Accommodation and Refractive Error in Children with Down Syndrome: Cross-Sectional and Longitudinal Studies

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Purpose. To examine the relationship between defective accommodation and refractive errors in children with Down syndrome.

Methods. Children with Down syndrome aged 4 to 85 months were seen at their homes as part of an ongoing study of visual development. Seventy-five children contributed cross-sectional data and 69 children longitudinal data. Accommodation was measured using a modification of Nott dynamic retinoscopy technique, and refractive error measurements were obtained using Mohindra retinoscopy.

Results. Accommodation was poor, regardless of the refractive error present. The total accommodation produced by the children was related to the refractive error at the time of the test, with the degree of accommodation deficit increasing with the amount of positive refractive error. The longitudinal results showed that although children with Down syndrome did not accommodate accurately, the amount of accommodation elicited did not reflect their maximum amplitude of accommodation. Each child showed a consistent degree of underaccommodation for a given stimulus. Spectacles to correct hypermetropia did not improve the accommodative response.

Conclusions. In children with Down syndrome, underaccommodation is substantial, even when there is no, or a fully corrected, refractive error. The accommodation system of children with Down syndrome may have the physical capacity to respond to a given stimulus, but the neural control of the system has an anomalous set point. Spectacles do not remedy the situation. This has important implications, especially for children in a learning environment, because near vision is consistently out of focus. (*Invest Ophthalmol Vis Sci.* 2001;42:55–63)

Accommodation is poor in children with Down syndrome—i.e., the majority of children do not focus accurately on near targets. In our previous studies using dynamic retinoscopy,[1–3] we have reported that the majority of children with Down syndrome show a large underaccommodation, or lag of accommodation, at all distances tested. This lag may be as large as 5.00 D for a target at 10 cm from the child's eyes, whereas control children of the same age range show a lag of less than 1.00 D at this distance.[1,3] This reduced accommodative response is present even when infants as young as 3 months of age are tested.[2] Accommodation may be influenced, of course, by refractive errors, and these have a high prevalence among children with Down syndrome.[4–7] Hypermetropia, the most common refractive error, may be expected to limit the available accommodation for near, because a child with uncorrected hypermetropia must exert accommodation to overcome the refractive error, in addition to that required to focus on a near target. We have reported that children with hypermetropia who have Down syndrome and show accommodative responses below the norm tend to have a higher degree of hypermetropia.[1] Conversely, myopia may be advantageous to a child, because the eye is naturally focused at a relatively closer distance. Thus, if large numbers of children with Down syndrome have high uncorrected hypermetropia, this may explain the observed underaccommodation.

Herein we report both cross-sectional and longitudinal data on accommodation performance in children with Down syndrome and examine, for the first time, the relationship of their refractive errors and spectacle correction with accommodation.

Methods

Subjects

Cross-sectional accommodation and refractive error data were available for 75 children with Down syndrome who are participating in a longitudinal study of visual and cognitive development. Recruitment procedures are described in a previous article.[1] The recruitment and experimental protocols were conducted in compliance with the Declaration of Helsinki and were approved by local ethics research committees in the areas of residence of the children. The youngest children to enter the cohort were 3 months of age; others were already older at the outset of the study in 1992–1993. Cross-sectional data reported herein represent the most recent visit for each child at which the child cooperated for all tests. The mean age of the children was 42.7 ± 23.4 months (range, 4.7–84.7).

During the course of the study, one child died after cardiac surgery, two children moved away from the area and were lost to follow-up, and three children were recruited toward the end of the study period and were seen on only one occasion. Longitudinal accommodation data were thus available for 69 children.

Data from an earlier study[8] in which identical techniques were used with 131 developmentally normal children aged 1 to 45 months were used as control data.

Procedures

The children with Down syndrome were assessed in their home environment, to minimize the distractions that may be present in a

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clinic setting, thus improving cooperation with the tests, as well as enabling families from distant and rural communities, who would find traveling to the university difficult, to participate in the study. Refractive error was assessed objectively using the Mohindra retinoscopy technique.[9] Retinoscopy was performed in darkness with a dimmed retinoscope beam. A working distance compensation was made of 0.75 D for infants aged 2 years and less and 1.00 D for children aged more than 2 years.[8] Studies have shown that the Mohindra technique yields equivalent results to cycloplegic retinoscopy, both for normally developing children[10] and for children with Down syndrome.[2]

A modified Nott dynamic retinoscopy technique[3,11] was used to assess accommodation. While the child looked at targets mounted on the sides of an internally illuminated translucent polymethylmethacrylate cube, the examiner performed retinoscopy to assess the accommodation. The targets consisted of pictures designed to attract the child's attention: a clown, fish, cat, or concentric circles. (The cube was rotated at intervals to reveal a new picture, to maintain the child's interest.) The cube was mounted on a rule and positioned at 10 cm, 16.6 cm, and 25 cm from the child's eyes, equivalent to 10 D, 6 D, and 4 D respectively. The size of the detail ranged from 0.4 mm to 5.2 mm, and therefore the angular subtense varied from 0.23° to 2.96° when the target was at 10 cm to 0.09° to 1.18° when the target was at 25 cm. (Our previous study had shown that this variation in angular subtense with linear target distance has no effect on the accommodative response.[1]) Although the child viewed the target with both eyes, the accommodative state was assessed in one eye only—in most cases, the right eye. However, in children with strabismus and a fixing left eye, accommodation was assessed in the left eye. The retinoscope beam was aligned with the meridian focused closest to the eye for near targets (most myopic or least hypermetropic—i.e., requiring the least accommodative effort for a near target). The retinoscope was moved toward or away from the eye and its position recorded when a neutral reflex was observed. The dioptric equivalent of this distance represented the accommodation response.

For assessment of longitudinal changes in accommodation, the repeatability of the dynamic retinoscopy technique should be known.[12,13] Repeatability was measured for two groups of children from the cohort: 12 infants less than 9 months of age (mean age on the first occasion, 5.90 ± 0.80 months) and 8 older children aged between 4 and 9 years (mean, age 6 years 4 months ± 19.50 months). Each child was seen on two occasions, with an interval of 2 weeks between visits. The examiner was unaware of the first results on the occasion of the second test. The examiner's remembering the data from a previous test was highly unlikely, because several children were tested in the interim.

To provide a comparison for the longitudinal data from children with Down syndrome, we measured the accommodative response in a situation in which there is a known limited amount of accommodation available—that is, in a normal adult emmetrope with presbyopia, aged 36 years, with a subjective amplitude of accommodation of approximately 4.00 D. The same dynamic retinoscopy technique was used, and increasing hypermetropia was simulated with minus lenses (powers −0.50, −1.50, −2.50, and −3.00 D).

Terminology

Full Refractive Error. This is the uncorrected refractive error, expressed in diopters. For this study, the refractive error is defined as the ametropia in the meridian tested during dynamic retinoscopy.

Effective Refractive Error. This refers to the amount of uncorrected refractive error at the time of the test. Children who had spectacles wore their habitual spectacle correction during the test. In cases in which the spectacles only partially corrected the refractive error, the deficit was calculated. Thus, a child with +5.00-D hypermetropia and wearing spectacle lenses of +4.00 D has a full refractive error of +5.00 D but an effective refractive error of +1.00 D (the small effect of back vertex distance is ignored).

Total Accommodative Demand. When uncorrected hypermetropia is present, the total accommodation required to focus accurately on a near target consists of accommodation to eliminate any refractive error, plus accommodation in response to the near stimulus. (For example, to focus accurately on a 10.00-D stimulus, a child with 3.00 D uncorrected hypermetropia would need a total of 13.00 D of accommodation, whereas the same child wearing spectacles that fully correct the refractive error must accommodate by just 10.00 D.) Conversely, a child with myopia must accommodate by a smaller amount when uncorrected. The total accommodative demand therefore equals the dioptric equivalent of the distance of the near target plus any effective refractive error.

Total Accommodative Response. This is the actual accommodation exerted in response to the accommodative demand. It is the measured accommodation response (the retinoscopy neutral point or the focus point of the eyes) plus any effective refractive error.

AEI. The accommodative error index (AEI), first suggested by Chauhan and Charman,[14] describes the discrepancy between the measured accommodative response and the ideal response (i.e., accurate focus) and gives a single-figure value for the error in accommodation. In effect, it is the mean of the response error across the distances tested, divided by the correlation coefficient:

$$AEI = \frac{(1 - m)[(x_1 + x_2)/2] - c}{r^2}$$

where m is the slope of the response line, c is the intercept of the response line, r is the correlation coefficient, x_1 is the dioptric equivalent of farthest stimulus, and x_2 is the dioptric equivalent of nearest stimulus.

The AEI is expressed in diopters, and accurate accommodation at all distances is indicated by an accommodation error index of zero. A value of more than zero indicates inaccurate accommodation.

Repeatability. The repeatability coefficient of the AEI (based on two measurements on separate occasions) is defined as twice the SD of the differences in measurements.[12] Thus, 95% of all differences between two measurements are less than this value.

Results

Accommodative Error Index

Data are expressed as mean ± SD. The AEI was calculated for each child. Correlation coefficients ranged from 0.81 to 1.00 ± 0.035 (mean, 0.978). Thus, for individual children, the accommodative response showed a linear relationship with accommodative demand, and the AEI is representative of the mean accommodative response at the three near distances. AEI ranged from 0.00 to 6.68 ± 1.50 D (mean, 3.68).

Repeatability

For the younger group age group, the repeatability of the AEI was 2.20 D and for the older group 1.95 D. A paired t-test showed no significant difference between successive measurements for either the younger ($t = 0.45$, $P = 0.33$) or older ($t = 1.38$, $P = 0.211$) group.

For control children, the AEI was zero in the majority (55%) of cases,[1] and therefore repeatability of the index is an inappropriate statistic. The slope and intercept of the accommodation response function can be calculated. For the control group the mean difference between measurements on the two occasions was 0.0005 and 0.0024. For the younger group of children with Down syndrome (whose ages lie within the age-limits of the control group), the mean difference in pairs of measurements was 0.14 ± 0.12 and 0.91 ± 0.63 for slope and intercept, respectively.

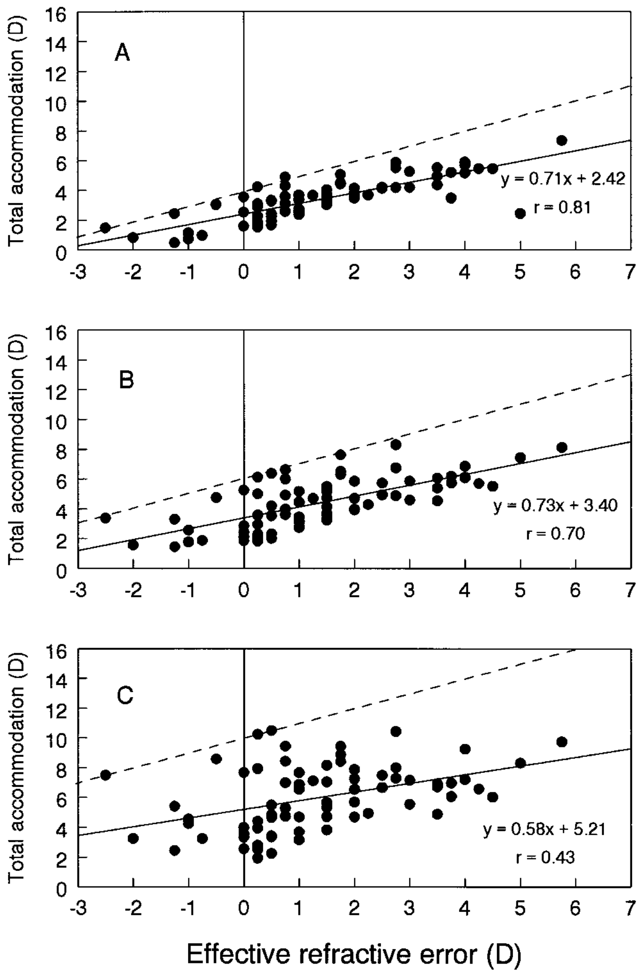

FIGURE 1. Total accommodation and effective refractive error in 75 children with Down syndrome, at three target distances: (**A**) 25 cm (4.00 D), (**B**) 16.6 cm (6.00 D), (**C**) 10 cm (10.00 D). The least-squares regression line through the data are shown in each case (*solid line*) with its equation and correlation coefficient. In each figure the *dashed line* represents accurate accommodation to the target.

Relationship between Accommodation and Refractive Error

Full refractive error (for the meridian tested) ranged from −8.00 D to +6.00 D (mean, +1.70 ± 2.48). Effective refractive error ranged from −2.59 D to +5.75 D (mean, +1.35 ± 1.64). Forty children had an effective refractive error of greater than ±1.00 D. Astigmatism ranged from 0.00 to 3.00 DC. Twenty-one children had effective astigmatism (i.e., when wearing spectacles) of 1.00 D or more, 11 had 1.00 DC, 9 had 1.50 to 2.00 DC, and 1 had 3.00 DC.

For each of the target distances, the total accommodative response was calculated. The results for all children are shown against effective refractive error in Figure 1. Also shown is the ideal relationship, which represents the total accommodative demand or accurate accommodation irrespective of refractive error. A few children showed accommodation close to the ideal; most did not. There was increased scatter at the closest target distance (10.00 D); nevertheless, in all three plots, the data describe a significant linear relationship, (r = 0.81, 0.70, and 0.43 for the target at 4.00, 6.00, and 10.00 D, respectively; analysis of variance [ANOVA], F = 138.9, 71.91, and 16.98, $P <$ 0.01, 0.01, and 0.01, respectively). The regression lines lay below the demand, showing a consistent underaccommodation for the majority of the children. The slope of the linear relationship was less than 1 in each case, which suggests that the greater the effective plus refractive error, and therefore the greater the accommodative demand, the greater the underaccommodation.

The regression lines in Figure 1 show that the total amount of accommodation that the children produced was dependent on the target distance. The discrepancy between the demand and the response increased as target distance decreased.

Effect of Spectacle Correction

Some children who provided the data illustrated in Figure 1 had low effective refractive errors, either because they were emmetropes or because they were wearing spectacles to correct the refractive error. Others had a higher effective refractive error because they were ametropes and had no spectacles. To investigate the role of the spectacle correction, the cohort was divided into refractive groups based on the full refractive error: myopia greater than −0.75 D; emmetropia or no significant error, between −0.75 and +2.75 D; hypermetropia, greater than or equal to +3.00 D. This division of refractive groups has been used in other studies to denote clinically significant errors.[15,16] The children were then further divided into those who were wearing spectacles and those who were not, resulting in five groups: (1) myopes with no spectacle correction, (2) myopes wearing spectacle correction; (3) emmetropes or no significant error, (4) hypermetropes with no spectacle correction, and (5) hypermetropes wearing spectacle correction.

The mean AEI for each of the groups is given in Table 1. ANOVA revealed that there was a significant effect of refractive group (F = 11.662, df = 4, $P < 0.001$, post hoc Tukey test $P <$ 0.05). Emmetropes had a more accurate response than hypermetropes, both corrected (P = 0.049) and uncorrected ($P <$ 0.001) and were also more accurate than corrected myopes (P = 0.049). Uncorrected myopes also had a more accurate response than hypermetropes (corrected P = 0.002, uncor-

TABLE 1. AEI for Children with Down Syndrome

	n	Effective Refractive Error	AEI
Emmetropes	41	+1.20 ± 0.89	3.07 ± 1.42 (0.00–5.29)
Myopes (no spectacles)	6	−1.50 ± 0.61	2.63 ± 1.52 (0.00–4.34)
Myopes (with spectacles)	4	+0.56 ± 0.66	4.77 ± 0.66 (3.82–5.27)
Hypermetropes (no spectacles)	14	+3.96 ± 0.75	4.78 ± 0.78 (3.50–6.24)
Hypermetropes (with spectacles)	10	+0.50 ± 0.61	4.93 ± 0.90 (3.55–6.68)

Children were divided into groups according to full refractive error and spectacle wear. Median AEI for normally developing children is 0.00 and 95% have AEI between 0.00 and 2.20D.[1] Data are in mean diopters ± SD. AEI range is in parentheses.

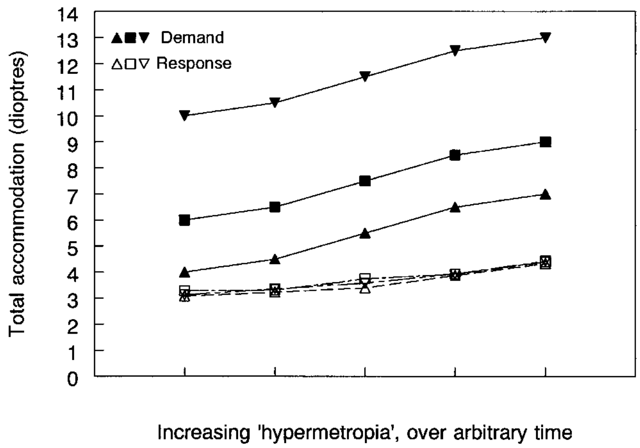

FIGURE 2. The effect of increasing hypermetropia, simulated with negative lenses, in an adult with presbyopia. Total accommodative demand (*filled symbols*) and total accommodative response (*open symbols*) to a stimulus at 4.00 (*triangles*), 6.00 (*squares*), and 10.00 D (*inverted triangles*).

rected $P = 0.003$). Surprisingly, there was no difference in the accommodative response between corrected and uncorrected hypermetropes ($P = 0.991$). Although the mean accommodative error of corrected myopes was greater than that of uncorrected myopes, the difference did not reach significance ($P = 0.054$).

The accommodative response was recorded in the right eye, except for cases of right strabismus. It is possible that in anisometropia, the eye not assessed could have determined the accommodative response. Only eight children had anisometropia of more than 1.00 D (two emmetropes, two corrected hypermetropes, two uncorrected hypermetropes, and two corrected myopes). Excluding these children from the analysis yielded similar results (ANOVA, $F = 6.59$, $df = 4$, $P < 0.001$), except that there was no significant difference between emmetropes and corrected myopes.

The accommodative response was recorded in the meridian deemed to require the least accommodative effort for near—that is, the most myopic or least hypermetropic meridian. Of the 21 children with significant astigmatism, 5 had uncorrected myopia, and 1 had corrected myopia. Thus, excluding these children left too few myopes to proceed with analysis. All children with significant astigmatism were excluded and the comparison confined to emmetropes and hypermetropes. The results were similar (ANOVA, $F = 12.86$, $df = 2$, $P < 0.001$): Emmetropes had a more accurate response than either corrected or uncorrected hypermetropes, and there was no difference between corrected and uncorrected hypermetropes.

Longitudinal Changes in Refractive Error

Hypermetropic refractive errors increased over time in some of the children of the cohort, and our longitudinal data allow us to examine the effect of refractive error changes on accommodation. First, for the purposes of comparison, accommodative responses in a normal adult emmetrope with presbyopia were examined. In Figure 2, total accommodation produced by the subject for the target at the three distances, in response to increasing accommodative demand due to (simulated) effective refractive error is shown. As expected, the curves for the different stimulus distances superimposed (i.e., the total accommodation exerted) were similar at all stimulus distances, being subject presumably to the individual's maximum amplitude of accommodation (in the case illustrated, 4.50 D). Thus, no matter what distance the target was from the subject, he exerted maximum accommodation in an attempt to make the target as optically clear as possible. Further, the total accommodation changed very little (just over 1.00 D) when the simulated refractive error increased.

By contrast, the longitudinal data for each individual child with Down syndrome show quite a different, and unexpected, response. Figure 3 shows the total accommodation in response to changing accommodative demand of one child seen at regular intervals between the ages of 8.5 and 18.5 months. Figures 3A, 3B, and 3C show responses for target distance equivalent to 4.00, 6.00, and 10.00 D, respectively. The curves for each stimulus distance closely follow any change in accommodative demand, imposed by a change in refractive error. At the age of 8.5 months, the refractive error was +1.75 D. When the child fixated the 10.00-D stimulus (Fig. 3C), the demand was $10.00 + 1.75 = 11.75$ D, and the total accommodative response was 5.32 D. Between 12 and 18 months of age, her refractive error increased; at 18.5 months it was +3.75 D. If the accommodation were limited at these demands, as in the case of a presbyope, little, if any, change in total accommodation would be expected. However, in response to a 10.00-D stimulus, we now measured a total accommodative response of 6.98 D, an increase of 1.66 D. At each target distance, as effective refractive error (and therefore accommodative demand) changed, the total accommodative response changed

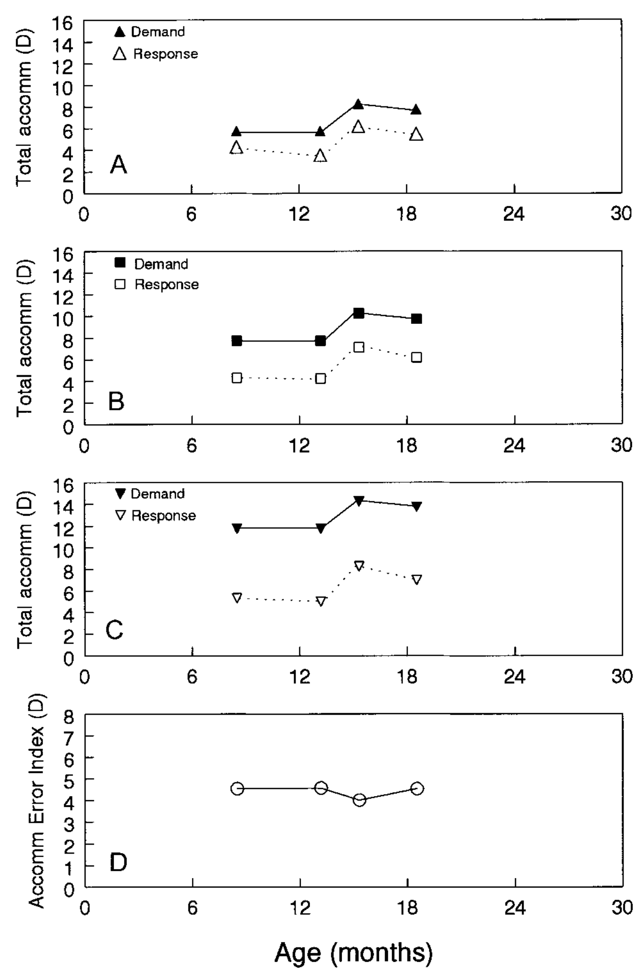

FIGURE 3. Total accommodative demand (*filled symbols*) and response (*open symbols*) in one child with Down syndrome whose refractive error changed over time, with stimulus at (**A**) 4.00 D (*triangles*); (**B**) at 6.00 D (*squares*); (**C**) at 10.00 D (*inverted triangles*). (**D**) AEI.

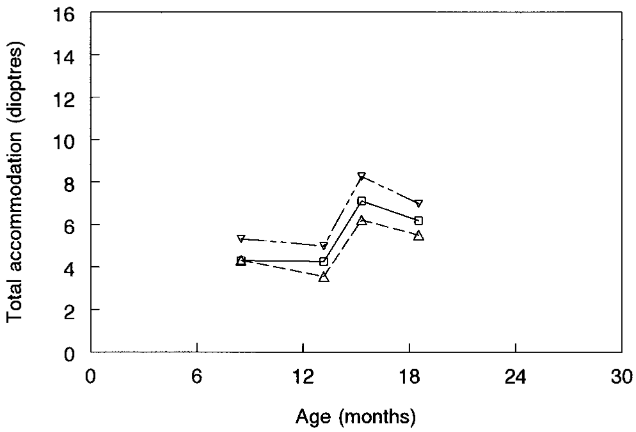

Figure 4. Total accommodative response, from Figure 3A through 3C, plotted on a single figure. Stimulus at 4.00 D (△); 6.00 D (□); and 10.00 D (▽).

accordingly. Further, the response to a stimulus at 10.00 D was always greater than the response to a stimulus at the other two distances. Figure 3D shows the AEI for this particular child, which remained similar (4.54 D at 8.5 months and 4.54 D at 18.5 months), despite large changes in refractive error and therefore in accommodative demand.

Figure 4 shows the response curves for the three target distances on a single graph. Rather than superimposing, as was the case for the presbyope (Fig. 2), the curves remained separate. This phenomenon was observed in each child who participated in the longitudinal study and who had an AEI greater than zero on each occasion ($n = 64$). In no case did the curves for the different target distances superimpose.

Effect of Spectacles

Most children in whom the refractive error increased substantially during the course of the study were prescribed spectacles (either by the study team or by the local hospital eye department). Spectacle wear rendered a large change in effective refractive error. For inclusion in longitudinal data analysis, we used the following criteria: data available for at least one occasion before spectacle wear and for at least three occasions beyond the age of 8 months. We excluded accommodation data before 8 months, because studies have shown that accommodation in the early months can be variable.[17,18] Data for 13 children (subjects A through M) fulfilled these criteria. Nine of these children (subjects A through J) were hypermetropes. Correction of hypermetropia with spectacle lenses would be expected to result in a greater amount of accommodation available to respond to a given near stimulus. If the children's accommodation were limited to that exerted before spectacle wear, total accommodation is expected to be similar with and without spectacles and accommodation to be more accurate with spectacles, represented by a lower AEI.

Data from one child (subject A), typical of the group, are shown in Figure 5. At the first recorded visit, the refractive error was +1.00 D. In response to a 10.00-D stimulus (Fig. 5C), the demand was $10.00 + 1.00 = 11.00$ D, and the total accommodation produced was 6.56 D. The AEI was 2.74 D (Fig. 5D). By the time this child was 30 months old, her refractive error had increased to +5.00 D, and spectacles had been prescribed. The spectacles fully corrected the hypermetropia, rendering an effective refractive error of zero. The demand to a 10.00-D stimulus was now 10.00 D, and we found a total accommodation of 4.76 D. The AEI remained large, 3.58 D. On a subsequent occasion, at the age of 36.5 months, this child refused to wear her spectacles. In response to a 10.00-D stimulus, (and a demand of 15.00 D) we measured a total accommodation of 8.33 D. Despite the absence of spectacle correction, the AEI did not increase significantly, 4.35 D. On the last occasion, she was wearing her spectacles, and the total accommodation exerted decreased, but the AEI remained high: 4.12 D. Thus, contrary to expectation, total accommodation varied by an amount roughly equivalent to the refractive error and, rather than showing more accurate accommodation with spectacles, the child maintained the same level of underaccommodation with and without spectacles.

The AEIs for the other hypermetropes (subjects B through J) before and after spectacle wear are shown in Figure 6, and the data are listed in Table 2. No child showed accurate accommodation with or without spectacles, and most showed no improvement in accommodation accuracy with spectacles. Only two children, subjects I and J, showed a large (i.e., outside the limits of repeatability) reduction in AEI immedi-

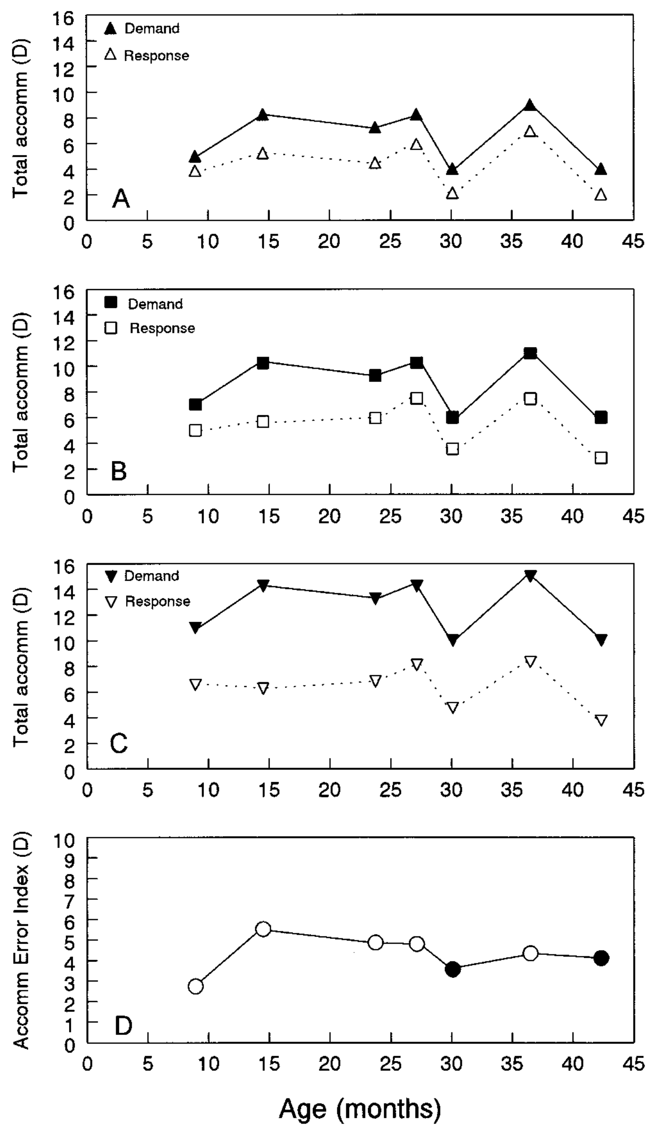

Figure 5. (**A**, **B**, and **C**) Total accommodative demand (*filled symbols*) and response (*open symbols*) in one child with Down syndrome wearing spectacles to correct hypermetropia during visits at 30 months and 42 months. (**A**) Stimulus at 4.00 D (*triangles*); (**B**) at 6.00 D (*squares*); (**C**) at 10.00 D (*inverted triangles*). (**D**) AEI without (*open symbols*) and with (*filled symbols*) spectacles.

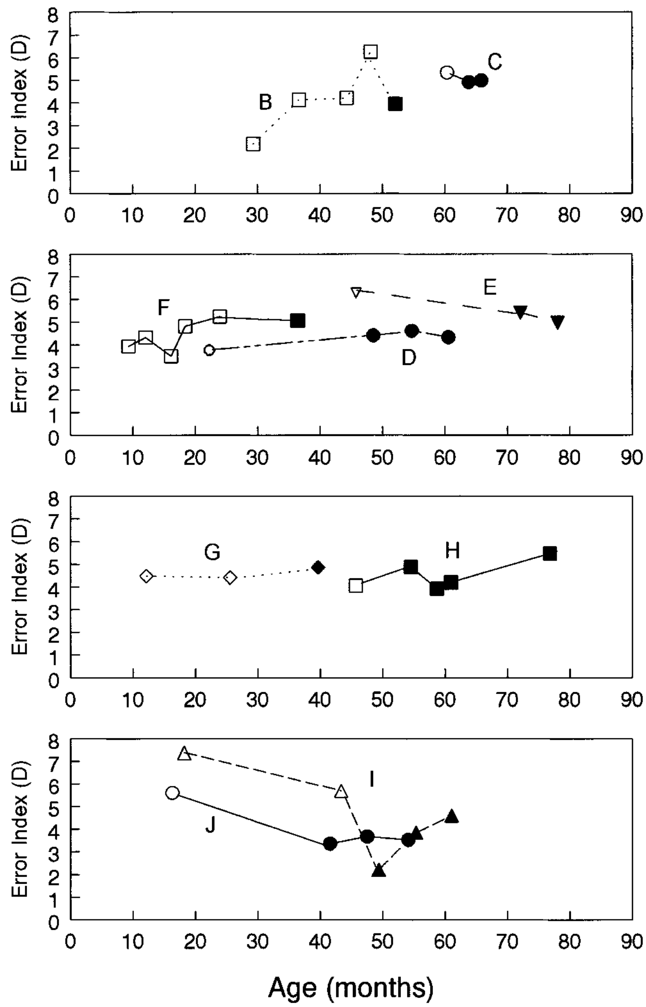

FIGURE 6. AEI in nine children with Down syndrome, prescribed spectacles for hypermetropia, without (*open symbols*) and with (*filled symbols*) spectacles.

ately after spectacle wear; in subject J, on subsequent occasions the accommodation error increased again. Overall, the provision of spectacles to correct hypermetropia did not influence the accuracy of accommodation as shown by the AEI (paired *t*-test for the occasion immediately before spectacle wear and the first subsequent visit at which spectacles were worn and the child cooperated for all tests, $t = 1.45$, $P = 0.181$). The mean effective refractive error change induced in the hypermetropic group by spectacles was 4.30 ± 0.73 D (i.e., from a mean refractive error of +4.78 D to a mean of +0.48 D). The mean change in AEI was 0.491 D (95% confidence interval −0.28–1.26 D). Only two of the children in Figures 5 and 6 had significant astigmatism, child D who had 1.50 DC and child F who had 1.00 DC.

The AEI for the other three children (subjects K to M) is shown in Figure 7 and Table 2. These show the effect of minus spectacle lenses on the accommodation response. Child K had low myopia fully corrected by spectacles. Child L had mild hypermetropic astigmatism. However, he was wearing spectacles (minus lenses) that overcorrected the refractive error, rendering the eye artificially hypermetropic (and an effective astigmatic error of 1.50 D; this child was included with the myopia group to show the effect of using a minus lens on the accommodation system). Spectacle wear slightly increased the accommodation error for both these children. Child M had higher myopia of −6.50 D, fully corrected by spectacles. Before spectacle wear, her eyes had a natural focus at near, and the accommodation error was very small. Provision of spectacles hindered her accommodation response, and the AEI increased dramatically with the spectacles.

The Effect of Age

Because in normally developing infants, accommodation becomes more accurate in the first months of life, longitudinal data for the very young infants were analyzed. Fifteen children were seen from the age of 3 to 4 months at regular intervals, and data were available for each child at the following ages: 4, 6, 9 to 12, 24, and 36 months. The mean AEI at each age is shown in Figure 8. A repeated-measures ANOVA ($F = 3.12$, $df = 4$, $P = 0.020$) showed that there was a significant difference in the AEI at these ages, with a higher error index at older ages. However, the increase in AEI between 4 and 36 months (from 2.84 to 3.54 D) is not outside the limits of repeatability (2.20 D).

When longitudinal data for all children were examined, only 11 children showed a change in AEI between first and last visit of greater than the repeatability error. Of these, three showed an improvement in accommodative response (lower AEI), and eight showed a deterioration in accommodation (higher AEI).

Discussion

Our results confirm the underaccommodation that we have previously reported in children with Down syndrome.[1–3] The results also show that it is not only hypermetropic children who exhibit underaccommodation, but children with all types and amounts of refractive error (Fig. 1).

Studies of accommodative response in normally developing children show accurate accommodation, implying that, if data were plotted as our Figure 1, control data would lie close to the ideal curve illustrated. In general young children show accurate accommodation to targets at 4.00 and 6.00 D,[3,11] with a small mean lag of 0.20 to 0.48 D for older children (up to 12 years) and/or for closer targets.[3,11,19] Of course, a limit to any comparison is that normally developing children do not show the same range of refractive errors as are exhibited by children with Down syndrome.[4]

The cross-sectional data also show a tendency for underaccommodation to increase with increased accommodative demand. Although the findings that hypermetropes have less accurate accommodation than the other refractive groups may not be surprising, it is clear that even emmetropes who have Down syndrome often show substantial underaccommodation. The normal value (95th percentile) for AEI in young children is 0 to 2.20 D with a median value of 0.00 D.[1] The mean AEI for emmetropes with Down syndrome (3.30 D) lies outside this normal range (see Table 1). Even among uncorrected myopes, who have the lowest accommodative demand for near targets, there is underaccommodation, and a mean AEI (2.94 D) outside the normal range.

One possible cause of underaccommodation could be lens mechanics setting a limit on the total accommodation possible, as in presbyopia. Indeed, we have previously argued that children with Down syndrome behave like adults presbyopes when responding to near targets and have suggested that accommodation is abnormally limited.[2] These new data emphatically demonstrate that this is not the case. There was no evidence of saturation of the accommodative response at the demands we set. The total amount of accommodation that children with Down syndrome produced to a near target was related to the accommodative demand imposed by their refractive error. In our cross-sectional data, the linearity of the rela-

TABLE 2. AEI and Effective Refractive Error for Children with and without Spectacles

Subject	Age Interval (mo)	AEI (D)		Effective Refractive Error (D)	
		Without	With	Without	With
A	27.14–29.96	4.81	3.58	+4.25	0.00
B	36.67–52.07	4.09	3.96	+4.50	+0.75
C	60.35–65.87	5.38	4.98	+5.00	+0.50
D	22.30–48.53	3.76	4.41	+4.50	+1.00
E	45.80–78.06	6.28	4.97	+6.00	0.00
F	23.95–36.44	5.21	5.07	+4.75	+1.25
G	12.20–39.69	4.47	5.15	+4.25	0.00
I	43.37–55.36	5.74	4.09	+5.50	+0.50
H	46.00–54.54	4.05	4.89	+5.00	+1.00
J	16.30–41.59	5.60	3.37	+4.00	0.00
K	48.50–66.73	3.62	4.41	−2.50	0.00
L	34.00–53.98	3.01	5.68	0.00	+2.00
M	35.00–42.25	0.73	3.56	−6.50	−0.50

The AEI is given for the visit immediately before spectacle wear commenced (without) and for the latest visit at which spectacles prescribed during the study were worn (with). The age interval column gives the age of each child at the two relevant visits. Data for subject A are shown in Figure 5, for subjects B through J in Figure 6, and for subjects K, L, and M in Figure 7.

tionship between effective refractive error and the total amount of accommodation produced by the children to a near target is striking (Fig. 1). It appears that individual children produce sufficient total accommodation for a predetermined amount of underaccommodation that is remarkably consistent among children with Down syndrome.

Our longitudinal data also refute our earlier suggestion that children with Down syndrome are presbyopes. When a presbyope is confronted with a series of near targets, the total accommodative response is similar for each target distance and represents the amplitude of accommodation. In other words, when a presbyope views a near target he or she exerts as much accommodation as is available, and the response curves for the different target distances superimpose (Fig. 2). In contrast, all children with Down syndrome who underaccommodated for near targets, showed underaccommodation that varied consistently with target distance, and in no case did the response curves superimpose. As refractive error changed, so did the total accommodative response (Fig. 3).

Spectacle correction for the distance refractive error does not appear to benefit the children's accommodative responses to near. The mean AEI for the young hypermetropes who were wearing spectacles at the time of testing was identical with that for uncorrected hypermetropes (Table 1). This finding is confirmed for individual children by our longitudinal data. In spite of relatively large changes in effective refractive error, the AEI of children with hypermetropia remained similar before and after spectacle wear. The hypermetropes did not take advantage of the spectacle correction to accommodate more accurately at near but maintained a consistent underaccommodation at each target distance. These data show that, although children with Down syndrome do not accommodate accurately, the total amount of accommodation exerted on any occasion does not necessarily represent their maximum amplitude of accommodation. Indeed, we have not demonstrated saturation of the response in any child and therefore have not reached the maximum amplitude of the children's accommodation.

In recording accommodation by Nott retinoscopy, we have made assumptions about the eye and meridian that determines the accommodative response. Anisometropia is uncommon, and so minimum error is introduced by the use of right eye data only for most children. Astigmatism can be a complicating factor; we have chosen to record responses in the meridian requiring least accommodative effort for near targets. If our assumption is incorrect, then we have overestimated accommodative accuracy, and the underaccommodation is even greater than we have recorded. Excluding children with astigmatism from cross-sectional data analysis does not change the outcome, and only three of the children whose longitudinal data are shown in Figures 5 to 7 had astigmatism.

The underaccommodation of children with Down syndrome is consistent with a large depth of focus. The depth of focus of any eye is dependent partly on pupil size; a smaller pupil gives rise to a larger depth of focus. We have not measured pupil size in the children of the cohort, because general clinical observations during data collection had not indicated any obvious abnormalities in size. Using Green's formula,[20] it can be shown that any optical depth of focus consistent with the data requires pupil sizes markedly smaller than any we have observed.

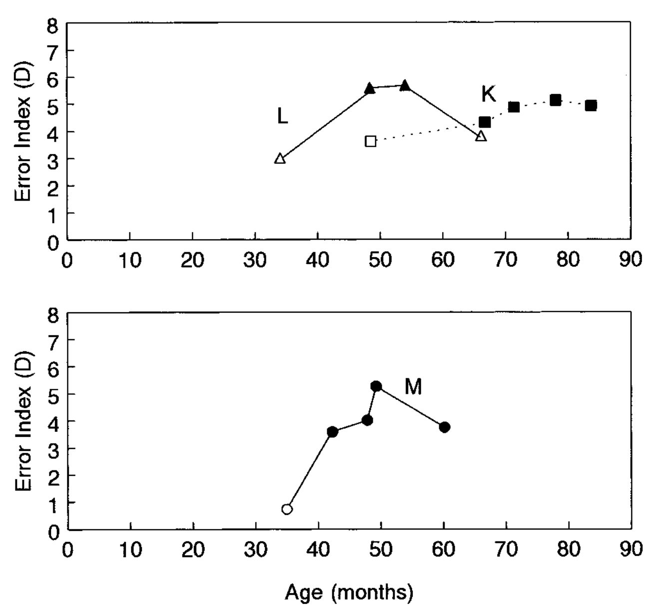

FIGURE 7. AEI in three children with Down syndrome prescribed spectacles for low myopia (K and L) and higher myopia (M), without (*open symbols*) and with (*filled symbols*) spectacles.

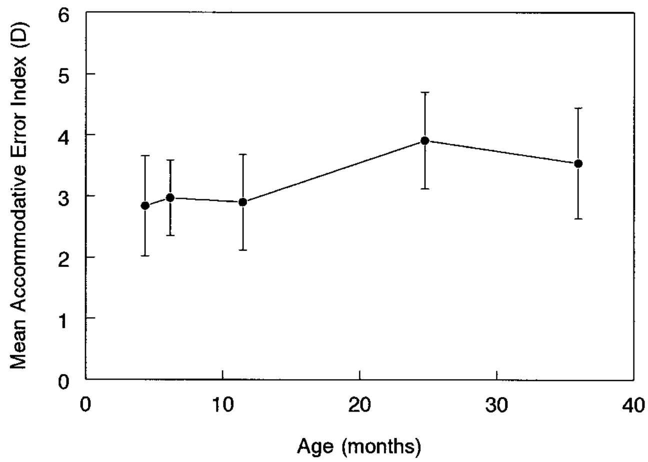

FIGURE 8. The mean AEI, with 95% confidence intervals, in 15 children with Down syndrome seen at the ages of 4, 6, 9 to 12, 24, and 36 months.

An alternative explanation for the underaccommodation is a large blur tolerance level, implying that the children produce only sufficient accommodation to achieve a perceptually clear image. The data are consistent with this hypothesis, although it is not clear whether the site of abnormal blur tolerance is at the retinal or cortical level. An abnormal accommodation–convergence relationship could also be postulated in children with Down syndrome.[1] The convergence demand of a near target is the same, irrespective of the effective refractive error; whether an absence of convergence-driven accommodation could then explain the consistent underaccommodation remains to be seen.

The deficit in accommodation cannot be attributed to delayed development in the accommodative response. Studies of normally developing children show a rapid improvement in accommodative accuracy in early infancy,[17,18] whereas our previous analysis had suggested a poorer accommodative response with age in children with Down syndrome.[1] In the present longitudinal data, the overall mean increase (0.86 D) with age does not fall outside the limits of repeatability. When individual children were considered, the majority showed no change in AEI outside the limits of repeatability.

Whatever the mechanism of the deficit, the retinal image at near for most children with Down syndrome is consistently optically defocused. It appears that the accommodation system of the children may have the physical capacity to respond to a given stimulus, but the neural control of the system is defective. The system appears to be well regulated, as evidenced by the consistency of the accommodative response in any individual child, but with an anomalous set point for a given near stimulus.

Underaccommodation may have implications for the defective visual development of these children. Visual acuity does not reach normal levels in children with Down syndrome,[2,21] and contrast sensitivity may be reduced from an early age.[22] A consistently blurred retinal image may be crucial in the onset of these deficits.

Refractive errors, rather than reducing during early childhood as they do in normally developing children,[15] increase among children with Down syndrome.[4] The role played by accommodation in emmetropization in normal visual development is not fully understood,[15,23,24] and there are conflicting reports on the association between refractive error and accommodation in normal adults and children.[25–29] Our data suggest that a simple comparison between refractive groups may not be helpful. Accommodative response, at least for children with Down syndrome, is a continuum when refractive error is considered. Higher hypermetropes show a greater accommodative deficit than do lower hypermetropes, although the absence of improved accommodation in corrected hypermetropes complicates this relationship. If accommodation indeed plays a role in the failure of emmetropization, then the substantial and persistent underaccommodation that we have demonstrated in children with Down syndrome may ultimately provide a model for the study of the emmetropization process.

Our findings have important clinical and educational implications. Because young children do most of their learning at near, especially at school, near visual function ought to be given greater importance in clinical evaluation of vision in these children. We have not yet measured near visual acuity in the children of our cohort, but the magnitude of the accommodation deficit suggests that it is severely reduced. Linstedt[30] reported reduced near acuity in eight children with Down syndrome, although data for only two children were described in detail. Prescribing spectacles for hypermetropia does not improve near focusing, and those with myopia may be worse off when wearing glasses. Further investigation of the effect of spectacles on near visual acuity is warranted. Teachers should be aware that, even when children in their classroom are wearing spectacles, vision may be below normal, especially for near tasks.

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