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A Dynamic Relationship between Myopia and Blur-driven Accommodation in School-aged Children

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Previously we reported that recently myopic children accommodated insufficiently to blur induced by negative lenses. The purpose of the present study was to relate changes in blur-driven accommodation to myopia development in children. Refractive errors and the accommodation response function (ARF) were measured in 23 myopic and 40 emmetropic children on two occasions separated by periods ranging from 6 to 12 months. Repeated measures of accommodation were made with a Canon R-1 autorefractor while negative lenses of increasing power were placed in front of the child's right eye viewing 20/100 letters at 4 m. Concomitant changes in refractive error and in accommodative function over periods of 6–12 months were found to be highly correlated in myopes (r=0.77) but not in emmetropes (r=0.09).

Myopia Accommodation Refractive error Children's vision.

INTRODUCTION

The etiology of juvenile myopia has been debated for centuries (for a review see Curtin, 1985). Epidemiological studies have shown a correlation between amount of near work, such as reading, and myopia onset and progression (Angle & Wissman, 1978; Richler & Bear, 1980). As a result of this link, increased accommodative effort during near work has been proposed as a causative factor in the development of myopia. Results of some animal studies, however, question the role of accommodation and point to local control of eye growth. A recent study in chickens indicated that atropine reduced experimental myopia by a nonaccommodative mechanism (McBrien, Moghaddam, & Reeder, 1993). In addition, newly myopic children were found to have reduced, rather than increased, accommodation induced by negative lenses (Gwiazda, Thorn, Bauer, & Held, 1993a). Functions relating accommodative response to accommodative demand in myopic children, when compared to functions of emmetropes, were characterized by shallower slopes. Based on these data, one possible scenario is that near work for children with reduced accommodation results in chronic blur, and that it is the blur, not the accommodative effort, that induces myopia. However, accommodative lag for real objects at a near distance is only slightly, but significantly, greater for young myopes than for emmetropes (Gwiazda *et al.*, 1993a). Thus, during near work myopic children would be exposed to only slightly more blur than emmetropes.

"Flat" accommodative response functions (ARFs), as shown by some myopic children, are seldom reported in the classic literature on accommodation. So-called "typical" ARFs of practiced adult observers usually show a small lead for low dioptric stimuli and a small lag for high dioptric ones, with a steep slope for the linear portion of the function. In an oft-cited study, Morgan (1944) tested 50 college students aged 20–30 yr and reported that

"in all cases the measurements of relative accommodation gave very similar results" (p. 186)

to the typical function described above. Contrary to this statement, Morgan in a later section of the same paper reported that the range of accommodation varied considerably among his subjects.

"There were great individual differences with some subjects showing a definite asymptote while others did not. As the limit of positive accommodation was reached, the apparent behavior of accommodation became erratic, sometimes the necessary effort was made and at other times it was not made" (p. 187).

In agreement with the later section of Morgan (1944), other studies using naive subjects reported large individual differences in accommodation, with some subjects accommodating accurately and others showing poor accommodation to blur (Charman & Tucker, 1978; Owens, 1984; Kergoat & Lovasik, 1990). In accord with our recent finding and that of Jones (1990), it is probable that many of the poor accommodators were recent myopes. Jones (1990) reported that the slope of the

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ARF was significantly lower in myopic compared to emmetropic subjects. He questioned whether this accommodative abnormality was a cause or an effect of myopia. Another possibility is that a common factor, as yet unidentified, accounts for both.

Clinicians have reported that accommodative problems such as accommodative insufficiency (difficulty stimulating accommodation or ill-sustained accommodation), low positive relative accommodation (difficulty increasing accommodation), and low amplitude of accommodation (reduced range of accommodation), often seen in newly myopic children, disappear when the myopia stabilizes (Birnbaum, 1981). However, these assertions are based solely on anecdotal reports. Longitudinal studies are necessary to determine the time courses of the development of accommodative deficiencies and myopia and the relationship between them, causal or otherwise. In the Infant Vision Laboratory at MIT we have been tracking refractive errors in a large group of children for 19 yr. Every 6 months to 1 yr the older children return to the laboratory for refraction and other measures, including measurements of accommodation. In order to determine the temporal relationship between the two, we measured concomitant changes in refractive error and accommodative responsiveness in a large group of children, some of whom either were or were becoming myopic.

METHODS

Subjects

We measured accommodation and refractive error on two occasions separated by 6 months to 1 yr in 63 children, aged 6–18 yr. The experiment was undertaken with the understanding and written consent of the subjects and their parents. Prior to measuring accommodation, all subjects were refracted using noncycloplegic distance retinoscopy with a target at 4 m. No subject had astigmatism >1.0 D and none had anisometropia, defined as a difference in spherical equivalent between the two eyes >1.0 D.

On the first visit 40 of the subjects were emmetropic (Rx range: −0.25 to +0.75 D) with a mean spherical equivalent of +0.13 D. Twenty-three were myopic (Rx range: −0.38 to −5.25 D), with a mean spherical equivalent of −1.51 D. On the second visit the mean spherical equivalent had decreased by 0.34 D for the myopic subjects and increased by 0.07 D for the emmetropic children. Seven of the 23 myopic children wore corrective lenses all the time, seven occasionally wore corrective lenses, and nine had no prescription. During testing all subjects wore their best subjective correction (most plus) within 0.25 D.

Procedure

The procedure has been described in a previous paper (Gwiazda *et al.*, 1993a). Accommodative responses were measured using a Canon R-1 Autorefractor, an optometer that allows targets to be viewed at any distance through an infrared reflecting mirror. The target consisted of 20/100 letters in a 3 × 3 illuminated array placed 4 m from the subject's eye. Luminance of the target was 10 cd/m^2.

All measurements were made on the right eye only, with an occluder covering the left eye. The subject's eye was aligned in the Canon R-1 autorefractor with the use of a chin and forehead rest. The subject was instructed to keep the letters as clear as possible, and periodically was asked to read a row or column.

For the first series of measures for all 63 children, trial lenses from 0 to −10 D in 0.5 D steps up to −6.0 D, and in 1.0 D steps thereafter in a sequence from least to most minus were placed in lens cells fitted to spectacle frames. For the second series of measures on the same children the lenses were sequenced from 0 to −10.0 D in 1.0 D steps. This range was used for subjects without refractive error. If the subject had a refractive error, the lens series was adjusted to use it as the zero point for the added lenses. For example, the range of lenses for a −2.0 D myope was −2.0 to −12.0 D. Only one lens was placed in the lens cell at a time. The lens cells were tilted forward by 10 deg in order for the autorefractor to make a reading unaffected by reflections. Tilting the lens induced a small astigmatism, which may have reduced the accommodative demand by 5% at most. A minimum of three measurements was taken for each lens value.

Data analysis

After correction for lens effectivity, the slope, range of accommodation, and area under the curve (AUC) were calculated for the linear portion of each individual ARF. Details of this analysis are described in the Appendix.

RESULTS

As shown in Fig. 1, the initial measures of accommodative range of the children vary from zero to almost 10.0 D, the limit in this study. No child actually achieved a range of 10.0 D because of correction for lens effectivity. The distribution of slopes of the linear portion of the ARF in this group is also broad. The Pearson

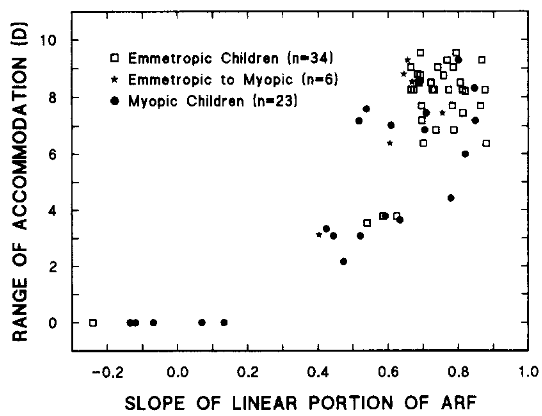

FIGURE 1. Scatter plot relating the range of accommodation to the slope of the linear portion of the accommodative response function in 63 children at first visit. Pearson $r = 0.84$.

TABLE 1. Comparison of range of accommodation and slope of the linear portion of ARFs for myopic and emmetropic children

	Myopes	Emmetropes	P value
Range of accommodation	4.7 D	7.5 D	<0.00001
Slope of ARF	0.50	0.70	<0.001

correlation between range and slope for all 63 children is 0.84, $P<0.00001$. When the functions with a range of zero are omitted from the analysis, the correlation drops to 0.64, but remains equally significant, $P<0.00001$. All but one of the emmetropic children who became myopic had initial slopes and ranges similar to the other emmetropes (who remained emmetropic), suggesting that reduced accommodation does not precede the development of myopia. Significant differences between myopes and emmetropes are found in both range and slope, as reported in Table 1. The mean accommodative range for lens-induced blur for the myopic children is 4.7 D, which is significantly less than the 7.5 D range shown by the emmetropes ($P<0.00001$). The mean slope of the linear portion of the ARF is 0.50 for the myopic children. This is significantly less than the mean slope of 0.70 for the emmetropic children ($P<0.001$). The mean slopes in the present study are steeper than those in our earlier study because of a methodological difference in calculating slope.

Figure 2 shows two accommodative response functions for one child, emmetropic on visit 1 and myopic a year later. On both occasions the testing procedure was the same, but the ranges of accommodative response were quite different. On the first visit, at 9.7 yr, the function was linear and did not have a break point over the full range of accommodative demands. On the second visit a year later the spherical equivalent of this child was 0.75 D more myopic and the function broke at 5 D. Thus within a year the range of accommodation was reduced considerably, as was the AUC. The fact that accommodative responses are occasionally negative for zero accommodative demand, as seen at 9.7 yr, suggests that the subject relaxed accommodation more during testing than during distance retinoscopy. This difference rarely amounts to more than 0.25 D.

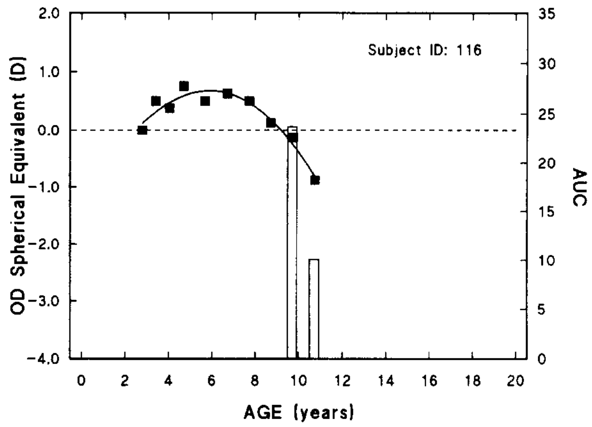

FIGURE 3. Change in spherical equivalent between 2.5 and 11 yr for the subject of Fig. 2. A measure of accommodative function, area under the curve (see Appendix), is depicted by the vertical bars for the two most recent visits.

Figure 3 shows, for the same subject as in Fig. 2, the change in refraction from age 2.5 to 11 yr. Emmetropia is found in the preschool years, followed by the onset of myopia at approx. 10 yr. The area under the curve, depicted by the vertical bars, is also shown for the two most recent visits. On the first visit at 9.7 yr, the AUC was almost 24, reflecting the linear ARF of Fig. 2. At 10.7 yr the AUC was reduced by more than half. The reduction in AUC occurs at the same time, and not before, the increase in myopia.

For children whose myopia has stopped progressing, at least temporarily, the pattern is quite different, as illustrated in Fig. 4. The spherical equivalents for this child show a rapid progression of myopia between 8 and 11 yr of age, then cessation after 11 until 14.5 yr, the last age tested. This subject does not show a large reduction in AUC as in Fig. 3, but quite the opposite, a doubling of the AUC between 13.6 and 14.5 yr.

Figure 5(A) shows the correlation between the change in refractive error (spherical equivalent) and the change in accommodative responsiveness (area under the curve) for the myopic children tested on two successive visits. The Pearson correlation is 0.77. When the spherical equivalent became more myopic by at least 0.5 D, the area

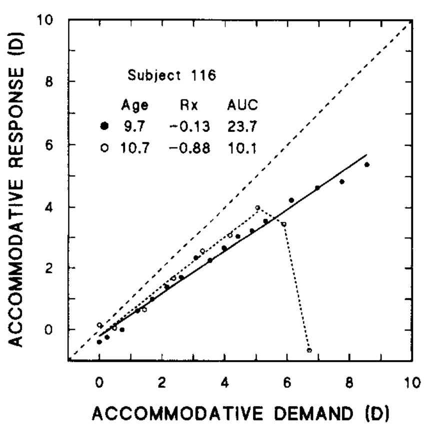

FIGURE 2. Accommodative response functions shown by one child in two test sessions separated by 1 yr.

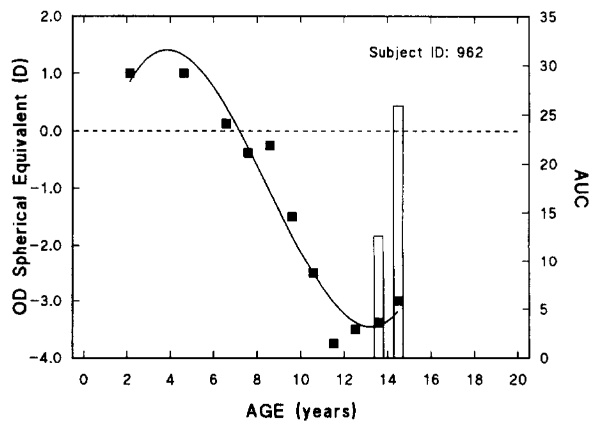

FIGURE 4. Change in spherical equivalent between 2 and 14.5 yr for one subject. The area under the curve is depicted by the vertical bars for the two most recent visits.

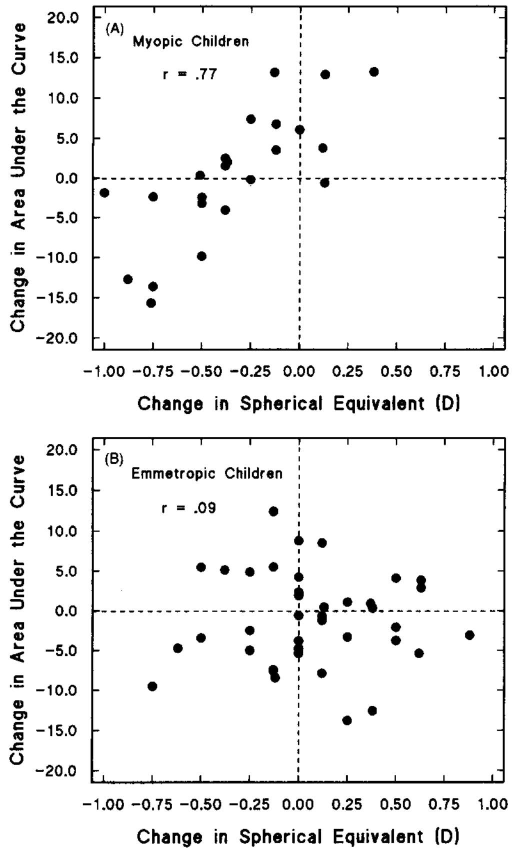

FIGURE 5. (A) Scatter plot relating change in area under the curve to the change in spherical equivalent for the myopic children. Pearson $r = 0.77$. (B) Scatter plot relating change in area under the curve to the change in spherical equivalent for the emmetropic children. Pearson $r = 0.09$.

under the curve decreased, shown in the lower left of the figure. When the spherical equivalent became only slighly more myopic ($\leqslant 0.25$ D) or slightly more hyperopic, the area under the curve increased. Points representing different amounts of spectacle wear, from full-time to none, were distributed in all quadrants of the figure. As shown in Fig. 5(B), the correlation between change in area under the curve and change in spherical equivalent for the emmetropic children was 0.09, a nonsignificant result differing significantly ($t = 3.4$, $P < 0.001$) from the 0.77 correlation found for the myopes.

DISCUSSION

Longitudinal measures of both refraction and blur-driven accommodation provide for the first time a quantitative picture of concomitant changes in myopia and accommodative responsiveness. By tracking both we have shown that accommodation worsens as myopia progresses and then begins to improve with slowed progression of myopia. In agreement with this, concomitant changes in myopia and tonic accommodation (TA) have been reported in a group of young adults followed over a 2 yr period (Adams & McBrien, 1993). TA values became lower as myopia developed, but not before its onset. These results taken together indicate that both blur-driven accommodation and tonic accommodation are reduced during the myopization process. In the future it will be important to ascertain the temporal relationship between increasing myopia and accommodation to real targets at near distances, as has been reported in this paper for optically-blurred targets.

In a previous study we identified risk factors for the development of myopia at school age (Gwiazda, Thorn, Bauer & Held, 1993b). Infants on the myopic end of the distribution of spherical equivalents and those with myopic parents were more likely to become myopic at school age. We suggested that reduced accommodation might also be a risk factor. However, the present results indicate otherwise. The steep slopes and adequate ranges of accommodation shown in Fig. 1 for the emmetropic children who later became myopic, reinforced by the data for the subject in Fig. 3, suggest that accommodative insufficiency is an accompaniment and not an antecedent of myopia. Further tracking studies are needed to clarify this issue.

Implications for mechanisms underlying myopia onset and progression

The correlation between blur-driven accommodation and myopia suggests that either one causes the other, or more likely, that a common factor influences both. Near work may be a factor in the myopization of at-risk eyes (Gwiazda, Bauer, Thorn, & Held, 1995). With increased volume of close work, children with a genetic predisposition for myopia may become myopic accompanied by a loss of accommodative responsiveness. Children without a familial history accommodate for near and do not become myopic. From a functional perspective, accommodation and myopia serve the same outcome in maintaining clarity of close objects, although their temporal courses differ. Failure to accommodate is compensated by myopia in a sort of reciprocal process.

Procedural factors that may influence the results

One possible explanation for reductions in accommodative responsiveness in children undergoing myopization is that they are undercorrected much of the time and therefore do not need to accommodate for near targets. When given a new prescription there may be a period of adaptation before they begin functioning as fully corrected myopes. However, our testing condition, with a distant target optically moved closer over a range of lens powers, should not be influenced by this effect.

Another possible explanation is that the size of the letters used in the present study, 20/100, is not an effective stimulus for accommodation. It has been shown, however, that the strongest drive for clearing a blurred image is provided by intermediate spatial frequencies (Owens, 1980). In agreement with this, in an earlier study we found that the slopes of the ARFs were significantly steeper with 20/100 compared to 20/30 letters, especially for myopic children (Gwiazda *et al.*, 1995).

Since accommodative responsiveness increased with repeated testing in some children but decreased in others, the observed changes cannot be attributed to increasing familiarity with the procedure or to practice effects. The lack of a correlation for the emmetropes is also important in this regard.

Therapeutic implications

The finding of reduced accommodation with myopia onset suggests that therapeutic intervention aimed at increasing accommodative functioning might prove effective in slowing the progression of myopia. Anecdotal reports from clinicians support the use of visual training in controlling myopia, but confirmation in the scientific literature is limited. Avetisov (1979, 1990a, b) reported reduced accommodation at the onset of myopia in children and recommended use of visual training with minus and plus lenses for "physiological massage of the ciliary muscle". According to his report in the proceedings of an international symposium on myopia (Avetisov, 1990a), this therapy regimen was effective in preventing or postponing the onset of myopia in almost 2000 Russian schoolchildren. The finding, however, has not been confirmed.

Biofeedback has been touted as a method for myopia reduction, but a carefully controlled study found no reduction in myopia after this form of therapy (Gallaway, Pearl, Winklestein, & Scheiman, 1987). The basic assumption used in biofeedback is that myopic individuals have learned to overaccommodate in response to blur and should be trained to relax their accommodation. In light of our finding of reduced accommodation to blur in recent myopes, this incorrect underlying assumption may be one reason why the outcome of such therapy has not been more positive.

Another method with potential for slowing the progression of myopia, suggested by animal models of myopia, involves treatment with drugs. However, much more needs to be learned about the etiology of human myopia before this therapy is available. Continued tracking of both accommodation and myopia in children should provide new information on the mechanisms involved in myopization. This could lead to the development of effective treatments for halting the progression of myopia.

Summary

In summary, we find that there is no "typical" accommodative response function in response to lens-induced blur, and that the atypicalities are related to refractive error. In agreement with our previous study (Gwiazda *et al.*, 1993a) and that of Jones (1990), the slope of the ARF is generally shallower in myopic individuals. New findings from this study are that the range of accommodation is also reduced in myopic compared to emmetropic children, and that range and slope are correlated. By tracking both accommodation for negative lenses and refractive errors in children, we report a dynamic relationship between blur-driven accommodation and the development of juvenile myopia.

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APPENDIX

The corrections for lens effectivity and the calculations of accommodative demand and response have been described in Gwiazda *et al.* (1993a). The procedure for determining the linear portion of the ARFs consists of a series of linear regressions of accommodative response on accommodative demand. It is best illustrated by example.

For the first regression, all data points are included. The overall slope and r^2 are calculated as shown in Fig. A1(A).

For the second regression, the rightmost data point is excluded, and the slope and r^2 are calculated for the remaining points as shown in

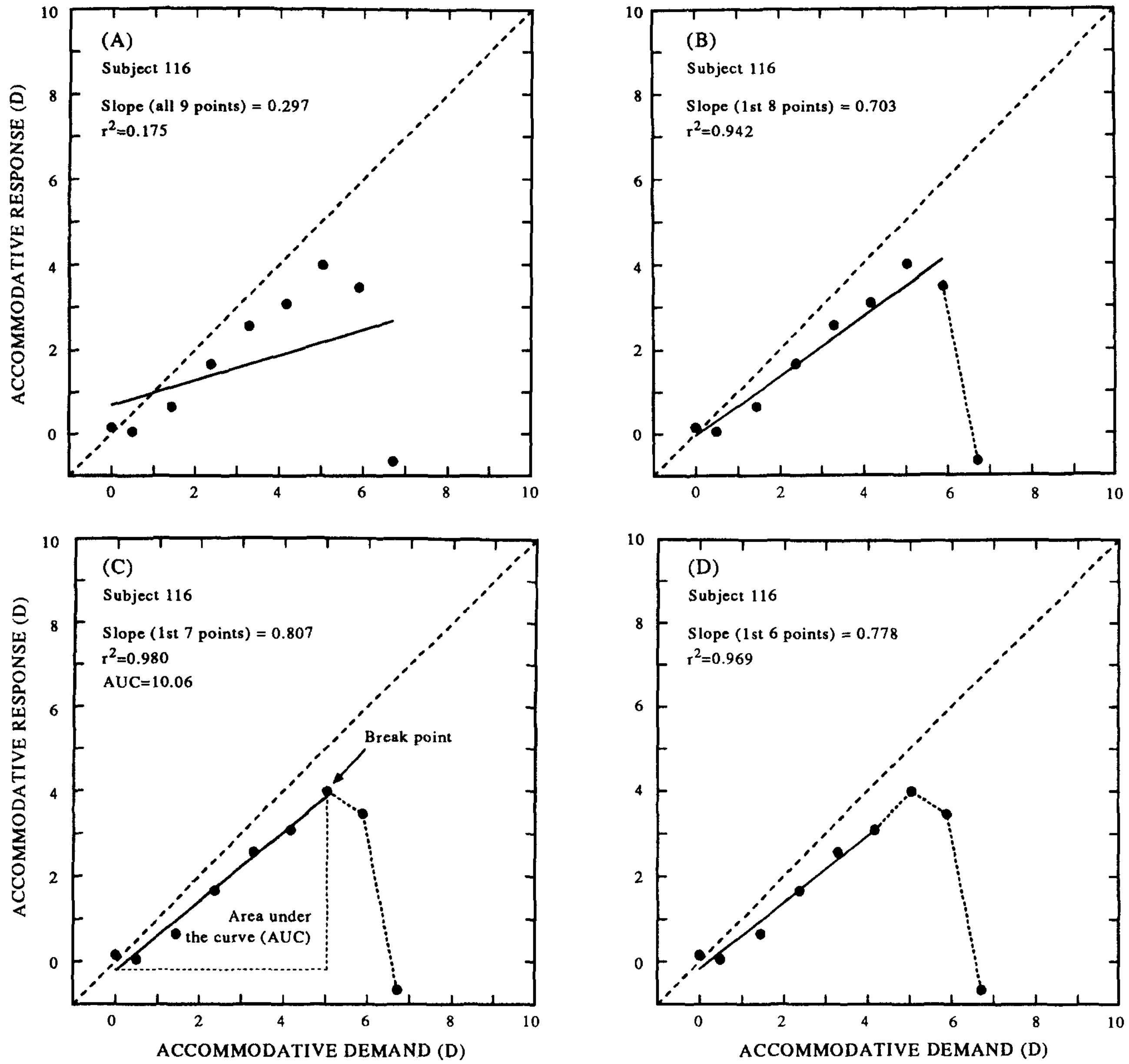

FIGURE A1. Plots of regression lines for the series of linear regressions of accommodative response on accommodative demand used to determine the linear position of the ARF for the subject shown in Fig. 2 at 10.7 yr.

Fig. A1(B). If the r^2 exceeds the previous one by at least 0.1%, the process continues. (If the r^2 does not exceed the previous one by at least 0.1%, the process is terminated and the results from the first regression are used.)

For the third regression, the two rightmost points are excluded, and the slope and r^2 are calculated for the remaining points as shown in Fig. A1(C). Again, the r^2 is greater than the previous one by at least 0.1%, so the process continues.

For the fourth regression, the rightmost three points are excluded, and the slope and r^2 are calculated for the remaining points as shown in Fig. A1(D). The r^2 does not exceed the previous one by at least 0.1%. This terminates the procedure and the linear portion of the curve is defined by the points used in the third regression of this example.

The functions of those subjects who did not accommodate for any of the lenses showed oscillations around zero. The above analysis resulted in slightly negative slopes for four subjects. However, for three of the four, the slopes were not significantly different from zero.

The *linear portion* of the ARF is defined by the points used in the regression prior to the one that satisfied the criterion for termination.

The *slope* of the linear portion of the ARF is the slope calculated in the regression prior to the one that satisfies the criterion for termination.

The *break point* or the *range* of *accommodation* is defined as the accommodative demand at the rightmost point of the *linear portion* of the ARF.

Finally, the *area under* the *linear portion* of the ARF or *area under* the *curve* (AUC) is calculated as follows:

$$\mathrm{AUC} = \frac{a \times b}{2},$$

where a = accommodative demand at the break point and b = accommodative response at the break point.