Table II. Clinical observations at end of experiment (day 30)*

	Control group (untreated, 18 eyes)	*% incidence*	*Experimental group (ascorbate-treated, 17 eyes)*	*% incidence*
Ulcers†	8	61%	1	5.9%
Descemtoceles	2		0	
Perforations	1		0	
No ulcers	7	39%	16	94.1%

*The difference in the number of ulcers, descemetoceles and perforations (combined) between the control and treated groups is statistically significant ($p < 0.001$; normal approximation for a test between two binomial frequencies).
†The category of ulcers extends from superficial to less than full-thickness ulcers.

result of altered corneal neovascularization patterns, since these were similar in both groups. It must be presumed that the mechanism of action of ascorbic acid in reducing corneal ulceration in acid-burned eyes is the same as that described in the Introduction for alkali-burned eyes.

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REFERENCES

1. Hughes WF: Alkali burns of the eye. II. Clinical and pathologic course. Arch Ophthalmol **36**:189, 1946.
2. Friedenwald JS, Hughes WF, and Herrman H: Acid burns of the eye. Arch Ophthalmol **35**:98, 1946.
3. Levinson RA, Paterson CA, and Pfister RR: Ascorbic acid prevents corneal ulceration and perforation following experimental alkali burns. Invest Ophthalmol **15**:986, 1976.
4. Pfister RR and Paterson CA: Additional clinical and morphological observations on the favorable effect of ascorbate in experimental ocular alkali burns. Invest Ophthalmol Vis Sci **16**:478, 1977.
5. Pfister RR, Paterson CA, and Hayes SA: Topical ascorbate decreases the incidence of corneal ulceration after experimental alkali burns. Invest Ophthalmol Vis Sci **17**:1019, 1978.
6. Barnes MJ: Function of ascorbic acid in collagen metabolism (Second Conference on Vitamin C). Ann NY Acad Sci **258**:264, 1975.
7. Slansky HH and Dohlman DH: Collagenase and the cornea. Surv Ophthalmol **14**:402, 1970.
8. Brown SI: Collagenase and corneal ulcers. Invest Ophthalmol **10**:203, 1971.
9. Allen JH, Manning JW, Guidry MA, and Kelly JB: Changes in aqueous flow and blood-aqueous barrier after hydrochloric acid burns to the eye. Arch Ophthalmol **57**:1, 1957.
10. Maickel RP: A rapid procedure for the determination of adrenal ascorbic acid. Application of the Sullivan and Clarke method to tissues. Anal Biochem **1**:498, 1960.
11. Zannoni V, Lynch M, Goldstein S, and Sato P: A rapid micromethod for the determinations of ascorbic acid in plasma and tissues. Biochem Med **11**:41, 1974.
12. Paterson CA, Eakins KE, Paterson E, Jenkins RM II, and Ishikawa R: The ocular hypertensive response following experimental acid burns in the rabbit eye. Invest Ophthalmol Vis Sci **18**:67, 1979.
13. Davson H: The Eye. New York, 1969, Academic Press, Inc., vol. 1, p. 97.

Assessment of vision in young children: a new operant approach yields estimates of acuity.

D. Luisa Mayer and Velma Dobson.

Behavorial assessment of visual function is now possible in 6- to 24-month-old children through the use of an operant preferential looking technique. Use of the technique to measure grating acuity shows that acuity develops from 6 to 8 min arc at 6 months of age to near adult levels by 2 years.

In humans, much is known about the development of visual acuity in the first 6 postnatal months.[1] However, although two studies have examined the development of visual acuity in infants up to 1 year of age,[2,3] the study of acuity in later infancy and early childhood has been hampered in general by lack of an adequate research methodology. Current methods of visual acuity assessment in children in the 1- to 2-year range are limited to relatively simple clinical tests such as observing the child's reactions to rolling balls or to moving dots.[4, 5] We have developed a technique, termed operant preferential looking (OPL), for the assessment of acuity in 6- to 24-month-old children.

OPL combines the visual reinforcement audiometry technique[6] used to test auditory sensitivity and speech perception in 5- to 18-month-old infants, with the forced-choice preferential looking procedure used primarily to test vision in infants between 2 weeks and 6 months of age.[7, 8] The technique is based on operant reinforcement of the child's tendency to look at a patterned stimulus in preference to a homogeneous field.

Materials and methods. A schematic drawing of the test apparatus is shown in Fig. 1. The apparatus consisted of a gray (Crescent cardboard No. 651) screen containing a 9-degree black-and-white striped acuity target (square-wave grating), similar to that described previously by Teller et al.[7] The center of the grating was located 18 degrees to the left or the right of the center of the screen. The grating was matched to the screen in space-average luminance (1.2 log cd/m^2 as measured with an S.E.I. meter). Gratings were high-contrast (82%) photographic prints. Two animated toys were positioned adjacent to the screen, one to the left and one to the right. These animated toys served as reinforcers, as described below.

During experimental sessions, the child sat on the parent's lap, with the child's eyes 57 ± 3 cm from each stimulus position. (To prevent the parent from influencing the child's performance, the parent's view of the screen was obscured by a gray cardboard shield.) A second adult, the observer, viewed the child's face through a 4 mm peephole located centrally in the gray screen, midway between the two stimulus positions. A third adult, the experimenter, positioned the stimulus on each trial, set the reinforcement device so that correct judgment of stimulus location by the observer activated the appropriate reinforcer, and recorded the observer's judgments.

The OPL procedure involved two phases, a training phase and a test phase. The training phase, in turn, consisted of two parts. During the first part, the experimenter presented grating stimuli selected to be well above threshold, and the observer was aware of the location of the stimulus. On each trial, the observer waited until the child looked toward the side of the screen containing the grating and then reinforced the response by activating the toy animal on that side. Training continued for four to 20 trials until the observer believed the child had learned the association between grating position and reinforcement. The second part of the training was to determine objectively whether or

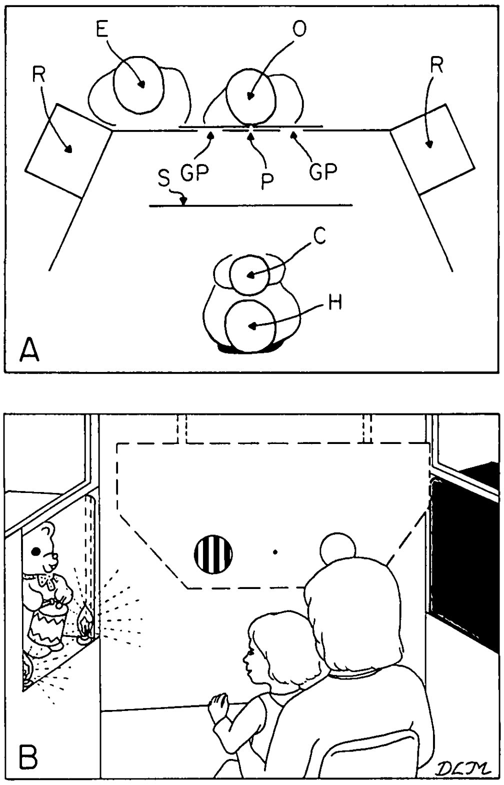

Fig. 1. Schematic drawings of OPL apparatus with animal reinforcers. **A**, Top view. *H*, Holder (parent); *C*, child; *S*, holder's shield; *R*, plexiglass box containing toy animal reinforcer; *E*, experimenter; *O*, observer; *P*, peephole; *GP*, grating position. **B**, Frontal view. Toy animals were illuminated and visible only when activated; otherwise a covering of darkened plexiglass obscured them from view. Dashed lines indicate position of holder's eye shield.

not the child was conditioned. Here the observer's task was different from what is was in the first part of training in that the observer was blind as to stimulus location and was required to use the child's looking behavior and/or motor responses, e.g. pointing or head turning, to judge whether the stimulus was on the left or the right. The stimulus used was the same grating as that used in the first part of training, but reinforcement was delivered to the child only when the observer correctly judged the left-right position of the grating. Duration of reinforcement ranged from 2 to 5 sec. Presentation of trials continued with pseudorandom ordering of left-right stimulus position, until the observer's performance met one of three pre-established criteria or until 12 trials were completed. Infants who did not meet a criterion of 5/5, 8/9, or 10/12

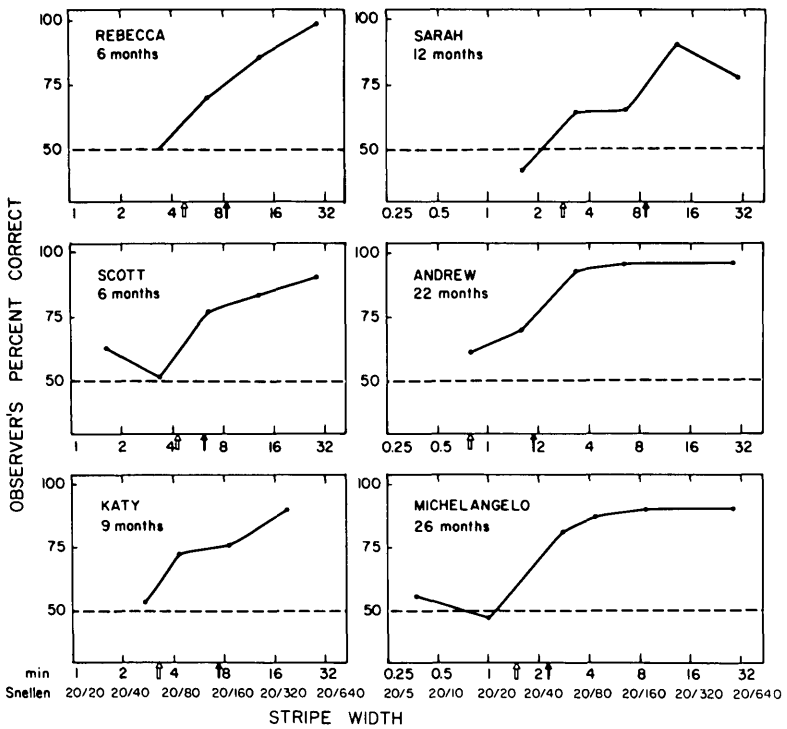

Fig. 2. Psychometric functions obtained from six infants tested with the OPL procedure. Observer's percent correct is plotted as a function of the stripe widths of the acuity gratings used to test each infant. Open and closed arrows indicate interpolated acuity values obtained with criteria of 60% and 75% correct, respectively. All data points are the result of 25 to 43 trials per point, except that the point at 1.6 min arc for Sarah resulted from 17 trials and data for Michelangelo resulted from 12 to 21 trials per point.

correct ($p < 0.05$, conditional binomial probabilities) by the observer were not tested further.

Following training, the acuity test phase of the procedure began. As in the second part of the training phase, delivery of reinforcement was contingent upon the observer's correct judgment of the left-right position of the stimulus. Infants were tested with 25 to 43 trials on each of at least four different grating stripe widths, with exceptions as noted in Fig. 2. During the test phase, stimulus position and stripe width on each trial were selected according to predetermined pseudorandom orders.

Results. Results from six children* tested with the OPL procedure are shown in Fig. 2. Each data set is the result of two to six 45 to 60 min test sessions. Observer's percent correct for each child ranged from near chance (50%), for the finest gratings used, to near 100%, for stimuli which were clearly suprathreshold. Acuity can be estimated as some point on each psychometric function between chance and 100%. Fig. 2 indicates acuity values for our subjects based on both 60% and 75% criteria. When the 75% criterion was used, interpolated acuity values were 8.3, 6.1, 7.5, 8.7, 1.9, and 2.3 min arc for Rebecca (6 months), Scott (6 months), Katy (9 months), Sarah (12 months), Andrew (22 months), and Michelangelo (26 months), respectively. A 60% criterion yielded acuity values of 4.7, 4.2, 3.3, 2.9, 0.8, and 1.5 min arc for these six children. If 1 min arc is assumed equivalent to 20/20 Snellen, the 75% values indicated that acuity ranged from 20/174 for Sarah to 20/38 for Andrew, whereas the 60% criterion yielded a range of acuity values from 20/94 for Rebecca to 20/16 for Andrew. Additional sessions were run with three of these children within 2 weeks of the first set of sessions in

*Data are presented from the first six children tested successfully with the OPL procedure. Ten other children between 9 and 23 months tested in the same period did not complete testing; of these, three did not complete the training phase (did not meet criterion), six would not sit still long enough to complete testing, and one did not complete testing due to scheduling difficulties.

order to obtain second psychometric functions. Thresholds (75% criterion) obtained from the second psychometric functions were 8.6 min arc (20/172) for Rebecca, 3.3 min arc (20/66) for Andrew, and 1.6 min arc (20/32) for Michelangelo. Thus data from the three children who were retested yielded similar acuity values (within one octave) to those found initially for these children.

For comparison, seven adults were tested in the same apparatus by the method of constant stimuli. Five trials were presented for each of five grating patterns (stripe widths of 0.4, 0.7, 0.8, 1.0, and 1.3 min arc). Each adult was asked to indicate on each trial whether he or she could see the striped pattern. Acuity thresholds (the interpolated value for 50% "yes" responses) for the seven adults were 0.6, 0.6, 0.7, 0.7, 0.7, 0.7, and 1.0 min arc.* Thus acuity thresholds for the adults agreed to within a factor of 2 with the acuity values found for 2-year-olds based on the 75% criterion. The 60% criterion yielded acuity values for the 2-year-olds that were virtually identical to those found for adults.

Discussion. Comparison of data from the present study with data from other behavioral studies of grating acuity in young children indicates agreement to within a factor of 2 for infants 6 to 12 months of age.[2, 7, 9] †, ‡ However, our data do not show the improvement in acuity between 6 and 12 months found in other studies.[2] Since we tested only four subjects in this age range, it is impossible to know if the lack of acuity improvement we find is due to individual differences or to a feature of the technique. To our knowledge, no other data exist concerning grating acuity obtained by behavioral testing in 1- to 2-year-old children, and therefore comparison of the data of our 2-year-old subjects with the results of other studies is not possible.

In summary, we have developed a new technique to assess visual function in a notoriously difficult-to-test age range of children. We have demonstrated that this new technique, called operant preferential looking, is effective for measurement of grating acuity in children 6 months to 2 years of age.* The acuity values we found for the younger subjects are comparable to those of infants of similar ages tested by others using behavioral methods. Our report of the measurement of grating acuity in 2-year-olds is unique and shows that visual acuity is near adult levels by this age. Use of other types of stimuli in conjunction with the OPL procedure should enable laboratory assessment of other basic visual capabilities such as color vision and stereopsis as well as investigation of higher cognitive functions such as pattern discrimination, visual memory, and multimodal perception. With appropriate modifications to reduce the required test time and thereby allow successful testing of a greater proportion of children, the OPL technique should also prove useful for clinical assessment of young children at risk for visual abnormalities.

*Although a yes-no procedure for an adult corresponds to the infant's task in the OPL procedure, we also tested two of our adult subjects using a forced-choice procedure. Thresholds estimated as 75% correct with the forced-choice procedure yielded acuity values identical to those obtained from the same adults with the yes-no procedure.

†However, Harris et al.[10] found an acuity value of 2 min arc for one 6-month-old.

‡Visually evoked potentials obtained from infants up to 12 months of age have yielded estimates of acuity that are somewhat better than behaviorally obtained acuity values. Possible reasons for these differences have been discussed extensively elsewhere.[11]

*Recently, Cooper and Feldman[12] compared results from clinical measures of stereoscopic vision to estimates obtained by a match-to-sample operant procedure in children 2 to 5 years of age. However, only two of the 13 2- to 3-year-olds were able to meet criterion on a discrimination training task, and only one of these was tested successfully by the operant procedure.

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REFERENCES

1. Dobson V and Teller DY: Visual acuity in human infants: a review and comparison of behavioral and electrophysiological studies. Vision Res 18:1469, 1978.
2. Gwiazda J, Brill S, Mohindra I, and Held R: Infant visual acuity and its meridional variation. Vision Res 18:1557, 1978.

3. Pirchio M, Spinelli D, Fiorentini A, and Maffei L. Infant contrast sensitivity evaluated by evoked potentials. Brain Res **141**:185, 1978.
4. Catford GV and Oliver A: Development of acuity. Arch Dis Child **48**:47, 1973.
5. Sheridan MD: The STYCAR graded-balls vision test. Dev Med Child Neurol **15**:423, 1973.
6. Moore JM and Wilson WR: Visual reinforcement audiometry with infants. *In* Early Diagnosis of Hearing Loss, Gerber SE and Mencher GT, editors. New York, 1978, Grune & Stratton, Inc., p. 177.
7. Teller DY, Morse R, Borton R, and Regal D: Visual acuity for vertical and diagonal gratings in human infants. Vision Res **14**:1433, 1974.
8. Teller DY: The forced-choice preferential looking procedure: a psychophysical technique for use with human infants. Infant Behav Dev **2**:135, 1979.
9. Fantz RL, Ordy JM, and Udelf MS: Maturation of pattern vision in infants during the first six months. J Comp Physiol Psychol **55**:907, 1962.
10. Harris L, Atkinson J, and Braddick O: Visual contrast sensitivity of a 6-month-old infant measured by the evoked potential. Nature **264**:570, 1976.
11. Dobson V and Teller DY: Assessment of visual acuity in infants. *In* Visual Psychophysics and Physiology, Armington J, Krauskopf J, and Wooten B, editors. New York, 1978, Academic Press, Inc., p. 385.
12. Cooper J and Feldman J: Operant conditioning and assessment of stereopsis in young children. Am J Optom Physiol Opt **55**:532, 1978.

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