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Reduction of Infant Myopia: a Longitudinal Cycloplegic Study

D. L. EHRLICH,* J. ATKINSON,* O. BRADDICK,* W. BOBIER,† K. DURDEN*

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Changes of cycloplegic retinoscopy refraction from 8.5 to 38.5 months of age were compared in two infant groups in the Cambridge population: "infant myopes", having at least one myopic axis (0 to −3.5 D inclusive), and a second, "control" group with low hyperopia (⩽ +3.5 D). Cycloplegia eliminated the variable accommodation of infants. The myopic group showed a significant emmetropization of the mean spherical equivalent towards low hyperopia by 3 yr. There was no significant change in the control group's mean spherical equivalent power. Both groups showed a significant reduction in astigmatism with age. Analysis of the vertical and horizontal powers showed significant "emmetropization" of these meridians, in both groups, towards low hyperopia from 8.5 to 38.5 months. These meridional emmetropization changes were significant for both With-the-Rule and Against-the-Rule astigmatism.

Infant refraction Emmetropization Myopia Astigmatism

INTRODUCTION

There have been a number of studies of "emmetropization" of infant refraction (for recent reviews of refractive development, see Baldwin, 1990; Grosvenor & Flom, 1991; Howland, 1993). When general populations have been studied, most report little change in the mean cycloplegic refraction over the first few years of life. In some cross-sectional studies of clinical, or selected, populations there has been a temporary rise in mean hyperopia followed by a decrease, whereas in others there has been little change or a decrease (see Baldwin, 1990). There is also debate about changes in the variability of refraction with age; some studies show a marked reduction whereas others show little change (e.g. Ingram & Barr, 1979). Many of these differences can be accounted for by the differences in selection criteria for the populations under study (Hirsch, 1967).

The distribution of refractive errors at birth has been found to be a normal distribution (Curtin, 1985). Studies of the cycloplegic refraction of normal, healthy, full-term infants at birth report an incidence of congenital myopia up to 25%, although 4–6% is more frequently reported (Curtin, 1985). This variation in the extent of the myopic "tail" of the refractive distribution is again likely to be partly due to the selection of the particular populations under study, with a higher incidence of congenital myopia likely in certain groups compared to others. Apart from cross-sectional studies that indicate myopia declines from birth to less than 2% at 5 years of life (Grosvenor, 1987; Baldwin, 1990), little is known about how the cycloplegic refraction changes in normal, myopic, full-term infants during the early years of life.

Most studies of infants' refractive changes over the first few years of life have one or both of two limitations. First, selection of subjects for these studies has frequently been from specific groups (e.g. those attending clinics) which has meant that the groups were not necessarily representative of the general infant population. Second, they have frequently been based on cross-sectional studies and so allow less direct inferences about refractive change than do repeated measurements on the same children. For example, changes in the mean refraction could conceal different patterns of refractive change for the myopic and hyperopic subjects.

A further limitation in some studies is that infant refractions have been measured without the use of cycloplegia. Up to 6 months of age, whilst accommodation and convergence systems are developing and attention is variable, the accommodative response changes (Braddick, Atkinson, French & Howland, 1979; Banks, 1980; Aslin, 1993). In older children the non-cycloplegic far point has been shown to depend not only on the subject's cycloplegic refractive state and age (Hiatt, Braswell, Smith & Patty, 1973; Sato, 1981; Otsuka, 1967), but also on the level of tonic accommodation, the previous accommodative response and the relaxing power of the measurement technique (Ehrlich, 1987, 1989). The reliability of the astigmatic measurements can also be reduced unless the meridians are measured simultaneously and close to the visual axis (Ehrlich, Anker & Braddick, 1994).

*Visual Development Unit, Department of Psychology, University College London, Gower Street, London WC1E 6BT, U.K.
†School of Optometry, University of Waterloo, Ontario, Canada N2L 3G1.

The aim of this study was to investigate longitudinally the changes in refraction of a group of infant myopes from the age of 7 months to 3.5 yr old. The refractions were measured by retinoscopy after effective cycloplegia. The results were compared with a control group of normal low hyperopes (the normal state in infancy). Cyclopentolate 1% was chosen for rapid and effective cycloplegia (Mindel, 1982).

METHOD

A population-based community screening programme of 3166 infants (74% of the geographical population who were sent appointments) took place in Cambridgeshire community clinics over a 2-yr period (as described by Atkinson, Braddick, Durden, Watson & Atkinson, 1984; Atkinson, Braddick, Wattam-Bell, Durden, Bobier & Pointer, 1987; Atkinson, 1993). All infants attending, aged 6–8 months old, had an orthoptic examination and cycloplegic isotropic photorefraction (after 1–2 drops 1% cyclopentolate). The photorefractive procedure has been fully described by Atkinson *et al.* (1984).

The infants considered in this paper were those selected for longitudinal study on the grounds that photo-refractive screening revealed significant ametropia in either eye (+3.5 D or more positive in any meridian, −0.5 D or more negative in any meridian, 1.5 D or more difference between corresponding meridians in each eye) or if they were assigned to be in the control group (the next child screened who did not have a significant hyperopic or myopic refractive error). As low hyperopia is most common in this age range (Baldwin, 1990), the "control" group was designated as having a maximum value of +3.5 D and a minimum value of 0 D, in any meridian, according to the photorefractor. This was the control group used in the study of the characteristics of the high hyperopes (see Atkinson *et al.*, 1987; Atkinson, 1993).

All myopes selected, and the control group, had normal binocular vision (no strabismus on cover test) and no pathology or clinically significant anisometropia (difference between mirror-image paired meridians $\leqslant 1$ D). The myope and control groups showed no abnormality on ophthalmological examination and all the infants were full-term (within ± 2 weeks) except one child in the control group who was 4 weeks premature.

Longitudinal follow-up visits were scheduled for the selected infants as near as possible to the ages of 8.5, 12.5, 16.5, 20.5, 24.5, 30.5 and 38.5 months old (the size of the first five intervals was 4 months and the last two intervals was 8 months). Not all children attended all scheduled visits; Fig. 3 shows the numbers attending at each age. Cycloplegic retinoscopy was carried out by experienced optometrists on the follow-up visits (30 min following 1–2 drops of 1% cyclopentolate in each eye). They used spot retinoscopy, neutralizing the reflex with spherical hand held lenses or a lens rack. The axes of the power meridians were noted on the record by a cross to give an approximate indication of their orientation. The meridians of these astigmatic eyes were assigned to categories "nearest horizontal" or "nearest vertical". This allowed the astigmatism to analysed according to the magnitude or type of astigmatism, i.e. "With-the-Rule": vertical power meridian more negative than horizontal, or "Against-the-Rule": horizontal power meridian more negative than vertical (range ± 45 deg).

Myopes over 3.5 D by cycloplegic retinoscopy were referred to the ophthalmology department in the local hospital and were not included in the present study. About 0.5% of the screened population fall into this latter group (Atkinson *et al.*, 1984). None of those analysed in the present study were prescribed spectacles (this excluded only one subject).

These selection criteria, when considered in terms of retinoscopy power range, defined a "myopic" group of eyes having their most negative meridians within 0 to −3.5 D inclusive and their most positive meridians within −3.5 to +3.5 D and a "control" group having both meridians within 0.0 to +3.5 D inclusive.

Right eyes only were analysed for the purposes of the present paper. Subjects were only accepted provided at least two retinoscopy visits were recorded with an interval greater than 8 months. 60 infants (90%) met this classification as "myopes" and 80 (90%) as "controls".

RESULTS

The population of infant myopes represents the tail end of the normal refractive distribution [see Fig. 2(a)], and the absolute astigmatism was not normally distributed (Fig. 1). Conservative non-parametric tests were therefore used for analysing these groups and parametric tests for the rest. The astigmatism was analysed in three ways. First, *absolute* or *unsigned astigmatism* which indicates the magnitude of astigmatism without regard to orientation. Secondly, *signed astigmatism* which was assigned positive values for With-the-Rule (W-T-R) astigmatism, negative values for Against-the-Rule (A-T-R) astigmatism and zero for spherical refractions. The signed astigmatism, providing some representation of both astigmatic orientation and magnitude, is mainly used for graphical illustration of the results. Thirdly, the vertical and horizontal meridians were analysed separately for each type of astigmatism.

Figure 3 illustrates the results of all follow-up visits for both the myopic group and low hyperope control group.

Refraction at 8.5 months old

At 8.5 months old, the mean spherical equivalent and absolute astigmatism of the myopic and control groups had the distributions illustrated in Figs 1 and 2. As expected from the selection criteria, the myopic group was significantly more myopic than the control group in terms of mean spherical equivalent (myopic group: mean = −0.61 DS, SD = 0.76 DS, n = 47; control group: mean = +1.37 DS, SD = 0.60 DS, n = 70; two-tailed Mann–Whitney test, $P < 0.0001$). The slight overlap occurred because the myope group was defined by any one meridian being myopic.

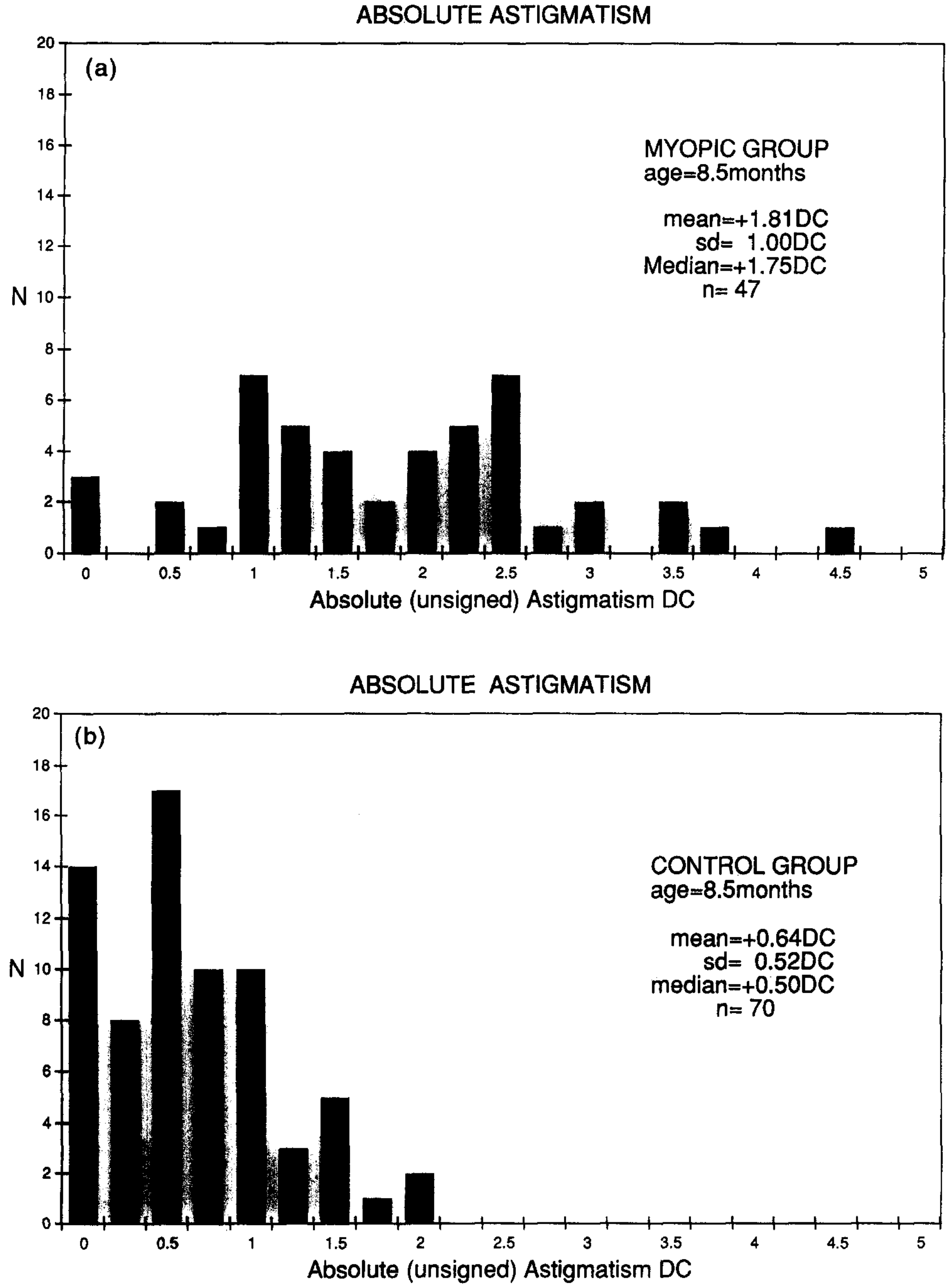

FIGURE 1. The frequency distribution of the absolute (unsigned) astigmatism at 8.5 months of age. (a) Myopic group. (b) Control, low hyperopic group.

The absolute astigmatism of the myopic group was also greater than the control group (myopic group: mean = 1.82 DC, SD = 1.00 DC, $n = 47$; control group: mean = 0.64 DC, SD = 0.52 DC, $n = 70$; two-tailed Mann–Whitney test, $P < 0.0001$).

The distribution of the type of astigmatism (W-T-R, A-T-R, spherical), was analysed using a 2 × 3 Chi-square test. Although the myopes had more A-T-R astigmatism and fewer spherical refractions than the control group (see Table 1), this was not significant ($P < 0.09$).

Longitudinal changes

The variation in number of infants at the different age intervals was caused by their variable attendance. The changes with age in the whole set of data, in Fig. 3, may therefore be affected by differences in the group composition at different ages. The true longitudinal trends are seen when the same subjects are compared across follow-up visits. This, however, greatly reduced the numbers available for analysis. Analysis of the changes from 8.5 to 38.5 months was carried out by comparing the paired results available from these visits (see Tables 2, 3 and 5). There were 34 infants in this myopic longitudinal subgroup and 54 in the control longitudinal subgroup. For examination of the changes within this period and over sufficient numbers of infants, it was necessary to pool the visits at 12.5 with 16.5 months, 20.5 with 24.5 months and also 30.5 with 38.5 months (Figs 5 and 6). The broad pattern of refractive change in these data is similar to that in Fig. 3 (of which they form a subset).

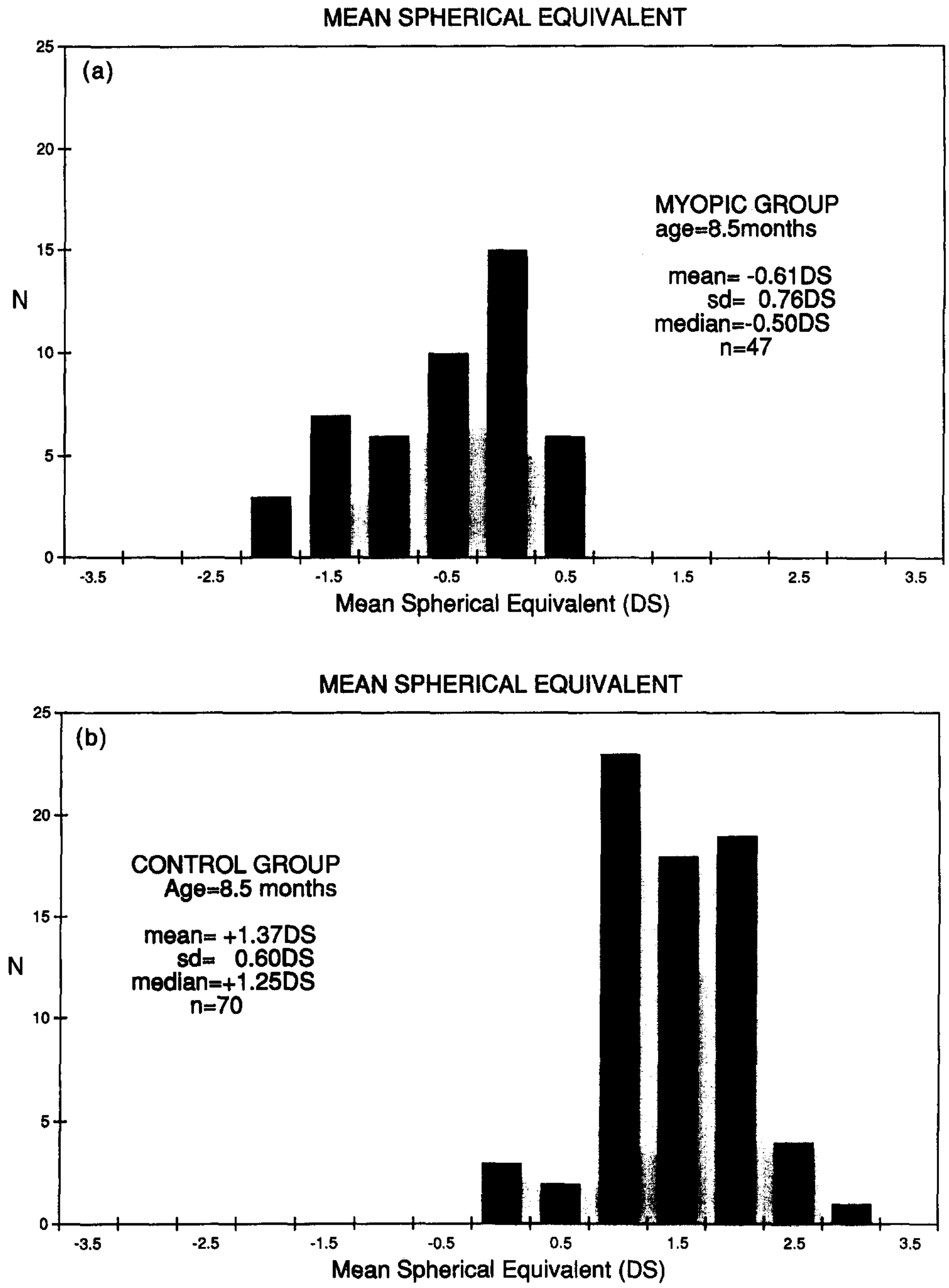

FIGURE 2. The frequency distribution of the mean spherical equivalent refraction at 8.5 months of age in (a) the longitudinal myopic group and (b) the longitudinal control, low hyperopic group.

Mean spherical refraction

When the infants were aged 8.5 months, the spherical equivalent refractions of the myopic and control groups were significantly different (myopic group: mean = −0.53 DS, SD = 0.71 DS, $n = 34$; control group: mean = +1.42 DS, SD = 0.60 D, $n = 54$; two-tailed Mann–Whitney test, $P < 0.0001$). That is, this subgroup, showed a similar pattern to the results for the total group at 8.5 months presented above.

At the end of the study, the longitudinal myopic group's mean spherical equivalent refraction at the age of 38.5 months (mean = +0.61 DS, SD = 0.63 DS, $n = 34$) was significantly more hyperopic than at 8.5 months old (two-tailed, Wilcoxon matched-pairs signed-ranks test, $P < 0.0001$), see Table 2. The mean rate of change was +0.44 D/yr. The control group's mean spherical equivalent refraction at the age of 38.5 months (mean = +1.44 DS, SD = 0.55 DS, $n = 54$) showed no significant change from 8.5 months old (two-tailed, Wilcoxon matched-pairs signed-ranks test, $P < 0.7$), see Table 2. A comparison of the spherical equivalent refraction of the longitudinal myopic and control groups, when aged 38.5 months old, showed a small but still significant difference (two-tailed Mann–Whitney test, $P < 0.0001$).

Astigmatism (unsigned)

The absolute (unsigned) astigmatism of the longitudinal myopic group was significantly greater than that of the longitudinal control group when the infants were

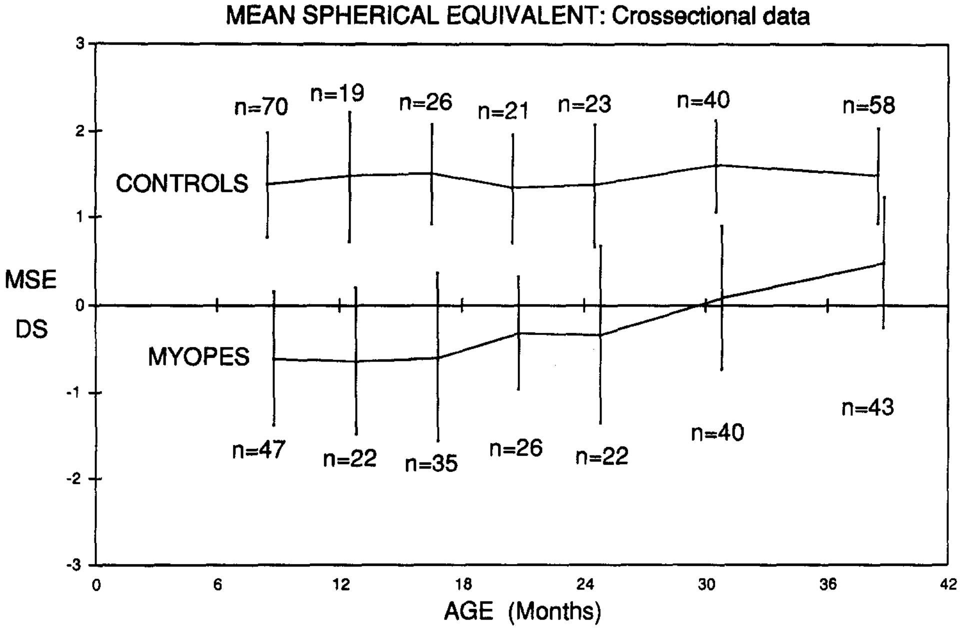

FIGURE 3. A cross-sectional plot of the myopic and control groups' mean spherical equivalent refraction with age, from 8.5 months to 38.5 months of age. The variable number of infants at each of the visits was due to variable attendance. Each point represents the mean ± 1 SD.

TABLE 1. Astigmatism at 8.5 months old

	W-T-R	A-T-R	Spherical
Myope group (n = 47)	16 (34%)	28 (60%)	3 (6%)
Control group (n = 70)	25 (36%)	31 (44%)	14 (20%)

Chi-square test.
d.f. = 2, $P < 0.09$.

TABLE 2. Mean spherical equivalent refraction (DS)

	Myopic group		Control group	
	8.5 months	38.5 months	8.5 months	38.5 months
Mean	−0.53	+0.61	+1.42	+1.44
SD	0.71	0.63	0.60	0.55
Median	−0.31	+0.81	+1.31	+1.43
Mode	−0.25	+1.00	+1.25	+1.25
Minimum	−2.25	−0.75	0.00	0.00
Maximum	+0.62	+1.62	+3.00	+3.00
n	34	34	54	54

2t, Wilcoxon matched-pairs, signed-ranks test, $P < 0.0001$ (myopic group); 2t, Wilcoxon matched-pairs, signed-ranks test, $P < 0.7$ (not significant) (control group)

TABLE 3. Absolute (unsigned) astigmatism (DC)

	Myopic group		Control group	
	8.5 months	38.5 months	8.5 months	38.5 months
Mean	+1.93	+0.80	+0.62	+0.33
SD	1.05	0.88	0.50	0.32
Median	+2.00	+0.50	+0.50	+0.25
Mode	+2.50	0.00	+0.50	0.00
Minimum	0.00	0.00	0.00	0.00
Maximum	+4.50	+3.00	+1.75	+1.25
n = 34	34	34	n = 54	54

2t, Wilcoxon matched-pairs, signed-ranks test, $P < 0.0001$ (myopic group); 2t, Wilcoxon matched-pairs, signed-ranks test, $P < 0.001$ (control group)

aged 8.5 months, (myopic group: mean = +1.93 DC, SD = 1.05 DC, n = 34; control group: mean = +0.62 DC, SD = 0.50 DC, n = 54; two-tailed Mann–Whitney test, $P < 0.0001$), see Fig. 4 and Table 3. Again, this subset of data is similar to the results for the whole group at 8.5 months old.

At the end of the study, the longitudinal myopic group's mean absolute (unsigned) astigmatism at 38.5 months old (mean = +0.80 DC, SD = 0.88 DC, n = 34) was significantly less than at 8.5 months old (two-tailed, Wilcoxon matched-pairs signed-ranks test, $P < 0.0001$), see Fig. 4 and Table 3. The control group's mean absolute (unsigned) astigmatism at 38.5 months old (mean = +0.33 DC, SD = 0.32 DC, n = 54) was also significantly less than at 8.5 months old (two-tailed, Wilcoxon matched-pairs signed-ranks test, $P < 0.001$), see Fig. 4 and Table 3.

A comparison of the absolute astigmatism of the longitudinal myopic and control groups, when the infants were aged 38.5 months, showed a small but still significant difference (two-tailed Mann–Whitney test, $P < 0.05$).

The analyses were repeated after removing those retinoscopy results which had comments that suggested poor reliability (9% of the myopes), but the significance levels were unchanged.

Astigmatism (signed)

The percentages of W-T-R, A-T-R and spherical refraction in the two groups at the beginning and end of the study are illustrated in Table 4. The distribution of these types of astigmatism in the two groups was not significantly different at either 8.5 or 38.5 months of age (χ^2 test, d.f. = 2, P = NS).

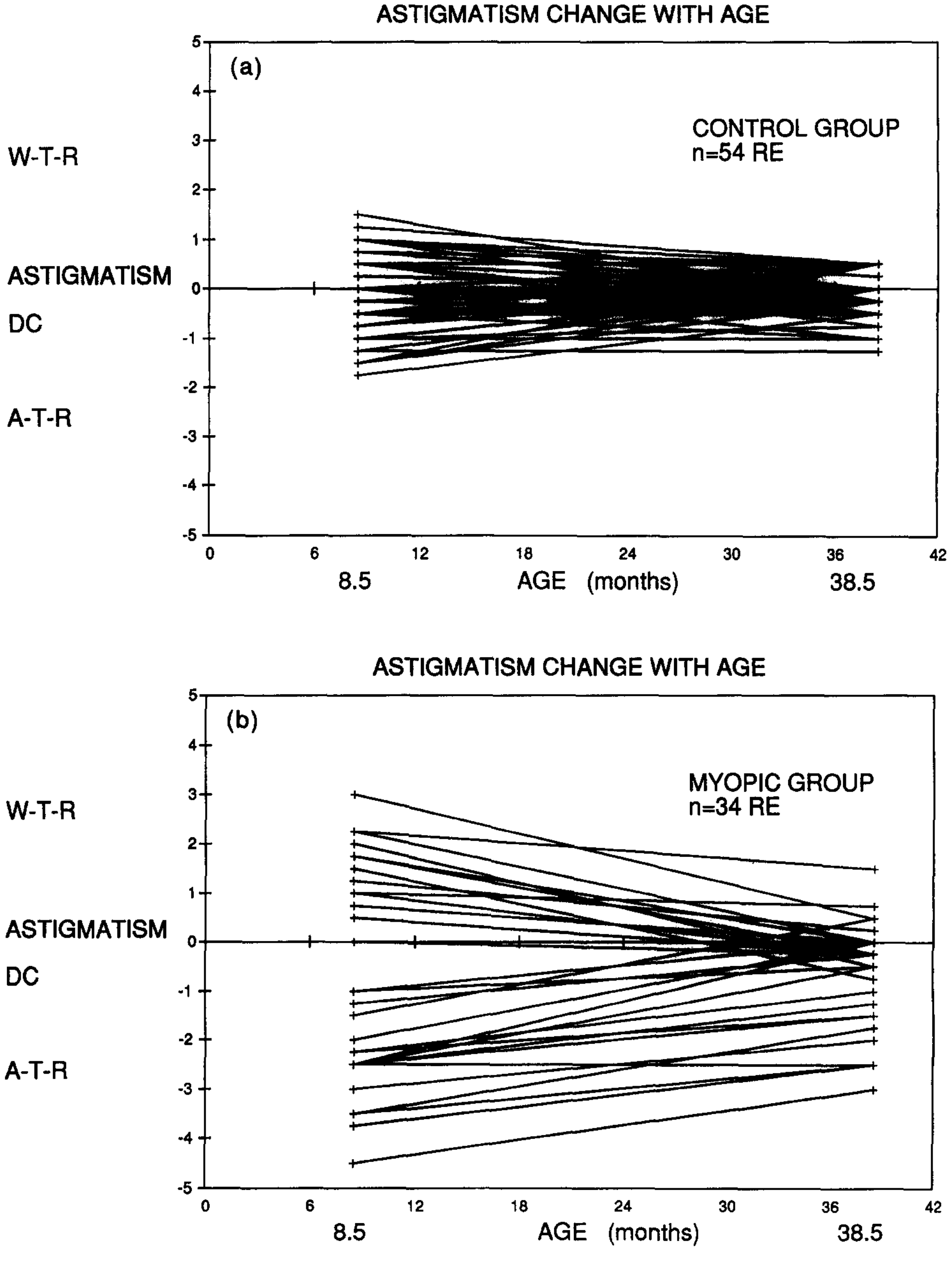

FIGURE 4. The longitudinal changes of individual infants' astigmatism from 8.5 to 38.5 months of age. The astigmatism values are positive if "With-The-Rule", negative if "Against-The-Rule" and zero if spherical. (a) The longitudinal control, low hyperopic group, $n = 54$ right eyes. (b) The longitudinal myopic group, $n = 34$ right eyes.

Rate of change with age

The rate of change of the mean spherical equivalent and the astigmatism appeared fairly constant from 8.5 to 38.5 months (see Figs 5 and 6). The mean rate at which the spherical equivalent reduced in the myopic group was +0.44 D/yr. The meridional rate of change (horizontal or vertical), however, was dependant on the refractive power (see Figs 7 and 8), the most myopic meridian tending to show the fastest reduction.

The change in mean spherical equivalent refraction with age

When the change in power with age was analysed to see if it was related to the initial value, the change (final minus initial power) was plotted against the mean of initial and final measurements as advised by Bland and Altman (1986). Mean spherical equivalent and astigmatism are less directly related variables so it was considered

TABLE 4. Astigmatism type

	W-T-R	A-T-R	Spherical
Astigmatism at 8.5 months old			
Myope group ($n = 34$)	13 (38%)	19 (56%)	2 (6%)
Control group ($n = 54$)	18 (33%)	24 (44%)	12 (22%)
Chi-square test. d.f. = 2, $P < 0.13$ (NS)			
Astigmatism at 38.5 months old			
Myopic group ($n = 34$)	6 (18%)	20 (59%)	8 (23%)
Control group ($n = 54$)	11 (20%)	22 (41%)	21 (39%)
Chi-square test d.f. = 2, $P < 0.3$ (NS)			

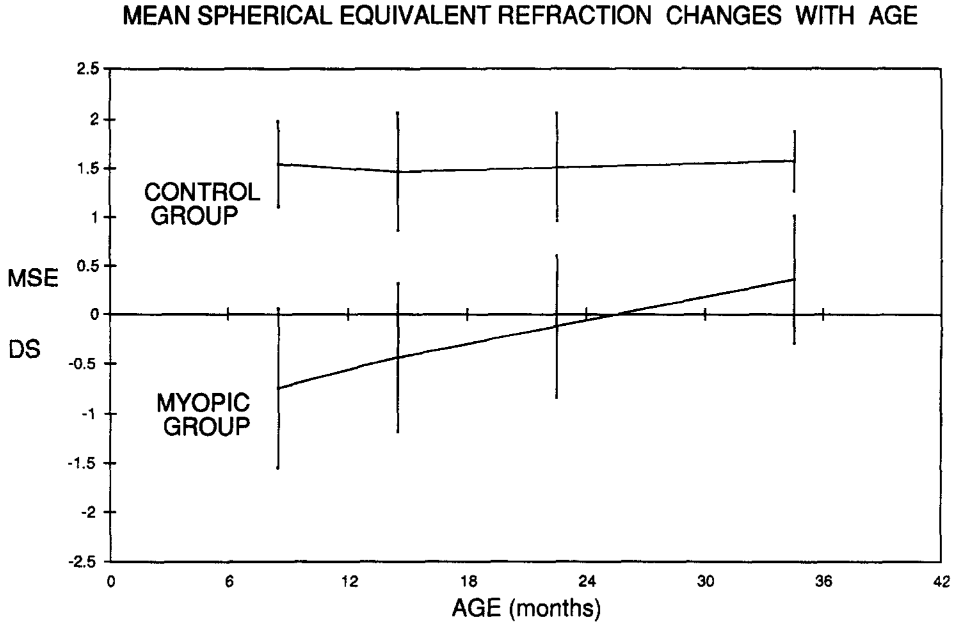

FIGURE 5. A longitudinal plot of the myopic and control groups' mean spherical equivalent refraction with age, from 8.5 months to 38.5 months of age. Each point represents the mean ± 1 SD. The upper line represents the control, low hyperopic group, $n = 17$ right eyes. The lower line represents the myopic group, $n = 18$ right eyes. To maximize the longitudinal groups, it was necessary to pool visits (12.5 with 16.5 months, 20.5 with 24.5 months and also 30.5 with 38.5 months).

reasonable to analyse the change in spherical equivalent with the initial value of astigmatism.

Myope group. As the incidence of absolute astigmatism was greater in the myopic group, it was examined to see whether the change of the mean spherical equivalent refraction with age was related to astigmatism. In the myopic group, the change in mean spherical equivalent refraction showed no significant relationship with the magnitude of the initial absolute astigmatism (Spearman correlation: $r = -0.02$, NS $n = 34$), the initial signed astigmatism (Spearman correlation: $r = 0.07$, NS, $n = 34$), or the change in the absolute astigmatism (Spearman correlation: $r = -0.09$, NS, $n = 34$). The change in the mean spherical equivalent did not appear to be related to the mean magnitude of myopia (Spearman correlation $r = -0.19$, NS, $n = 34$), but no strong conclusions should be drawn from this because of the limited refractive range.

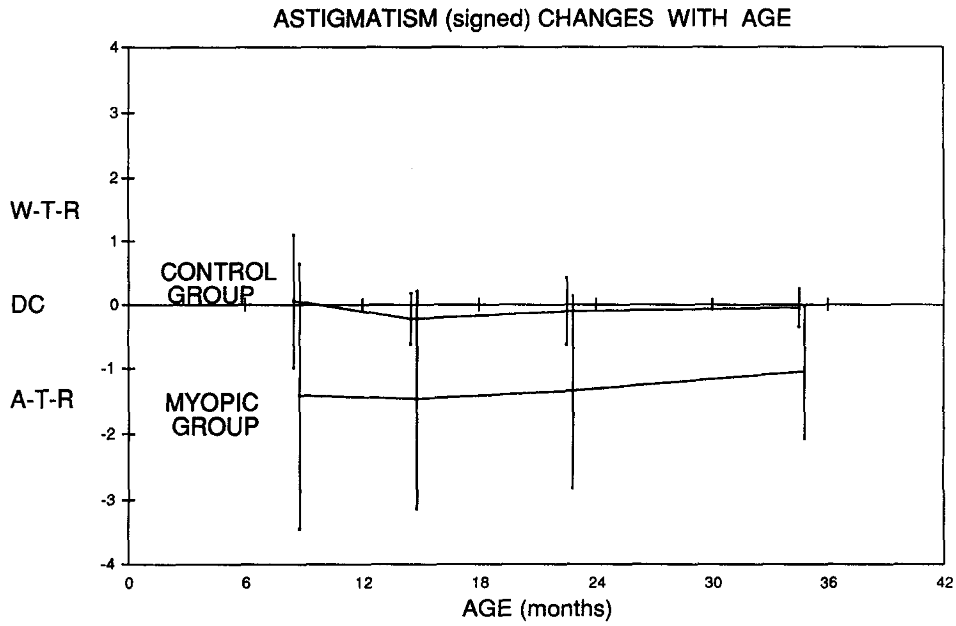

FIGURE 6. A longitudinal plot of the myopic and control groups' signed astigmatism with age, from 8.5 months to 38.5 months of age. Each point represents the mean ± 1 SD. The upper line represents the control, low hyperopic group, $n = 17$ right eyes. The lower line represents the myopic group, $n = 18$ right eyes. To maximize the longitudinal groups, it was necessary to pool visits (12.5 with 16.5 months, 20.5 with 24.5 months and also 30.5 with 38.5 months).

TABLE 5. Meridional power change by type of astigmatism

Astigmatism type	Myopic group: With-the-Rule (dioptres)		Myopic group: Against-the-Rule (dioptres)		Myopic group: Spherical (dioptres)		Control group: With-the-Rule (dioptres)		Control group: Against-the-Rule (dioptres)		Control group: Spherical (dioptres)	
Meridian	**Vertical** most negative	**Horizontal** most positive	**Vertical** most positive	**Horizontal** most negative	**Vertical**	**Horizontal**	**Vertical** most negative	**Horizontal** most positive	**Vertical** most positive	**Horizontal** most negative	**Vertical**	**Horizontal**
8.5 month Mean	−1.19	+0.36	+0.60	−1.79	−0.62	−0.62	+1.35	+2.07	+1.82	+0.96	+1.04	+1.04
8.5 month SD	±0.80	±0.65	±0.74	±1.08	—	—	±0.47	±0.46	±0.66	±0.53	±0.71	±0.71
38.5 month Mean	+0.65	+0.75	+1.04	−0.05	+1.00	+1.12	+1.50	+1.57	+1.46	+1.22	+1.62	+1.40
38.5 month SD	±0.65	±0.61	±0.66	±1.03	—	—	±0.54	±0.60	±0.37	±0.54	±0.89	±0.73
38.5–8.5 month mean change	**+1.85**	**+0.38**	**+0.43**	**+1.74**	**+1.75**	**+1.62**	**+0.15**	**−0.50**	**−0.36**	**+0.26**	**+0.58**	**+0.35**
Wilcoxon matched-pairs, 2t signed-rank test, $P <$	0.01	0.07 (NS)	0.05	0.001	—	—	0.2 (NS)	0.01	0.01	0.09 (NS)	0.05	0.05
N	13	13	19	19	2	2	18	18	24	24	12	12

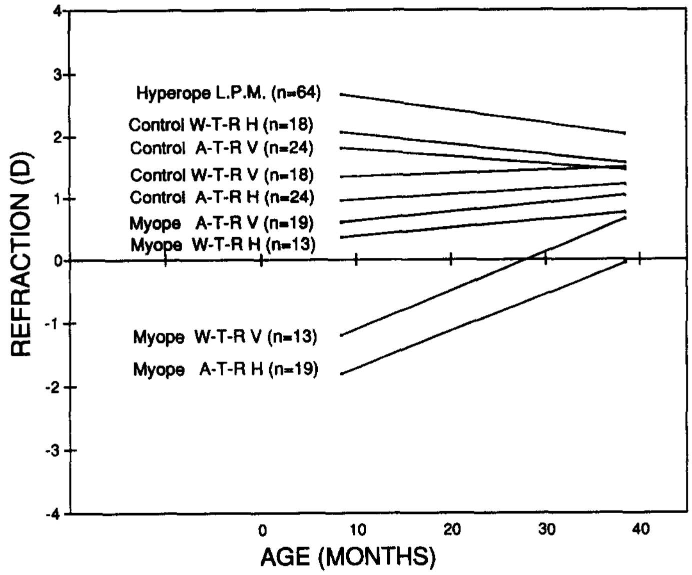

FIGURE 7. A longitudinal plot of the mean horizontal (H) and vertical (V) power changes, by astigmatism type, from 8.5 months to 38.5 months. In With-the-Rule (W-T-R) astigmatism, vertical powers are the most negative and horizontal powers are the most positive. In Against-the-Rule (A-T-R) astigmatism, horizontal powers are the most negative and vertical powers are the most positive. The myopic group, low hyperopic "control" group, and also the high hyperopic group's least positive meridian (L.P.M.) from Atkinson (1993) are presented. These groups are all from the same Cambridge infant population study. The meridional powers converge towards + 1.5 D, from 8.5 to 38.5 months of age, regardless of astigmatism type. (Error bars were excluded for clarity, values are given in Table 5).

Control group. In the control group, the change in mean spherical equivalent refraction was weakly correlated with the initial absolute astigmatism (Spearman, $r = -0.33$, $P < 0.02$, two-tailed, $n = 54$) and the change in the absolute astigmatism (Spearman $r = 0.28$, $P < 0.04$, two-tailed, $n = 54$), but not correlated with the initial signed astigmatism (Spearman $r = -0.03$, NS, $n = 54$). The change in the mean spherical equivalent power was also not correlated with the mean of initial and final spherical equivalent powers (Spearman $r = -0.12$, NS, $n = 54$).

Both groups combined. However, the myopic and control groups can be considered to represent a continuous population. Thus the significant difference in refractive change in the mean spherical equivalent between the myopic and control groups (discussed above) does demonstrate a dependence of the refractive change on power which it is not possible to find over the narrower range of powers within each group alone.

Meridional power change and astigmatism type

An analysis of the vertical and horizontal powers by astigmatism type, see Table 5 and Fig. 7, shows there was a significant emmetropization process of these meridional powers towards low hyperopia. The trend is found in both the myopic and the control group, regardless of the type of astigmatism (Table 5). Figure 7 illustrates the mean change of the various meridians (the most positive and the most negative) for each type of astigmatism. The combined data, plotting refractive

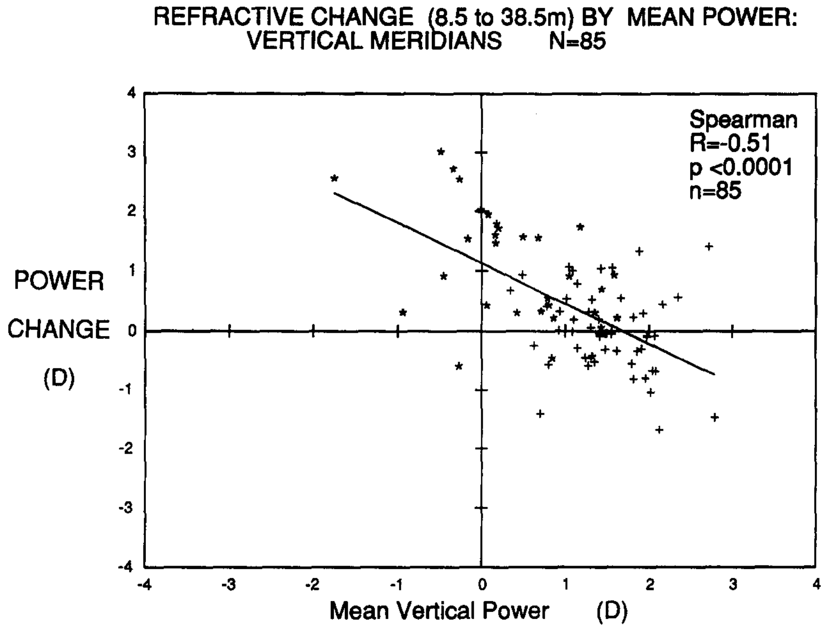

FIGURE 8. The longitudinal vertical power change, from 8.5 months to 38.5 months of age, by mean vertical power. Both the control group (indicated by cross symbols, $n = 54$) and the myopic group, with reliable retinoscopy results (indicated by star symbols, $n = 31$) were included. "Power change" was the final power minus the initial power. The "mean power" was the mean of these powers. Intercept value for power showing zero refractive change was + 1.69 D.

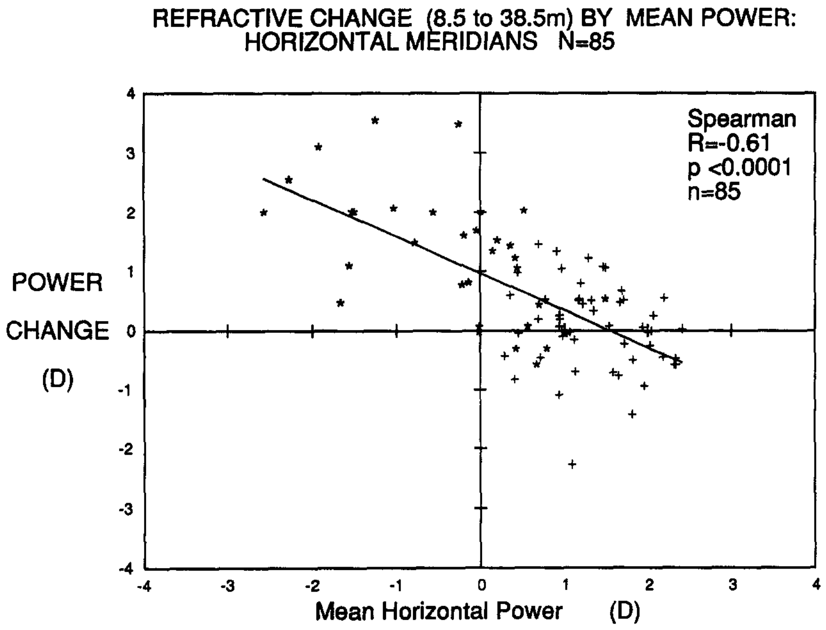

FIGURE 9. The longitudinal horizontal power change, from 8.5 months to 38.5 months of age, by mean horizontal power. Both the control group (indicated by cross symbols, $n = 54$) and the myopic group, with reliable retinoscopy results (indicated by star symbols, $n = 31$) were included. "Power change" was the final power minus the initial power. The "mean power" was the mean of these powers. Intercept value for power showing zero refractive change was + 1.54 D.

change against the mean of the initial and final power, indicates that the emmetropization trend is towards the low hyperopic value of + 1.6 D at 38.5 months for both horizontal and vertical powers (Figs 8 and 9). (This value can be derived from the intercept value for the power showing zero refractive change. It was similar to that obtained from separate analyses of the control group and that of the myope group with reliable retinoscopy results.)

DISCUSSION

"Emmetropization" of the mean spherical equivalent

The myopic group showed a significant emmetropization of the mean spherical equivalent, with a + 1.14 D change towards low hyperopia by 3 years of age (see Table 2). There was no significant change in the mean spherical equivalent power of the control group (see Table 2) which represented the bulk of the infant population.

This "emmetropization" process in myopic infants is similar to that previously reported in the other tail of the refractive distribution, the medium to high hyperopes. In the same screening population (Atkinson *et al.*, 1987; Atkinson, 1993) the group of infants who were over +3.5 D hyperopic (any one meridian) at 7–9 months showed a significant reduction in hyperopia between 9 months and 3.5 yr in their least hyperopic meridian (mean change of −0.6 D). The refractions of both the myopic and markedly hyperopic infants, therefore, tend to converge towards the low hyperopia of the control group.

Since the incidence of high hyperopia is much greater than that of high myopia in infants in this population (Atkinson, 1993), the emmetropization of the hyperopes contributes more to the change of the mean of the population than that of the myopes. This is likely to dominate any change in the mean spherical equivalent of the population for the first few years of life. These early infant emmetropization changes are distinct from the later childhood changes from approximately 5 yr of age. From 5 yr, generally the medium to high hyperopes are found to remain almost stable and myopic progression starts in the emmetropes or near emmetropic children, which also causes a reduction in the population mean spherical equivalent (Curtin, 1985; Baldwin, 1990).

It is worth emphasizing that, in a population-based study, significant numbers of myopic infants can only be studied if the criteria for myopia are set to very modest refractive errors (by adult standards). Congenital high myopes are rare and whether these infants show any tendency to emmetropization is a separate question, but one which can make little contribution to the emmetropization of the overall distribution of refractions.

Changes in astigmatism

Both groups showed a significant reduction in astigmatism with age, although the astigmatism of the myopic group was significantly greater during all the three years (Fig. 4 and Table 3). However, analyses of the horizontal and vertical meridional powers showed a significant change towards low hyperopia (+1.6 D), regardless of whether the astigmatism was of W-T-R or A-T-R type. The further the infant's initial refraction was from this value, the greater was the change (see Figs 7, 8 and 9). That the astigmatic reduction in the myopic group did not show a correlation with the reduction of the mean spherical equivalent, was most likely due to the narrow range of the mean spherical equivalent values.

High levels of astigmatism, particularly A-T-R, are common in the first year of life (Howland, Atkinson, Braddick & French, 1978; Mohindra, Held, Gwiazda & Brill, 1978; reviews by Baldwin, 1990; Lyle, 1991). If, as in this study, the criterion of ametropia is that the refraction of any one axis exceeds a cut-off value, then many of the infants meeting this criterion will do so primarily because of astigmatic errors. Thus greater initial astigmatism of the myopic group is to be expected. A number of studies have shown that infantile astigmatism reduces with age (e.g. Atkinson, Braddick & French, 1980), and this trend was visible in both the control group and the myopic group in this study. However, the fact that in the myopic group both meridians (whether W-T-R or A-T-R) became less myopic supports the view that the reduction in myopia cannot simply be ascribed to the processes which make the refraction more spherical.

The reduction of absolute astigmatism was not accompanied by any marked change in the mean signed astigmatism, for either myopes or controls. That is, astigmatism reduced in magnitude but its balance did not shift from W-T-R to A-T-R or vice versa. This is in contrast with the astigmatism of markedly hyperopic infants, which has been studied in the same screening population (Atkinson, 1993). In these hyperopes, early W-T-R astigmatism tended to reduce more rapidly than A-T-R.

Does the ranking order of refractions remain constant for the first 3 yr?

The recent non-cycloplegic longitudinal studies of Gwiazda, Thorn, Bauer and Held (1993) and Howland *et al.* (1993) have suggested that myopic states in infancy, found by using near retinoscopy and photorefraction respectively, may be predictive of childhood myopia. This raises the question of whether a refraction towards the myopic end of the distribution during the first year of life also determines the likelihood of myopia in later teenage years.

Our study did show the spherical equivalent of the myopic group and the low hyperopic group, although closer, were still significantly different at 38.5 months of age. This suggests that if an infant at 8 months of age is in the myopic "tail", this may be correlated with their refraction at 38.5 months. In later childhood, emmetropes or near emmetropes are probably the ones that are more susceptible to myopic progression as hyperopia, or a hyperopia "buffer", is generally considered to provide protection from myopic progression (Curtin, 1985). In considering whether early refraction can be a useful predictor of later refraction, however, it must be remembered that although our two groups remained significantly different, there was an overlap in their distributions at 38.5 months. As the non-cycloplegic measurements by Gwiazda *et al.* (1993) are under accommodative open-loop conditions (Rosenfield, 1989), it could be that high tonic states of accommodation and/or high proximal responses, as well as or rather than a more myopic cycloplegic refraction, are associated with later childhood myopia.

A comparison with myopic premature infants

Ophthalmic literature suggests that severe and rare (< 1%) pathological "congenital" myopias over −3 D, in infants under 4 yr, can be associated with ocular or general abnormalities and/or prematurity (Curtin, 1963; Lavrich, Nelson, Simon, Dean & Dong-Ming, 1993).

Greater prematurity tends to be associated with medium and high myopia (Dobson, Fulton, Manning, Salem & Peterson, 1981; Grose & Harding, 1990). Although Lavrich *et al.* (1993) reports that congenital high myopes exhibit a variable pattern of refractive change (32% progression, 18% reduction, 50% having changes under one dioptre); healthy, myopic, premature babies generally reduce their myopia within 5 months of birth to near emmetropia (Dobson *et al.*, 1981; Scharf, Zonis & Zeltzer, 1975; Grose & Harding, 1990). They tend to have greater astigmatism (but like normal infants it is mainly A-T-R) which also regresses (Baldwin, 1990).

Our full-term myopic group do share some similar characteristics with the healthy, premature, myopic, babies. They both have myopia, relatively high astigmatism and reduction of both within early infancy. Further studies are needed on the ocular components in full-term myopes to know whether there are anatomical similarities with the delayed ocular development of the premature myopes—steeper corneas, stronger lens and shorter axial length (Baldwin, 1990).

The changes in refraction we have observed in healthy full-term myopes are relatively slower than those observed in healthy premature infants over an earlier period of life [Linfield (1993) reported rapid +0.3 to +0.4 D per week regression]. From this comparison we do not know whether the rate of change was different with our full-term myopes over this early period or whether they started as new-borns with an overall low level of myopia and have always been emmetropizing at a slower rate.

CONCLUSION

The myopic group showed a significant emmetropization of the mean spherical equivalent towards low hyperopia by 3 yr. There was no significant change in the control, low hyperopic group's mean spherical equivalent power. Both groups showed a significant reduction in astigmatism with age. Analyses of the vertical and horizontal powers showed significant "emmetropization" of these meridians, in both groups, towards low hyperopia (+1.6 D) from 8.5 to 38.5 months. These meridional emmetropization changes were significant for both W-T-R and A-T-R astigmatism.

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