.	hyperopes %	hyperopes no. corrected	hyperopes %
5-15	155	61	39.4	16	26.2	77	49.7	14	18.2
15-30	177	115	63.9	71	61.7	38	21.5	21	55.3
30-45	90	29	32.2	13	44.8	50	55.6	32	64.0
45+	97	17	17.5	16	94.1	67	69.1	62	92.5
all ages	519	222	42.8	116	52.2	229	44.1	129	56.3

Table 27 presents data comparing the percentage of those wearing corrections in the present study with the United States (HEW) study.

Table 27. Proportion of those wearing corrections for myopia or hyperopia in the present study, and in the United States (HEW) 1978 study

Age	Present study		United States study		Ages
	myopes	hyperopes	myopes	hyperopes	
5-15	58.5%	40.0%	51.5%	45.5%	6-11
			87.1%	10.7%	12-17
15-30	76.6%	20.4%	84.8%	12.8%	18-24
			77.6%	19.5%	25-34
30-44	33.0%	63.1%	66.6%	29.7%	35-44
			40.0%	54.9%	45-54
45+	18.1%	80.0%	19.8%	76.6%	55-64
			15.7%	81.5%	65-74

In the American study, myopic corrections are worn from 40 to 87.1% up to age 45, whereas in the present study, the most myopic corrections are worn in those under 30 (58.5 to 76.6%).

Comments

The United States (HEW) 1978 study reported that 48.1% of spectacles worn were concave, and 48.3% were convex, with 3.4% plano. In this study, 44% were concave, 50% were convex, and 7% were plano. The distributions in the two studies are very similar. Availability of care influenced the other major finding, that 52.4% of the American population wore glasses while only 37% of this population were corrected. In the present investigation females outnumbered males among persons corrected for ametropia. In the United States population, use of concave lenses is fairly constant until about age 45, while in this population, most concave lenses are worn by those under 30.

The most compelling finding in the present investigation is the hidden morbidity particularly among the young, with important public health implications. In the young school age years, a very high proportion of myopes and an even higher proportion of hyperopes are uncorrected. Even given the conservative cut-off levels chosen (-1 D. and +1 D.), the proportions are high. If school work becomes disagreeable because of uncorrected poor vision, the likelihood of the child dropping out of school is increased, with all the consequent personal loss this entails. The proportion of uncorrected adults is serious as well. Many of the adults drive cars and trucks, sometimes at night, and poor vision in this and other tasks is a hazard.

Chapter V

NEAR WORK AND REFRACTION

Introduction

Cohn (1867) was probably the first to theorize that excessive near work caused myopia. He showed that the incidence of myopia rose in direct proportion to the amount of schooling of the subject, and that myopia seemed to first appear after two or three years in school. From these observations, he deduced that school work (i.e. near work) caused myopia, and called this "school myopia." His work was influential in bringing about improved hygiene and lighting in the schools of Europe. Ask (1925) reported that improved conditions of hygiene and lighting reduced the incidence of myopia in Swedish schools. The influence of close work on myopia was also espoused by Rasmussen (1936), who reported on 120,000 clinical cases collected over 25 years in China. He implicated the posture of myopes, who bent their heads close to school books, their myopia resulting from the effects of gravity stretching the eyeball and over-accommodation.

Goldschmidt (1968) questioned the claims of Ask (1925), as he found no change in prevalence of myopia in Denmark over 80 years. He noted that the earlier studies in the Scandinavian countries claiming reduced prevalence of myopia with improved hygiene were questionable, since some of the earlier screenings were by untrained personnel, since incidences of myopia fell with increasing numbers of pupils, and since the incidences in different areas varied considerably. He also argued that comparing prevalences between countries might be invalid, as the genetic background could vary considerably from country to country.

Previous Studies

Several relatively recent studies in human populations bear on the question of the relationship between near work or schooling and myopia. Young et al (1954) examined 651 children, the majority of whom resided in a university town in the United States, while the remainder were from the neighboring farming countryside. Myopia was more prevalent in the university group. These children also spent more time reading than the rural children. Unfortunately, the parents' refractions were not reported, so hereditary possibilities cannot be evaluated.

Young (1955) further studied 425 of these children aged 6 to 17, and measured the time they spent reading. The correlation of age to refractive error was -0.28, indicating the older were more myopic. After partialling out the age effects, the correlation of reading time to refraction rose from +0.25 in the 6 year olds to -0.53 in the 17 year olds. Myopes read more than non-myopes and this association increased progressively with age.

On the other hand, Nadell (1957) studied 409 school children and found no significant difference between myopes and hyperopes in time spent reading.

In a study of the relationships between age, reading, and refraction, Angle and Wissman (1978) concluded that heavy reading could greatly increase myopia. They reported an increase in myopia of 0.22 D. per year of schooling. Using multiple regression analysis, they found however that only 2% of the variance in myopia could be accounted for by education. Using partial correlations, they found that with education controlled, age was not related to a higher degree of myopia; on the contrary there was tendency to emmetropia with increase in age. Their 4204 subjects were from 12 to 17 years old, so the authors noted that much of the variance could have occurred before age 12. It should be noted that the authors used data collected by others, which in most cases consists not of refractions but of estimates based on either acuity tests or power of glasses habitually worn. Those few refractions actually performed were done by 35 refractionists, thereby reducing the comparability of the values.

Childress et al (1970) reported that posture in front of the television set and while reading, could influence the amount of refractive error. He also implicated the axis of astigmatism and suggested that the position of the printed page in relation to the midline could be a factor.

Several studies have compared changes in mean refraction during the school year with those during the summer vacation. Lukiesch and Moss (1939) investigated 103 students between the end of grade 5 and the start of grade 6. The average change in refraction during this period was towards hyperopia by 0.2 D. However, the mean change during grade 5 was +0.1 D. and during grade 6 was +.27 D., indicating no significant difference in mean refractive change during summer vacation. Kephart (1951) and Hirsch (1951) conducted similar surveys, and reported no significant changes.

Animal Studies

In an early study, Young (1961) confined 6 Macaca nemestria (ring-tailed) monkeys in such a manner that the animals' heads were confined and the animals' vision was limited to 15 inches. During the 12 month period of the experiment, the animals were given a respite of 2 days every 2 to 4 weeks. There were two control groups: Control Group 1 (9 animals) kept caged in a normal sized room with no confinement of visual space, and Control Group 2 (5 animals) confined to chairs but with no hoods and no visual restrictions. The animals were refracted with homatropine cycloplegic at various times during the experiment.

Because the monkey eye is quite similar to the human eye, Young thought that the results could be generalized to humans. Table 28 summarizes the results.

Table 28. Changes in refraction of primates following visual confinement (from Young, 1961)

	C.G.1 n=9		C.G.2 n=5	Experimental Group n=6					
	init. ref.	8 mo. ref.	4 mo. ref.	init. ref.	2 mo. ref.	4 mo. ref.	6 mo. ref.	9 mo. ref.	11 mo. ref.
mean	0.00	-0.19	-0.54	-0.33	-0.71	-0.90	-1.1	-1.1	-1.1
median	0.00	-0.125	-0.58	-0.33	-0.69	-0.88	-1.0	-0.87	-0.87

Males showed a higher increase than females in myopia. The author claimed without further evidence that no ciliary accommodative spasm could account for the changes. After release from the hoods at the end of the 12 month period, some monkeys in the experimental group showed an increase in myopia for up to 18 months, while none of the other animals became more myopic.

Young and Farrar (1964) studied 43 chimpanzees (26 male and 17 female). The mean ages of the males were higher, the females being 6 months to 1 year younger. Refractions were conducted using thiopental sodium as cycloplegia, and results were recorded as equivalent sphere. With age partialled out, sex and refraction were uncorrelated. Comparing the refractions of the animals to humans of equivalent age, the animals showed more myopia than humans, the suggestion being that this was because they were caged animals. The females were more myopic than the males. Intraocular pressure was found to be lower in myopic apes than in hyperopic apes.

Young et al (1971) reported on a study of 224 male and 185 female chimpanzees. Refraction and the ocular components were measured, the latter using ultrasound. The animals had been confined into restricted visual space as in the 1964 investigation, and were refracted cycloplegically. It was found that females developed a higher degree of myopia than the males, and the changes towards myopia in all the animals increased with age and time of confinement, with increased axial length.

Sherman, Norton, and Casagrande (1977) studied the effects of suturing the eye lids of the tree shrew. They found that the deprived eye was consistently and considerably myopic when compared with either the unsutured eye or to the eyes of normally reared tree shrews. In each case, the deprived eye developed a longer optic axis, but there was no correlation between the change in axial length and the degree of myopia.

Weisel and Raviola (1977) observed the same results from suturing one or two eyes in 10 Macaca mulatta monkeys. The myopia produced was axial in origin.

Rose, Yinon, and Belkin (1974) reported that 68.2% of 11 caged cats developed myopia with a mean of -0.62 D. while the control group of 12 street cats remained hyperopic (87.5% with a mean of +1.14 D.) The caged cats were confined under near point conditions. Because in both groups the optic axes were practically equal, the authors speculated that changes in the lens might be the factor causing myopia.

Wallman and Turkel (1978) studied restricted peripheral vision in chicks, finding an abnormal increase in myopia with attendant growth of the optic axis. When the central vision was restricted there was no change in refraction. Monocular deprivation of form vision also caused myopia with an increased anterior chamber depth. The authors suggested that the chicks restricted to frontal field had to accommodate more, leading to increased convergence, which could have caused the myopia. Another possibility suggested by the authors was that location of the image on the retina could be a factor, the restricted frontal fields eliminating proper retinal stimulation.

Comments

The studies reviewed describing associations of near work and ocular refraction in humans generally show a change to more negative refraction with schooling or near work. The most direct human study (Young, 1955) indicates a correlation between time spent reading and myopia as does the Goldschmidt (1966) analysis by social class (p. 33). The equivalent studies on refraction change during school vacations present almost predictable results, since vacation is so short.

The experiments with caged animals showed that those animals that had had their visual environment restricted artificially to a near point distance became myopic. Control animals, which had been caged but not visually restricted also showed lesser changes to myopia. It is entirely possible that confinement of any kind could cause a change in refraction. This would be expected, for instance, on the hypothesis that stress is a factor in refractive change (van Alphen, 1961). The cat experiments of Rose et al (1974) showed no change in optic axis length. They thought that the lens might be implicated in myopia. On the other hand, the experiments of Young (1971), Weisel et al (1977), Wallman et al (1978) and of Sherman et al (1977) showed that the optic axis lengthened with myopia.

In most of the animal and human investigations, no mention is made of the fact that when vision is restricted to near work, the eyes converge, and as was mentioned earlier, when the eyes converge, accommodation takes place. Therefore, overconvergence might be a factor in refractive changes, as was implied by Wallman and Turkel (1978).

Available data therefore suggests that near work can lead to myopia. Studies linking refraction with education and intelligence will be reviewed as they bear on this point. It is noteworthy that studies directly examining the relationship of refraction and near work, as opposed to education, are conspiculously rare.

Such extensive, direct comparison, for the population of the present study, will be drawn in due course.

Refraction, Intelligence and Education

As mentioned earlier, Ware (1813) seems to have been the first to note the considerably higher prevalence of myopia in the educated classes as compared to the less educated. Lindner (1949) made similar observations in reporting a much higher prevalence of myopia in priests as compared to other groups, implicating higher education in myopia. The previously cited Tscherning (1882) and Goldschmidt (1968) studies also showed the relationship of higher education with myopia. Education is of course generally closely related to near work.

There have been corollary investigations showing the correlation of high hyperopia to lower intelligence. Baldwin (1964) listed several studies demonstrating this phenomenon, including that of Pfingst (1921), showing the association of feeble-mindedness and high hyperopia, Stocker (1934) who showed that 124 institutionalized children with low or subnormal IQ had a high incidence of hyperopia, and Schwartz (1938) who among 1100 poor readers found 58% hyperopic and only 3.6% myopic.

Hirsch (1959) examined 554 school children (aged 6 to 17) and correlated the CTMM scores with refraction. He found a value of r of -0.19 ($p < .001$), and thought that reading ability was the determining factor. Because the myope has better reading skills, he scored better on the test. On the other hand, Young (1955) found no correlation of IQ with refractive error when he controlled for reading achievement.

Nadell and Hirsch (1958) examined the correlation of refraction with IQ as measured by the California Test of Mental Maturity (CTMM). Four hundred and fourteen subjects ranged in age from 13.5 to 17.9 years. They found a correlation of -0.082 ($p < .01$), i.e. a small but non-predictive relationship.

Morgan (1958) found a negative correlation for "bookishness" as rated by counsellors, and female but not male refraction. Males who were low hyperopes were less bookish. "Bookishness" was a subjective rating of the amount of time spent in reading and cultural activities.

In another study, Young et al (1970) studied the relationship between vertical ocular refraction and results in the Betts II Verbal Reading Test, as well as in the California Achievement Test. The study was done on Eskimo children in Alaska, in grades 3 to 6 inclusive. There were 204 students, equally divided by sex, although sex differences were not reported. Two percent cyclogyl was used for refraction. Subjects scoring higher on the tests were more myopic, a result similar to the Pullman study (1954), which studied Caucasian children and was reported previously (p. 108). The results were attributed to superior reading skills and not to higher IQ.

Karlsson (1975) reported the performance of myopes on the Lorge-Thorndike IQ Test, a reading test. Myopes scored 114 against the general average of 106 in 2527 subjects, aged 17 or 18. The author assumes that myopia is inherited, and therefore the myopia and intelligence are increased by the same gene. He also reports that the myopes had higher intelligence scores at age 8, before the onset of their myopia. Karlsson did not refract the subjects, indeed some of the myopes were identified from photographs in a high school year book. The author appears not to have considered that some students might have preferred to be photographed without glasses, and that the difference between concave and convex lenses would be difficult to differentiate from a photograph. He takes no account of differences of home environment which might influence both the IQ and refraction of young children.

Peckham et al (1977) studied 403 children at age 11 and reported myopia to be more common in non-manual families. Myopes were better at school compared to non-myopes, when tested in reading, arithmetic and general abilities. When adjustments were made for social class, the advantage in IQ was still more than one year; this advantage was apparent from the age of 7 years. They reported that myopic children read more and that their parents showed more concern with their school progress.

Young (1963) studied 251 subjects, first comparing scores on the Stanford Binet test, the CTMM, and the Durrell-Sullivan Test of Reading Achievement. He reported a high correlation between the CTMM and the DS tests, concluding that the reading element was more important in the CTMM than in the Binet test. When he partialled out the reading achievement, the correlation for refraction with the Binet score was -0.012 and to the CTMM was -.11, not significantly different from 0. Put another way, refraction is more correlated with reading ability than with IQ.

Grosvenor (1970b) related refraction, IQ scores, and academic ability in a study of 707 white Europeans, 11 to 13 years old, in New Zealand. He used the retinoscope and the subjective visual acuity to report the refraction, and the Otis, a self-administered verbal test, and the Raven Progressive Matrices test which is non-verbal, to evaluate intelligence. His cut-off for myopia was -1 D. and for hyperopia +1 D.

Table 29 indicates Grosvenor's results with the Otis test.

Table 29. Mean scores on Otis test for myopes, hyperopes and emmetropes (from Grosvenor, 1970b)

	n	Otis mean score
Myopes	33	117
Hyperopes	23	103
Emmetropes	651	112 (controls)

t tests indicated that the Otis scores of myopes and emmetropes were non-significantly different; neither were those of hyperopes and emmetropes; myopes vs hyperopes were significantly different ($p < .05$).

In examining the refraction vs Otis and Raven scores in 290 subjects, he found the following given in Table 30.

Table 30. Refraction vs Otis and Raven scores for 290 subjects with t tests

n=290	n	Otis	Raven
myopes	10	120	110
hyperopes	17	110	106
emmetropes	263	109	101

t tests for:	Otis	Raven
myopes vs emmetropes	n.s.	n.s.
hyperopes vs emmetropes	n.s.	n.s.
myopes vs hyperopes	0.1	n.s.

These results were interpreted to indicate that reading is important in intelligence testing only when myopia is compared to emmetropia. Both tests require good visual perception but only the Otis test requires reading. The low statistical significance weakens the argument that there is a relationship between refraction and reading ability, but Grosvenor states the refraction-intelligence correlation is stronger. Aside from the higher Otis scores than Raven scores, he found higher myopia in the "high ability" classes, although he did not record the refractive errors.

Grosvenor addressed Hirsch's suggestions that higher correlation of myopia with CTMM test than with the Binet as found by Young (1963) could be due to the former requiring rapid and sustained visual perception giving the myope an advantage. Hirsch (1959) notes four possible links:

1) Myopia is an overdevelopment of the ocular components, and ocular and cerebral development are related.
2) IQ scores are coloured by the amount of the subject's habitual reading.
3) More intelligent people read more, leading to more myopia.
4) A premium is placed in the test on the ability to perceive fine details, so the myope has the advantage.

Low Intelligence Studies

Manley and Schuldt (1970) compared 25 mentally retarded males (mean age 19) who wore glasses, with 28 normal IQ males (mean age 17) who wore glasses. In the normal group, 24 were myopes, and 4 hyperopes. In the mentally retarded, 6 were myopes and 19 were hyperopes. The samples were comparable in age, sex, and socio-economic status (Table 31).

Table 31. Frequency of hyperopes and myopes in normal and retarded groups of children (from Manley and Schuldt, 1970)

	normal		retarded	
	n	%	n	%
hyperopes	4	14	19	76
myopes	24	86	6	24

$X^2 = 20.46$ ($p < 0.001$)

Because only spectacle wearers were considered, the results may well be biased in favor of the higher number of myopes in the control group.

Courtney (1971) attempted to test Hirsch's (1959) and Grosvenor's (1970) hypothesis that ocular and cerebral development are related, by testing whether there is any association between hyperopia and IQ in institutionalized mentally retarded and emotionally disturbed children. The children in a special school in Georgia were grouped according to IQ and emotional stability. Categories were intellectually normal but emotionally disturbed children (ED), educable mentally retarded (EMR), and trainable mentally retarded (TMR) children. The IQ test in most cases was the Weschler Intelligence Scale for Children (WISC).

Table 32. Sample description of TMR, EMR, and ED children

	Sample Description				
	n	mean age	SD age	mean IQ	SD IQ
TMR	40	12	2	44	8.4
EMR	69	13.3	2.2	61.5	9.9
ED	106	14.5	2.1	87.9	10.6

No cycloplegia was used, with the static retinoscopy in the horizontal meridian being the measure of refraction. Figure 15 shows the refractive error distribution of the two groups. It will be seen that the skew for the retarded groups is to the hyperopic side with no high myopes. Table 33 shows the distribution of refractive error for each of the three groups. The indications are that retarded children are more hyperopic than intellectually normal children of the same age, and that there is little difference between emotionally disturbed children and normal children with respect to the distribution of refractive error.

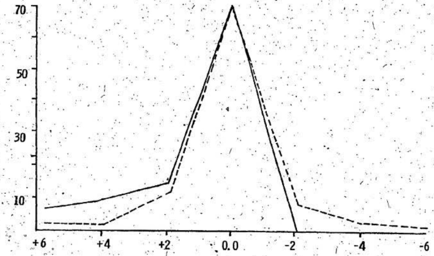

Figure 15. Refractive error distribution for horizontal meridian, right eye. Solid line represents TMR and EMR (retarded) children, dotted line represents ED (emotionally disturbed) children.

(from Courtney, 1971)

Table 33. Means and standard deviations for spherical equivalent refraction for TMR, EMR, and ED children (from Courtney, 1971)

	TMR	EMR	ED
Mean refraction	+1.18	+1.02	+0.02
Standard Deviation	2.38	1.84	2.05

t test comparisons of the retarded group (TMR and EMR) with the ED group was significant ($p < .01$), but the comparison of TMR with EMR was non-significant.

Comments

The studies reviewed above cannot confirm that myopes are more intelligent than non-myopes, but they do show that the mentally retarded tend to hyperopia rather than myopia. One could deduce from the Young studies (1955, 1970) that myopes read more than hyperopes, perhaps because it is more comfortable for them to do so. By reading more, they could become more educated, and if the near work hypothesis is correct, by reading more they could also become more myopic. There are more myopes in higher grades, as was shown earlier, and it was also demonstrated that myopes have a higher IQ. Those who read more develop better skills at near work and will do better at school, and therefore if those with poor reading skills drop out more often than those with better reading skills, the proportion of myopes in higher grades would be higher than of non-myopes. The proportion of myopes in higher grades is examined in the next section.

Both Karlsson and Peckham et al found that myopes excel in school achievement before the onset of myopia, thus questioning the view that myopes read more because they are more comfortable at it, and also that myopes are myopic because they read more.

Unlike Karlsson, Peckham et al consider, albeit briefly, factors of family environment which may be relevant to educational achievement and refraction. The question of the relationship of IQ with refraction is still unanswered, and studies using non-verbal IQ tests might be informative. The one study using the Raven Test, showed no significant relationship between IQ and refraction.

Occupation and Refraction

There have been many studies attempting to link certain occupations that require near work with increases in myopia.

Goldschmidt (1968) refers to the work of Tscherning (1882) who examined 7523 military conscripts and who reported the following prevalence of myopia in six occupational classes, ranked according to the prevalence of myopia by degree (Table 34).

The prevalence of myopia was much higher in students compared to the other occupational categories. The ratio is almost 10 to 1, comparing students to the unskilled ($p < .001$). This analysis assumes that all subjects were of the same age.

The refractive status of those in the printing trade has been studied by several investigators. Seggal (1884) found compositors showed a 56.7% prevalence of myopia compared to farm workers with a prevalence of only 2.4%.

Duke-Elder (1930) examined 244 printing apprentices aged 14 to 20 and he tabulated the findings as given in Table 35.

Table 34: Prevalence of myopia by occupational category (from Tscherning, 1882)

Category	n	Prevalence of myopic refractions 2.0 D	3-6 D	7-9 D	greater than 9 D	% total myopes
advanced students	491	6.72	20.37	4.28	1.02	32.38
clerks; shop assistants	1009	3.87	8.92	2.28	0.69	15.76
educated middle class	270	4.07	7.41	1.85	--	13.33
fine hand workers (watchmaker, jeweller, etc.)	566	4.06	6.36	1.06	0.18	11.66
gross hand workers (barber, plumber, etc.)	2861	1.36	2.59	0.49	0.80	5.24
farmers, fishermen, stone-mason, stoker	2326	0.69	0.86	0.26	0.64	2.45
n	7523	161	340	75	51	627
%		2.11	4.52	1.00	0.68	8.33

Table 35. Proportion myopic by occupations in apprentices in the printing trade (from Duke-Elder, 1930)

Type of work	n		% myopes 1st exam	% myopes 2nd exam
compositors	80		42.5	77
machinists and letter pressmen	72	combined	31.0	45
binders and warehousemen	44			
lithographers	10			
stereotypers	12			
general apprentices	26			

Not only were the compositors at the first examination more myopic than the others, but the increase in proportion myopic was greater in this group at the second examination. The rate of change was stated to be greater for low myopia (< 5 D.) in both groups when compared to the rate of change in the non-myopes (usually less than 1.00 D.), but data were not shown, and the time between examinations was not reported.

In a study on 206 hosiery loopers over 50 months, Tiffin (1947) noted that those who passed the distance acuity test dropped from 70% to about 48% whether glasses were worn or not.

The working distance on this job is 8 inches. Hyperopes would not be successful at this job, so it is possible that the majority or all of the 206 tested were myopes or emmetropes, information not reported. Tiffin did not record the ages of the employees, and this could affect the findings, for older people tend to lose acuity with age whether they are myopes or hyperopes (Slataper, 1950).

Lindner (1947) reported that members of the Roman Catholic clergy were more myopic than those in other occupations in two Austrian commu-

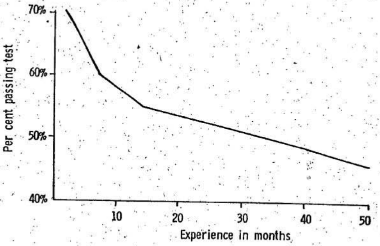

Figure 16. Changes in distance visual acuity with increasing experience on the job of looping hosiery. Curve based on 206 hosiery loopers. (from Tiffin, 1947)

nities. The prevalence of myopia among priests was 48%. Lindner attributed this to the great amount of near work performed by these subjects.

In another study, Lindner (1953) explained the lack of myopia in watchmakers as due to the fact that they

> need very little change of their nutritional fluids, as they see continually through their lenses the same enlarged picture. (sic)

Frana and Vlcek (1951) observed leather cutters in Czechoslovakia. Out of 265, 132 were myopes. Records going back 10 years were examined and showed:

1) Myopia increased according to age and length of employment, with the greatest increase in those over age 30.
2) Myopia in degree and number was directly proportional to weight.
3) Right eye myopic changes were greater than left eye changes.
4) There was no relationship to disease, distance of domicile to the factory, hobbies, or heredity.

The increases of myopia were up to -3.00 D. with no fundus changes, starting after 6 to 8 years of employment. The authors felt accommodation and convergence, as well as the dispersion and reflection of light on the leather, could account for these changes, but no control data were collected.

Goldschmidt (1968) studied school children and military conscripts and compared his own military findings with those of Tscherning (1882), and his school findings with those of Bjerrum (1884) and Philipsen (1884), as reported earlier (pp. 51-53).

He found that of 9243 school children attending schools in Copenhagen who were born in 1948 and examined non-cyclopegically in 1962 (certain few were re-examined with cycloplegic where necessary), 877, or 9.49%, were myopic. More girls were myopic than boys ($p < .001$). When the 8981 children in normal schools were classified according to academic streams, the results in Table 36 were obtained.

Table 36 indicates more myopes in the academic stream than in the general stream, with the comprehensive stream somewhere between the two. Of the 877 myopes, three were high myopes (over 6 D.), and 30% had myopia of less than -1.50 D.

Goldschmidt then examined 3651 military conscripts from the ages of 18 to 30, in 1964, and compared his results with those Tscherning (1882). He found 531 of the conscripts (14.5%) were myopes, with 337 having myopia greater than 1.50 D. Myopia was more common in university students, viz. 33.6% vs 28.3% for the grammar school students, a difference not statistically significant. Tscherning divided his material into six categories: 1) students, 2) clerks and shop assistants, 3) "cultured people" who do not fall into the first two groups, 4) craftsmen in fine work, 5) laborers in fine work, and 6) seamen and ordinary laborers (unskilled).

Tscherning counted -1.00 D. and more as emmetropic, because he recorded errors of refraction in 1 Diopter steps, his least degree of myopia was -2.00 D. Goldschmidt attempted to group his material into similar categories, adding a seventh comprising those who could not be classified in the first six.

Category 1 comprised students of all types.

Category 2 were bank clerks, shopworkers, etc.

Category 3 were those from higher commercial college, and other educated classes of this type.

Table 36. Prevalence of myopia among 8981 children from normal schools, classified according to school streams (myopia cut-off 0.25 D.) (from Goldschmidt, 1968)

Stream	Boys			Girls			Total		
	no.	myopes	%	no.	myopes	%	no.	myopes	%
A. General	2086	131	6.28	2154	172	7.99	4240	303	7.15
B. Academic	1592	175	10.99	1674	236	14.10	3266	411	12.58
C. Comprehensive	303	28	9.24	351	33	9.40	654	61	9.33
D. 'Retarded readers'	243	11	4.53	92	3	3.26	335	14	4.18
E. Private schools	230	35	15.22	256	44	17.19	486	79	16.26
	4454	380	8.53	4527	488	10.781	8981	868	9.66

Category 4 included master technicians, tailors, compositors, etc.

Category 5 were skilled workmen, such as mechanics, bakers, masons, carpenters, etc.

Category 6 included laborers, chauffeurs, and gas-station attendants.

Category 7 included any non-classifiable persons, or those for which no occupational data was available.

Table 37 compares the data from the two studies.

Goldschmidt found an overall prevalence of myopia of 14.5% in his material compared to 8.33% in Tscherning's material. However, in comparing myopes of -1.50 D. or more in his material to Tscherning's, the incidence was 9.2%, not significantly different. He also noted a similarity in prevalence of myopia by occupation in the two studies.

Figure 17 compares five studies concerned with occupation and refraction. The near workers show a greater prevalence of myopia than the non-near workers.

Comments

The studies reviewed show that people in certain occupations and activities requiring near work are more myopic than those who habitually do less near work. Tscherning (1882) and Goldschmidt (1968) both reported this phenomenon for a wide range of occupations, and both showed that students were more often myopic than laborers. Duke-Elder (1930) and Tiffin (1947) also studied the refraction of those engaged in near work, and reported the myopic characteristics of compositors and hosiery loopers. Lindner (1947) reported that priests were more myopic than other Austrians, and he attributed this to the sustained reading required of priests. It is entirely possible that the priests studied took orders because they were myopic. Myopes might tend generally to gravi-

Table 37. Incidence and degree of myopia in percent in Medical Board material from 1964 and 1882 (Tscherning), classified according to occupational category (from Goldschmidt, 1968)

Category	No. examined	No. of myopes: Degree of myopia ≤ 1.50	1.75–2.5	2.75–6.5	6.75–9	> 9	Total	Total > 1.5
1	419	8.6	11.5	16.5	1.9	0.2	38.7	30.1
2	634	7.7	4.4	6.5	1.0	–	19.6	11.8
3	144	6.2	5.6	8.3	–	–	20.1	13.9
4	340	6.2	4.1	4.7	0.3	–	15.3	9.1
5	1301	4.2	1.9	2.2	–	0.2	8.5	4.3
6	753	2.8	1.3	1.5	–	0.1	5.7	2.9
7	60	5.0	5.0	3.3	1.7	1.7	16.7	11.7
Total	3651	5.3	3.7	4.9	0.4	0.2	14.5	9.2

Tscherning

Category	No. examined	No. of myopes: Degree of myopia 2.0	3.0–6.0	7.0–9.0	> 9	Total
1	491	6.72	20.37	4.28	1.02	32.38
2	1009	3.87	8.92	2.28	0.69	15.76
3	270	4.07	7.41	1.85	–	13.33
4	566	4.06	6.36	1.06	0.18	11.66
5	2861	1.36	2.59	0.49	0.80	5.24
6	2326	0.69	0.86	0.26	0.64	2.45
Total	7523	2.11	4.52	1.00	0.68	8.33

tate to occupations requiring reading because to a myope, reading is less of a problem than other work, and probably more comfortable than distance vision tasks. It seems however most unlikely that this could account for the graded connection between near work and mean refraction found in studies by both Tscherning and Goldschmidt across all strata of Danish society.

Discussion

From the evidence, the incidence of myopia varies considerably between different social classes and occupations. Genetic differences could be the cause, or different amount of close work, or both in varying degrees.

It is possible that selective pressures have caused the accumulation of genes predisposing to myopia in certain groups identified with certain occupations, although one can question this with respect to the Catholic clergy. On the other hand, selection of an occupation or profession could precede the termination of growth, and the onset of myopia. Nor can such occupational selection theory explain the late development of myopia in compositors, leather workers, hosiery loopers, etc. as reported by Duke-Elder (1930), Frana and Vlcek (1957), Tiffin (1947). Myopia which develops later in life might be a different type of myopia, unlike "simple" or "school" myopia. Some myopia seems therefore to be environmental. Goldschmidt (1968) asserts that high myopia seems to have decreased in Denmark during the 80 years between the study of Tscherning and his own, indicating that this type of myopia could be environmental in origin since,

> a rapid alteration in the frequency of a particular character is rarely caused by alterations in the gene frequency (from Goldschmidt, 1968).

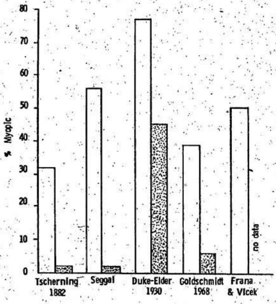

Figure 17. Comparison of the incidence of myopia in near workers and non-near workers: from 5 studies.

clear bars- nearworkers
shaded bars- non-nearworkers

Studies have shown sudden appearance of myopia in several areas when modern schooling and more close work were introduced into the environment (Young, 1969, 1970). The studies cited above referring to the 'epidemic of myopia' in the Canadian North also reflect this phenomenon (Boniuk, 1973; Morgan, 1973).

The demonstrated emergence of myopia in animals that have been subjected to a restricted visual experience (Young, 1964, 1971) is also supportive of environmental factors operating.

A simple environmental argument cannot however explain why all persons exposed to near work do not all become myopes. The answer may lie in whether the close work that might lead to myopia is a "thinking" type as hypothesized by van Alphen (1961), with certain people who are affected accommodatively by this type of close work becoming myopes, while others do not.

The degree of hyperopia in the subject before starting school may determine the shift towards myopia. As shown by Hirsch (1964) if the subject is more hyperopic at the start of school, his refraction will shift to the myopic side, but not enough to become a myope, while if he was only moderately hyperopic or emmetropic on entering school, he will experience the same quantitative shift to the myopic side, and will thus become a myope.

Genetic lability to myopia may be increased by assortative mating within social classes. However this cannot be the case in those communities where myopia has suddenly appeared when schooling was introduced into the area.

Myopia that suddenly appears in older people such as compositors, cannot be selective, nor can it be genetic. Goldschmidt (1968) suggested that this type of myopia might be due to a change in lens power, since the lens grows throughout life, and its refractive power alters. It must be noted however, that if this were the case, there would be myopia of this type found in people who do not do excessive close work throughout the working day. Such myopia might result from the effects of severe emotional strain on susceptible genotypes.

It is possible that environment can cause some myopia. Whether excess schooling or reading can generally affect refraction is the question at hand and it appears from the work of Hirsch that constitution-genetic predisposition is also relevant. The question is, can these hints be improved upon?

PERSONAL INVESTIGATION II

REFRACTION AND OCCUPATION

Aims

It was possible in the present data to investigate the extent to which occupation was related to measures of refraction.

Method

The recorded occupations for the subjects were classified as in Table 38. Means and standard deviations for these tabulated groups were computed.

Results

As the effects of age have on inspection been demonstrated, each occupational category was subdivided by age, and means and standard deviations of refraction calculated.

Group 1. Fish plant workers: The mean refraction is the most hyperopic of all, but since this group contains only three subjects, the significance of this is unknown.

Group 2. Fishermen: Fishing is the main occupation in these communities and only males pursue it. Of the 106 subjects, the younger subjects showed a more negative refractive mean than those in the older group.

Group 3. Farmers, etc.: There were 44 in this group, all male, with the only negative mean refraction in the oldest group. The 17 subjects in this oldest group consisted of some who suffered from senile cataract, which causes the eye to show a negative refraction. The general

Table 38. Mean refractions, standard deviations, for each age group in each occupational category, with number in each age group

Group	age	mean RVERT	SD	number
1. Fish plant worker	15-29	+0.5826	0.6595	2
	30-44	0.6190	0	1
	Total	0.5948	0.4668	3
2. Fishermen	15-29	-0.0013	0.4915	29
	30-44	-0.1592	0.5480	22
	45+	0.1012	0.6932	55
	Total	0.0191	0.6180	106
3. Farmer, forest worker, labroer	15-29	0.0607	0.3642	15
	30-44	0.3022	0.5441	12
	45+	-0.3174	0.4398	17
	Total	-0.0195	0.5070	44
4. Carpenter, plumber, electrician, truck driver	5-14	-2.5877	0.0	1
	15-29	0.0995	1.0840	18
	30-44	0.0776	0.4691	21
	45+	-0.0552	0.5957	17
	Total	-0.0019	0.8140	57
5. Housewife	15-29	-0.0094	0.9968	112
	30-44	0.0137	0.9001	75
	45+	-0.0506	1.0621	85
	Total	-0.0159	0.9992	272
6. Sales clerk	15-29	0.2456	0.6599	7
	30-44	-0.4767	1.25	10
	45+	0.7215	1.7807	8
	Total	0.1089	1.3759	25
7. Bookkeeper, health personnel, skilled draftsman, mechanic	15-29	-0.1194	0.8328	16
	30-44	0.9654	0.5443	3
	45+	-0.0094	1.5997	3
	Total	0.0435	0.9536	22
8. Teacher	15-29	-0.1883	2.0528	9
	30-44	-0.3813	1.7257	4
	45+	-0.6761	0.0	1
	Total	-0.2783	1.8170	14
9. Student	5-14	0.0078	0.8452	330
	15-29	-0.0153	0.7322	58
	Total	0.0044	0.8285	388
10. None listed				26
Total				957

refraction in Group 3 is very slightly hyperopic.

Group 4. Carpenters, etc.: Of the 57 subjects in this group, all male, the only subject in the youngest age sub-group was myopic (-2.5877 D.). This relatively high negative value affected the overall group mean considerably. In the over 45 age group, there were two subjects with senile cataract changes, who also added some negative values.

Group 5. Housewives: The largest proportion (272, or 52.4%) of the adult females claimed this occupation. The youngest showed a slightly negative mean refraction (mean -0.0094 D.). The oldest sub-group, also including several women with senile changes, showed a slightly negative refractive mean.

Group 6. Store sales clerks: Of the 25 in this group, which included males and females, the 30-44 age group showed a minus mean refraction, while the oldest and youngest age groups showed positive mean refractions. The 30-44 age group contained two former teachers, whose favorite activity was reading, and as will be shown below, this reduced the group mean.

Group 7. Bookkeepers, etc.: Of the 22 in this occupational group, only the youngest sub-group had many members (16). This group showed a negative mean refraction.

Group 8. Teachers: The 14 persons with this occupation showed the highest mean negative mean refraction. This group also reported the highest number of hours spent at close work, as will be shown below.

Group 9. Students: Of the 388 in this group, 330 were in the youngest age group. Of these 330, 195 were aged 5 to 9, and in the earliest primary grades. As was shown earlier, the mean refraction of this age group is +0.62 D., so it is not surprising to find in young students as a whole a slightly positive mean refraction.

Comments

In general, the effects of occupation are not clear-cut as they are obscured by age and sex effects. The mean refractions for members of groups 7, 8, and 9 (-.0029 D. for 424 subjects) is more negative than the mean refraction for all members of the first six groups (+.0024 D., 507 subjects), but the difference is not statistically significant. Members of the first six groups do less near work in the pursuit of their occupations than members of the last three groups. In all groups, the younger subjects had more mean negative refractions than the older subjects. The age group 30 to 44 showed the greatest range of mean refraction (+0.9654 D. to -0.4767 D.). As was shown, this age group is much more heterogeneous in occupations than any other group, with only students not represented. The reason for the greater range in the oldest group is possibly the presence of several subjects with senile ocular changes such as early cataract. It is also a possibility that some of the negative refractions in Group 7 (Bookkeepers, etc.) could be late myopias, as defined and reported by Goldschmidt (1968) and by Duke-Elder (1970) (pp. 131). Occupation, as such, does not seem strongly related to refraction in the study population. Related factors such as education and hours spent at near work must be studied.

PERSONAL INVESTIGATION III

REFRACTION AND NEAR WORK

Introduction

In the previous investigations near work emerges as a factor possibly influencing refraction. Occupational demands for near work were not however generally reflected in group mean refractions. Related factors such as education and leisure activities are now examined.

The effect of education can be uniquely studied in this population as compulsory education was introduced relatively recently, in 1948. Prior to this there was scant schooling as the following excerpts from a teachers' log indicates.

The Teachers' Log Book, preserved, for the years 1915 to 1921, contains illuminating indications of the primitive state of education in this area during that period. It contains entries by four different teachers in Community C, the largest of the three.

December 17, 1915	-- "(out of 10 pupils in the 3rd class) 2 of them only began to attend school a couple of weeks ago. They were not advanced enough for 3rd class."
December 22	-- "school was opened today for the first time for this week (sic) . . . number present 18."
January 19, 1916	-- "owing to not having any wood we had to close school in the afternoon yesterday. 3 children have left school since Christmas."
February 10	-- "8 pupils left during the last quarter."
March 14	-- "several of the bigger children have left, their parents want them to help at home."
May 4	-- "Lately the work has been unsatisfactory owing to about half of the children not having any ink and none in the place to be had."

May 12	-- "one of our drawbacks is irregular attendance."
September 4	-- "16 enrolled . . . reading on the whole very poor."
October 20	-- "dismissed the class for the reason that there is no wood to make a fire."
November 14	-- "6 present."
November 15	-- "it is no harm to say that the children of C get their education under difficulties. The lighting is ridiculous and many other inconveniences."
May 4, 1917	-- "only 2 present."
November 6-26	-- School closed, teacher ill.
November 25	-- "I came to the school today but no children came along."
November 27	-- "no wood--no children."
May 19, 1920	-- Report of the examiner: "The building is wholly unsuitable for school work and the equipment wholly inadequate."
September 6	-- "2 in attendance, as most of the children are gone with their parents hay making."

Table 39 presents data recorded in the Log Book on the number of children enrolled, and the number and percentage of attendance, for seven school years. The data were recorded by month and grouped by school year.

The Newfoundland Census for 1921 for Community C reports that there were 33 children between the ages of 5 and 10, and 19 children between the ages of 10 and 15, totalling 52 children who were eligible to attend school between the ages of 5 and 15. The Census reports that there were 42 attending school that year. However, the Log Book records an average monthly attendance of only 21.05 in the school year 1920-21, and of 29.38 in the subsequent year. This suggests that at least 23 of the 52, or 44% did not attend school.

Table 39. Number of school children enrolled, number in attendance, percentage of attendance, for 7 school years, for Community C,

School year	Average monthly no. enrolled	Average monthly no. attending	%	Actual attendances of those eligibles (%)
1915–1916	30.71	21.97	72	
1916–1917	26.07	14.34	55	
1917–1918	19.5	13.16	68	
1918–1919	28.56	18.42	64	
1919–1920	30.8	22.28	72	
1920–1921	21.05	15.93	76	
1921–1922	29.38	30.24	69	31.0
Mean	26.58	18.05	68	

The Census also records that of the 113 inhabitants over the age of 10, 46 could neither read nor write, i.e. an illiteracy rate of 41%.

Aims

The present investigation into the effects of education and near work on refractive status are now presented.

Methods

Educational level was recorded as the last completed grade for each subject. When a subject had left school and returned for "upgrading" the upgrading years were counted as grades. Upgrading refers to the return to primary education as an adult.

Near work refers to any task such as reading, sewing, knitting, that is performed within a 20 inch distance. The amount of time spent by the subject with his eyes focussed at this distance was recorded.

Height measured in inches was considered because of the studies, reported earlier, that investigated height and refraction.

Leisure activities were recorded by asking the subject to report his favorite activity. Nine categories of leisure activities were recorded.

Figure 10 (p. 87) illustrated the distribution of refraction in the total population, showing three distinct trends of refraction with age, from age 5 to age 15, from age 15 to about age 40, and from age 40 and up. Those subjects who entered school in 1948, i.e. when school attendance became compulsory in order to receive child benefits, had reached the age of 30 in 1974 when the data were collected. Because of these three age trend relationships, and in order to investigate changes due to introduction of schooling in 1948, four age groups were used, viz. age 5-14, 15-29, 30-44, and 45+.

Means and standard deviations of education and near work were examined in the four age intervals. Product moment correlations between the variables mentioned were examined in each age interval. Partial correlations, with refractions, removing effects of other variables in order to assess the independent effects of height, education, and near work, were calculated for each age group. Multiple regression analysis was performed to assess the variation in refraction accounted for by each variable. A close statistical relationship of near work to refraction was found (to be discussed), prompting a further examination of the distribution of near work by 5-year age groups.

The effects of the other variables were removed by regression from refraction and the residual value, called RFC, was compared across different categories of leisure activity.

Results

Tables 40 and 41 present means and standard deviations of refraction, age, education, and near work in hours, in the four age groups.

It will be seen that mean refraction is negative only in the 15 to 29 age group; this group also has the highest educational level, and the most time spent at near work. The earlier lack of education is evident from inspection of the educational level of those over 45. The mean grade is 5.38, half that of the 15 to 29 age group. Even though low, this value is misleading, as this group contained two retired school teachers, and one retired professional engineer. The oldest group also spent the least amount of time at near work at the time of the study, even including the three subjects mentioned. Because they also had the lowest education value, they probably spent less time at near work during their early years. Educational level gives an indication of the amount of near work performed during the childhood and adolescent years, but it obviously is a very imperfect measure of habitual near work.

For most of the older women near work meant principally knitting and sewing. Knitting and sewing was the third most often cited favorite leisure activity, with most of those listing these as favorite activities being over age 45. It can be surmised that reading is considerably less in this age group compared to the other groups.

Age group 30 to 44 also shows a misleading mean grade level, as this group included four teachers, and two former teachers now employed as clerks. By subtracting the data of these six subjects from the totals in Table 41 (p. 144), the mean refraction increased from +0.636 D. to +0.76 D., mean education changes from 8.885 years to 8.67 years, and mean near work changes from 1.270 hours to 1.14 hours. This age group also contained 75 housewives with a mean positive refraction.

Table 40. Means, standard deviations, for RVERT, age, educational level, near work, in hours, for age groups 5-14 and 15-29

	age 5-14			age 15-29		
	n	mean	SD	n	mean	SD
RVERT	331	+0.262	1.171	226	-0.711	1.606
Age		8.99	2.73		21.46	4.44
Education		9.22	2.66		10.627	1.857
Near work		0.985	0.998		1.613	1.37

Table 41. Means, standard deviations, for RVERT, age, educational level, near work, in hours, for age groups 30-44 and 45+

	age 30-44			age 45+		
	n	mean	SD	n	mean	SD
RVERT	148	+0.636	1.145	186	+0.873	1.366
Age		37.18	4.42		56.84	9.706
Education		8.885	2.966		5.38	3.309
Near work		1.270	1.5591		0.898	1.141

Table 42. Data for six subjects in age group 30-44, with respect to age, refraction, near work, education, sex, and occupation

Subject	Sex	Age	RVERT	Near work	Education	Occupation
1	M	37	-1.75	8	17	teacher
2	M	37	-4.50	3	17	teacher
3	M	38	-0.50	3	16	teacher
4	M	32	0.00	3	13	teacher
5	M	40	-6.00	1	12	clerk/ex-teacher
6	M	40	-1.25	8	9	clerk/ex-teacher
means			-2.23	4.33	14.0	

Correlations

The association between variables was examined more precisely by correlation techniques.

Table 43 shows the Pearson Product Moment correlations (r) of refraction with the variables previously argued to affect refraction, in each of the four age groups. Because heights of 26 subjects were unrecorded, the data presented are for 931 subjects.

Discussion of the Results

Age Group 5-14

In the youngest age group (5-14), the close relationships of height with age (0.916), education with age (0.940) and education with height (0.899) are predictable. Near work shows substantial correlations, ±.40 or better, with refraction, height, age and education, again predictable as children progress through school. The substantial correlations, on the order of -.40, of refraction with height, age, near work,

Table 43. Correlations among RVERT and other variables grouped by age

	Age 5-14					Age 30-44				
	Height	Age	Sex	Education	Near work	Height	Age	Sex	Education	Near work
RVERT	-0.374 ***	-0.364 ***	-0.088	-0.433 ***	-0.426 ***	-0.113	0.081	0.003	-0.393 ***	-0.485 ***
Height		0.916 ***	0.037	0.899 ***	.404 ***		-0.013	-0.722 ***	.158 *	.040
Age			.048	.940 ***	.415 ***			-0.054	-0.380 ***	-0.101
Sex				.085	.215 ***				-0.043	-0.006
Education					.454 ***					.476 ***

	Age 15-29					Age 45+				
	Height	Age	Sex	Education	Near work	Height	Age	Sex	Education	Near work
RVERT	0.135 *	0.164 **	-0.222 ***	-0.210 ***	- .325 ***	-0.231 ***	0.114	0.081	-0.142 *	-0.219 ***
Height		.049	- .649 ***	.180 **	.050		-0.127 *	-0.687 ***	.075	-0.038
Age			-0.053	-0.029	-0.105 *			.029	-0.222 ***	-0.065
Sex				-0.055	0.091				.044	.159 *
Education					0.310 ***					.531 ***

Significance: *** .001; ** .01; * .05

and education, are the only ones not readily explicable in terms of age trends in height and education. Sex shows little relationship to other variables, except for a modest correlation (0.215) with near work. It may be remembered that more negative refraction means were noted in females than in males in this age interval.

Age Group 15-29

Correlations observed in the 15-29 year interval are generally smaller, and some are greatly reduced. This reflects cessation of the period of greatest growth and the fact that only the younger persons in this group are required to attend school. The correlations of height with sex (-0.649) and education (0.180) indicate that females are shorter and have completed more years of schooling. Education and age are not related in this group. Near work is correlated with education (0.310) and refraction (-0.325) but slightly negatively correlated with age (-0.105), presumably because many in this age group have left school. Females show more negative refractions, the older more positive refractions. As in the first age interval, education and near work show substantial correlations (-0.210 and -0.325 respectively) with refraction, despite reversals in the relationships of refraction with height and age, and are in themselves correlated (0.310).

Age Group 30-44

In the 30-44 year interval, substantial correlations, on the order of 0.40 to 0.50, are again seen among education, refraction and near work. Refraction is but weakly related to height, age and sex. The other noteworthy change from the 15-29 year group pattern is the negative correlation (-0.380) of age and education. The heterogeneity of this group with respect to occupation and therefore education, may account for the increased correlations involving this variable, by comparison with the 15-29 year group.

Age Group 45+

In the 45 year and older interval refraction shows weaker correlations with age and education, perhaps because of senile lens changes and presbyopia, though it is still correlated with near work (-0.219). Near work and education remain highly correlated (0.531), age and education negatively so (-0.222). The older are shorter (-0.127) probably because they are predominantly female. The taller are more myopic (-0.231) possibly because they are younger, that is, there are more females who are more hyperopic at the oldest ages (65 years and above).

Comments

Apparent in this shifting pattern of correlations with age is the constant relationship of refraction and near work, and of near work with education. The latter is only to be expected, the former is demonstrated here. Refraction remains correlated with near work throughout essentially the entire life span, despite the non-consistent relationship of near work with age, despite the complete reversal in the relationship of refraction to age in the mid-teens, and despite the more gradual but even greater reversal in the relationship of education and age.

Partial Correlations

Because of the interdependence of the several variables of interest, partial correlations were calculated for refraction and height; refraction and education; and refraction and near work. In each case, age and sex, as well as the other two variables were partialled out. Tables 44, 45, and 46 present the results.

Table 44 generally confirms the findings of Goldschmidt (1966) and Alsbirk (1979) that height and refraction are not significantly related, although in the oldest age group, there is a significant relationship between the two variables. Table 45 indicates that education is highly significantly correlated (negatively) with refraction ($p < .01$) in the first three age groups, but in the over 45s these variables are not significantly correlated. With respect to near work and refraction (Table 46), all correlations are significant at the 1% level for all age groups. Greater heterogeneity of occupation and therefore of education possibly explains the relatively large correlation in the 30-44 age group.

Comments

It is apparent after statistically removing the effects of age and sex and the minimal effects of height, that refraction and education, and even more so refraction and near work, are inversely related.

Multiple Regression Analysis

In order to determine the contribution of education and near work to variation in refraction, multiple regression coefficients were calculated as indicated in Table 47. With refraction as the dependent variable, regression coefficients were calculated removing in order the effects of age, sex, height, near work and education, and with education removed before near work.

R^2 change is the proportion (percentage) of refraction which can be explained by each independent variable entered in the regression in

Table 44. Partial correlations of RVERT and height: by age; age and sex; age, sex, education; age, sex, education, and near work

Controlled for:		age	age,sex	age,sex, education	age,sex,education, near work
RVERT & height	age 5-14	-0.1093*	-0.1108*	-0.0368	-0.0332
	15-29	0.1285*	-0.0158	0.0285	0.0168
	30-44	-0.1125	-0.1611*	-0.1049	-0.1284
	45+	-0.2193**	-0.2291**	-0.2179**	-0.2154**

Table 45. Partial correlations of RVERT and educational level, by age; age and sex; age, sex, and height; and age, sex, height, and near work

Controlled for:		age	age,sex	age,sex, height	age,sex,height, near work
RVERT & education	age 5-14	-0.2837**	-0.2775**	-0.2584**	-0.2182**
	15-29	-0.2077**	-0.2257**	-0.2268**	-0.1442**
	30-44	-0.3934**	-0.3942**	-0.3774**	-0.1928**
	45+	-0.1208*	-0.1254*	-0.1024	0.0130

Table 46. Partial correlations of RVERT and near work, by age; by age and sex; by age, sex, height; and by age, sex, height, and education

Controlled for:		age	age,sex	age,sex, height	age,sex,height, education
RVERT & near work	age 5-14	-0.3242**	-0.3162**	-0.3113**	-0.2799**
	15-29	-0.3135**	-0.3031**	-0.3030**	-0.2499**
	30-44	-0.4809**	-0.4809**	-0.4805**	-0.3695**
	45+	-0.2131**	-0.2293**	-0.2153**	-0.1908**

** significance .01

* significance .05

Table 47. Multiple Regression Analyses of RVERT with five other variables affecting refraction

Dependent variable: RVERT

Variable	Ages: 5-14 R^2	R^2 change	15-29 R^2	R^2 change	30-44 R^2	R^2 change	45+ R^2	R^2 change
age	0.133	.133	.027	.027	.007	.007	.013	.013
sex	.138	.005	.073	.046	.007	.000	.019	.006
height	.148	.011	.073	.000	.032	.026	.070	.052
near work	.231	.083	.158	.085	.256	.223	.114	.043
education	.267	.037	.175	.018	.283	.028	.114	.000
education	.205	.057	.120	.048	.170	.138	.000	.009
near work	.267	.062	.175	.054	.283	.113	.114	.033

the specified order.

In the younger age groups, about 8% of the variance of refraction is explained by near work, if it is partialled out before education, and only a little less, about 6%, if it is partialled out after education. In the youngest group, when refraction is changing rapidly, age plays the most important role in refractive change. In the 15 to 29 age group, sex is more important than age, but near work still is the most important variable explaining variance in refraction. The difference between males and females in mean refraction in this age group, already shown, is reflected in this finding.

In the 30 to 44 year group, education and near work are more closely related, and more important in the variation in refraction; 22% of this variation is accounted for if near work is removed before education, and 11% if near work is considered last. Sex and height count for little. The occupational heterogeneity of this age group may be recalled. By this time, refraction has reached its ultimate value, and those in occupations requiring most near work are also in this age group.

In the oldest group, education accounts for none of the variance in refraction and near work very little, probably because of senile changes, as mentioned. Those over 45 have the least education; the influence of height on variation in refraction (5%) is approximately equal to that of near work.

Comments

Near work accounts for from about 4 to 22% of variation in refraction in different age groups. While its influence on variation in refraction is not necessarily large, it is the most influential variable in the two middle age groups. Only in the first age group is it secondary to age, as expected. In the oldest group it is about as influential as height.

Population/Age Distribution of Near Work and Refraction

Figure 18 illustrates by 5-year age intervals, for the entire population, the mean time spent on near work and the mean refraction. Both curves peak at age 15-19, and the two curves are strikingly parallel. It would be difficult to find a more parsimonious explanation for this relationship than that near work and refraction are strongly associated.

Leisure Activities

Each subject was questioned as to his favorite leisure activities. The data were divided into nine categories, two considered to be near-point activities, and six considered to be far-point activities. Thirty-six subjects reported no leisure activity at all.

The nine categories were:

- reading
- sewing, knitting
- fishing (hobby)
- hunting
- housework (reported as a leisure activity)
- driving
- television viewing
- games, sports, outdoor play
- none

Table 48 presents the data in these nine categories relating to mean refraction, standard deviations, and the number of subjects in each category.

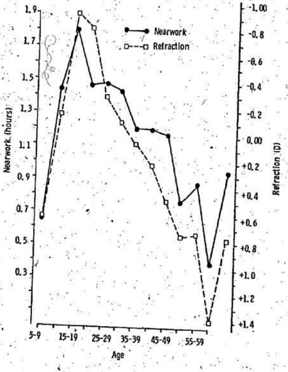

Figure 18. Mean refraction (RVERT), mean nearwork (hours) for total population, present study, by 5 year age intervals. n=957.

Table 48. Leisure activities for 957 subjects, mean refractions, standard deviations, and number of subjects in each category

Activity	mean RVERT	SD	n	group mean
reading	-0.2173 D.	0.9505	207	-.192 D.
sewing, knitting	-0.0790	1.0868	46	
fishing	0.0457	0.5933	9	
hunting	0.3022	0.5393	4	
housework	0.1015	0.8152	26	
driving	0.3589	0.0963	2	+.0717 D.
television	0.0612	0.8861	10	
games, outdoor, etc.	0.0665	0.8448	591	
none	0.1034	0.8917	36	
unrecorded			26	
			957	

The two near-point categories both showed negative mean refractions, although only that of the reading category was strikingly so. Most of the other leisure activities were claimed infrequently except for outdoor activities; this group (591) had an essentially emmetropic mean, as did the far-point categories taken together.

Comment

It appears that in this population those who read for pleasure have more negative refractions than those who prefer outdoor activities. Little can be made of this comparison since only favorite leisure activities are considered, and since time spent at leisure activities was not recorded.

Discussion

Results of the analyses of correlations, partial correlations, and multiple regressions, all confirm that those doing more near work have more negative refractions over all age groups. Trends for occupation and leisure activities are also in agreement with the findings of Goldschmidt (1968), and Tscherning (1882), who showed that more negative refractions are associated with near work activities. The significance of these findings is enhanced when they are related to the trend seen in the under 30 age group to more negative refractions. It was shown earlier that those under 30 had more education and spent more time at near work tasks than those over 30. Moreover, those under 30 have, generally, an altogether better type of education than those over 30, and yet the education/refraction/near work relationships were similar in both age groups.

From the literature, and from the population distribution of refraction, it could be suggested that refraction and near work were related. It is more improbable that persons would consciously and to a fine degree tailor their near work to their refraction. From the findings presented in this chapter, of the close association of the two variables throughout the study population, it can be concluded that near work is a substantial influence conditioning refraction in man.

The investigations reported so far have focussed on environmental factors. Chapter 6 examines the influences of heredity on refraction.

Chapter VI

THE INHERITANCE OF REFRACTION

Introduction

Because several studies indicate a substantial hereditary component in the determination of ocular refraction, this chapter reviews previous work on the genetics of ocular refraction, briefly reviews the concept of multifactorial inheritance, and presents analyses of familial resemblances in refraction and near work in the material of the study population.

Multifactorial Inheritance

Refraction is a continuously varying trait, much like height. This in itself suggests that its genetic background may be polygenic, that is that its heredity is based on the additive effects of several or many genes (Cavalli-Sforza and Bodmer, 1971). Since environmental factors have also been shown to influence refraction, it is appropriate to analyze familial resemblances in refraction in terms of multifactorial inheritance. This approach does not prejudge the issue of the genetic basis of refraction since the methods used can be expected to reveal departures from the genetic assumptions which underlie them.

Close relatives are expected to show certain correlations in traits of polygenic inheritance. First degree relatives (parents, offspring, sibs) have half their autosomal genes in common, and should therefore exhibit a correlation of 0.50; second degree relatives (aunts, uncles, nephews, neices) should have a correlation of 0.25; third degree relatives should have a correlation of 0.125. These expected correlations will be observed only when variation in the trait is entirely genetic and additive. This is referred to as complete additive control. If the correlation is less, the difference from expectation may be taken to indicate an environmental component in variance of the trait. On the other hand, common family environmental conditions may increase the value of a correlation of relatives, inflating estimates of the genetic component of variance. When sib-sib correlations exceed parent-offspring correlations, common familial environment must be suspected. If husband-wife correlations are non-zero, assortative mating may apply for the trait, or common environment may be increasing the resemblances of spouses. Dominance effects will also increase the correlation of sibs compared to that of parents.

In examining the heredity of refraction, and more specifically of myopia, one has to differentiate simple and degenerative types of myopia, as well as what Duke-Elder (1970) calls pathological myopia. Pathological myopia is associated with degenerative changes in the eye, usually in the posterior segment of the eyeball, and is usually accompanied by a longer axis. This type of myopia is relatively common and can lead to eventual blindness. Its genetics is multiplex in that one must distinguish between genetic cases where high myopia exists unrelated to other genetic pathology, and those conditions such as albinism in which ocular and other pathology is related. In such cases the multifactorial basis for the inheritance of refraction may be inappropriate. These types of high myopia are often simple mendelian traits (Francois, 1961). The inheritance of ocular refraction has been approached through twin studies, pedigree studies and family studies.

Twin Studies

In twin studies, comparisons are made between concordances of dizygotic (DZ) and monozygotic (MZ) twins for a trait or condition. The conventional approach is to reason that hereditary variation can be postulated if concordance is greater for MZ than DZ twins and the concordance for DZ twins is approximately that of sibs.

Early twin studies reporting influence of heredity on refraction reviewed in Waardenberg (1963) and Sorsby et al (1962), Francois (1961), Jablonski (1922), Waardenberg (1930), and v. Rotthe (1937) reported higher concordance for refraction in MZ compared to DZ twins. Otsuka (1956) studied Japanese twins, and reported similar results.

Sorsby et al (1962) investigated 78 pairs of MZ twins, with refractive distributions similar to that found in the general population. Table 49 presents data for concordances between ocular components for MZ, DZ, and unrelated control pairs, and criteria by which concordance was defined.

From the higher concordance in MZ compared to the DZ twin and control pairs, Sorsby concluded that refractive errors were due to faulty correlation between components, largely due to heredity. He did not find a statistically significant difference in concordance between the DZ twins and the control pairs for all refractions. Concordance in the MZ pairs was higher in emmetropia than in ametropia, but the concordance for MZ in all refractions was higher in all cases compared to DZ and controls.

Goldschmidt (1968) reported on two pairs of MZ twins in his study, finding greater concordance for refraction in the MZ twins compared to nine DZ twin pairs. Reviewing earlier twin studies, he concluded MZ

Table 49. Incidence of concordance for the different components of refraction in MZ, DZ, and control pairs (from Sorsby et al, 1962)

Component	All refractions			Myopia of any degree hyperopia over +2.25 D. astigmatism over 1.25 D.			Range for concordance
	MZ	DZ	Control	MZ	DZ	Control	
corneal power	71.8	37.5	27.1	62.5	36.4	18.5	0-0.5 D.
anterior chamber depth	66.7	42.5	33.4	71.9	40.9	22.2	0-0.1 mm
lens power	74.4	40.0	35.5	78.1	40.9	33.3	0-0.9 D.
axis length	83.3	37.5	41.7	75.0	27.3	33.3	0-0.5 mm
vertical ocular refraction	70.5	30.0	29.1	40.6	13.6	3.7	0-0.5 D.

concordance to be higher than DZ, with greater concordance in the emmetropic range and in lower degrees of ametropia compared to higher errors. The differences in concordance between MZ and DZ twins were present for all types of error, but were greater in higher ametropia. These conclusions are similar to Sorsby's (1962).

In reviewing Sorsby's 1962 study, Goldschmidt found the variance to be higher in myopia than in hyperopia in the DZ pairs indicating a greater genetic variability for myopia. Because intra-pair variance of MZ twins was also higher in myopia than in hyperopia, he postulated a greater environmental influence in myopia than in hyperopia. He further noted a greater intra-pair variance in myopia over -6 D. in MZ twins compared to DZ twins, with greatest variance in the optic axis, and no difference in other components. This suggested that in myopia over -6 D. external factors work mostly on axial length. Because MZ twins share the same genes, discordance must be due to low penetrance or environmental factors. From this Goldschmidt concluded that all discordance was due to the influence of environmental factors on the genetic background.

Comments

Stern (1973) and Goldschmidt (1968) have pointed out several limitations in twin studies. In comparing MZ and DZ twins, it has been assumed that environmental variances in both types are identical. However, this is not necessarily so. In general, environments of DZ twins are more disparate than those of MZ twins; a lesser concordance of DZ compared to MZ twins might be due to differences in environment. It is also known that monochorionic twins may have inequalities in placental blood supply (Stern, 1973; Goldschmidt, 1968) which could increase intra-pair differences and reduce estimates of hereditary influences. Ascertainment and reporting of single pairs or small series of twins tends to be biased by the curiosity value of concordant and discordant pairs; only unselected series can be given much weight. In studies of concordant twins, twins with single gene disorders, such as degenerative myopia, tend to be over-represented (Edwards, 1963).

Pedigree Studies

Pedigree studies have led to different interpretations of the mode of transmission of refractive errors by various investigators. Table 50 lists authors by mode of transmission suggested.

These studies cannot be very informative regarding the general inheritance of refraction, as they tend to be selective in choice of pedigrees studies, and will not be discussed in more detail.

Table 50. Modes of transmission of myopia as reported by different authors, as reviewed in Baldwin (1964)

Autosomal Dominant	Autosomal Recessive	Dominant Sex-linked
Clausen, 1920	Paul, 1938	Wold 1949
Holm, 1926	Jaensch, 1939	
Waardenberg, 1962	Ferrarrio, 1952	
Wolfflen, 1949	Aligno-Massei, 1965	
Wold, 1949	Jablonski, 1922	

In addition, Goldschmidt (1968) suggested that myopia was transmitted polygenically, in an irregular fashion.

Family Studies

It is more useful to consider resemblances in a large series of families, the selection of which was not based on a need for visual care.

Young et al (1958) examined 207 pairs of siblings in Pullman, Washington, United States, reporting the overall partial correlation (correcting for age) for sibs to be 0.14. For the 43 pairs of female sibs, the correlation was 0.24, compared to the correlation for 56 male pairs of sibs of 0.14.

In a study of 28 unselected families, Sorsby et al (1966) found the parent-child correlation for refraction to be 0.227 (100 pairs), while the sib-sib correlation was 0.358 (24 pairs in 22 sibships). The correlation of mothers to fathers was -0.119 (28 pairs).

Ditmars (1967) studied 258 myopes and their families. In this visually selected material, he reported 22 or 8.5% had both parents myopic; 73 (28.3%) had only one parent myopic; 163 (63.2%) had neither parent myopic. He noted that 223, or 86.4%, exceeded their parents' degree of myopia. The offspring in this study ranged in age from 5 to 24. This data were reanalyzed by Hirsch and Ditmars (1969) paying attention to the degree of myopia. They reported that as the degree of myopia increased, the percentage of parents myopic increased, and the percentage of neither parent being myopic decreased.

Young et al (1969) compared the refractions of Eskimo children to that of their parents and grandparents in Point Barrow, Alaska. The total number of subjects was 508. Refractions were non-cycloplegic followed by cycloplegic examination. Correlations were calculated between the parents' refractions and that of the offspring in 41 family units (197 subjects) as well as amongst siblings. Myopia was considered as being of -0.25 D. or more (equivalent sphere). The parent offspring correlations were not significantly different from zero, while the sibling correlations were high and significant. Table 51 presents the results.

Table 51. Partial correlations (removing age effects) between right eye refractions of parents and children (Eskimos in Alaska) (adapted from Young, 1969)

Groups	N (pairs)	Partial r
Father-son	59	0.22
Father-daughter	56	0.11
Father-children	115	0.19*
Mother-son	59	0.16
Mother-daughter	56	0.08
Mother-children	115	0.12
Brother-brother	52	0.12
Sister-sister	36	0.72**
Brother-sister	100	0.45**

Significance * 5%

** 1%

Keller (1973) studied 200 visually selected families from his clinical files. He reported a greater influence of the mother than the father on the refraction of the offspring, with the mother-daughter correlation being greater than the father-son, a finding opposite to that of Young (1969) (Table 51).

Alsbirk (1978) studied spherical refraction in adult West Greenland

Eskimos. Subjective refractions were recorded; the subjects, aged 15 or over, numbered over 500 (93% of the population). He reported the typical refraction frequency curve, i.e. leptokurtotic and skewed to the minus side. The husband-wife regression of refraction was essentially zero. Parent-offspring regression based on 159 family units was relatively low compared to the sibling correlation.

Table 52. Family resemblance of refractive error (from Alsbirk, 1978)

	Husband-wife regression coefficient	Child-parent regression coefficient	Sib-sib intra-pair correlation
Refractive error	0.03	0.07	0.25
Standard error of estimates	0.10	0.08	0.07
No. of pairs examined	108	159	160

All analyses based on age and sex independent deviation scores.

Young and Leary (1972) examined 71 Alaskan Eskimo families, of which 30 were first generation (grandparents), and 41 were second generation (parents) with a total of 158 generic children involved, 127 males and 131 females.

In the total population of 258 children in the Young and Leary (1972) study, 38 (14.7%) were more hyperopic than either of the parents; 83 (32.2%) were within 0.25 D. of one or both parents; and 137 (53.1%) were more myopic than either parent. This disparity was taken to indicate that some factor other than heredity was acting on the offspring's refractions.

The mean vertical ocular refraction of the mothers was +1.4 D. The children were almost 1.0 D. more myopic than the parents, with the girls 0.25 D. more myopic than the boys.

Partial correlations (age effect removed) for father-children was 0.12 and non-significant, while for mother-children was 0.34 and significant at .01.

In four of these families, with 10 male and 7 female children, there was a mid-parent refractive error of +3 D. and above. When these were excluded, the partial mother-children correlation dropped to 0.19; the father-children partial correlation to 0.03, with the average parent-offspring partial correlation to 0.11. This gives some support to an earlier assertion by Hirsch (1964) that high hyperopic parents will produce high hyperopic children.

Hegmann et al (1974), in a study primarily concerned with Strabismus, also report, for 866 randomly selected control subjects, the following correlations for refraction between parents and offspring:

Mother-daughter	.08
Mother-son	.18
Father-daughter	.12
Father-son	.115

Comments

These family studies report, for the most part, correlations. High familial correlations do not necessarily indicate an hereditary component in variation, and low correlations do not preclude substantial hereditary variation. A low correlation may indicate that neither genetic nor environmental factors are influential, or that substantial environmental effects are decreasing the resemblances of relatives. The studies of Young et al (1969) on Alaskan Eskimos, and Alsbirk (1978) on Greenland Eskimos found a closer resemblance between sibs than between parents and children in refraction; and Alsbirk demonstrated an absence of resemblance in refraction between parents. Hirsch and Ditmars (1969) reported that low myopia and high myopia probably have different causative mechanisms, based on the reanalysis of Ditmars' 1967 study. Their conclusions agreed with the views of Goldschmidt (1968) who asserted that heredity is probably more of a determinant in higher degrees of myopia, while in lower myopia heredity plays a lesser or non-existent part. It may be remarked that this pattern is also compatible with multifactorial inheritance, for which severity of defect is expected to be associated with a greater frequency of affected among relatives (Carter, 1969).

Statistical examination of the resemblances of relatives is the method of choice for measuring genetic variation in refraction. The smooth, continuous distribution suggests a metric rather than a qualitative approach. The Dioptre scale of refraction is linear; increments of 1 D. in correcting lens power moving the focal point about one third of a millimetre toward or away from the retina. Hirsch's (1962) finding that persons often change from hyperopia to emmetropia or from emmetropia to myopia, depending upon initial refraction, mitigates against qualitative analysis as does the demonstration of strong correlations of nearwork and refraction.

Correlation and regression techniques applied to resemblances between relatives are specifically designed for evaluating metric data. A genetic scheme of analysis (p. 157) allows at least in theory the distinguishing of major gene and environmental effects using these methods. Environmental and other correlates can be statistically adjusted for.

PERSONAL INVESTIGATION IV

FAMILY RESEMBLANCES IN REFRACTION

Aims

The analyses now reported were undertaken to determine the resemblances between first degree relatives in the population of the present investigation in ocular refraction and near work.

Methods

The basic data were the measured refractions for each individual. Family relationships in the population were recorded as part of the larger West Coast Health Survey (Marshall, 1975).

The individual values used in the calculations for resemblances between first degree relatives were residual refraction (RFC in tables), computed as follows: In each of the four age intervals, corresponding to the four divisions of the refraction curve (see pp. 142) refractions were regressed upon age, sex, height, education, and near work, to remove in sequence the variation in individual values attributable to these influences, and thereby gain a truer estimate of individual refraction.

The intraclass correlations of spouses was examined for evidence of assortative mating or progressively increasing resemblance. Measures of sib resemblance were derived by intraclass correlation (Sokal and Rohlf, 1969, pp. 208-213) which expresses the degree of similarity between sibs as the percentage of variance which can be attributed to membership of such a group (within group variance). This method has the advantage of allowing proper weighting for sibships of different sizes (Falconer, 1963). Standard errors of these intraclass correlations were estimated following Osborne and Paterson (1952).

The resemblance of offspring to parents was evaluated by the weighted regression method of Falconer (1963), again taking account of unequal family size. Presentation of the numbers, and of standard errors and/or significance levels, allows appraisal of the confidence which may be accorded to the correlation and regression statistics.

Results

Table 53 presents husband-wife intraclass correlations, in age intervals.

Table 53. Husband-wife intraclass correlations (r_t) of RFC for complete data, indicating numbers of pairs in each age group.

	no. pairs	r_t	significance
Complete Data:	111	-0.1113	n.s.
Age: 15-30	13	0.0698	n.s.
30-45	33	-0.2716	n.s.
45+	38	-0.1423	n.s.

There were no significant correlations in age intervals, or for the total material. Thus there is no indication of assortative mating for refraction or of a trend toward increasing resemblance of spouse after marriage.

Parent-offspring regressions for residual refraction were calculated for the material as a whole, without regard to age, and are presented in Table 54.

It may be seen from Table 54, that the like-sex regression values are similar and significant, while the opposite sex values are lower and non-significant.

Table 54. Parent-offspring regressions for RFC for the total population (n = 919 pairs)

	b	n (pairs)
Complete Data:		
Father-son	0.205*	177
Father-daughter	0.135	188
Mother-son	0.006	267
Mother-daughter	0.217***	287

* .05

*** .001

As described, data were grouped into four age intervals to investigate age and secular trends in refraction. Regressions of parents on offspring were calculated for offspring in each of these age intervals.

Table 55. Parent-offspring regression coefficients for RFC by four age groups

Age (offspring):		5-14	SE	15-29	SE	30-44	SE
Father-son	b	0.212 (98)	.155	0.251** (60)	.07	0.243 (15)	.20
Father-daughter	b	0.002 (80)	.16	0.216* (79)	.13	0.078 (23)	.13
Mother-son	b	-0.053 (158)	.06	0.174 (68)	.087	-0.182 (26)	.210
Mother-daughter	b	0.120 (124)	.10	0.417*** (109)	.078	0.061 (40)	.076

Numbers in brackets are numbers of pairs

Significances: * .05

** .01

*** .001

From Table 56 it is seen that the only age group showing statistically significant resemblances is the 15 to 29 year interval. Those between the ages of 5 and 14, and 30 and 44 show no significant resemblance in residual refraction to their parents. The number of pairs in the 30 to 44 age interval is relatively small. (Values in age 45 and over are not presented as there are few or no parent-offspring pairs in the material.)

Sib-sib Relationships

The intraclass correlations for sibships by age interval are presented in Table 56.

Table 56. Intraclass correlations for RFC for sibs, by ages

	% variance	n	SE
Complete Data:	0.2195**	180	.05
Ages: 5-14	0.1803**	85	.07
15-29	0.1827*	56	.09
30-44	-0.0708	28	.13
45+	0.3862**	40	.10

Significances: * .05

** .01

It can be seen from Table 56 that resemblances between sibs for refraction are quite significant, except in the 30 to 44 age interval, where observations are relatively few. In the population as a whole, sib-sib correlations and parent-offspring regressions are quite similar, with the exceptions of the mother-son comparison, and that of sibs aged 30 to 44.

In order to examine further the sib resemblances in refraction, intraclass correlations were obtained for male and female sib-pairs separately. Table 57 presents the results.

The resemblance between sibs appears to be due primarily to the resemblance between sisters (Table 57). Values for resemblance between brothers are non-significant and erratic, and therefore difficult to interpret.

Comments

As in the studies of Young (1969) and Alsbirk (1978), the husbands and wives in this population showed no similarity to each other in refraction, while sibs and parents and offspring showed a moderate resemblance. Young (1958, 1969) found that sisters were more alike than brothers in refraction and this was seen in the present investigation. However, in Alsbirk's (1978) material, brothers were somewhat more alike than sisters.

The father-child, mother-child findings were inconsistent with other studies. Young (1969) reported father-son and mother-son resemblances to be greater than father-daughter, mother-daughter resemblances, while Hegmann et al (1974) reported mother-son resemblances to be larger than the others. In this investigation like-sex resemblances were found to be stronger than unlike-sex resemblances, with essentially no mother-son resemblance indicated.

Regression coefficients for residual refractions between parents and offspring for the total population, and for three age groups, indicated this variance to be in the neighborhood of 20%, in agreement with previous studies. Present results give less indication than those of

Table 57. Intraclass correlations of like-sex sib pairs for RFC and intraclass correlations in the parents of the pairs, with significances and numbers of pairs

	Intraclass correlation			Intraclass correlation		
	% explained brother-brother	SE	parents I-C correlation	% explained sister-sister	SE	parents I-C correlation
Complete Data:	0.0062 (85)	.08	0.0902 (35)	0.2567** (89)	.08	-0.0449 (37)
Ages: 5-14	-0.0971 (43)	.12	0.0261 (23)	0.2155 (30)	.14	-0.1471 (16)
15-29	0.2549 (17)	.20	0.1672 (13)	0.2183* (33)	.14	0.0319 (18)
30-44	-0.8094 (7)	.14		0.1105 (15)	.22	-0.1668 (5)
45+	0.1594 (17)	.19		0.5608** (13)	.16	

Numbers in brackets refer to number of pairs.

Significances: * .05
** .01
*** .001

previous investigations of sib-sib resemblances being stronger than parent-offspring resemblances, presumably because of the steps taken in the present investigation to statistically remove environmental variance in refraction.

Both parent-offspring regressions and sib-sib intraclass correlations suggest that the hereditary component in refraction variance to be on the order of .20, that is, substantial but conspicuously less than expected on the hypothesis of complete additive genetic control.

Familial resemblances in near work were examined to determine whether its effects could be inflating familial resemblances in refraction.

Family Resemblances in Near Work

Methods

The calculations performed to determine the resemblance of first degree relatives in near work parallel those done previously for refraction. The individual values used were residual near work (RNW in tables). As with refraction, regressions were calculated for each of the four age intervals removing the effects of age, sex, height and education from individual near work values.

Table 58 presents the intraclass correlations for residual near work for husband-wife pairs.

Table 58. Intraclass correlations for RNW for husband-wife pairs, for complete data, and in age intervals

	no. pairs	r
Complete Data:	111	−0.1001
Ages: 15–30	13	−0.3390
30–45	33	−0.0842

None of the values achieved statistical significance. There is no indication that spouses resemble/or come to resemble one another in near work and there is no indication of assortative mating.

Table 59 presents, for the total population of 919 pairs, parent-offspring regressions for near work.

Table 59. Regression of RNW for parent-offspring, total population = 919 pairs

	b	SE	n (pairs)
Complete Data:			
Father-son	0.134*	.065	177
Father-daughter	0.164*	.076	188
Mother-son	0.121**	.052	267
Mother-daughter	0.163**	.051	287

Table 59 indicates that the regressions of children on parents are similar and significant in each sex combination, and considerably larger than husband-wife correlations (Table 58).

Intraclass correlations of sibs for near work were calculated, as were intraclass correlations for the parents of the sibships considered. Table 60 presents the results for the entire material.

Table 60. Sibship intraclass correlation, and intraclass correlation of parents for near work

	Intraclass correlation (sib-sib)	Intraclass correlation (parents of sibs)
Complete Data:	0.1237**	-0.1001
n (pairs)	177	111

Significance: ** .01

Comment

Overall, the correlation of sibs (Table 60) is little different from the parent-offspring regressions (Table 59). The overall husband-wife correlation and that for the actual parents of the sibs (Table 60) is negative. Thus in this material it is seen that sibs come to resemble their parents and each other in near work habits to a moderate degree, while the parents themselves do not come to resemble each other. If near work habits additively influence refraction, near work as an aspect of common familial environment could indeed inflate estimates of the genetic component in variation in refraction.

The data were broken down into age groups in order to determine if there is any important secular effect in near work resemblances. Table 61 presents results arranged by age group of parent-offspring regressions and for sib-sib correlations.

From examination of Table 61, several findings emerge. Parent-offspring resemblances are greater in higher age groups, while sibs resemble each other more in younger age groups. This suggests that younger persons resemble their sibs in near work habits, while older persons retain their parents' near work habits to a greater extent. By sexes, girls and women resemble their parents more than boys and men in near work patterns. The conspicuous resemblance of young girls to their mothers in a relatively large sub-group prompted examination of whether sisters resembled each other more than brothers. Results are presented in Table 62.

Table 62 shows statistical significance is achieved only in the sister-sister relationships for near work in the complete data and for age group 15-29; however all but one of the sister-sister correlations

Table 61. RNW, parent-offspring regressions by age interval, sibship intraclass correlations, and intraclass correlations of parents of sibs

age (offspring):	5-14	SE	15-29	SE	30-44	SE	45+	SE
Father-son (b)	.064	.11	0.192	.133	-0.01	.323		
n (pairs)								
Father-daughter (b)	0.061	.115	0.279*	.144	0.6171**	.213		
n (pairs)	80		79		23			
Mother-son (b)	0.011	.07	0.282**	.092	0.512	.3488		
n (pairs)	158		68		26			
Mother-daughter (b)	0.345***	.092	0.000	.09	.296**	.099		
n (pairs)	124		109		40			
Sibs (r)	0.1874**	.07	0.1170	.09	0.0050	.14	-0.014	.10
n (pairs)	85		56		28		40	
Fathers-mothers	—		-0.3390		-0.0842			
n (pairs)			13		33			

Significance: * .05
** .01
*** .001

Table 62. Intraclass correlations of like-sex sibs and their parents for near work

	% variance brother-brother	SE	Intraclass correlation parents	% variance sister-sister	SE	Intraclass correlation parents
Complete Data:	0.0765	.08	0.1805	0.1712*	.08	-0.1352
n (pairs)	85		35	89		37
Age 5-14	0.1153	.13	0.1313	0.2004	.14	-0.2207
n (pairs)	43		23	30		16
Age 15-29	0.1082	.21	0.0533	0.2340*	.14	0.0127
n (pairs)	17		13	33		18
Age 30-44	0.1439	.40	--	-0.0561	.21	0.0711
n (pairs)	7			15		5
Age 45+	-0.0844	.17	--	0.2525	.20	--
n (pairs)	17			13		

Significance: * .05

is approximately 0.20. It will be recalled that in Table 57 it was demonstrated that the refractions were more similar in sisters than in brothers.

Given the previously demonstrated effect of near work on refraction, the similarity found between sisters in near work enhances the possibility that resemblances in near work habits may contribute to familial similarities in refraction, particularly for females.

Discussion

This investigation has produced several interesting findings and has confirmed several others. These are summarized and compared with other studies in Table 63.

First, no similarity between husbands and wives in refraction has been found where investigated, nor has any similarity in near work measures been found in the present population. Assortative mating with respect to refraction and near work habits is thus not indicated, but since few studies of this point have been completed, generalization to all human groups is precluded.

Second, the parent-offspring similarities in refraction are greater, across all studies, than are husband-wife similarities. In this investigation parent-offspring regressions were calculated for each parent-child relationship separately, showing this trend, but also indicating greater similarity between fathers and sons and between mothers and daughters. This finding of like-sex similarity being stronger than opposite sex is not consistent with results of other studies, but the other studies are not consistent among themselves, so no conclusions can be drawn as to relative strengths of the different parent-offspring resemblances.

Table 63. A comparison of family relationships in refraction as reported by Alsbirk, 1978; Young, 1958, 1969; Sorsby, 1966; Hegmann, 1974, and this investigation, and near work familial relationships reported in this study

	Alsbirk, 1978	Young, 1958	1969	Sorsby, 1966	Hegmann, 1974	Richler, 1979 Refraction	Richler, 1979 Near work
Husband-wife	.03 (SE .10)			-.119		-.11	-.1001
Parent-offspring	.07 (SE .08)			.227			
Father-son			.22		.115	.205*	.134*
Father-daughter			.11		.12	.135	.164*
Father-child			.19*				
Mother-son			.16		.18	.006	.121**
Mother-daughter			.08		.08	.217**	.163**
Mother-child			.12				
Sib-sib	.25 (SE .07)	.14	.45**	.358		.2195**	.1237**
Brother-brother	.39 (SE .16)	.12	.32			.0062	.0765
Sister-sister	.27 (SE .13)	.24	.72**			.2567**	.1712*

Significances: * .05
** .01
*** .001

Third, in this investigation, similarity in refraction among sibs is about equal to that of parents and offspring. Resemblances among sibs result primarily from greater resemblances in refraction between sisters. This is in contrast to previous studies showing greater resemblances between sibs compared to those of offspring to parents in the present investigation, and may reflect adjustment of values for education and near work done in this investigation, but not by other workers. Of interest also is the same trend in resemblances in near work.

Fourth, in near work patterns, sib-sib similarities are about the same as all parent-offspring relationships. Familial resemblances in near work are consistent with the possibility that the effects of near work can inflate familial resemblances in refraction.

There are major differences in educational and near work patterns in several populations in which familial resemblances in refraction have been investigated. In the Alaskan Eskimo material (Young, 1969), and in the material in this investigation, young children received far more formal education than their parents. Young (1969) finds a large difference between parent-offspring and sib-sib resemblances in refraction; the present study does not. An economical explanation is that the present investigation adjusted refraction for education and near work, while Young did not, thus obviating the statistical effects of the educational change. Both Sorsby's 1966 study and Alsbirk's 1978 study are in areas where education is more stable, yet differences between parents-offspring and sib-sib resemblances were seen. In the absence of data on the stability of educational practices and near work habits in the populations of those two studies, it can be postulated that these influenced refraction less for the parents. This lack of information prevents the firm conclusion that increasing near work related to modern education is increasing the resemblances of sibs in refraction.

The influence of near work patterns at younger ages, when refraction is more amenable to change is indicated by examining the resemblances of relatives in the several age intervals. There appears in the present material to be some difference in refraction and near work similarities in males and females. Sisters resemble each other in refraction and in near work, except for the 30 to 44 age interval, and girls resemble their mothers in near work especially in the 5 to 14 age interval, while they also resemble their mothers in refraction most in the 15 to 29 age interval. Brothers resemble one another little in near work and not at all in refraction. Daughters resemble their fathers more in refraction and near work than sons resemble their mothers. Sons do however resemble their fathers to a moderate degree in refraction. It was demonstrated earlier that females do more near work in this population than males, especially in the 5 to 14 age interval.

All of these observations are compatible with a near work effect in the developing years, not removed by statistical manipulation of the raw data, increasing resemblances of females in refraction towards more myopic refractions. If this is the case, the father-son regressions on the order of .20 to .25, are good measures of genetic variation in refraction with school-associated near work influences excluded. When near work effects are not adjusted out, the genetic component in the total refraction variation may be relatively smaller than present findings suggest.

The resemblances of first degree relatives indicate that the heredity component in refraction variance is substantial, though substantially less than would be expected if refraction were completely under additive genetic control. Evidence has been presented for the influence of near work on refraction.

Chapter VII

PERSONALITY AND REFRACTION

Introduction

Several studies cited in Chapter 5 reported a relationship between intelligence, school grades, and refraction (Hirsch, 1959; Grosvenor, 1970; Young, 1955). This present study also demonstrated that refraction is related to education and near work. There have been observations as well by clinicians and researchers, that myopes had different personalities from non-myopes. In light of these previous studies and observations, this investigation was designed to study previously reported relationships between refraction and personality.

Previous Studies

The myope was reported to be introverted, shy, with few friends, and who disliked outdoor activities, by Thorington (1900). Introversion in myopes was reported by Gould (1918), who also labelled the myope as being meticulous, egotistical, dogmatic and tyrranical. These reports were mainly anecdotal in nature, based on personal clinical observations.

Godard (1927) on the one hand asserted that myopia influenced personality at a tender age, when refractive state changes, and on the other hand that personality characteristics start before the onset of myopia. These two statements are difficult to reconcile. According to his view, myopia is affected by hearing, touch, and heredity; the refractive state influences artistic state, moral temperament and behavior. Godard went on to describe the myope and hyperope in artistic and psychological terms, which as even he admitted, cannot stand the test of statistical analysis.

Rice (1930) also described the myope and hyperope in psychological terms. Basically, the myope is described as an introverted, friendless student because it is easier for him to be one.

Introversion of myopes was also asserted by Pimantel (1943), Dunbar (1947), and Gesell (1947). Henderson (1934) claims that myopes were introspective and sedentary.

A study on the influence of the nervous system on myopia was conducted by Harrington (1947), who found a ciliary spasm, associated with emotional disturbances, in myopes up to -2.00 D.

Dobson (1949) examined 16 subjects using cocaine homatropine as cycloplegic. He described the effect of the parasympathetic nervous system on accommodation. He asserted that emotional disturbances caused visual disorders, and that parasympatheticotonia led to myopia. He did not take hyperopia into account.

More recent studies have utilized various personality tests in an attempt to put considerations of the relationship of the personality to refraction on a firmer basis.

Schapero and Hirsch (1952) used the Guildford-Martin Temperment Test on 119 optometry students, and found myopes to be more inhibited, with excessive control over their emotions. Myopes also displayed inertness and a disinclination for motor activity, but were more inclined to social leadership, a somewhat contradictory finding.

Schultz (1960), using the Cornell Index of Neuroticism, found hyperopic university students were more neurotic than myopes.

Van Alphen (1952) used the Rorshach Test on 77 myopic and 100 hyperopic males, all about aged 20 years, in junior college. He found myopes to be more compulsive, less interested in details, not self-critical, not as accurate, more ambitious, bolder thinkers, more capable of mental isolation, more influenced by depressions, more scientific, theoretical, and thought more abstractedly, compared to hyperopes.

Young (1967) used the Edwards Personal Preference Schedule, a forced choice test in which the subject scores valued behaviors, on 100 college males. He performed no refractions, gathering his refractive information from a questionnaire.

He found myopes and hyperopes to score the same in four variables: autonomy, affiliation, nurturance, and endurance. Myopes scored higher in achievement; intraception; succurance; abasement; heterosexuality; and aggression, while hyperopes scored higher in deference; order; exhibitionism; dominance; and change.

The only statistically significant findings were elevated abasement for the myope, and elevated exhibitionism and dominance for the hyperope. The results of this study seem to agree basically with the anecdotal observations of Rice and others. Young asserts that because, from the psychologist's point of view, personality is determined in the first five years of life, and refractive error does not become evident until the ages of 9 or 10, personality must have more effect on refraction than vice versa.

Comments

The studies reviewed either reported clinical observations, or were investigations of rather limited material, usually male, university students, about the age of 20 years. No study reported on female psychological characteristics, and none investigated samples or populations unselected for vision or education. In the studies on university students, the effects of education were not taken into account, although it was shown earlier that educational level is correlated with refraction, i.e. education could affect the results.

Young (1967) poses the question of whether personality affects refraction, or whether the reverse is true, a question raised by other investigators, viz. Dobson (1927) and Rice (1930). Generally, personologists agree that personality characteristics emerge very early in the development of the child. It was also shown earlier that refraction starts to change at about the age of 9 to 11 (Hirsch, 1952; Sorsby, 1961). It would seem therefore, that if personality and refraction are interconnected, personality would have an effect on refraction.

From the literature surveyed, it appeared that the most likely personality factors to be involved in refraction were introversion-extraversion.

Measuring Introversion-Extraversion

Attempts to categorize individuals in everyday life by association or by interview are generally too subjective and at the mercy of the observer's impressions and biases. In an attempt to reduce the subjective assessments, methods have been devised of classifying people according to traits and types.

By using factor analysis the thousands of adjectival terms used to describe individuals have been reduced to basic concepts. Cattell (1965) for example produced 16 relatively homogeneous (and usually independent) personality factors, which account for the interrelationships between the descriptive variables. This is essentially a multivariate, intercorrelational approach.

Eysenck (1968) also used the factor analytical method to reduce the descriptive terms to just two factors, then developed the Eysenck Personality Inventory (EPI) as a short reliable questionnaire to measure these personality factors. The EPI consists of 24 questions related to Extraversion-Introversion, and 24 related to Neuroticism. It also includes a built in LIE scale consisting of nine items, which measures the respondent's response set, or desire to "fake good." The EPI has two parallel forms allowing for test-retest with no complications that could arise from memory.

The test is self-administered and the subject is asked to answer YES or NO to each of the 57 questions. The scoring is standard and objective. The wording is claimed to be easily understood by persons of low intelligence and/or little education.

By Eysenck's definition,

> The typical extravert is sociable, likes parties, has many friends, needs to have people to talk to, and does not like reading or studying by himself. He craves excitement, takes chances, often sticks his neck out, acts on the spur of the moment and is generally an impulsive individual. He is fond of practical jokes, always has a ready answer, and generally likes change. He is carefree, easygoing, optimistic, and likes to 'laugh and be merry.' He prefers to keep moving and doing things, tends to be aggressive and to lose his temper quickly. His feelings are not kept under tight control, and he is not always a reliable person.
>
> The typical introvert is a quiet, retiring sort of person, introspective, fond of books rather than people; he is reserved and distant except to intimate friends. He tends to plan ahead, 'looks before he leaps,' and distrusts the impulse of the moment. He does not like excitement, takes matters of everyday life with proper seriousness, and likes a well-ordered mode of life. He keeps his feelings under close control, seldom behaves in an aggressive manner, and

> does not lose his temper easily. He is reliable, somewhat pessimistic, and places great value on ethical standards.
>
> High Neuroticism scores are indicative of emotional lability and overreactivity. High scoring individuals tend to be emotionally overresponsive and to have difficulties in returning to a normal state after emotional experiences. Such individuals frequently complain of vague somatic upsets of a minor kind, such as headaches, digestive troubles, insomnia, backaches, etc., and also report many worries, anxieties, and other disagreeable emotional feelings. Such individuals are predisposed to develop neurotic disorders under stress, but such predispositions should not be confused with actual neurotic breakdown; a person may have high scores on N while yet functioning adequately in work, sex, family, and society spheres.

The above descriptions refer to the "typical" extravert or introvert. Most people will lie somewhere between these extremes and will display a mixture of these characteristics. In essence the Extraversion scale represents a continuum from the extreme Extravert (high E scores) to the extreme introvert (low E scores). Similarly the Neuroticism scale reflects a continuum from extreme neuroticism (high N scores) to extreme stability (low N scores.)

Reliability of the EPI

The EPI scales were originally constructed in England, and standardized on 3000 subjects drawn from various classes of society. The test-retest reliability studied on two groups of normal English subjects demonstrated correlations of 0.80 to 0.97. This level of reliability is higher than for most tests of personality.

Relationships Between the Scales

Extraversion and Neuroticism are considered to be uncorrelated and independent dimensions of personality. The scales were tested on Normals, Neurotics, and Psychotics, and the absence of correlation between E scores and N scores was confirmed.

The EPI has a Lie Scale built in to the 57 questions which is designed to measure the degree to which the subject's "response set" is affecting his answers. Many subjects attempt to answer questions in order to please the examiner, i.e. to "fake good."

For subjects up to and including the age of 16, Eyesnck (1963) developed the Junior EPI, which consists of 24 items relating to E, 24 relating to N, and 12 on the L scale.

As an instrument for individual clinical diagnosis, this inventory is not widely used. However it has been extensively used in surveys and in clinical trials where a short, reliable measure of personality is required in a group of subjects. In this investigation it permitted the features of personality to be treated as continuous variables to be related to refraction.

Physique, Personality and Refraction

The idea that physical morphology could affect personality has been held for a long time and can be traced back to Hippocrates (Mowbray and Rodger, 1975). Contemporary work on this topic leans heavily on the investigation of Sheldon (1940) who from factor analysis of physical measurements on a large number of subjects, isolated three major components of physique:

Endomorphy, more dependent on the digestive system (fat predominant;
Mesomorphy, hard, firm, strong, and sturdy (muscle predominant);
Ectomorphy, more fragile, linear, with a flat chest and more delicate (bone predominant).

In his system, each of these three components was graded on a scale from 1 to 7, so that each person could be allotted a composite score. For instance, a true ectomorph would be 7-1-1 on his scale.

In addition to this somatotyping, three traits of temperament were similarly found from ratings of the personal characteristics of the subjects. These temperamental traits were labelled:

Viscerotonia (amiability, love of comfort);

Somatotonia (assertiveness, competitiveness);

Cerebrotonia (social inhibition, restraint).

Again a composite score on these components of temperament could be derived such that the extreme Viscerotonic would be denoted as 7-1-1.

Sheldon found significant positive correlations between the primary components of physique and temperament, such that endomorphs showed predominantly viscerotonic characteristics, mesomorphs somatotonic characteristics, and ectomorphs cerebrotonic characteristics. While there are doubts about his methods, Sheldon's work has stimulated a great deal of interest in the role of physical constitution.

Eysenck (1968), Eysenck and Rees (1965) have demonstrated a correlation between physique and neuroticism such that neurotics are more leptomorphic (tall and lean). Rees (1950) demonstrated that amongst women, hysterics were more eurymorphic (short and fat), dysthemics were more leptomorphic, and the more leptomorphic subjects were more severely neurotic. This means that the dysthemic (as defined by Eysenck as a neurotic introvert) is generally leptomorphic, while the normal extravert will be generally eurymorphic. These generalizations agree in substance with the findings of Sheldon, but they are only generalizations.

Among studies relating refraction to body build, Incze (1929) found that of 188 myopes, 72% were asthenic (leptomorphic), and Crisp (1936) using anthropological measurements, found more hyperopes among pyknics (endomorphs), and more myopes among leptosomes (ectomorphs), while Morgan (1958) using androgynous measures, found male myopes to be slightly more hypermasculine.

These few studies seem to imply that myopes tend to be thinner and taller, and hyperopes to be fatter and shorter in physique. On the basis of a relationship with personality, this would conform to the expectation of the myope as introverted.

PERSONAL INVESTIGATION V

REFRACTION AND PERSONALITY

Aims

This investigation was designed to evaluate the relationship between refraction and personality (measured by the EPI), and physique (measured by the Body Mass Index).

Methods

For adults (those over the age of sixteen), the Eysenck Personality Inventory, Form A was used. Three hundred thirty-six females and 232 males were able to complete the test. For those from the age of 5 to 16 inclusive, the Junior EPI was used; 162 females and 178 males were able to complete the test.

The breakdown of completed EPI tests is shown in Table 64.

Table 64. Number of completed EPI tests by age and sex

	Female	Male	
age 5–16	162	178	
17+	336	232	
Totals	498	410	908

Of the 957 subjects in the study, 49 were unable to complete the EPI, either because of age or illiteracy. Though some illiterates were assisted in answering the questions, there were some who could not complete the task even with this help.

Comparability of EPI Results

To first assess the comparability of EPI results, the distribution of scores on the EPI were compared to those derived from large scale studies in the United Kingdom and the United States.

Table 65 presents means and standard deviations for the senior population, regardless of sex for E, N, and L, compared to results for 1003 American college students, and to a sample of 1931 of the normal United Kingdom population (Eysenck and Eysenck, 1968).

Table 65. Comparison of E, N, L scores in this study to two sample norm populations of American college students and a normal population

	Mean		Mean		Mean			
	E	SD	N	SD	L	SD	n	male/female
American college	13.1	4.1	10.9	4.7	3.8	1.7	1003	
Normal population	12.1	4.4	9:0	4.8			1931	1055/876
This study	11.91	4.5	11.60	4.6	4.52	1.8	568	232/336

From Table 65, it can be seen that in the study population the mean N scores are higher than both comparison groups, and the mean L score is higher than in the college sample. Eysenck (1968) found L scores tended to be higher in people with lower IQ.

To ascertain that the scores in this investigation were not significantly different from the reported standards, the effects of age were examined. As pointed out by Eysenck and Eysenck (1968), the norms for any group should be treated with caution, especially when used for comparison.

Age Adjustment

E, N, and L scores were found to be correlated with age in each sex on both the Junior and Senior EPI scales for this population. Before further analysis, the effect of age was regressed out of the E, N, and L scores, using a separate regression for each scale, score, and sex combination. The age adjusted scores are labelled, ERA, NRA, LRA in the tables, with results presented in Table 66.

Table 66. ERA, NRA, LRA scores for total population (n=908)

	ERA	NRA	LRA
mean	13.280	11.478	4.594
SD	3.718	5.271	2.913

When age is accounted for an increase in the mean E score occurs. These age adjusted scores indicate that the mean scores for this population are very similar to those reported as norms by the authors of the test. Eysenck and Eysenck (1968) presented a graphic demonstration of selected groups on the two dimensions of the EPI, E and N, for Form A of the test. The 568 adults of this investigation would be placed slightly to the left of the dividing line for the E scale, and on the neurotic side of the N scale, the position marked with an X in Figure 19.

The relationship between personality tests and refraction was tested by computing correlation coefficients between the scores on the three EPI dimensions, and right vertical refraction (RVERT).

The Body Mass (BMI) for each subject was calculated using the formula Height/Weight^2, as described by Keys et al (1972). They found this index superior to other Ponderal Indices used.

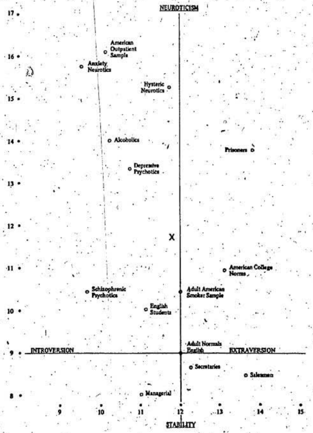

Figure 19. Graphic presentation of selected groups on Dimensions of Extraversion-Introversion and Neuroticism-Stability. (EPI Form A), and of this present study. (n=568) (from Eysenck, 1968)

Results

Table 67 presents the correlations of RVERT with EPI scores.

Table 67. Correlations of RVERT with EPI scores by age, sex, for both Senior and Junior EPI scales

Ages:	5-16		17+	
	male	female	male	female
with:				
E	-0.097 ns	-0.108 ns	0.080 ns	-0.043 ns
N	-0.091 ns	-0.178*	-0.060 ns	-0.067 ns
L	0.239**	0.170*	0.183**	0.188**

Significance: ** 1%
* 5%

From Table 67 it is seen that the only significant finding regarding E and N measures is in the young females who show higher N scores with more negative refractions. The Lie score trends in relation to refraction are all significant, indicating lower L scores with more negative refractions.

There is no clear-cut evidence that the refractive values are related to the personality factors of extraversion or neuroticism. The findings of differences on the Lie scale are interesting but cannot be generalized, as the scale was not intended to be a measure of personality.

In order to examine whether education effects could be compounded in the Personality scores, correlations were calculated between age adjusted EPI scores and educational level. Table 68 presents the data by age and sex.

Table 68. Correlations of educational level with ERA, NRA, LRA by age groups and by sex

Ages:	5-15		17+	
	male	female	male	female
Education with:				
ERA	0.005 ns	-0.032 ns	-0.232**	-0.011 ns
NRA	0.018 ns	-0.114 ns	-0.078 ns	-0.041 ns
LRA	-0.050 ns	-0.247*	-0.146*	-0.176**

In Table 68 the only significant correlation is for older males who had higher E scores with less education. In all cases those with more education have lower L scores, hardly unexpected, since education is inversely related to refraction, and those with more negative refractions had lower L scores.

Comments

The findings in the present investigation of the relationship between personality variables and refraction offer little confirmation of the previously reported relationships of myopia with neurotic and/or introverted personalities. These findings emerged from studies which investigated specialized pre-selected groups (university students, males about age 20, etc.) which might be expected to contain more introverts, and more myopes (because of having more education).

As a further test it was decided to test to what extent a comparison between myopes and hyperopes would yield differences in the scores on the personality inventory. This was carried out by using "t" tests

Table 69. Tests of significance for differences in EPI scores for high and low refraction groups

Ages 5-16

Refraction	males							females						
	n	E	SD	N	SD	L	SD	n	E	SD	N	SD	L	SD
-1 D and less	14	12.81	3.99	10.25	3.86	6.71	2.46	11	14.67	3.60	9.20	4.99	7.77	2.13
+1 and over	11	14.01	2.92	11.27	3.94	8.12	3.57	[illegible]	14.23	3.63	6.97	4.84	9.51	1.90
	t	E - .84						t	E 0.29					
		N - .64		df 23					N 1.09		df 21			
		L -1.17							L -2.06*					

Ages 17+

Refraction	males							females						
	n	E	SD	N	SD	L	SD	n	E	SD	N	SD	L	SD
-1 D and less	12	12.34	4.08	10.60	4.76	2.37	2.02	40	11.72	4.07	14.83	4.48	3.01	2.05
+1 D and over	10	13.31	2.03	11.12	4.11	1.88	2.07	37	12.96	3.51	14.97	4.04	3.52	2.17
	t	E - .68						t	E -1.42					
		N - .27		df 20					N -0.15		df 75			
		L 0.56							L -1.07					

Significance: * 5%

to determine whether those having refractions of −1 D. or less would have significantly different EPI scores from those having refractions of +1 D. or over, and Table 69 presents the results.

Inspection of Table 69 indicates only one significant finding, the L scores in young females. This comparison confirms the previous finding of no relationship between personality scores on the EPI with refractions in this population.

Body Build and Personality

Table 70 illustrates the correlations of BMI with age adjusted EPI scores.

Table 70. Correlations of Body Mass Index (BMI) with ERA, NRA, LRA by age groups and sex

Ages:	5-16		17+	
	male	female	male	female
BMI with:				
ERA	−0.013 ns	−0.077 ns	−0.089 ns	−0.020 ns
NRA	−0.090 ns	0.265*	−0.069 ns	−0.072 ns
LRA	0.002 ns	−0.096 ns	−0.009 ns	0.037 ns

Significance: * 5%

As can be seen from Table 70 there are no significant correlations between the body mass index and the age adjusted EPI scores, except for the Neuroticism score in young females for whom a larger body mass goes with higher neuroticism scores. It is very difficult to account for this single finding or to even speculate as to the possible reason for the result. In the absence of any corroborative evidence it is quite possible that it is a chance phenomenon. In summary, it can be safe to say that no relationship between body mass and personality could be detected in this population.

Body Build and Refraction

As previous studies (pp. 192) had indicated a relationship between myopia and ectomorphy, the residual refractions (RFC) of this population were correlated with age corrected Body Mass Index (for four age intervals, and the results are presented in Table 71.

Table 71. Correlations of RFC with age-corrected BMI in four age intervals

Ages:	5-14	n	15-29	n	30-44	n	45+	n	n
Male	-.020	180	-.094	91	-.076	64	.210*	90	425
Female	.012	151	.027	175	-.195*	84	-.016	96	506
									931

*p = 0.05

Table 71 suggests no consistent relationship of Body Mass to Refraction in this population. There are two significant relationships, but there is no clear-cut trend, that would have been expected from previous studies and observations.

Comments

Neither the Body Mass correlations with EPI scores or with refraction have shown any significances in this population. The present investigation seems to be the first large scale investigation of physique and refraction, and the results indicate that in a non-visually selected population, refraction and physique are not related.

Discussion

The suggestion that myopes show introverted personality characteristics was not confirmed in this investigation when no correspondence could be demonstrated between the distribution of refraction and the personality dimensions measured. Further, the straightforward comparison between myopes and non-myopes did not yield significant differences on the Extraversion and Neuroticism scales.

This negative finding could have arisen because of the nature of the test which is strictly an experimental tool, used to evaluate as objectively and as simply as possible the placement of each subject on the two orthogonal dimensions, Neuroticism-stability and Extraversion-Introversion. The population under study was not sophisticated in taking tests of this sort and some of the subjects did not thoroughly understand all the questions, while others had to have the questions read to them.

Again, two tests were used, the Senior and Junior EPI. The Junior test was derived from the established Senior test, but has still not been evaluated thoroughly. As admitted by the author of the test, some unexplained correlations exist, as for instance between N and L scores.

In spite of these two problems, the distribution of the scores and their intercorrelations show sufficient agreement with the data reported by the authors to suggest that the EPI was appropriately used. Cultural or educational differences could have contributed to the somewhat higher N scores in this population than was reported in the authors' normative sample. This higher absolute value could not have obscured a relationship with refraction as this would be dependent upon a range of scores, although it could have had an effect on minimizing differences between myopes and non-myopes.

A search of the literature did not reveal any study on the psychological characteristics of a complete population with respect to refraction. Earlier studies investigated special sub-groups such as university students, or males, or subjects within a narrow age limit. Members of special groups, such as military school students, or university students, will have certain personality characteristics that may not be reflected readily in a larger and more heterogeneous population. In the normative data, students, for instance, were found to show higher Neuroticism scores than other groups. It is not surprising then, that the studies of Young (1967), van Alphen (1952), Schapero and Hirsch (1952) would find myopes to be introverted or neurotic. The conclusion must be that their findings cannot be generalized to a complete population that was non-visually selected, and not selected for age or sex.

As a step in further work, a re-examination of the claims of these authors should be undertaken using selected homogeneous samples similar in composition to those whom they studied. Any replication of their results could provide a firmer basis for testing more widely.

In a similar fashion the differences between studying a selected sample and an unselected population may have contributed to the failure to demonstrate a relationship of body build with personality and with refraction in this investigation. No study was found that investigated these relationships in a complete population. Further, the few studies cited earlier that showed some correspondence between body build and refraction were based more on anecdote than on the systematic methods used in the present investigation. This negative finding agrees with

Baldwin (1964) who was unable to demonstrate a relationship between certain anthropometric measures (head size, vault size) and refraction. This investigation found no relationship between refraction and body build; however the question must remain open until another similar study has been completed.

PART C

Chapter VIII

SUMMARY AND GENERAL DISCUSSION

Myopia has been studied for over one hundred years, as much from a preventative and prophylactic point of view, as from curiosity regarding its etiology. Some myopias are debilitating, and high degrees of myopia can limit vocational choice. The wearing of spectacles to clear any blurred vision at distance can be a problem, especially in extreme climates and in vigorous activities. Heavy glasses are a constant nuisance to the automobile mechanic and to the skier, to the surgeon and to the tennis player. The myope is constantly pushing his spectacles up on his nose and many myopes would rather squint than wear glasses. It is important to determine whether the condition can be prevented, or its progress in the young slowed. Ideally, the aims of research should be predictive tests to discover the "at risk" child, and to develop appropriate prohylactic treatment.

To achieve this aim, preliminary studies are first required of incidence and distribution of refractive error, with systematic attempts to identify related and causative factors. The investigations reported here were undertaken on a population chosen because it provided a unique opportunity to examine the effects of recently introduced education and near work. Additionally, its stability offered an opportunity to acquire familial data to evaluate the influences of heredity.

The choice of methods of surveying the total prescribed population in the three communities precluded the use of sampling techniques, and the institution of controls. Nevertheless, the collection of data was undertaken rigorously and without preconceptions that could introduce bias.

Goldschmidt (1968) pointed out that many studies on myopia were inadequate in terms of scientific method, claiming that in the literature of the past one hundred years, he had not found a "single proband investigation that fully meets these requirements." In addition, there is difficulty in comparing the findings of studies because of their diverse methodologies, including the use or non-use of cycloplegia.

The categorization of myopia also varies among studies. Few investigators treat refraction as the continuous variable it is. This approach was adopted in the present study as it does not presume any arbitrary cut-off for myopia and because it permits the use of parametric statistics.

A problem of analysis arises from the practice of some investigators who count eyes rather than subjects. This method tends to inflate the statistical significance of differences, and thus confuse the interpretation of results. After confirming the high correlation between the measured refraction for both eyes in subjects, subsequent analyses in this study were conducted using the single measure of right eye vertical refraction.

In considerations of the control of ocular refraction, the outmoded notion of a hereditary-environmental dichotomy has been pursued for so long, and so vigorously, that rancor and conflicts have often clouded important findings.

The present study, as part of a larger health survey, directly addressed the variables refraction, near work, heredity, personality and body mass, as seen in the five investigations described. The findings directly describe refraction and its correlates in the studied population. Extension of findings to other populations must necessarily be very cautious indeed.

This population was unselected. Over 80% of those aged 5 and over were examined whether they had a visual problem or not. Studies on refraction usually draw their material from urban, highly educated populations. In contrast, the non-urban population used in this study has a general educational level lower than that generally available in North America, and its exposure to formal education is relatively recent. Given the demonstrated association of refraction with near work, this educational difference is of primary importance in comparisons with other populations.

INVESTIGATION I

The population distribution of refraction in this population was leptokurtotic and skewed to the minus side, that is, there were more emmetropes and myopes than would be expected were refraction normally distributed. The females showed more refractive values in the myopia range than did the males, starting at an earlier age than the males. The females also had a greater range of refractive errors than the males, that is, there were more high degrees of myopia and hyperopia in females compared to males. A striking excess of myopia was noted in those under the age of 30 compared to those over 30 years of age. Compulsory education started in 1948, i.e. those who started school then were aged 30 at the time of this investigation. This finding parallels that in the other populations, where the introduction of education has been followed by a dramatic rise in myopia in one generation (Young, 1969; Morgan, 1973; Boniuk, 1973). It is in contrast to findings in populations where education has been more generally available, and for a longer period of time, and in which myopia prevalence appears relatively consistent at all ages (Alsbirk, 1979; United States (HEW), 1978). This contrast suggests that near work, related to education, can increase population levels of myopia.

It was found that by comparison with the United States population, a considerably higher proportion of persons in this population had uncorrected refractive errors. This prevalence finding is important from a Public Health viewpoint, as it indicates serious morbidity requiring action by health authorities.

INVESTIGATION II

Occupation and leisure activities were examined in relation to refraction, and it was found that those involved in occupations requiring considerable near work, or who professed to spend considerable time at near work in leisure activity, had more negative refractions.

INVESTIGATION III

Of variables previously reported to influence ocular refraction, among age, sex, height, education and near work, the most influential was found to be near work. This was indicated by the substantial partial correlations of refraction and near work in various age intervals, after the influences of the other variables had been statistically controlled. The relationship was confirmed by the striking parallel course of the means of near work and refraction distributed in the total population in five year age intervals. Because in this population, near work and education are probably less than in urban populations, the relationship of near work to refraction might well be even stronger in societies with higher levels of near work and education.

INVESTIGATION IV

Similarities of refraction were studied within family units. Correlations and regressions showed moderate familial resemblances in refraction, somewhat less than would be expected if refraction were completely under additive genetic control. A pattern of familial similarities in near work habits was found which suggested that family similarities in refraction could be inflated by family similarities in near work. The genetic correlation of first degree relatives for refraction appears to be on the order of .20 to .25.

INVESTIGATION V

Previous reports of a relationship between personality characteristics and myopia were not confirmed in this study, nor were any correspondences found between body mass and refraction. Earlier studies were of examined selected groups that would be expected to have certain psychological characteristics, and at the same time to be more myopic. It must therefore be assumed for the present that the results of this study reflect the state of affairs in an unselected population. More work is required in this area before conclusions can be drawn.

In the population of this study, young females have a more negative mean refraction than young males, and achieve this state sooner than young males. In the fifth decade, the mean female refraction is more positive than the mean male refraction. Near work is closely associated with negative refraction at all ages. The hereditary component in refraction variance is less than would be expected if refraction were completely under additive genetic control and it is postulated that the familial near work environment could inflate the similarities in refraction in families. There was no connection between refraction and psychological characteristics nor between refraction and body build in this population.

Indications for Further Study

The question of why only some persons exposed to near work become myopic may perhaps be explained by a reappraisal of Hirsch's (1963) study. He demonstrated that those children who entered school with a refraction between plano and +0.75 D. would probably become myopic by age 14. Those with an initial refraction of over +0.75 D. stood less chance of becoming myopic; the myopia of those with initially myopic refractions usually got worse. The initial refraction, as determined by the individual components, is probably under mainly genetic control. School work, or near work generally, is on the results of the present study, an environmental factor shifting refraction to the minus side, probably in most individuals (to judge from Hirsch's findings of a general tendency to lower refraction).

van Alphen (1961) postulated that stress, particularly the stress of studying, could cause over-accommodation, which in turn could cause myopia. According to this hypothesis, ordinary near work, such as sewing, or reading for pleasure, does not cause the same over-accommodation, because there is less or no stress or anxiety involved. The stress of studying, mediated through the parasympathetic nervous system, acts on the ciliary body leading to myopia.

Studies have shown that certain ethnic groups (Japanese, Jews, Chinese) have more myopia than other groups (Rasmussen, 1936; Sorsby, 1940; Sato, 1957). Lynn (1971) has shown that certain races are more anxious than others as measured by heart rate, and reaction to pain, inter alios. Those shown to be amongst the most anxious in these ratings were Jews and Japanese. Lynn also speculated that climate could affect anxiety, and it is of interest to note that those studies showing epidemics of myopia were all concerned with Northern people. Studies were cited by Lynn showing that anxiety could be inherited.

The possibility that stress, as opposed to personality in general, can influence refraction should therefore not be rejected on the results of the relatively weak investigations of this relationship to date. Stress is notoriously difficult to quantify, but further attempts to define a relationship between stress and refraction are probably warranted.

PART D

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APPENDIX A

Examination Form

Form III - WEST COAST HEALTH SURVEY

EYE AND VISION EXAMINATION RECORD

Internal Number [| | 1]

NAME: ______________________________
last first middle

PLACE: ______________ DATE: ______________

MCP NO.: [| | 2] [| | 3] [| | 4] [| | 5]

FAMILY NO.: ______________ PATIENT NO.: ______________

AGE: ________ MALE: ___ FEMALE: ___

TYPE OF WORK: ______________ HRS PER DAY: ______________

READS HRS PER DAY: _____ TV HRS PER DAY _____ LAST GRADE ______

OLD Rx	OD	VA	
	OS	VA	
	ADD		

NV VA OD OS OU Ishihara [6]

Snellen ___ Illit ___

Ophthalmoscopy

OD OS

[7]

NV VA OD OS OU Ishihara ____ 6

Snellen ___ Illit ___

Ophthalmoscopy OD OS 7 8

Eye colour ________ Remarks ________ 9

External ________ 10

Cover dist ________ near ________

versions ________ rotations ________

Dominance: eye ________ hand ________ 11 12

Keratometry OD ________ OS ________

corneal astig. OD ________ OS ________

near point distance ________ (inches)

Static retinoscopy OD ________

OS ________

Dynamic ret. OD ________

OS ________

phorias Dist ________ Near ________

ductions Dist ________ Near ________

Subjective Rx: OD ________

OS ________

ADD ________

Tonometry time OD ________ OS ________ 13

Light home ________ work ________

remarks

remarks to patient

body type 14

favorite activities

examined by: ________

APPENDIX B

Second Questionnaire

PART B

INTERNAL NUMBER ______

HOUSEHOLD NUMBER ______

TO BE FILLED OUT FOR EVERY MEMBER OF HOUSEHOLD FIVE YEARS OF AGE OR OLDER.

NAME ____
LAST FIRST MIDDLE

ADDRESS ____

1. Does (or did) your father wear glasses? yes ___ no ___ don't know ___
   If yes, were they worn: all the time ___
   close work only ___

2. Does (or did) your mother wear glasses: yes ___ no ___ don't know ___
   If yes, were they worn: all the time ___
   close work only ___

3. Do you spend any time in the following activities?
   (a) washing ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
   (b) ironing ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (c) sewing ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (d) cooking ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (e) reading ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (f) carpentry ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (g) sports ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (h) driving ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (i) hunting ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk
   (j) a drink at

1 of

3. Do you spend any time in the following activities?

(a) washing ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(b) ironing ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(c) sewing ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(d) cooking ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(e) reading ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(f) carpentry ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(g) sports ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(h) driving ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(i) hunting ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(j) a drink at the club ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(k) others ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(l) card games, bingo ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.
(m) watching TV ___ yes ___ no ___ IF YES, approx. ___ hrs/day or ___ hrs/wk.

4. Are you now or have you ever attended school? yes ___ no ___

5. If you are not now in school, what was the last grade you attended? ___________

6. Do (did) you like school? yes ___ no ___

7. Do you ever see double? yes ___ no ___

8. Do you ever get headaches? yes ___ no ___

9. Have you ever had any eye injuries or eye operations? yes ___ no ___

10. Do you often get sick to the stomach? yes ___ no ___

11. Do you read lying down? yes ___ no ___

12. Do you read sitting up? yes ___ no ___

13. If you work indoors, describe the kind of light you have at work.

_____ Fluorescent tubes _____ Regular light bulbs

14. What do you like to do when you are through with your regular work? ___________

____

15. Have you ever had an eye bandaged for any reason? yes ___ no ___

16. Have you ever had both eyes bandaged at the same time for any reason? yes ___ no ___

If yes, for how long? ___________________________

APPENDIX C

Determination of the Refraction

APPENDIX C

DETERMINATION OF THE REFRACTION

Retinoscopy

The technique of retinoscopy with the subject fixating at 20 feet (static retinoscopy) was the first step in the determination of the refraction in the present study. This technique is objective, and combined with the subjective examination (described below), is the most reliable method for assessing the refractive state of the eye, as it is not based solely on the subject's personal estimate of clearest vision. The common "retinoscopic error" rarely exceeds ±0.25 D., as reported by Duke-Elder (1970). Either fogging or cycloplegia is used to inactivate the accommodation, in order to precisely measure the power of the spherical and cylindrical (if any) corrections. The method used for retinoscopy in this study was the non-cycloplegic fogging technique of Hebbard as described in Borish (1970).

Fogging involves relaxing the accommodation of the subject with a convex lens (usually +1.50 to +2.00 D.) and then measuring the refraction in the two principal meridians with either a spot or streak retinoscope. Once any astigmatism has been determined, the spherical error is measured, and with the resultant correction in the phoropter in front of the subject's eyes, the subjective portion of the examination is carried out. This involves refining the objective determination, again using the fogging technique, the examiner reducing or increasing convex lens power in the phoropter for each eye separately until 20/20 acuity, or the closest possible, is achieved with the least amount of concave or the greatest amount of convex lens in place. Following this, the refraction is further refined binocularly. This was the variable used in this study to compute vertical ocular refraction from Appendix D.

Cycloplegic and Non-cycloplegic Refraction

The non-cycloplegic technique was chosen for several reasons. The eye under cycloplegia is under abnormal conditions, with functional accommodation paralyzed, and in some cases ciliary tonicity as well. If incomplete cycloplegia is a result of improper instillation of the drug, results are questionable, and the subjective test has to be used to correct the imperfect cycloplegic examination (Borish, 1970).

Several studies have compared the two methods in the same individuals. Bannon (1947) reported on a comprehensive study of 1000 eyes (594 hyperopic and 406 myopic) using non-cycloplegic followed by cycloplegic examination. The testing was carried out by eight experienced refractionists at the Dartmouth Eye Institute, in New Hampshire, using a double blind technique. For children the cycloplegic was 1% atropine, one drop in each eye, three times per day for three days. In other cases, homatropine 5% with paredrine 1% was used, one drop of each at three minute intervals with a final second drop of homatropine. The refraction was performed after one hour.

He found that in 74.4% of the cases, the spherical findings obtained by the two methods agreed within ±.50 D. In 84.5% of the cases, astigmatism was the same within ±.25 D. In 81.8% of the cases, the axis of the cylinder agreed within ± 5 degrees.

The younger subjects showed more hyperopia under cycloplegia than the older subjects, and the percentage of hyperopic cases in which greater hyperopia was found with cycloplegia was greater than the percentage of myopic cases in which greater myopia was found under cycloplegia.

The greatest difference between the two methods was found in the younger hyperopes. However, for most cases, the results were the same, and with the qualification that following retinoscopy, a subjective test is done, the few differences are minor.

Bannon further commented that the subjective refinement was more difficult to perform with an eye under cycloplegia, because in the non-cycloplegic method, the eye is in a natural functional state.

Hiatt et al (1973) also compares the two methods in two groups of subjects, the first consisting of 260 eyes in subjects aged 6 to 41, and the second consisting of 42 eyes in subjects over age 40.

The first group was examined first with non-cycloplegic static retinoscopy followed by a subjective test using the fogging method. Then two drops of 1% cyclogyl and 1% mydriacyl were instilled. Most of the subjects were 14 years of age or less, and 68 of the eyes were myopic. In the myopic eyes, differences of ±0.50 D. in the two methods occurred only in errors of -4 to -5 D. In the 192 hyperopic eyes differences between methods occurred only in higher degrees of hyperopia. Differences increased as the power of the convex lens needed increased. In the lower ranges of hyperopia, the maximum difference between the two methods was +0.50 D. They also noted, as did Bannon (1947), that the differences were greater in the younger groups (ages 6 to 10 compared to ages 11 to 25).

The second group was given two drops of 10% phenylephrine as cycloplegic. Differences between the two methods never exceeded ±0.50 D. with the difference being ±0.25 D. in 79% of the cases, and 50% of this group showed no difference at all between the two measures.

Borish (1970) cited several other studies with similar findings. He refers to the fogging method as the "most perfect non-cycloplegic control of accommodation for subjective testing." Without the use of drugs to paralyze accommodation, the refraction can be carried out under physiological normal circumstances.

The Subjective Routine Used in This Study

After fogging the eyes with a +2.00 D. lens, usually for one to two minutes, the subject had one eye occluded, and gazed at the Lancaster Astigmatic dial which was at 20 feet in the darkened room. The fog was then reduced until the 20/40 line on the Snellen chart could be read by the subject. At this point the astigmatism was determined with the dial to confirm any astigmatism and its axis previously determined with the retinoscope. The same procedures were repeated on the other eye. Once the cylinder and axis (if any) were determined, the sphere was determined monocularly by increasing the fog to 20/60 and reducing the fog until maximum convex or minimum concave lens produced an acuity of 20/20. The binocular subjective was then performed to refine the previous monocular findings. In cases of high astigmatism, the cylinder and axis were confirmed using the keratometer. The final prescription was then written for distance and entered on the record as the data to be converted to vertical ocular refraction.

Dynamic retinoscopy at 20 inches was then performed, verified by a subjective test at 20 inches or closer, depending on the habitual reading distance of the subject. This subjective determined the reading addition needed in cases of presbyopia.

In cases of strabismus or suspected muscular imbalance indicated by the cover test, phorias and ductions were performed. Any anomaly requiring further attention was referred. The data gathered by Dynamic Retinoscopy, phorias, and ductions, were not included in this study.

APPENDIX D

Conversion Chart for Vertical Refraction

Surface Power of cylinders in oblique meridians (from G. A. Leary)

Cyl Power (D)	95 85	100 80	105 75	110 70	115 65	120 60	125 55	130 50	135 45	140 40	145 35	150 30	155 25	160 20	165 15	170 10	175 5	Direct
0.25	0.00	0.01	0.02	0.03	0.04	0.06	0.08	0.10	0.12	0.15	0.17	0.19	0.21	0.22	0.23	0.24	0.25	
0.50	0.00	0.02	0.03	0.06	0.09	0.12	0.16	0.21	0.25	0.29	0.34	0.37	0.41	0.44	0.47	0.48	0.50	
0.75	0.01	0.02	0.05	0.09	0.13	0.19	0.25	0.31	0.37	0.44	0.50	0.56	0.62	0.66	0.70	0.73	0.74	
1.00	0.01	0.03	0.07	0.12	0.18	0.25	0.33	0.41	0.50	0.59	0.67	0.75	0.82	0.88	0.93	0.97	0.99	
1.25	0.01	0.04	0.08	0.15	0.22	0.31	0.41	0.52	0.62	0.73	0.84	0.94	1.03	1.10	1.17	1.21	1.24	
1.50	0.01	0.05	0.10	0.18	0.27	0.37	0.49	0.62	0.75	0.88	1.01	1.12	1.23	1.32	1.40	1.45	1.49	
1.75	0.02	0.05	0.12	0.20	0.31	0.44	0.58	0.72	0.87	1.03	1.17	1.31	1.44	1.55	1.63	1.70	1.73	
2.00	0.02	0.06	0.13	0.23	0.36	0.50	0.66	0.83	1.00	1.17	1.34	1.50	1.64	1.77	1.87	1.94	1.98	
2.25	0.02	0.07	0.15	0.26	0.40	0.56	0.74	0.93	1.12	1.32	1.51	1.69	1.85	1.99	2.10	2.18	2.23	
2.50	0.02	0.08	0.17	0.29	0.45	0.62	0.82	1.03	1.25	1.47	1.68	1.87	2.05	2.21	2.33	2.42	2.48	
2.75	0.02	0.08	0.18	0.32	0.49	0.69	0.90	1.14	1.37	1.61	1.85	2.06	2.26	2.43	2.57	2.67	2.73	
3.00	0.02	0.09	0.20	0.35	0.54	0.75	0.99	1.24	1.50	1.76	2.01	2.25	2.46	2.65	2.80	2.91	2.98	
3.25	0.02	0.10	0.22	0.38	0.58	0.81	1.07	1.34	1.62	1.91	2.18	2.44	2.67	2.87	3.03	3.15	3.23	
3.50	0.03	0.11	0.23	0.41	0.63	0.87	1.15	1.45	1.75	2.05	2.35	2.62	2.87	3.09	3.27	3.39	3.47	
3.75	0.03	0.11	0.25	0.44	0.67	0.94	1.23	1.55	1.87	2.20	2.52	2.81	3.08	3.31	3.50	3.64	3.72	
4.00	0.03	0.12	0.27	0.47	0.71	1.00	1.32	1.65	2.00	2.35	2.68	3.00	3.29	3.53	3.73	3.88	3.97	
4.25	0.03	0.13	0.28	0.50	0.76	1.06	1.40	1.76	2.12	2.49	2.85	3.19	3.49	3.75	3.97	4.12	4.22	
4.50	0.03	0.14	0.30	0.53	0.80	1.12	1.48	1.86	2.25	2.64	3.02	3.37	3.70	3.97	4.20	4.36	4.47	
4.75	0.03	0.14	0.32	0.56	0.85	1.19	1.56	1.96	2.37	2.79	3.19	3.56	3.90	4.19	4.43	4.61	4.72	
5.00	0.04	0.15	0.33	0.58	0.89	1.25	1.65	2.07	2.50	2.93	3.35	3.75	4.11	4.42	4.67	4.85	4.96	
5.25	0.04	0.16	0.35	0.61	0.94	1.31	1.73	2.17	2.62	3.08	3.52	3.94	4.31	4.64	4.90	5.09	5.21	
5.50	0.04	0.17	0.37	0.64	0.98	1.37	1.81	2.27	2.75	3.23	3.69	4.12	4.52	4.86	5.13	5.33	5.46	
5.75	0.04	0.17	0.39	0.67	1.03	1.44	1.89	2.38	2.87	3.37	3.86	4.31	4.72	5.08	5.36	5.58	5.71	
6.00	0.05	0.18	0.40	0.70	1.07	1.50	1.97	2.48	3.00	3.52	4.03	4.50	4.93	5.30	5.60	5.82	5.95	

APPENDIX E

Data on Subjects with Extreme Refractions

APPENDIX E

Data on Subjects with Extreme Refractions

Fourteen subjects had refractions more extreme than ± 6 D. and are presented separately here. Eleven were myopes, and three were hyperopes with amblyopia in the right eye and excluded from all consideration because no right eye refraction could be obtained.

The myopes ranged in age from 8 to 37 years. Seven were females and four were males. None were closely related to one another. The mean level of education was 10.18 years, somewhat higher than that for the general population, and mean near work time was 2.82 hours, also higher than the mean for the general population. By occupation, this group included two housewives, four students, three fishermen, a carpenter, and a teacher. The four males (the fishermen and the carpenter) had low near work occupations, compared to the seven females.

Mean Extraversion-Introversion score was 12.91, mean Neuroticism score was 15.6, and mean Lie score was 4.64. The Neuroticism score is somewhat higher than that of the general population; however, because of the small number of subjects, no conclusions are drawn.