The Effect of Age, Size of Target, and Cognitive Factors on Accommodative Responses of Children with Down Syndrome

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Purpose. To investigate possible factors that may be implicated in the poor accommodative responses of individuals with Down syndrome. This article evaluates the effect of age, angular size of target, and cognitive factors on accommodation.

Methods. Seventy-seven children with Down syndrome who are participating in an ongoing study of visual development were assessed. One hundred thirty-one developmentally normal children took part in a previous study and provided control data. Accommodation was measured using a modified Nott dynamic retinoscopy technique.

Results. Children with Down syndrome showed considerably poorer accommodative responses than normally developing children. No target used in the present study produced an improved response in children with Down syndrome. Age, angular subtense of target, and cognitive factors could not fully account for the poor accommodation in children with Down syndrome.

Conclusions. Poor accommodation is a common feature of Down syndrome, regardless of the target used. The etiology of the deficit has yet to be established. It is imperative that educators and clinicians are aware that near vision is out of focus for these children. (*Invest Ophthalmol Vis Sci.* 2000;41:2479–2485)

Changes in fixation from a distant to a near object necessitate an increase in the refractive power of the ocular lens, to maintain a focused retinal image. This is the process of lens accommodation. Developmentally normal children usually have large amplitudes of accommodation,[1] and accommodation to near targets is accurate to within 0.75 diopters (D).[2,3] There have been reports of individual children as young as two months old focusing in a controlled and accurate fashion.[4,5] We have reported that defective accommodation is common in children with Down syndrome[6] even at 3 months of age;[7] that is, the children under-accommodate for near targets. Here we compare the accommodative responses of children of our study cohort with those of developmentally normal children and examine some of the factors that may contribute to their under-accommodation.

In our previous studies[7,8] of children with Down syndrome, we have reported an under-accommodation (or "lag" in accommodation), which increases with stimulus demand; the closer a near target, the larger the lag. The target used for our previous studies and for the main part of the present study is of constant size; that is, it remains the same linear size at all distances, and therefore increases in angular size as it approaches the eye. It is possible that a nearer target discourages accurate accommodation because its relatively large components can be readily seen. As part of the present study, we have controlled for this change in the angular size of the accommodative target.

Another possible explanation of the reduced accommodation response in children with Down syndrome is the poorer level of concentration exhibited by these children. Studies have shown that increasing the cognitive demand of the target can induce an increase in the accommodation to a near stimulus.[9,10] The instructions given to a subject also can influence the amount of accommodation.[11] It may be that children with Down syndrome produce enough accommodation for their level of interest in the target, but their lack of motivation discourages precise accommodation. As part of the study described below, we have measured the effect of increasing the cognitive demand on accommodation, in adults and normally developing children, by use of a dynamic retinoscopy technique. If changes in cognitive demand bring about a large change in accommodative accuracy in normally developing subjects, then this will strengthen the argument that under-

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accommodation in children with Down syndrome is due to poor concentration. In a different approach, our cognitive assessments of the children with Down syndrome allow us to examine any association between accommodation performance and the level of cognitive development in individual children.

METHODS

Subjects

The Cytogenetics Department of the University Hospital of Wales identified children born within the cohort area of South and West Wales. Consent for inclusion into the cohort was sought from each child's pediatrician and from parents. Only two families approached in this way refused to join the study, and one family withdrew. The result of this highly successful recruitment protocol is that social class does not bias the cohort. The cohort comprises 81 children, 55 boys and 26 girls: this gender bias of 68% male children is only slightly higher than the published figure for Down syndrome in Australia (59% male children)[12] and the birth rate in Wales since 1991 (60% male children).[13]

Cross-sectional accommodation data were available for 77 of the 81 children. Except where otherwise stated, the mean age of the children was 42.5 ± 23.3 months (mean ± SD; range, 4.7–84.7 months). Data from an earlier study[14] that used identical techniques for measuring accommodation with 131 developmentally normal children aged 1 to 45 months are used as control data (mean ± SD; 13.79 ± 9.79 months).

For the study of the effect of cognitive factors, two additional groups were recruited, one of adults and one of developmentally normal children. The adult group consisted of 24 university students from 19 to 24 years of age (mean ± SD; 20.9 ± 1.31 years). Each subject's refractive error was no greater than 0.75 D of myopia or hypermetropia, and there were no cases of strabismus or amblyopia. The child group consisted of 17 children aged 8 to 11 years (mean ± SD; 9.6 ± 0.79 years) attending a local primary school. Although the refractive errors of the children were not assessed, no child wore a corrective prescription or had manifest strabismus, and all the children had either passed the School Eye Screening Tests carried out by the local Health Authority or had recently undergone an eye examination. Informed consent was obtained from parents, school staff, and the children themselves. Local Education Authority approval was obtained before the study began.

For all parts of the study, the recruitment and experimental protocols were conducted in compliance with the Declaration of Helsinki and were approved by Local Ethical Research Committees in the areas of residence of the children.

Procedure

All children with Down syndrome were assessed during home visits. Accommodation was measured using a modified Nott dynamic retinoscopy technique.[3,6] The child fixated, with both eyes, on a translucent polymethylmethacrylate cube that was internally illuminated and contained detailed pictures (designed to interest a young child). Each face of the cube was approximately 4.5 cm^2. The target was mounted on a rule and set at 10, 16.6, and 25 cm from the child's eyes, equivalent to 10, 6, and 4 D, respectively. In most cases, the accommodative state of the right eye was assessed. However, in children with strabismus and a fixing left eye, accommodation was assessed in the left eye. The examiner assessed the retinoscope reflex along the meridian focused closest to the eye (i.e., the least hypermetropic or most myopic meridian). The examiner therefore made the assumption that in astigmatism, the accommodation would be appropriate to the least hypermetropic or most myopic meridian. Any deviation from this in an individual child would result in our procedure *overestimating* the accommodative accuracy. The accommodative state was measured by moving the retinoscope toward or away from the child and recording its position when a neutral reflex was observed.

During the same visit, visual acuity was measured by Teller Acuity Cards[15] for children aged 12 months or younger and by Cardiff Acuity Test[16,17] for children aged over 12 months. Strabismus was identified from the Hirschberg test (evaluation of corneal reflexes) and, when the child could cooperate sufficiently, the cover test.

Angular Subtense

The linear size of the detail in our usual target ranged from 0.4 to 5.2 mm, which meant that the angular subtense varied from 0.23° to 2.96° when the target was at 10 cm and from 0.09° to 1.18° when the target was at 25 cm. This part of the study was designed to assess whether the change in angular subtense in our target had an effect on accommodation responses. Two series of additional targets were constructed. The first series consisted of alternating black and white squares in a checkerboard pattern. The checks increased in linear size (and the number of checks on the face of the cube decreased) as the target distance increased, so that a constant angular subtense of 0.5° per single check was provided. This type of target proved relatively uninteresting to the children, and at times it was difficult to maintain their concentration. A second series of targets was therefore designed using a cartoon-style picture of a chicken, which proved more effective in maintaining the children's attention. The size of the picture increased proportionally with stimulus distance, and the detail in the picture ranged in angular subtense from 0.06° to 0.45° at all distances. Nine children with Down syndrome, aged 3.5 to 8.5 years (mean ± SD; 6 ± 1.9 years) participated in this part of the study.

Cognitive Factors

The effect of the cognitive demand on accommodation responses was assessed in developmentally normal adults and child subjects. Three interchangeable pictures, of varying detail, with a common outline were used. The basic outline was that of a cartoon-style cat, designed to appeal to young children, and this constituted the "Control" target. The second target was given detail by adding 1.5-mm spots to the body section. The resolution of each spot was 0.53° at the distance of 16 cm and is referred to as the "Large Spots" target. The third target had 0.5-mm spots on the body section, with a resolution at the eye of 0.18°, and is referred to as the "Small Spots" target (Fig. 1). Simple observation of the targets constituted the low cognitive demand task, whereas counting the spots constituted the high cognitive demand task.

Only one target distance was used; the cube target was placed at 16 cm (6.25 D accommodative demand) from the

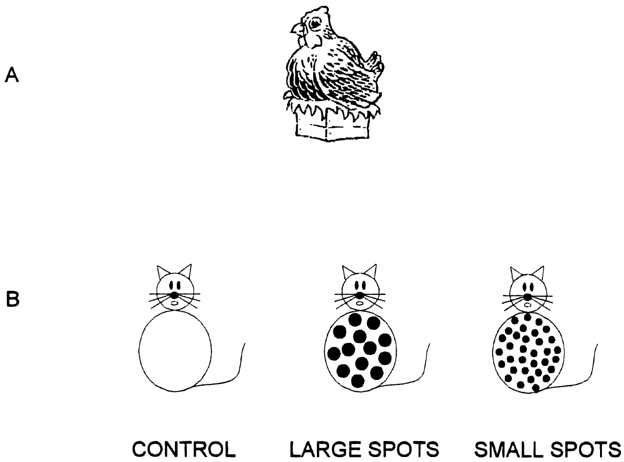

FIGURE 1. (**A**) The "cartoon chicken" target which remained constant in angular size at the three distances. (**B**) The targets used to evaluate the effect of cognitive demand on accommodative response.

subject. The subject was first familiarized with the three targets and then participated in five tasks: (1) Control, observe the control target; (2) Large Spots, observe the large spots target (OLS); (3) small spots, observe the small spots target (OSS); (4) count large spots, count the spots on the large spot target (CLS); and (5) count small spots, count the spots on the small spot target (CSS).

Each task was described on an instruction card ("look at the cat" or "count the spots") presented to the subject by an assistant, so that the examiner did not know which target or task was being used. The tasks were presented in pseudorandom sequence. For the children, the assistant explained that the examiner should not be aware of what task they were doing, by describing it in terms of a guessing game. All children could "count in their head," and were asked to do so.

The effect of cognitive factors was assessed in a different approach by analysis of the cognitive development of the children with Down syndrome. Children of the cohort received regular assessment by means of the Bayley Scales of Infant Development. These scales assess areas of mental and motor development and are standardized for (developmentally normal) children aged 1 to 30 months. Their use has often been described in studies of children with Down syndrome,[18-20] although the repeatability of the items making up the scales may be poor in these children.[21] Data from both the Bayley Scales and measurements of accommodation were obtained at the same ages in 34 children, who ranged in age from 12 to 84 months (39.7 ± 17.6 months). For the purposes of analysis in the present study, raw scores on the mental scales were converted to Developmental Quotient, which is given by mental age/chronological age.

Terminology

The full refractive error 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.

Accommodative Error Index

This single-figure value, suggested by Chauhan and Charman,[22] describes the discrepancy between the ideal accommodation response (i.e., accurate focus) and the measured response for a number of accommodation stimuli at different distances (Fig. 2). In effect, it is the mean of the response error, divided by the correlation coefficient. It is given by

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

where m is the slope of response line; c is the intercept of response line; r^2 is the correlation coefficient; x_1 is the dioptric equivalent of the furthest stimulus used; and x_2 is the dioptric equivalent of the nearest stimulus used.

The accommodative error index (AEI) is expressed in diopters, and accurate accommodation at all distances would be indicated by an accommodation error index of zero. A value of greater than zero indicates inaccurate accommodation.

RESULTS

Visual Acuity

The poorest visual acuity recorded for the children with Down syndrome was 6.49 minutes of arc, or 0.11° for one of the youngest children, aged 6 months. All other children had better acuity than this. Thus, the level of detail offered in our target was within the visual resolution of all the children.

Comparison with Control Children

Consistent with our previous reports, the majority of children with Down syndrome show under-accommodation at near distances compared with normal children. Figure 3 shows the mean response for all the children with Down syndrome in the cohort, alongside data for control children as previously reported.[7] The mean accommodation showed that the children with Down syndrome under-accommodated at all distances tested, by ≥50%. The amount of under-accommodation increased with increasing demand. Figure 4 shows typical individual data for four children with Down syndrome: one child (subject 1) has accurate accommodation, and three show con-

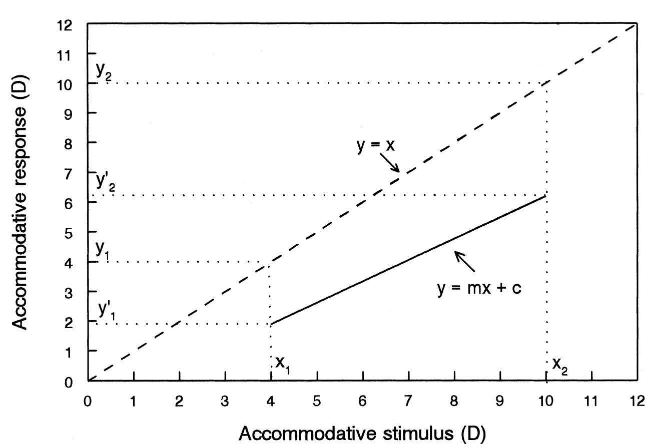

FIGURE 2. Illustration of the AEI, which describes the discrepancy between the ideal or accurate accommodative response ($y = x$) and the observed response ($y = mx + c$). Reprinted from Chauhan K, Charman WN. (Single figure indexes for the steady-state accommodative response. *Ophthal Physiol Opt.* 1995; 15:217–221) with permission from Elsevier Science.

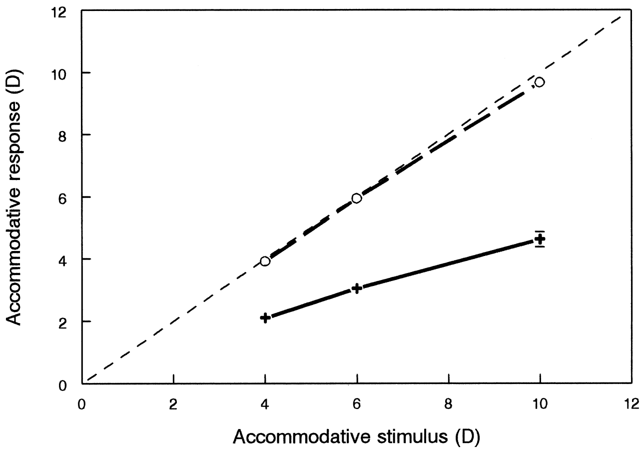

FIGURE 3. Mean accommodative response (with SEs) to three near targets, for control children (○; $N = 131$) and children with Down syndrome (+; $N = 77$). Where not visible, error bars are smaller than the markers. The *dotted diagonal line* represents the "ideal" (i.e., accurate accommodation at all distances).

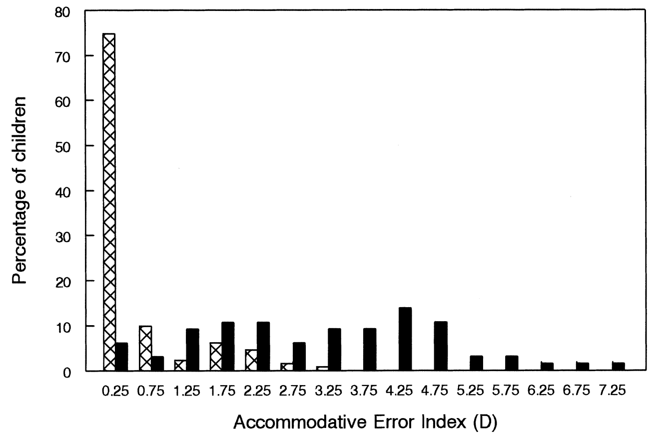

FIGURE 5. AEI for (*hatched bars*) 131 control children and (*filled bars*) 65 children with Down syndrome, aged 1 to 45 months. Bins cover a range of 0.50 D (e.g., the first bin represents 0.00–0.49 D, the second 0.50–0.99 D, and so forth).

sistent under-accommodation. The degree of under-accommodation varies from child to child.

Individual responses from each child, such as those in Figure 4, were used to calculate the AEI, shown in Figure 5. Because the control children were ≤45 months old, data for 65 of the children with Down syndrome, within the age range of the control group, are presented in the figure (mean ± SD; 18.33 ± 11.58 months). Median Accommodative Error Index for the control children was 0.00 D (range, 0.00–3.05 D), whereas for the children with Down syndrome, the median AEI was 3.18 D (range, 0.00–7.37 D). Seventy-two (55%) of the control children had an AEI of 0.00 D, whereas only three children with Down syndrome (4.6%) had an AEI of 0.00 D. A Mann–Whitney test showed a significant difference between the AEI of the control children and that of the children with Down syndrome (U test statistic = 622, $P < 0.001$).

Norms were established from the control data to evaluate the results from the children with Down syndrome. Among the control children, 95% had an AEI of 0.00 to 2.20 D (0–95th percentile). Only 21 (32%) of the 65 age-matched children with Down syndrome fell within this normal range. These 21 children ("normal-index" group) were then compared with the remainder ("abnormal-index" group, $N = 44$). There was no difference between the two groups in terms of absolute ametropia (i.e., magnitude of refractive error, either myopia or hypermetropia) ($t = 1.85$, $P = 0.070$) or visual acuity ($t = 0.98$, $P = 0.333$), but there was a difference in age ($t = 2.17$, $P = 0.034$). The mean age of the group with a normal AEI was 11.16 months (95% confidence interval, 7.88–15.77 months), whereas the mean age of the group whose AEI fell outside the norms was 16.66 months (95% confidence interval, 13.62–20.40 months).

The above comparison of refractive errors was made on the basis of the absolute value of ametropia, so that a positive refractive error would not cancel out a negative refractive error. However, uncorrected myopes could be considered to be at an advantage when accommodating, being naturally focused at near distances. If the myopes were excluded before both groups were compared, the children whose AEI fell outside the norms had a higher degree of hypermetropia than the

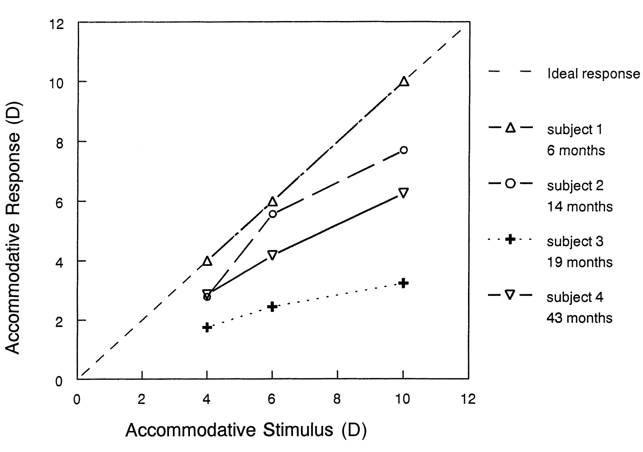

FIGURE 4. Accommodative responses to three near targets, for four children with Down syndrome, whose ages appear alongside the figure. The *dotted diagonal line* represents the "ideal" (i.e., accurate accommodation at all distances).

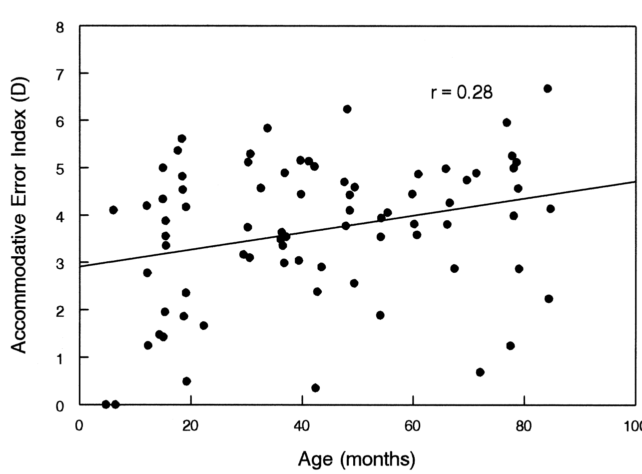

FIGURE 6. AEI and age for 77 children with Down syndrome. The least squares regression line is shown.

TABLE 1. Mean Under-Accommodation (Lag) for Children with Down Syndrome for Three Near Targets

		Mean Accommodation Lag (diopters)		
	n	10-D Stimulus	6-D Stimulus	4-D Stimulus
Original target*	9	6.26 ± 1.43	3.44 ± 1.06	2.22 ± 0.69
Checkerboard†	7	6.16 ± 1.63	3.28 ± 1.34	2.14 ± 0.89
Chicken†	9	5.56 ± 1.60	3.16 ± 1.24	2.21 ± 0.67

Values are means ± SD.
* Varying spatial frequency.
† Constant spatial frequency.

normal-index group ($t = 2.51$, $P = 0.015$). Mean hypermetropia of those in the abnormal index group ($N = 40$) was +2.63 D (95% confidence interval, 2.16–3.12 D), whereas mean hypermetropia of the children in the normal-index group ($N = 17$) was +1.63 D (95% confidence interval, 1.09–2.17 D).

Twenty-nine (38%) of the children with Down syndrome had strabismus, either constant or intermittent (one child was monocular, with a coloboma left eye, and was excluded from this analysis). The children with strabismus had a significantly greater mean AEI (4.35 D) than the children without strabismus (3.32 D) ($t = 3.09$, $P = 0.003$). However, there was no difference in the mean refractive error of the strabismus and no-strabismus groups ($t = 0.41$, $P = 0.683$).

Relationship between Accommodation and Age

Figure 6 shows the age of the children with Down syndrome and their AEI. The least squares regression line fitted to the data shows a significant trend of increasing accommodative error with age ($r = 0.28$, ANOVA $F = 6.381$, $P = 0.014$).

Effect of Change in Angular Subtense

The checkerboard target was successful for only 7 of the 9 children tested. Table 1 compares the effect of changing the angular subtense of the target on the accommodative responses at the three distances. A greater lag was obtained for the shorter stimulus distances regardless of the target used, but there was little difference between targets overall. The data of Table 1 were converted to AEI and each "angular subtense invariant" target was compared with the original target (Table 2). There was no significant difference in the AEI obtained for each target. For the original versus checkerboard target, the mean difference equaled −0.094 D (95% confidence interval, −0.476–0.288) ($t = 0.62$, $P = 0.560$), and for the original versus "chicken" target, the mean difference equaled −0.410 D (95% confidence interval, −0.874–0.054) ($t = 2.04$, $P = 0.076$).

Cognitive Factors

Mean accommodative responses for the (developmentally normal) adult and child groups to each of the five tasks are given in Table 3. For both subject groups, there were increases in accommodative response when a higher cognitive demand task was presented; that is, the subjects were asked to count the spots rather than simply look at them. A main effect of accommodative stimulus was found for both the adult group (ANOVA $F = 2.85$, $P < 0.05$) and for the child group ($F = 3.28$, $P \leq 0.05$). A post hoc Tukey test ($P < 0.05$) showed a significant difference for the adults between task 1 and task 5 and for the children between task 1 and task 5 and between task 3 and task 5.

Data for both cognitive development and AEI were available for 34 children with Down syndrome aged 12.2 to 84.2 months (mean age, 39.7 months). These data are shown in Figure 7. The developmental quotient ranged from 0.29 to 0.91 (mean ± SD; 0.57 ± 0.16), and the AEI ranged from 0.35 to 6.72 D (mean ± SD; 3.84 ± 1.04 D). There was no significant association between the developmental quotient and AEI ($r = 0.207$, ANOVA $F = 1.433$, $P = 0.240$).

DISCUSSION

This investigation, in a far larger sample of children than those groups previously studied,[6,7] confirms that a large majority of children with Down syndrome under-accommodate for near targets. Compared to our age-matched control group, 68% of children with Down syndrome had an AEI that was outside the normal range. Hypermetropic children with Down syndrome who had an AEI within the normal range were younger and showed a lower hypermetropic error than those who had an abnormal AEI.

Accommodation appeared to vary significantly with age, being less accurate among older children. However, the intercept of the linear regression shows that even the youngest children had an average AEI (2.91 D) outside the normal range. The trend with age is not great, showing only a 1.50 D increase in AEI over the age range of our cohort. Nevertheless, the trend is in the opposite direction to that reported in normally developing children, who usually show more accurate accommodation with age, at least in early childhood.[23,24] Refractive errors, especially hypermetropia increase with age in young children with Down syndrome[8] and, as discussed above, the children

TABLE 2. Accommodative Error Index for Children with Down Syndrome for Three Near Targets

		Accommodative Error Index			
Target Used	*n*	Mean (D)	Median (D)	SD (D)	Range (D)
Original target*	7	4.32	4.88	1.02	2.39–5.18
Checkerboard†	7	4.23	4.49	1.21	2.15–5.45
Original target*	9	4.36	4.26	0.94	2.67–5.65
Chicken†	9	3.95	4.03	1.14	2.25–5.54

* Varying angular subtense.
† Constant angular subtense.

Table 3. Comparison of Mean Accommodation Responses to a 6.25-D Target in Developmentally Normal Adult and Child Subjects for Five Tasks Associated with the Target

	Adults (n = 24)		Children (n = 17)	
Task	Accommodation Response*	Lag (−) or Lead (+) of Accommodation	Accommodation Responses*	Lag (−) or Lead (+) of Accommodation
1. Control	5.92 ± 0.45	−0.33	5.82 ± 0.63	−0.43
2. Large spots	6.03 ± 0.50	−0.22	5.84 ± 0.56	−0.41
3. Small spots	6.15 ± 0.43	−0.10	5.79 ± 0.38	−0.46
4. Count large	6.11 ± 0.39	−0.14	6.08 ± 0.48	−0.13
5. Count small	6.34 ± 0.39	+0.09	6.33 ± 0.53	+0.08

* Values are means ± SD.

with more accurate accommodation were more likely to be younger and less hypermetropic. It may be, therefore, that the observed decline in accommodative accuracy with age in children with Down syndrome can be explained by increasing refractive errors. A more extensive analysis of the effect of refractive errors will be needed to determine the interaction between accommodation and age.

The accommodative responses are not significantly affected when the angular subtense of the target is maintained at a constant value, rather than varying as it does with our conventional target. Tan and O'Leary[25] found that for tests at near distances, the accommodation response (of normal adult subjects) was virtually independent of letter size. Thus, the difference in accommodation responses at different target distances cannot be explained by the varying angular subtense of the target. The visual acuity of the children with Down syndrome was sufficient for resolution of all the detail of the targets, with the exception of the finest detail at 25 cm for one child.

We also examined the effect of cognitive factors on the accommodative responses of normally developing adults and children. For tasks requiring little cognitive attention ("look at the target") there was a small amount of under-accommodation or lag, consistent with that recorded in previous studies.[2,3] For both adult and young normal subjects, a detailed task with a greater cognitive demand (counting the small spots on the target) resulted in a greater amount of accommodation (a difference in the means of 0.42 and 0.51 D, respectively). Our findings are consistent with those of Kruger,[9] who found that the average level of accommodation for a target of 2.50 D accommodative demand increased by 0.28 D in 75% of his subjects when the task was changed from reading two-digit numbers to adding the numbers, without changing the visual stimulus. Winn et al.[10] reported a mean increase in accommodation of 0.17 D when subjects were asked to give a response when a target (at a demand of 3.50 D) contained a particular letter. Stark and Atchison[11] found that, for adult subjects, the level of accommodation was influenced by the instructions given, although this occurred only for their Badel optical system, which removes other cues of proximity. Their findings may not be relevant to ours, in which a real-space target was used.

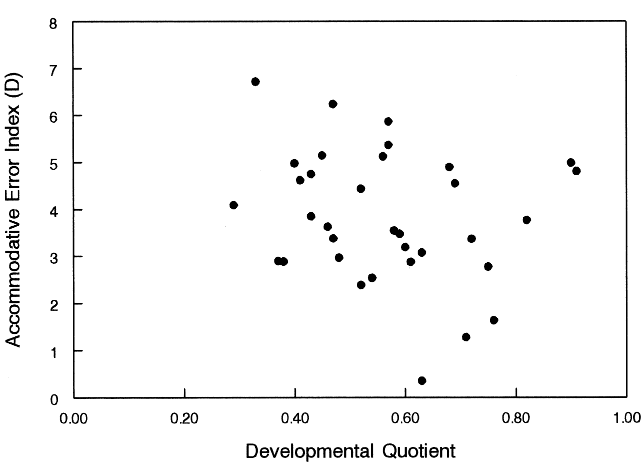

Figure 7. Developmental quotient (mental age/chronological age) and AEI for 34 children with Down syndrome.

We did not attempt to vary the cognitive demand for children with Down syndrome, although some of the children are capable of counting. Overall, children with Down syndrome may not be able to respond to cognitive demand in the same way as normally developing children, and this may therefore play a part in their under-accommodation. However, the differences recorded for tasks of different difficulty among normally developing children are very small (a maximum difference of 0.54 D). Consequently, this effect is insufficient to account fully for the large difference in under-accommodation between normally developing children and children with Down syndrome (2.90 D at a target distance of 16.6 cm; see Fig. 3).

We also examined the relationship between under-accommodation to the retinoscopy target and overall cognitive development. If cognitive factors were important for precise accommodation, we might expect the more able children with Down syndrome to exhibit more accurate accommodation. This was not the case; no association between cognitive development and accommodative accuracy was demonstrable. This suggests that the underlying learning disability inherent in Down syndrome and the under-accommodation may have different etiologies.

Accommodative inaccuracy may be related to a sensory deficit (in the detection of blur) or to a motor deficit (in the response to blur). Similarly, the accommodative deficit may be peripheral rather than central, due to different lens mechanics, and therefore unrelated to general neurologic development. Another possibility is that an abnormal interaction between accommodation and convergence is present, resulting in under-accommodation. We have not yet measured convergence systematically in the children of the cohort, although on clinical examination, the children appear to converge to near targets. The high prevalence of strabismus in Down syndrome suggests that the accommodation/convergence relationship may be compromised in many of the children. Our finding that children with strabismus exhibit greater under-accommodation adds weight to the suggestion of an abnormal linkage between convergence and accommodation, which deserves further investigation.

The studies reported here confirm that children with Down syndrome exhibit a large under-accommodation for near targets that cannot be explained on the basis of target properties. It is a real effect, present at all ages tested, which must give rise to a substantially blurred retinal image. It is apparent that the majority of children with Down syndrome are probably visually impaired at near distances, and it is imperative that clinicians and educators are made aware of this. For example, a normally sighted adult with presbyopic blur at near distance of 3.00 D would not be expected to read conventional print sizes of N8 to N12. In our studies, we have not measured near visual acuity and are therefore unable at present to evaluate the functional consequence of the under-accommodation. Linstedt[26] was the first person to suggest that children with Down syndrome have reduced accommodation, which she identified (in 11 children) by recording a poorer visual acuity for near targets than for distance. The development of a suitable near acuity test to evaluate the impairment for near tasks is now a priority.

Acknowledgments

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