Accommodative Response in Pre-presbyopes with Visual Impairment and Its Clinical Implications

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Purpose. There are isolated reports that accommodative response is reduced in some populations with low vision. The purpose of this study was to measure accommodative response in a wider range of pre-presbyopes with visual impairment and to examine what factors may affect accommodation among the low vision population.

Methods. Accommodative responses for accommodative demands between 4 and 10 D were measured with dynamic retinoscopy in 21 subjects with low vision due to a variety of disorders and in 40 control subjects, aged 3 to 35 years. The control subjects were divided into age groups of 3 to 5, 6 to 10, 11 to 26, and 27 to 35 years, and the response of each subject with low vision was compared against the age-matched control group. The slope of the accommodative function and the mean error of the accommodative response were also calculated.

Results. Eighty-six percent of the subjects with low vision showed responses that were outside the 95% range of normal. The deficit increased with increasing accommodative demand. Reduced accommodation was not predicted by age, visual acuity, presence of nystagmus, refractive error or time of onset of the disorder. The results show that the accommodation errors are often greater than predicted by increased depth of focus due to poor visual acuity.

Conclusions. It seems likely that accommodative response is based on many factors that may be present in an eye with low vision, which interact in a complex fashion. (*Invest Ophthalmol Vis Sci.* 2007;48:3888–3896) DOI:10.1167/iovs.06-0582

Clinically, accommodation is almost never measured in children and young people with low vision. There are probably two reasons for this. First, accommodation is not routinely measured in children generally, since it is assumed to be adequate for their near-vision purposes. Second, the usual clinical measurement involves the subjective measurement of the amplitude of accommodation, that relies on the patient's detection of the blur point as a target is brought closer to the eye (push-up technique) or as negative lenses are added in front of the eye.[1] People with low vision are less likely to be able to detect blur accurately. Yet, reading additions are frequently required by children with low vision, to relieve the accommodation strain of their closer-than-average working distance.[2,3] It is currently suggested that the calculation for the starting point for an add assessment be based on the expected accommodation for the age.[2] The purpose of this study was to determine whether this assumption is correct—that is, is accommodative response normal in pre-presbyopes with visual impairment?

Accommodation may be reduced compared with age-related norms in certain groups of children and young adults with low vision.[4–10] Lindstedt[4] found that near acuity is frequently a factor of two or more poorer than is distance visual acuity, even in children with only moderate levels of low vision (6/9–6/18). Using dynamic retinoscopy, we have shown reduced accommodation accuracy, in a few children and teenagers with albinism.[5] White and Wick[6] have shown reduced accommodative response in people with juvenile macular degeneration and Heath[7] has demonstrated similar reductions in people with achromatopsia and in artificially reduced visual acuity.[8] Reduced accommodation has been documented in amblyopia and is thought to be due to the degraded image—that is, a reduction in the afferent signal rather than a deficit in either the motor controller or peripheral apparatus.[9,10] Ong et al.[11] reported reduced accommodation in 50% of people with congenital nystagmus. Accommodative response is affected by such factors as spatial frequency content of the retinal image, contrast, retinal image movement, and eccentricity of the retinal image.[12,13] Thus, it is not surprising to find reduced accuracy of accommodation in people with low vision, who, similarly to amblyopes, also have a degraded visual image due to reduced visual acuity (reduced high spatial frequency perception) and may also have nystagmus and/or eccentric fixation.

Nott dynamic retinoscopy is a method of objectively determining the accuracy of accommodation and as such may be used to assess accommodation in populations in which subjective testing is not possible. This technique has been shown to be valid and repeatable and is readily applicable in clinical practice, as well as in research settings.[14,15] The technique has good validity, as compared with autorefraction,[14] and gives estimations of the amplitude of accommodation that correlate with the push-up technique.[16] This method has shown that accommodation is reduced in a large percentage of children with Down Syndrome[16,17] and in children with cerebral palsy.[18,19] Normal age-related data have been published against which other populations may be measured.[20,21]

The purpose of this study is to measure accommodative response in a wider range of pre-presbyopes with visual impairment than has been documented thus far and to examine what factors may predict reduced accommodation among the low-vision population. We have also assessed the interobserver repeatability of the dynamic retinoscopy technique. The results are discussed in terms of the clinical significance of the findings.

Methods

General Method of Dynamic Retinoscopy

Dynamic retinoscopy, using a modification of Nott retinoscopy[22,23] was performed in the same way as has been described elsewhere.[16,20] Briefly, an internally illuminated cube was mounted on a bar with a chin rest and could be positioned at different dioptric distances from the subject. Various high-contrast black and white pictures and letters were printed on the cube with spatial frequency ranging from 0.07 to

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22 cyc/deg (1.6–0.13 logMAR equivalent) at the 25-cm viewing distance. Thus, the target contained spatial detail that was visible, even for those with the poorest VA. Two cubes with different pictures and letters were interchangeable, and each could be rotated so that the pictures could be varied to maintain the subject's interest—particularly important with the youngest subjects. The bar was marked in diopters from the subject's eye. One difference from previous studies was that a measuring tape was fixed to the retinoscope so that zero was at the sight hole. Once the neutral position was determined, this tape was used to measure more accurately the distance between the retinoscope and the subject's eye. The observer started somewhat behind the stimulus and moved closer (or in some cases farther away) until a neutral retinoscopic movement was seen. One other slight difference was that the observer was allowed to "bracket" the neutral point (i.e., to move away until an "against" movement was seen and then closer until a "with" movement was definitely seen before estimating the neutral point between).

The accommodative response was measured at target distances of 4, 6, 8, and 10 D and in this order. Two measurements were taken for each accommodation demand and averaged to give the final value.

The research adhered to the tenets of the Declaration of Helsinki and was approved by the Office of Research Ethics at the University of Waterloo. Informed consent was obtained from all participants or the parents or guardians in the case of children after an explanation of the nature of the study.

Control Data

Because the technique had slight differences from that used by Leat and Gargon[20] and because neither interobserver repeatability nor the effect of order of measurement has been reported, accommodative response was measured in subjects with normal vision aged 5 to 35 years. The subjects were recruited into age categories according to Leat and Gargon. Inclusion criteria were good general health, no known eye diseases, no medication that would affect visual performance, no previous ocular surgery, no strabismus, and monocular visual acuity of at least 6/6 (0.0 logMAR). Refractive error was checked with subjective refraction (and/or objective refraction in the youngest observers). If the manifest refraction differed from the habitual spectacle refraction by more than 0.25 D mean sphere, 0.5 D sphere, or 0.75 D cylinder, measurements were taken through the manifest refraction in a trial frame. Otherwise measurements were taken through the current spectacles. These were the same criteria used by Leat and Gargon[20] for their control data. Measurements were taken on the sighting dominant eye.

Repeatability

Accommodative response was measured in subjects with normal vision aged 11 to 35 years. The inclusion criteria were as for the control data. The interobserver repeatability was measured in 20 subjects. Two observers (SL, AM) undertook measurements without knowing the other's results. The order of the two observers was randomized.

In most of the previous studies, the order of accommodation measurements has started with the lowest accommodative demand and worked toward the highest.[16,18,20] To investigate the possible influence of the order of measurements, we repeated measurements in the reverse order (i.e., starting with the highest demand and working to the lowest). Ten subjects, aged 11 to 26, took part in this evaluation, and both observers took measurements.

Accommodation in Low Vision

Participants with low vision but without intellectual impairment were recruited from the Low Vision Clinic at the School of Optometry, University of Waterloo. All participants had form vision, with visual acuity of 3/600 or better. The largest spatial frequency component of the target was 0.07 cyc/deg at the farthest distance, which is equivalent to 3/1800 Snellen acuity. Information regarding eye disorder, visual acuity, general health, medications, binocular vision status, and manifest refraction were taken from the record of low-vision assessment, which had been performed earlier the same day. If the manifest refraction differed from the habitual spectacle refraction by more than 0.25 D mean sphere, 0.5 D sphere, or 0.75 D cylinder, measurements of accommodation were taken with the subject both wearing the habitual glasses and the manifest refraction. In those subjects already wearing bifocals, measurements were taken with the subject viewing above the bifocal. Accommodative response was measured with dynamic retinoscopy, as described earlier. In some participants with low vision, the internal illumination of the target had to be increased to aid visibility. In all cases apart from one, the eye measured was the one with best visual acuity (VA) or the nonstrabismic eye. In one subject, who only had reduced VA in one eye but visual field loss in both, the eye with the poorer VA was chosen. Thus, we assumed that the accommodative response is generally driven by the eye with best visual acuity, as found by Hokoda and Ciuffreda[9] in the case of amblyopia.

Table 1. Slope and Mean Error for Control Subjects

		Slope		Mean Error	
	Mean Age	Mean	95% Range	Mean	95% Range
3–5 years (n = 10)	4.2	1.13	0.91–1.33	−0.33	−0.90–0.24
6–10 years (n = 10)	7.1	1.07	0.96–1.17	0.10	−0.60–0.80
11–26 years (n = 10)	23.4	0.54	0.41–0.72	1.51	0.77–2.24
27–35 years (n = 10)	29.7	0.54	0.42–0.67	1.34	0.72–1.94

The 95% range is calculated using $\pm 1.96 \times$ SD. Negative signs indicate overaccommodation.

Data Analysis

For each control and low-vision subject, the slope and mean error were calculated similar to the method of White and Wick[6] across the accommodative demands of 4 to 10 D inclusive. The mean error was the mean of the sum of the differences between the accommodative demand and the accommodation response. The slope was the slope of the regression line fitted to the accommodative response against accommodative demand. The higher accommodative demands were included in the calculation, as there was a linear response in the younger age groups, and a close to linear response in the older two groups. The calculation enabled a comparison of slope and mean error across all the accommodation demands that were measured. The control data were analyzed in terms of overall mean across all subjects in each age group. The 95% range was calculated as the mean ± 1.96 SD in each age group, in order that these values might be plotted alongside the accommodative response of each low-vision subject. Repeatability for the control group was analyzed by repeated-measures ANOVA and coefficient of repeatability. To investigate the factors that might determine reduced accommodation in the low-vision subjects, either correlation or the χ^2 test was used.

Results

Control Data

A total of 40 control subjects took part, 10 in each of the following age groups: 3 to 5, 6 to 10, 11 to 26, and 27 to 35 years. The ranges for each age group were based on Leat and Gargon[20] who found that there were no significant differences between subgroups in the age ranges of 6 to 10 and 11 to 26 years. The slopes and mean errors of the accommodative response in each age group, with the 95% confidence ranges, are shown in Table 1.

Repeatability

There was no significant difference in the measurements of accommodative response between the two observers (repeat-

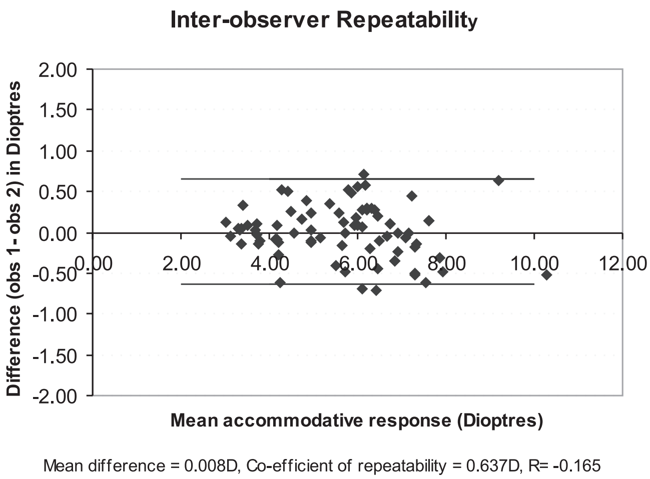

FIGURE 1. Interobserver repeatability for all accommodation demands. *Solid lines*: ±1.96 × SD of differences.

ed-measures ANOVA, two observers × four accommodation demands, $P = 0.89$). The interobserver repeatability is shown in Figure 1 in which the difference between observers 1 and 2 for each measurement of accommodative response is plotted against the mean of their measurements.[24] The mean difference between the two observers was 0.008 D, and it can be seen that there is no obvious trend line (i.e., the difference does not increase or decrease with the accommodation demand). The coefficient of repeatability was 0.637 D. It can be seen that there is a trend for the spread of differences to increase with increasing accommodative demand. Therefore the coefficient of repeatability was calculated for each accommodative demand separately. The results are shown in Table 2.

There was no significant difference in the measurements taken with increasing or decreasing accommodation demand (repeated measures ANOVA, two direction × two observers × four accommodation demands, $P = 0.15$) and again no effect of observer ($P = 0.67$). The coefficient of repeatability was 0.747 for AM and 0.788 for SL and the mean difference between increasing and decreasing accommodative demand was 0.00 for AM and −0.20 for SL.

Low-Vision Subjects

Twenty-one subjects with low vision took part. They were grouped into the same age groups as the published control data of Leat and Gargon.[20] The mean ages were 5 ($n = 1$), 7.6 ($n = 9$), 16.4 ($n = 10$), and 31 years ($n = 2$). Table 3 shows the demographic and ocular information of the participants with low vision, and Figure 2 shows the accommodative responses for each subject with low vision. The accommodative responses with the habitual spectacles are presented, and, in cases in which there was a difference between the habitual and the measured refraction, both sets of data are shown or the data are modified by the difference between the habitual glasses and the measured refraction. Although a few subjects with low vision had a significant difference between the manifest and the habitual refraction, the results with the two corrections were similar and resulted in the subjects being classified in the same group with regard to whether accommodation was normal or abnormal in all cases except one (subject 12).

Three subjects had accommodation within the normal range at all accommodation demands (subjects 10, 11, and 13). Subject 12 had accommodation in the normal range at all demands with the measured refraction but not with the habitual glasses. Subject 12 with the measured refraction and subject 13 were the only subjects to show responses that were close to the mean for his or her age, and in fact subject 13 had a slope that was greater than the 95% range of normal. There was one other subject[6] whose responses (at each accommodative demand) were close to being within the 95% range. Most of the subjects showed large deficits and/or deficits at most accommodation demands. Based on the criteria of being outside the 95% range of normal, 11 subjects (52%) showed a defect of slope, whereas 76% showed a greater mean error (Table 3). Eighty-six percent of all the subjects with low vision demonstrated an anomaly of either the slope or the mean error or both. This is a significant percentage (χ^2 $P < 0.0001$).

The deficit in accommodative response tended to increase with increasing accommodation demand. Only nine (43%) subjects showed an accommodative response outside the normal range at 4 D demand, while 62%, 71%, and 62% were outside the normal range for 6, 8, and 10 D, respectively. There were five subjects who seemed to show a saturation of response at the higher accommodative demands (subjects 3, 5, 7, 8, and 9). The data of these subjects were reanalyzed using only the apparently linear part of their responses. Still, four of the five showed abnormal slope or mean error, although subject 3 now demonstrated a slope that was steeper than normal, with an error greater than normal.

Because there were nine subjects with low vision in both the 6- to 10-year group and the 11- to 26-year group, we were able to pool the results in each age group to undertake further statistical analysis of the accommodative responses. *t*-Tests were undertaken between the control and low vision groups at each accommodation demand. Bonferroni adjustment indicates that P must be < 0.006 for significance (i.e., 0.05/8). There were significant differences between the normal and the low-vision groups at all accommodative demands (P < 0.006, $df = 8$) except for the 4-D demand for the 6- to 10-year-olds ($t = 2.688$, $P = 0.016$).

Factors Associated with Reduced Accommodation

Visual Acuity. Figures 3A and 3B show scatterplots of slope and mean error against VA, respectively. It can be seen that there is a wide range of slopes even when VA is quite good (logMar, 0 to 0.5). The same is true for mean error. Pearson correlation coefficients were nonsignificant between VA and slope ($r = 0.028$, P = 0.9, $df = 19$) and between VA and mean error ($r = -0.078$, $P = 0.74$, $df = 19$).

Age. Figure 4A and 4B show scatterplots for slope and mean error against age respectively. Again, there is considerable scatter and low, nonsignificant correlations (although that for mean error is borderline). The Pearson correlation coefficient was $r = -0.207$, $P = 0.368$, $df = 19$ and $r = 0.384$, $P = 0.086$, $df = 19$ for slope and mean error, respectively.

Nystagmus. There was no association between the presence of nystagmus and reduced accommodation (χ^2 test, $P = 0.655$, $df = 1$).

Refractive Error. It has been shown that there may be differences in accommodation response between myopes and hyperopes. It is well documented that progressing myopes tend to show a greater lag in accommodation than do emmetropes.[25] We therefore separated our subjects into myopes

TABLE 2. Coefficient of Interobserver Repeatability[24] for Different Stimuli to Accommodation

	Accommodative Demand			
	4 D	6 D	8 D	10 D
Mean difference (D)	−0.04	−0.01	0.04	0.03
Coefficient of repeatability (D)	0.372	0.667	0.708	0.764

TABLE 3. Summary of Low-Vision Patients

Subject	Age (y)	VA (logMAR)	Diagnosis	Strabismus	Nystagmus	Slope	Mean Error	Diagnostic Group	Refraction	Add. (D)
1	6	0.4	Peter's Anomaly, bilateral corneal grafts	√	√	0.78*	1.46*	O	OD 1.50/−8.00×170 OS −0.25/−8.00×105	
2	34	1.1	Rubella, cataract	√	√	0.47	2.57*	O	OD +11.00 DS OD +11.25 DS	+4
3	17	1.2	Rubella, microphthalmos		√	0.54	2.7*	R	OD −2.25/−2.25×036 OS −1.00/−1.25×041	+6
4	9	0.78	Rubella, iris and chorioretinal coloboma, microphthalmos, retinal detachment		√	0.57*	1.85*	R	OD +6.00/−4.75×175 OS +6.00/−4.00×165	
5	7	1.0	Ocular Albinism		√	0.39*	1.8*	R	OD +3.00/−2.75×013 OS +6.00/−2.75×165	
6	9	0.78	Albinism	√	√	0.86*	0.79	R	OD +1.00/−2.50×120 OS +8.50/−2.00×010	
7	6	0.7	Albinism		√	0.69*	1.4*	R	OD +4.50/−1.25×176 OS +4.50/−1.25×179	
8	10	0.8	Albinism		√	0.55*	2.13*	R	OD +2.00/−3.25×040 OS +4.75/−4.50×162	
9	8	0.9	Albinism		√	0.56*	2.03*	R	OD +1.50/−3.50×012 OS +2.50/−3.25×178	
10	21	1.0	Cone dystrophy		√	0.59	2.06	R	OD −6.00/−3.00×020 OS −7.50/−3.00×155	
11	11	0.8	Achromatopsia		√	0.44	2.1	R	OD +1.50/−1.25×180 OS +2.00/−2.00×002	
12	15	0.8	Achromatopsia		√	With habitual Rx 0.64	 2.29*	R	OD −4.00DS OS −5.00DS	+4
						With measured refraction 0.64	 1.54		OD −5.00DS OS −4.25DS	
13	16	0.65	Retinitis pigmentosa			0.75†	1.09	R	OD +0.75/−2.75×180 OS +0.75/−2.50×177	
14	28	0.6	Retinitis pigmentosa			0.51	2.41*	R	OD −1.75/−1.25×180 OS −2.00/−1.75×140	
15	14	1.2	Aniridia and glaucoma		√	0.56	2.91*	N	OD +0.75/−1.00×105 OS +5.50/−1.00×090	+6
16	21	0.2	Traumatic homonymous hemianopia		√	0.5	2.62*	N	OD −1.75DS OS −3.25DS	
17	5	0.2	Refractive amblyopia			1.02	0.58*	C	OD +4.25/−1.75×180 OS +2.00/−1.00×180	
18	18	0.2	Refractive amblyopia			0.34*	2.94*	C	OD +1.50/−3.50×172 OS +0.50/−3.00×005	
19	19	0.2	Refractive amblyopia, myopia		√	0.45	3.14*	C	OD −16.50/−0.50×075 OS −16.50/−1.00×115	
20	7	0.1	Congenital nystagmus	√	√	0.41*	2.69*	C	OD +1.50/−1.00×180 OS +1.25/−1.50×101	
21	6	0.4	Cerebellar syndrome, vertical nystagmus		√	0.14*	3.07*	C	OD −5.00/−1.00×180 OS −5.00/−1.00×180	

The slope and mean error are marked * if they are poorer (lower slope, higher mean error) than the 95% range for the age (see Table 1) and with † if they are better than the 95% range. The last column indicates the addition, if any, that the subject had prescribed in his or her current glasses. The diagnostic groups were O, optical media disorder; R, retinal disorder; N, optic nerve disorder; C, cortical defect.

and hyperopes, based on the mean sphere of the tested eye. There was no significant difference in the presence of reduced accommodation between the two groups (χ^2 test, $P = 0.28$ and 0.70, $df = 1$, for slope and mean error, respectively). Numerically, there were more hyperopes with abnormal slope than myopes, and an equal number of myopes and hyperopes with abnormal mean error in accommodation. When the subjects with myopia in the age group when myopia might be progressing (6–15 years) were eliminated (four subjects), there were still more hyperopes than myopes with reduced accommodative response. Thus, the increased accommodation lag in progressing myopes does not seem to be an explanation.

Visual Diagnosis. Subjects were classified according to the site of the primary cause of low vision as disorder of optical media, retinal disorder, optic nerve and pathway disorder, and cortical disorder, and these classifications are shown in Table 3. People with albinism were classified as having a retinal disorder, since the foundational reason for reduced VA is foveal hypoplasia. Because of the small numbers, it is difficult to draw any conclusions except to say that the subjects with normal accommodation all had a retinal disorder. There is only one specific disorder for which we have enough numbers to make comment, and that is albinism. In this group there were no subjects who had normal accommoda-

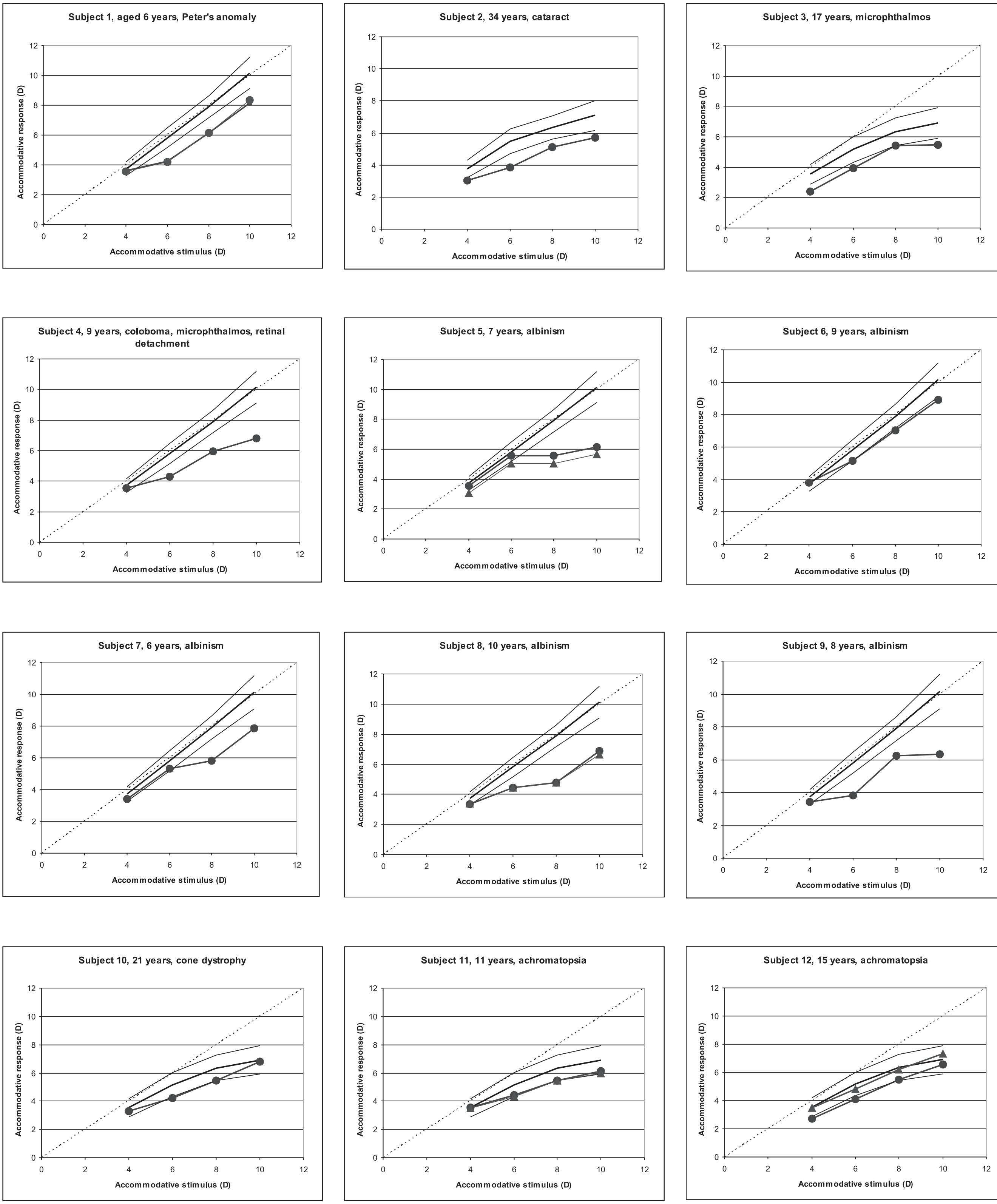

FIGURE 2. Accommodative response for each subject with low vision against accommodative demand. *Circles*: response with habitual spectacles; *triangles*: data with the measured refraction. In cases in which the response was not measured with the measured refraction, the response with the habitual glasses was adjusted by the difference of refraction between the habitual and measured in the horizontal meridian (because the retinoscope streak was vertical). In some cases, there was no difference between the habitual and measured refraction (e.g., subject 20) and only one data set is shown. *Dashed line*: perfect response; *thick* and *thin solid lines*: mean and 95% range of normal for the control group age-matched to that subject.

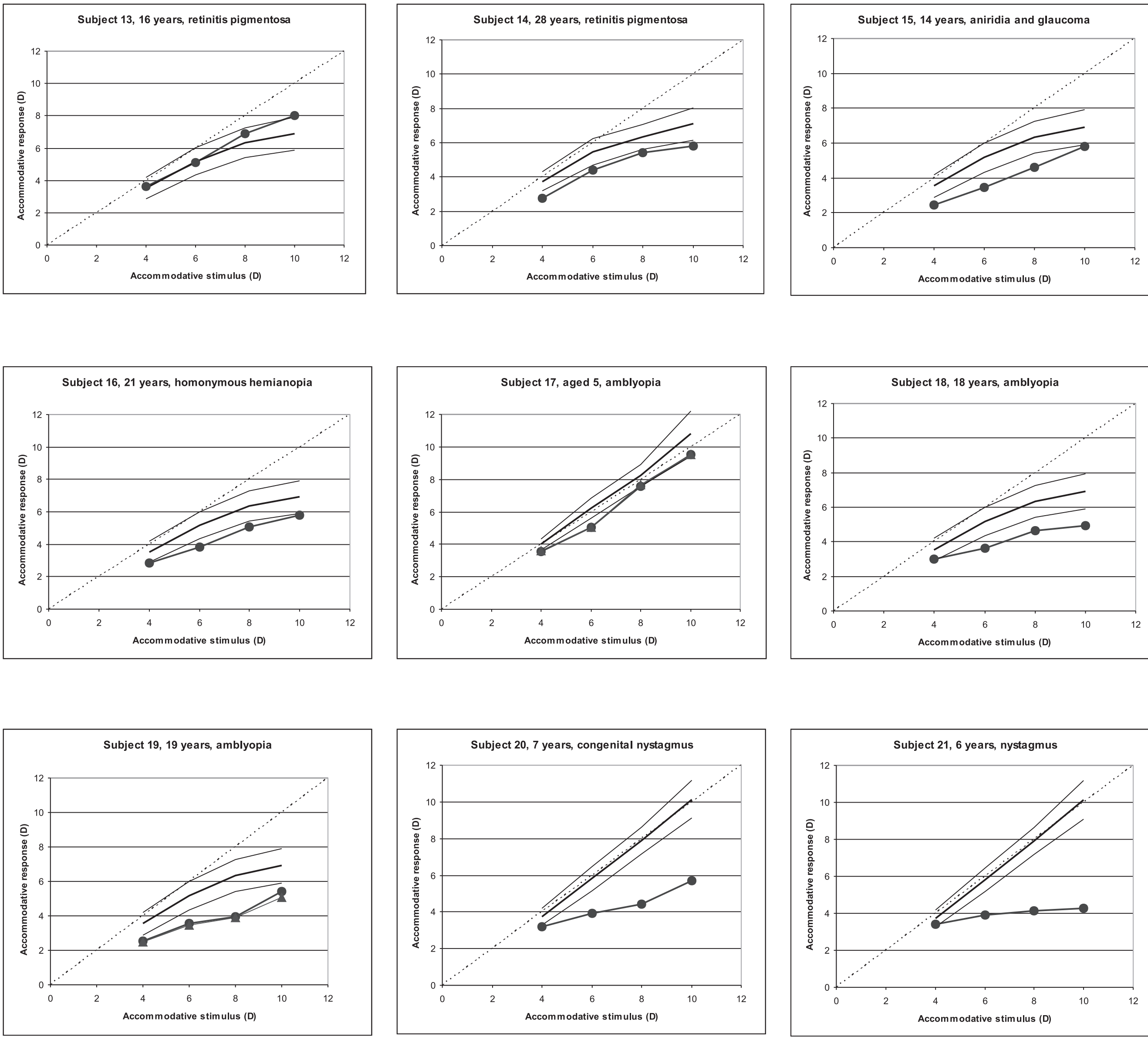

FIGURE 2. *(Continued)*

tion, meaning that 100% of people with albinism had reduced accommodation.

Onset of Disorder. Is it possible that people who once had normal visual acuity and therefore would be expected to have normal accommodation at that time, retained the use of proximal accommodation? Alternatively, those with congenital disorders may have been used to using different amounts of blur as a stimulus for accommodation and/or may have learned to use binocular clues from the outset. We therefore divided our subjects into acquired and congenital conditions. Among the congenital disorders 81% had abnormal accommodation while among those with acquired disorders the percentage was 75%. A *t*-test between the groups showed no significant difference: $t = 0.46$, $P = 0.65$, $df = 19$ for slope and $t = 0.57$, $P = 0.58$, $df = 19$, for the mean error.

DISCUSSION

The control data show general agreement to that published before by Leat and Gargon[20] and by McClelland and Saunders.[21] We have reported the interobserver repeatability of the dynamic retinoscopy technique. At a 4-D distance the interobserver coefficient of repeatability was 0.37 D (although this increased to 0.76 D at the closest working distance). This is comparable with measures of refractive error. Subjective refraction typically has a 95% repeatability of between 0.25 and 0.5 D and retinoscopy between 0.35 and 0.76 D,[26] and it is clinically measured in steps of 0.25 D. The coefficients of repeatability found in the present study are slightly lower than the (presumably) intraobserver repeatability in the study by McClelland and Saunders,[21] who found 0.56 for 4-D demand and 1.34 for 10 D in subjects in the age range of 6 to 35 years. There are three possible reasons for these slight differences: (1) The age ranges in the two studies differed; (2) in the present study a bracketing technique was used, whereas McClelland and Saunders[21] moved from the target until the first neutral position was found; and (3) in the present study a measuring tape was affixed to the retinoscope. The studies are in agreement that the coefficient of repeatability increases for increasing demands, as would be expected because smaller

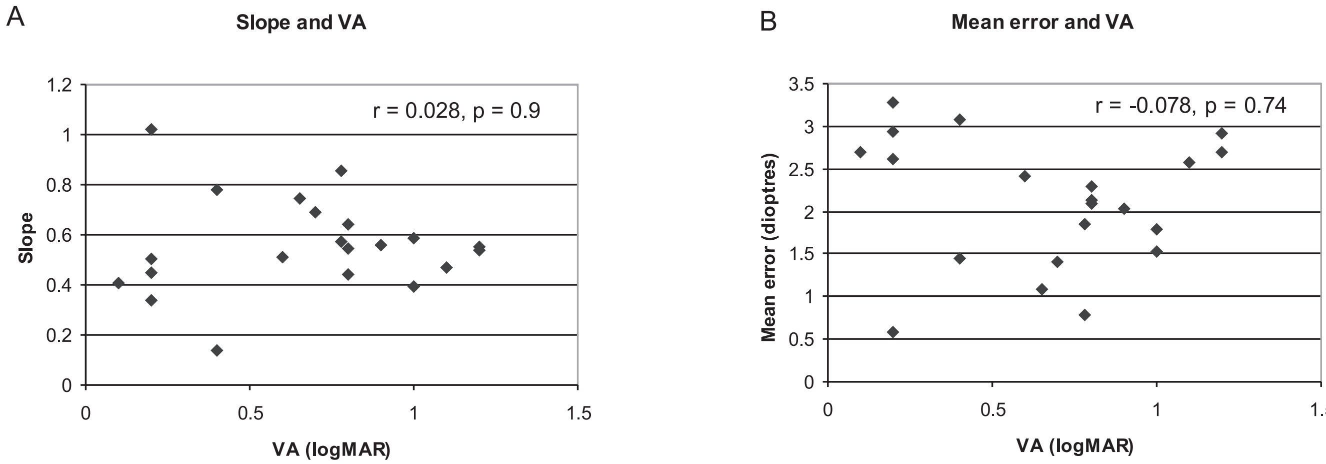

FIGURE 3. Scattergram of (**A**) slope of accommodative response against VA and (**B**) mean accommodative error against VA.

distances represent greater dioptric changes when closer to the subject. The order of taking measurements (from lower to higher accommodative demands or vice versa) did not influence the measurements. McClelland and Saunders[14] also compared dynamic retinoscopy with the Shin-Nippon autorefractor and found good agreement between the two techniques. We confirm that dynamic retinoscopy is a repeatable measure.

The main finding of this study is that a considerable percentage of pre-presbyopes with visual impairment, including children, had significantly reduced accommodation. This finding was particularly true of the accommodation demands greater than 4 D. Our overall results of reduced accommodation are in agreement with White and Wick[6] and Heath,[7] showing that subjects with low vision frequently have anomalies in accommodation. White and Wick[6] found that all their subjects with macular disease had some anomaly in accommodative response, either in slope or mean error. Heath[7] found that his subjects were unresponsive to change in the accommodation stimulus (i.e., the slope was flatter than normal). However, in both these studies a lower range of accommodative demand (from 0–5 or 6 D) was used than in the present study. Their subjects tended to overaccommodate for the lower accommodative demands, thus still giving rise to a flat stimulus response curve. In our study we found that accommodation was quite accurate at 4 D for many subjects, but that the lag in accommodation increased for increasing demands. Reanalysis of Ong et al.,[11] using the same criterion as the present study (outside the 95% range of normal), showed that 50% of their subjects with congenital nystagmus (including albinism) had accommodative response slopes that were lower than normal while 33% had slopes that were greater than the control group. This is in contradistinction to our results in which only two subjects showed a slope that was greater than the normal range (subject 13, with retinitis pigmentosa and subject 3 with microphthalmos). Subject 3 demonstrated this greater than normal slope only when the response to the 10-D stimulus was not included. All our subjects with congenital nystagmus or albinism ($n = 7$) showed accommodative responses below the normal range. However, again we used a higher range of accommodative demands than was used in other studies. If we consider our results at 4 and 6 D only, then 43% had normal accommodation. However, from a clinical perspective, the higher prevalence of reduced accommodation when the higher accommodation demands are included is potentially important. Many of these subjects would use a closer than normal habitual distance for reading tasks.

A comment is necessary regarding the order of presentation of the stimuli (i.e., the fact that accommodative demand was presented in increasing order). It is possible that there may be a fatigue effect influencing the higher demands. Although in the control group we showed that there was no effect of either increasing or decreasing accommodation demand, subjects with low vision may be more prone to fatigue. However, if they cannot maintain accommodation longer than is required to take a measurement with dynamic retinoscopy (approximately 10 seconds) their accommodative function would not be nor-

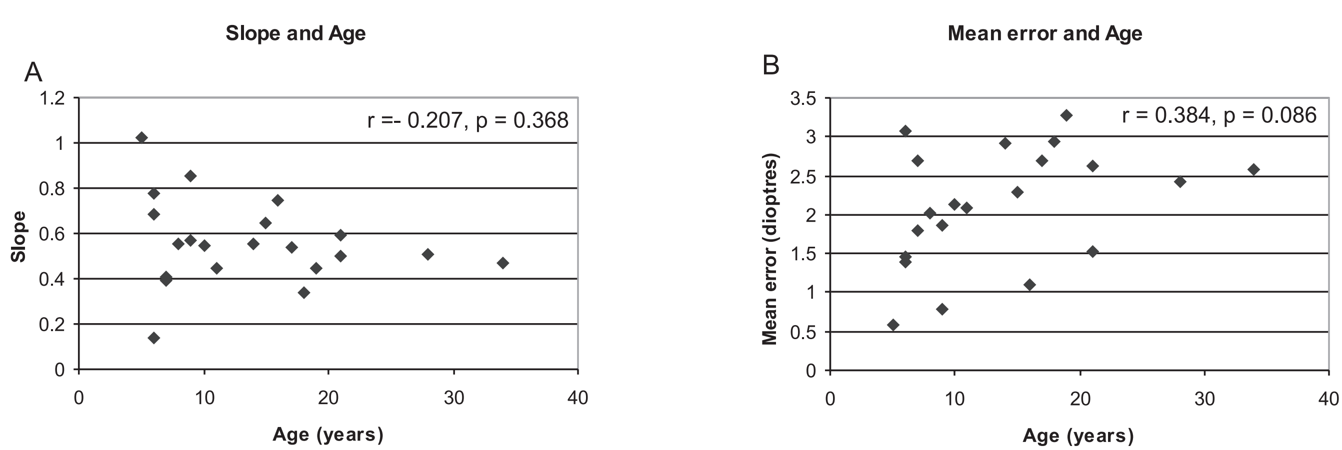

FIGURE 4. Scattergram of (**A**) slope of accommodative response against age and (**B**) mean accommodative error against age.

mal, for all practical purposes. The same procedure was used for control and low-vision subjects, and the low vision subjects showed comparatively different responses.

Initially, the finding that accommodation is reduced is not surprising, as we expect lower sensitivity to blur. If loss of high-spatial-frequency perception is the cause of compromised accommodation, we would anticipate a correlation between visual acuity and accommodative response. Heath[8] and White and Wick[6] found an association between VA and accommodative response (i.e., those with poorer VA had a greater error in accommodation). We did not find a significant association in the present study. However, previous study populations were more homogeneous than that in the present study, in which some subjects with fairly good visual acuity showed significantly reduced accommodation. Cuiffreda and Hokoda[27] showed similar findings in their study of amblyopes. Some amblyopes, who had only slight losses of VA or contrast sensitivity, still showed significantly reduced accommodative response to targets of different spatial frequencies. These subjects would be expected to be able to respond to gratings of 1 to 30 cyc/deg,[12] which have been shown to be good accommodative targets for observers with normal vision.

We can calculate the error in accommodation that would be predicted due to increased depth of focus in cases of poorer VA. An eye with a visual acuity of 6/60 and a pupil diameter of 3 mm would have a predicted depth of focus of 0.78 D.[28] Most of our subjects had VA better than 6/60 (logMAR = 1), yet show mean lags in accommodation that are larger than this, despite the fact that they were viewing binocularly (Fig. 3B). Thus, reduced VA does not seem to be a sufficient explanation.

Accommodation accuracy is dependent on the spatial frequency content, contrast, movement, and retinal eccentricity of the target,[9,10,12,13] which may all be compromised in people with low vision. Yet, accommodation is fairly robust with regard to many of these parameters. For example, accommodation is well maintained for square-wave grating stimuli of all spatial frequencies below 20 to 30 cyc/deg,[12] (i.e., with a broad-band stimulus such as a square-wave grating, loss of high frequencies would not be expected to have an effect). The targets we used were broad-band stimuli with a range of spatial frequency content. Therefore, we might expect good responses from low vision subjects. Thus, many of our subjects show greater reduction in accommodation than would be predicted from what is known about the effectiveness of the spatial frequency content of stimuli for accommodation.

Cuiffreda and Hokoda[27] have suggested that there are higher factors that have a significant influence on accommodative function. They conclude that "reflex, voluntary and higher perceptual aspects of accommodation may interplay in a complex. . .manner." In addition, there has been no definitive consensus of whether accommodation responds primarily to optimize the contrast of an image or the sharpness of high frequency components.[27] Indeed, it may be that some subjects respond in the former fashion and others in the latter and that this may vary with instructional set. Certainly a low-contrast target is a less effective stimulus for accommodation, and subjects with reduced contrast sensitivity would have perceptually reduced contrast. In fact, as contrast is decreased there is a quite sudden cut off, below which the target is no longer an effective stimulus for accommodation, which then reverts to the tonic level.[12] This cutoff point is at higher contrast levels for amblyopic eyes.[29] It is possible that lower perceived contrast, because of reduced contrast sensitivity, is a more important factor in determining accommodative response than is visual acuity loss in observers with low vision. It is also possible that accommodative response is based on many interacting factors that may be present in an eye with low vision, including a lower perceived contrast image, image movement, use of eccentric fixation, loss of high spatial frequencies, poorer contrast discrimination, that interact in a complex fashion,[30] with the result that the system may be described as being insensitive to blur.

This high prevalence of reduced accommodation may have important clinical implications in the low-vision rehabilitation of young people with visual impairment. This high prevalence, together with the habitual close working distance of these patients, may be used to argue in favor of routine assessment for, and more frequent prescription of, near additions. This has been suggested in some rehabilitation literature,[2,3,5] although, in general, little attention has been given to whether these young patients experience visual difficulties or asthenopia due to insufficient accommodation. Many practitioners assume that most phakic children can exert ample accommodation for their closer-than-normal reading distances and that reading adds are more the exception than the rule.[31] Alternatively, the present results may be used to argue that, because of the system's insensitivity to blur, there is less need for accurate accommodation and thus less demand on the system and no need for a near add to focus the system. The present results cannot theoretically distinguish between these arguments. Further study is needed to demonstrate whether near VA is improved with reading adds when accommodation is decreased.

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