Influence of age on peripheral refraction

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Abstract

To investigate how age affects peripheral refraction we measured objective peripheral refraction for 55 young subjects (24±4 years) and 41 older subjects (59±3 years) out to 35 degrees eccentricity in temporal and nasal visual fields. Subjects were compared in 1D subgroups based on central spherical equivalent refractions (low hypermetropes +0.54D to +1.51D, emmetropes +0.50 D to –0.49 D, low myopes -0.50 D to –1.49, moderate myopes1.50 D to –2.58 D). Overall, young and older subjects with similar refractive corrections had similar peripheral refraction components. Both age groups showed relative hypermetropic shifts in the peripheral fields as myopia increased and also decreases in peripheral astigmatism J_{180} as myopia increased. J_{45} varied little across the visual field with linear relationships occurring between J_{45} and visual field angle for all but one subgroup (older emmetropes). Peripheral refraction in emmetropes to moderate myopes is relatively unaffected by age for healthy eyes of similar refractive errors.

1. Introduction

There are considerable changes during adult-life in the anatomical parameters of the eye that affect the optics. Relatively little change takes place in the cornea but considerable changes take place in the lens (Atchison & Smith, 2000). In the unaccommodated state, it becomes more curved, its thickness increases, and the gradient index distribution changes (Moffat, Atchison, & Pope, 2002). Artel and co-workers (Artal, Berrio, Guirao, & Piers, 2002) noted changes in the central (foveal) aberrations of the eye, with the often reasonable balance between those of the cornea and lens in the young eye being lost with increase in age because of changes in the aberrations in the lens.

Most investigations of optics of the eye, including changes with age, have concentrated on the optics associated with central vision. However, there is a literature regarding peripheral optics dating back about 70 years when Ferree *et al.* (Ferree & Rand, 1933; Ferree, Rand, & Hardy, 1931, 1932) first measured the peripheral refraction of the eye. They and subsequent authors have found peripheral refractive errors to be very high, such that eyes with little central astigmatism can have several dioptres of astigmatism by 40° from fixation. These errors are usually asymmetrical about fixation, and in the case of the horizontal visual field, the astigmatic refractive errors are usually higher in the nasal side than the temporal side (Rempt, Hoogerheide, & Hoogenboom, 1971; (Lotmar & Lotmar, 1974) (Millodot, 1981) (Gustafsson, Terenius, Buchheister, & Unsob, 2001) (Dunne, Misson, White, & Barnes, 1993; Rempt, Hoogerheide, & Hoogenboom, 1971; Seidemann, Schaeffel, Guirao, Lopez-Gil, & Artal, 2002). There are changes in the pattern of peripheral refractive errors as the central refraction changes. Although there is considerable inter-individual variation, most emmetropic eyes become myopic into the periphery. The rate of change is even greater for hypermetropic eyes, but myopes have a lesser rate of change and may become relatively hypermetropic into the peripheral field (Millodot, 1981; Seidemann et al., 2002). The astigmatism increases into the peripheral visual field at a lesser rate for myopes and a greater rate for hypermetropes than it does for emmetropes (Millodot, 1981; Seidemann et al., 2002).

We are aware of only two studies that investigated how peripheral refractions are affected by age. Millodot (Millodot, 1984) measured peripheral astigmatism along the horizontal visual field in an older group (10 eyes of 5 subjects aged 62 to 67 years) to compare with his previous study with a “young” group of subjects (Millodot, 1981) involving 62 eyes of 32 subjects (ages 18 to 57 years, mean spherical equivalent refraction range –7.87D to +4.50D). He found mean peripheral astigmatism in the older age group to be more than twice that in the young group. No details of the central refractions of the older group were given. Scialfa *et al.*(Scialfa, Leibowitz, & Gish, 1989) measured refractions in the temporal visual field in a young subject group (22-31 years, mean 26 years, n = 10) and an older subject group (57-69 years, mean 63 years, n = 10). The older group was more hypermetropic than the young group, but the extent of this was not stated. Scialfa *et al.* found the opposite result to Millodot in that their young group had more peripheral astigmatism than their older group, but there was no control for the confounding effect of central refractive errors, nor any mention of the central astigmatism, and they did not take into account the sign and direction of refractive correction.

Because of the shortcomings of the previous two studies in the area, we have undertaken a study to further investigate the effect of age on peripheral refraction. Given that over 35 years there is approximately a 1.5D hypermetropic shift in mean spherical equivalent refraction (Saunders, 1986), we compared emmetropes and subgroups of approximately 1.0D difference in mean spherical equivalent refraction of ages 35 years apart.

2. Methods

The study received ethical clearance from the Queensland University of Technology's Human Research Ethics Committee. Informed consent was obtained from each subject after explanation of the nature of the study.

2.1. Subjects

Two groups consisting of 55 young subjects (24±3 years) and 41 older subjects (59±3 years) were examined. The groups were subdivided on the basis of mean spherical equivalent correction: low hypermetropes (+1.51 D to +0.51 D), emmetropes (+0.50 D to –0.49 D), low myopes (-0.50 D to –1.49 D) and moderate myopes (–1.50 D to –2.50 D). [The classification of "moderate myopes" is for the purposes of this study, as this would usually be considered a low myopia group.] We did not examine a group of young low hypermetropes due to the expected age-related hypermetropic shift i.e. our interest was to compare the young emmetropes to the older low hypermetropes. Details of subject groups are given in Table 1.

Subjects with >0.50D of astigmatism as measured by subjective refraction, >0.80D astigmatism as measured by autorefraction, or with a corrected visual acuity poorer than 6/6 in the test eye were excluded. Subjects were also excluded if in either eye they had any ocular disease, previous ocular surgery, or had ocular tension > 21mm Hg. A subject's eye was excluded if according to the LOCS III classification system a nuclear cataract was graded greater than 1. Subjects with diabetes or hypertension were also excluded. Right eyes were measured in 82% of cases. The left eye was used where the eye met the inclusion criteria and the refraction of the right eye was outside spherical or astigmatic limits (14 cases), the right eye was amblyopic (1 case), had a very noticeable vitreous floater (1 case), or there was a cataract > Grade 1 in the right eye (1 case).

2.2 Measurements and analysis

The Shin-Nippon SRW5000 autorefractor was used for measurements. (Mallen, Wolffsohn, Gilmartin, & Tsujimura, 2001) found that this is a valid and reliable instrument for measuring central visual field refractions. Atchison (Atchison, 2003) found refractions with the instrument across the horizontal visual field to be in good agreement with those obtained using a Hartmann-Shack instrument. The autorefractor gives conventional sphero-cylindrical refractions S/C x θ, which were converted to vector components of mean spherical equivalent M, 90º-180º astigmatism J_{180}, and 45-135º astigmatism J_{45} by (Thibos, Wheeler, & Horner, 1997)

$$M = S + C/2 \quad (1a)$$
$$J_{180} = -C\cos(2\theta)/2 \quad (1b)$$
$$J_{45} = -C\sin(2\theta)/2 \quad (1c)$$

These quantities are analogous to the co-efficients c_2^0, c_2^2 and c_2^{-2}, respectively, of the 2nd-order Zernike aberration terms (Atchison, 2004). It should be noted that J_{180} is half the conventional cylinder when there is little oblique cylinder. The autorefractor requires pupil sizes of 3.0mm for valid measurements (Mallen et al., 2001) and room illumination was adjusted as necessary to ensure that pupil sizes were at least 4mm. Five measurements of refraction were taken in 5° steps between 35° temporal and 35° nasal visual field positions, with subjects looking at targets along a wall 3.3m away. Averages of two complete data sets were taken. The instrument was aligned such that the alignment mire was maintained in clear focus over the centre of the pupil**.** Subjects did not move their heads from the straight ahead position. As a previous study indicated that eye torsion may affect peripheral refraction (Seidemann et al., 2002), we made two repeated measures on five subjects at both 35° temporal and 35° nasal field, and both with and without eye torsion. For the condition with no eye torsion, the subjects rotated their heads by 35 degrees. We found no evidence of effect of eye torsion on any of the refraction components. The maximum mean difference between the two measurements at either eccentricity was only 0.17D, and the mean differences were always less that the standard deviations of the differences and were of the order of test-retest variability.

For statistical analyses, data corresponding to the optic disc (15° temporal) were disregarded because they were very variable. Statistical significances were determined using a criterion of $p < 0.05$. Where multiple comparisons were made between central refraction and difference in refraction in the periphery, a Bonferoni correction was also applied ($p < 0.004$).

Each subgroup's data were fit with a polynomial function that included only those orders found to contribute significantly ($p < 0.05$) to the variation in the data. Significance for this was determined using orthogonal polynomial regression (Edwards, 1979; Wilkinson, Mullins, Bjerknes, & McHale, 1991) of the mean data. A second-order fit was appropriate for most groups, but a first order fit was best for M with young low myopes and for J_{45} for all refractive error groups except older emmetropes. The fits used a weighted least squares procedure where the weightings were provided by the inverse of the variances at each field angle. First-order fits were given by the equation

$$y = bx + c \tag{2a}$$

and second-order fits were given by the equation

$$y = a(x + b)^2 + c \tag{2b}$$

where x is the visual field angle, y is the refraction component and a, b and c are coefficients. The coefficients were compared using t-tests.

To investigate whether peripheral M, J_{180} and J_{45} change as a function of the central field mean spherical equivalent at each visual field angle, the J_{180} and J_{45} at that angle and the differences between M at that angle and at the centre of the visual field were linearly correlated with the central field M for each age group.

3. RESULTS

Mean spherical equivalent M showed similar temporal-nasal asymmetry for young and older refractive error groups, in which changes in refraction into the peripheral field were generally greater for the nasal than the temporal visual field (Fig. 1). Both young and older emmetropes showed myopic shifts into the periphery (up to 1.5D for the older subgroup), but moderate myopes showed hypermetropic shifts into the periphery in both age groups (up to 1.1D for the older subgroup). These shifts were greater in older moderate myopes than in young moderate myopes. The young low myopes showed a linear relationship across the visual field, but the older low myopes had similar shapes to that of the emmetropic groups. Coefficients of the equation fits in Fig. 1 are reported in Table 2.

Differences between peripheral and central M were significantly correlated with central M at several visual field angles (shown by asterisks in Fig. 1) for young and older groups. Despite these significances, the second-order coefficients a in equation (2b), shown in Table 2, were not significantly different from zero for any of the young or older subgroups. The considerable inter-subject variation accounts for the lack of significance. When the results for the subjects in each group were “normalised” by removing variations in central refraction, a became significant for the older emmetropes only ($p = 0.03$).

As for M, there was temporal-nasal asymmetry for 90-180° astigmatism J_{180} in which changes in refraction into the peripheral field were generally samller for the nasal than the temporal visual field for both young and older groups (Fig. 2). The second-order coefficients a in equation (2b) was highly significant for both ages and all subgroups ($p < 0.001$). The shapes of the plots flattened slightly with increase in myopia for both the young (Fig. 2a) and older subjects (Fig. 2b), which was supported by the peripheral and central J_{180} being correlated significantly with central M at the higher nasal visual field angles (indicated by asterisks on the figure). The inter-subject variations of J_{180} for both ages and all subgroups were smaller than the corresponding variations in M (Fig. 1). The young and old emmetropes had similar shapes but the older low myopes and moderate myopes had slightly steeper curves than the young low myopes and moderate myopes, respectively. These differences, however, were not significant. A greater variability in the older subgroups seems to occur, but only because we have shown standard errors that are higher for the greater number of eyes in the older subgroups.

In contrast with J_{180}, the variation in 45-135° astigmatism J_{45} was very small across the visual field (Fig. 3). The older emmetropic subgroup showed a quadratic relationship between J_{45} and visual field angle, but all the other subgroups showed linear relationships. The coefficients were significant for young low myopes and young moderate myopes only (Fig. 3a), but differences between linear coefficients for corresponding subgroups of young and older groups were not significant. For the older group (Fig. 3b) the slopes steepened with increased in myopia and the peripheral J_{45} was correlated significantly with central M at five angles in the temporal visual field (asterisks on plot).

4. DISCUSSION

Contrary to our expectations, we found that young (mean 24 years) and older (mean 59 years) subjects with similar refractive corrections had similar peripheral refraction components for the horizontal visual field, with similar shapes of best fit curves for M, J_{180} and J_{45} across the visual field. Given the considerable changes taking place in the eye with increasing age, particularly in the curvatures, thickness and gradient index of the lens (Atchison & Smith, 2000), this is a surprising result.

Because there is a central hypermetropic shift throughout most of adult life (Saunders, 1986), we included a modest range of refractive errors (Table 1) to investigate whether this shift would have an effect on the shapes of peripheral refraction components. Despite the 35 years mean age difference, both groups showed similar peripheral refraction shapes. It is possible that age-related changes in peripheral refraction might occur outside the refractive correction range investigated in this study.

One minor variation from the lack of association between age and peripheral refractive error was the small J_{45} components that showed some dependence on refractive error for older but not young subjects. This was observed primarily in the temporal field (Figure 3).

Two trends were found for changes in peripheral refraction components in both age groups: there is a relative hypermetropic shift as myopia increases, and there is decreasing peripheral astigmatism J_{180} as myopia increases. Others authors, using greater refractive correction ranges, have previously reported these trends (Lotmar & Lotmar, 1974; Love, Gilmartin, & Dunne, 2000; Millodot, 1981; Mutti, Sholtz, Friedman, & Zadnik, 2000; Seidemann et al., 2002).

We compared our results to a cohort of children with an average age of 10 years (Mutti, Sholtz, Friedman, & Zadnik, 2000). The peripheral myopic shifts of our young emmetropic group and hypermetropic group were similar to that of Mutti *et al's* hypermetropic group (i.e. 0.96D and 1.13D, vs. 1.09D respectively at 30 º nasal), which suggests the peripheral refraction of hypermetropic children changes little over time.

The J_{180} components were similar for young and older subjects (Figure 2). Our results contrast with those of Millodot (Millodot, 1984) and Scialfa *et al.*(Scialfa et al., 1989), who found considerable age related changes in astigmatism (whose major component was presumably 90-180º J_{180}), however, these results were confounded by no control over refractive correction and other limitations as described earlier. Millodot found twice the peripheral astigmatism in an older group than in a young group. We suggest that his few older subjects had exceptionally high astigmatism, a small part of which may have been due to them being more hypermetropic than his young group.

We noted temporal-nasal asymmetry for *M* and J_{180}. Changes in refraction into the peripheral field are generally greater for the nasal than the temporal visual field, as reported previously (Dunne et al., 1993; Gustafsson et al., 2001; Millodot, 1981; Seidemann et al., 2002) We also found asymmetry in J_{45}, but only due to a change in sign with the temporal field having the negative sign (Gustafsson et al., 2001).

In summary, we have shown peripheral refraction in emmetropes to moderate myopes is relatively unaffected by age for healthy eyes of similar refractive errors.

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Figures

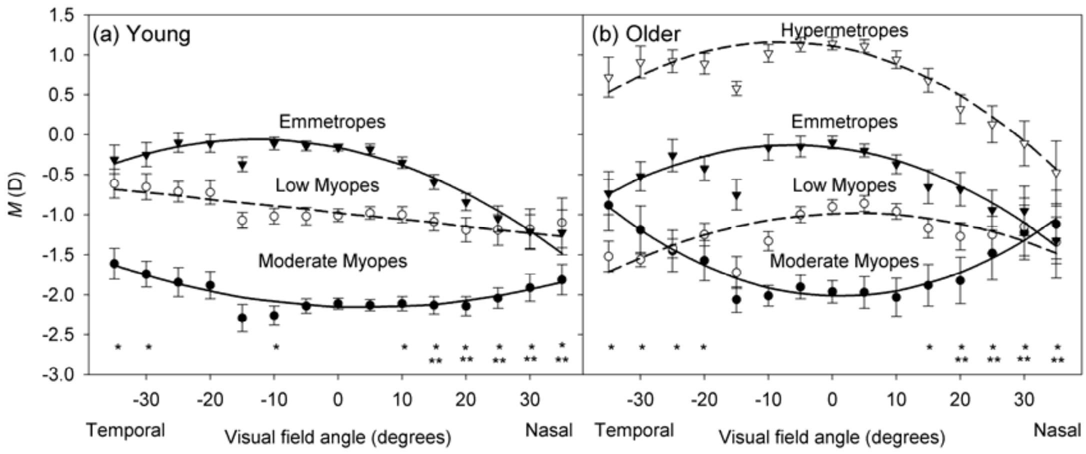

Fig. 1. Mean spherical equivalent refraction *M* as a function of visual field angle for each of the refractive subgroups for a) young subjects and b) older subjects. Errors bars indicate ± SE (some are not seen where they are similar to size of symbols). Visual field points marked with an asterisk are those for which the differences between peripheral and central *M* are significantly correlated with central mean spherical equivalent refraction (*M)*. A single asterisk indicates $p<0.05$ and double asterisks indicate $p<0.004$ (Bonferoni correction applied). Curve fits coefficients are shown in Table 2. The result for 15 degrees temporal field appears in the figure, but was not used in curve calculations.

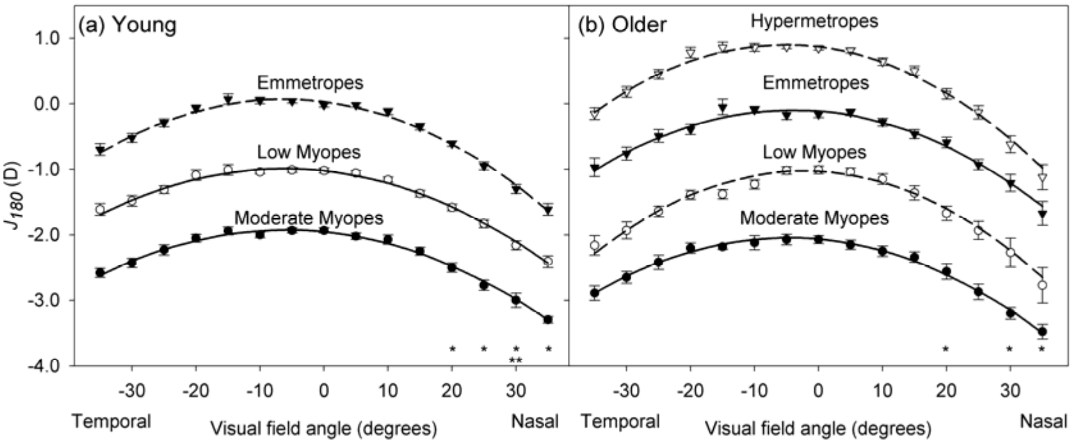

Fig. 2. Mean J_{180} astigmatism as a function of visual field angle for each of the refractive subgroups for a) young subjects and b) older subjects. Errors bars indicate ± SE (some are not seen where they are similar to size of symbols). Visual field points marked with an asterisk are those for which peripheral J_{180} is significantly correlated with central mean spherical equivalent refraction (*M)*. A single asterisk indicates $p<0.05$ and double asterisks indicates $p<0.004$ (Bonferoni correction applied). Results for hypermetropes, low myopes and moderate myopes (and the corresponding fitted curves) have been offset vertically for clarity by +1 D, -1 D and –2 D, respectively. Curve fit coefficients before the offsets are shown in Table 2. The result for 15 degrees temporal field appears in the figure, but was not used in curve calculations.

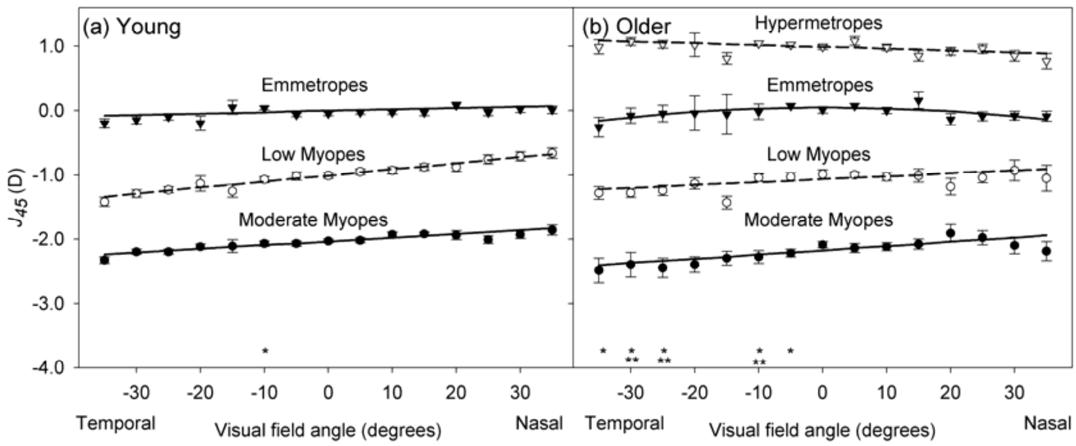

Fig. 3. Mean J_{45} astigmatism as a function of visual field angle for each of the refractive subgroups for a) young subjects and b) older subjects. Errors bars indicate ± SE (some are not seen where they are similar to size of symbols). Visual field points marked with an asterisk are those for which the peripheral J_{45} is significantly correlated with central mean spherical equivalent refraction (*M*). A single asterisk indicates $p<0.05$ and double asterisks indicates $p<0.004$ (Bonferoni correction applied). Results for hypermetropes, low myopes and moderate myopes (and the corresponding fitted curves) have been offset vertically for clarity by +1 D, -1 D and – 2 D, respectively. Curve fit coefficients before the offsets are shown in Table 2. The result for 15 degrees temporal field appears in the figure, but was not used in curve calculations.

Tables

Table 1. Subject numbers, age and *M* (mean spherical refraction) for the young and older refractive error groups.

	Young				Older		
	n	Age (yrs)	M (D)		n	Age (yrs)	M (D)
Low Hyperopes	-	-	-		17	59 ± 2	+1.14 ± 0.33 (+0.54 to +1.51)
Emmetropes	22	23 ± 3	-0.16 ± 0.21 (-0.45 to +0.29)		8	58 ± 2	-0.10 ± 0.20 (-0.38 to +0.18)
Low Myopes	17	24 ± 3	-1.01 ± 0.31 (-1.46 to –0.53)		8	58 ± 3	-0.90 ± 0.29 (-1.39 to -0.50)
Mod Myopes	16	25 ± 3	-2.11 ± 0.29 (-2.58 to –1.56)		8	59 ± 3	-1.96 ± 0.41 (-2.52 to –1.51)

Data are means ± SD, ranges in parenthesis

Table 2. Curve fit coefficients for *M* (mean spherical refraction), J_{180} (90 - 180 astigmatism) and J_{45} (45 -135 astigmatism) for each age and refractive error group shown in Figs. 1, 2 and 3 respectively. First-order fits are given by equation (2a) and second-order fits are given by equation (2b). * indicates $p < 0.05$.

		Young				Older			
		a	b	c	R^2	a	b	c	R^2
M	Low Hyperopes					-0.0009	+7.980	+1.162 *	0.90
	Emmetropes	-0.0006	+12.920	–0.059	0.95	-0.0007	+6.293	–0.128	0.92
	Low Myopes	-	-0.0085	–0.976*	0.79	-0.0005	–3.412	0.983*	0.84
	Mod Myopes	+0.0003	–4.402	–2.154*	0.84	+0.0008	–1.237	–2.014*	0.95
J_{180}	Low Hyperopes					-0.0012*	+5.260*	–0.099	0.99
	Emmetropes	-0.0010*	+6.290*	+0.070	0.99	-0.0010*	+4.060	–0.095*	0.98
	Low Myopes	-0.0008*	+6.221*	+0.008	0.99	-0.0012*	+2.240	–0.026	0.97
	Mod Myopes	-0.0008*	+5.904*	+0.078	0.99	-0.0009*	+4.730*	–0.044	0.99
J_{45}	Low Hyperopes					-	–0.0028	–0.011	0.55
	Emmetropes	-	+0.0022	-0.004	0.38	-0.0002	–0.637	+0.047	0.62
	Low Myopes	-	+0.0094	–0.006	0.98	-	+0.0045	-0.063	0.57
	Mod Myopes	-	+0.0058	-0.037	0.87	-	+0.0066	–0.176*	0.65