Visual Acuity in Newborn and Preterm Infants Measured With Grating Acuity Cards

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Binocular visual acuity of normal newborn infants, preterm newborn infants, and newborn, full-term infant patients with nonophthalmologic abnormalities was measured by means of grating acuity cards. Each test took about six minutes to complete, and 89% of the tests (154 of 174) were successful. Visual acuity of infants at 39 to 40 weeks of gestational age was about 0.023 stripes per minute of arc, or 0.69 cycles per degree (20/866). Between 34 and 44 weeks of gestational age, visual acuity improved at the rate of 0.46 octaves per month. This test is simple, fast, and reliable, and requires no apparatus except the cards themselves.

ROUTINE MEASUREMENT of visual acuity in newborn infants requires a test that is reliable, successful on most infants, and easy to use.

The visual acuity of newborn infants has been assessed behaviorally by several investigators[1-8] and also by visual-evoked potential.[3,5,9-11] The visual acuities obtained behaviorally were generally near 20/800 (0.75 cycles per degree). The visual acuity of newborns defined by visual-evoked potentials was between 20/800 (0.75 cpd) and 20/420 (1.43 cpd).[3,5,9,10] Norcia and Tyler[11] reported visual acuities measured by visual-evoked potential near 20/125 (5 cpd) in infants less than 1 week old.

The visual acuities of individual infants were often not obtainable by behavioral techniques[3,6,7] because the tests were generally long and newborn infants tend to be awake for only short periods (however, Dubowitz and associates[5,8] seemed to have better success than others). The techniques used in these behavioral and visual-evoked potential studies required both an apparatus and several trained personnel. Therefore, those techniques are not really suitable for routine testing of infants in the hospital or clinic.

The purpose of our study was to develop a technique for measuring visual acuity in infants under 44 weeks of gestational age. The technique had to meet several criteria. First, it had to produce valid, reproducible results. Second, it must be successful on most individual infants. Third, it had to require a minimum of resources: it must take little space in the crowded infant intensive-care unit and it must require no trained personnel other than those likely to be there anyway. Fourth, it must be fast. To meet these requirements, we developed a variant of the grating acuity card technique[12] for use on newborn infants. This technique has been successful for infants more than 1 month of age and has been shown to be much faster, more successful, and more convenient than forced-choice preferential-looking[13] which has proven unsatisfactory in this application. The grating acuity card technique therefore seemed a promising approach for use on newborns, who have very short alert periods. Since our data were collected, grating acuity cards have also been used successfully for testing healthy newborn infants by Dobson and associates.[14] In this report, we describe the new stimuli and technique we developed. We also report visual acuity values for normal newborn infants, healthy preterm infants, and young infants hospitalized for nonneurologic illnesses.

Subjects and Methods

The three groups of infants included in this study were free of neurologic and ophthalmologic abnormalities. Two groups were in the

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nursery of the infant intensive-care unit of Kobe Children's Hospital. The first group consisted of 24 preterm infants who were healthy except for their prematurity and the second group consisted of 37 full-term infant patients with nonneurologic diseases. The preterm infants were born before 36 weeks of gestation (average gestational age at birth was 32.4±2.4 weeks) and they ranged from 33 to 42 weeks of gestational age at the time they were tested. The full-term infant patients had been born after 36 weeks of gestation (average gestational age at birth was 38.7±1.4 weeks); gestational age at testing ranged up to 48 weeks. The third group consisted of 30 normal, full-term, newborn infants in the obstetrics ward of Ohta Community Hospital. These infants were born at an average of 39.7±1.0 weeks of gestational age and were less than 1 week old (average age, 5.1±3.3 days).

The grating acuity card technique we developed required the participation of two adults, and we conducted the experiments ourselves. One of us (M.Y.) is an ophthalmologist. He examined the fundus of each subject at least once and read each patient's chart before each test. The other (A.M.B.) is a psychologist with two years of intensive experience in visual testing of young infants. She was unaware of the age and diagnosis for all infants tested in Kobe Children's Hospital. To this end, the data books were kept in Japanese, which she could not read. We alternated across sessions as tester and observer. The observer presented the stimuli and observed the infant. The tester timed the tests, arranged the cards in order, selected the cards for the control phase of the procedure, and wrote down the results. Some infants were tested twice each week, once by each observer.

Three types of cards were used in this study (Fig. 1). Cards of the first type (Fig. 1, top) were gray and measured 35 × 56 cm. Each card had a 12 × 14-cm central rectangular window. A piece of photographic paper with black-and-white stripes was attached to the back of each card so that it showed through the window. The contrast of the stripes was 0.87, calculated as the difference in luminance between the white and black stripes, divided by the sum of their luminances. The space-averaged reflectance of the stripes was within 10% (0.05 $\log_{10}$ units) of the reflectance of the gray card. In the center of a central black stripe was a 2-mm peephole through which the observer could watch the infant.

The six cards were in a graded set: one card was blank, and the stripe widths were 0.11 to 1.68 cm in 1-octave steps. At a viewing distance of 36 cm they were equivalent to between 0.1 stripe per minute of arc (20/200) and 0.0063 stripe per minute of arc (20/3200). The cards were indistinguishable from the back. Cards of this type were used on all infants except for ten of the normal newborn infants.

The second type of card was similar to the first, except that the stripes were longer (23 cm), the card was taller (39 cm), and the set included twice as many cards in 0.5-octave steps (Fig. 1, middle). Cards of this type were used on ten of the normal newborn infants.

Cards of the third type were identical to the grating acuity cards of McDonald and associates.[12,15] These cards had two round stimulus windows, to the right and left of the peephole; one window contained a grating and one was blank.

All tests took place in the nursery where the infants normally stayed. Testing took place shortly before feeding, when the nursing staff reported them to be most alert. The infant was held by a nurse and viewed the cards binocularly. Some pilot data were collected in the obstetrics ward of Kobe Kaisei Hospital where the mothers held the infants. This was much less successful. The nurse stood with her back to a window so that the cards were illuminated with diffuse, indirect daylight. The luminance of the gray cards varied a bit, but was never below 300 cd/m^2.[16]

The observer decided whether the infant could resolve the stripes by observing the infant's fixation behavior in response to displacement of the grating stimulus. First, the observer placed his or her face in the infant's view, as close as possible to the infant's line of gaze. The distance between the infant's and observer's face was about 36 cm at that point. Next, the observer held up the card at that same 36-cm distance and observed the infant's face through the peephole. At that moment, the infant and observer were looking at each other's eyes through the peephole in the card. Next, the observer moved the card about 20 cm to the right or left, and again held it stationary for several seconds while continuing to observe the infant. At that moment, the infant would be looking at a region of blank gray cardboard. When the stripes were wide (and presumably visible), the infant would turn his or her gaze towards them, thus reestablishing eye-to-eye contact between the observer and the infant

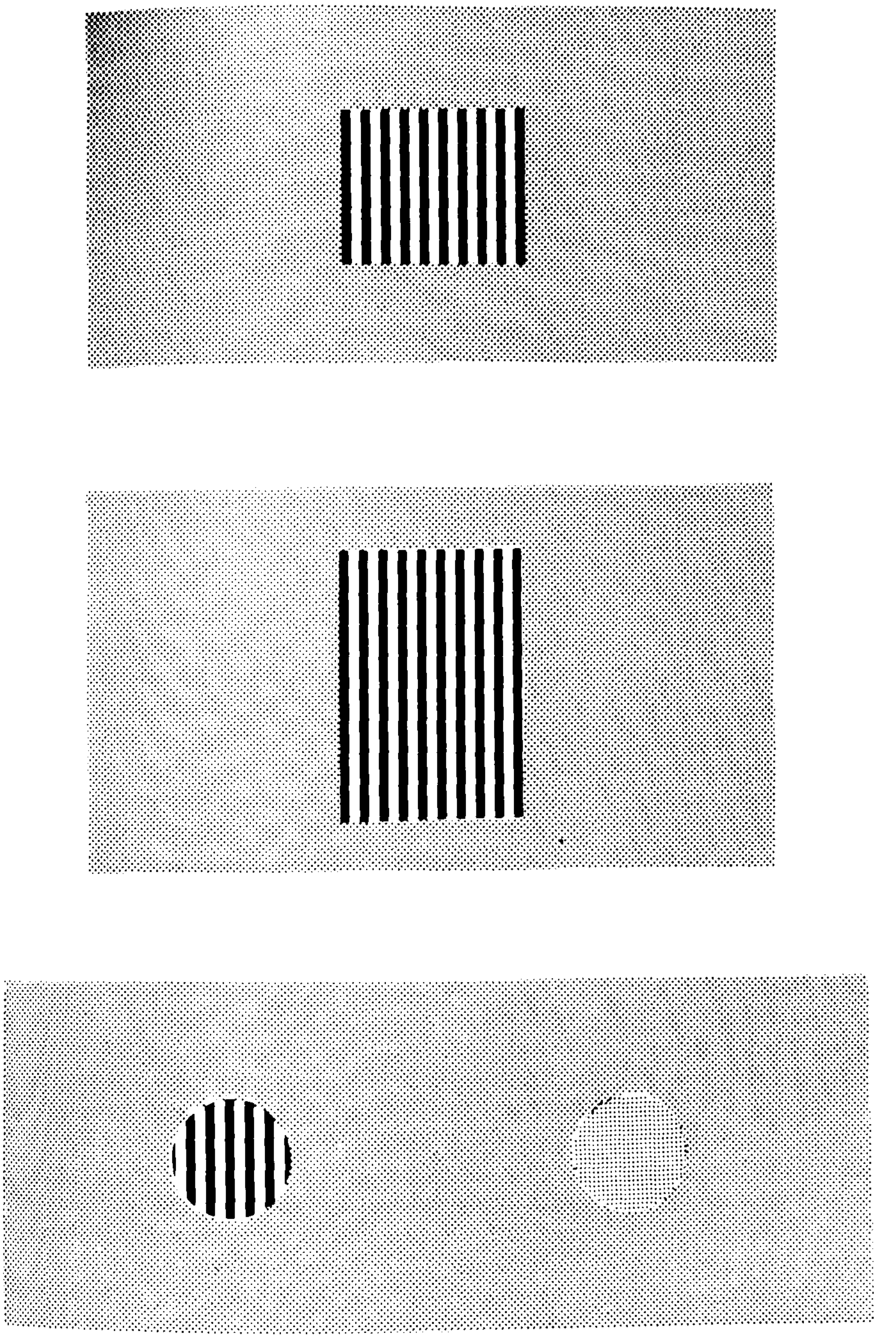

Fig. 1 (Brown and Yamamoto). The grating acuity cards. Top, The cards with short stripes. Middle, The cards with long stripes. Bottom, The cards with two stimulus locations.

(although of course the infant could not see the observer through the tiny peephole). When the stripes were narrow, the infant would either continue to stare at the blank card, start to fuss, or look elsewhere. The latency and accuracy of refixation was variable and depended on the age, health, and alertness of the infant.[17] However, repeated testing in both directions (left and right) often demonstrated that the stripes were visible even to infants with poor control over their direction of gaze. At the end of as many attempts to show refixation as the observer believed were profitable, he or she judged whether the stripes were or were not visible to the infant.

In the first part of the test, the cards were presented starting with whatever coarse grating seemed appropriate, and continuing to finer gratings until the infant no longer fixated the stripes. In this part of the test, the observer took advantage of whatever he or she knew or could guess concerning the infant to obtain a fast, rough estimate of the infant's visual acuity. The provisional estimate was the stripe width of the narrowest stripes the observer judged the infant could see.

The second phase of the test was the control test. The tester chose two cards near, but not necessarily straddling, the provisional visual acuity limit. The tester had watched the first part of the test, and was urged to include any cards for which he or she had disagreed with the observer. The observer was experimentally naive in this control part of the test: the observer did not see the stripes or know either their absolute or relative stripe widths.

The observer decided whether the infant could resolve the stripes on each control card. The observer could request additional cards, for example, the blank card or the card with the widest stripes, as a reminder of the infant's behavior when the stripes were not visible or to verify that the infant was still alert.

If the results of the control phase of the test confirmed those of the preliminary phase, the test was considered final after two control cards. If the observer was dissatisfied with the test or if the tester found the results to be inconsistent with those of the preliminary test, then additional control cards were run until either both observer and tester were satisfied that an assessment could be made from the data or until the infant fell asleep. The final visual acuity estimate was the width of the finest stripes that the observer judged the infant could resolve. All successful tests had to include at least one card the infant could resolve and one that he or she could not.

Immediately after the test was completed, the observer looked at the data and decided what the visual acuity of the infant was. In 126 of the 154 successful tests (90%), the preliminary and control phases of the test gave consistent results. In 102 of the tests, the control cards were chosen so that visual acuity could be estimated from the control data alone. In 37 tests, the visual acuity was taken from both parts of the test together. This occurred whenever the control cards were not optimally chosen to estimate visual acuity, for example, when all of the control cards were seen or the just-visible stripe width was not used as a control. It was important to have tests like this if the observer was to be unable to guess the stripe widths of the control cards. In each of those tests, the results of the two halves of the test were consistent. In the remaining 15 tests (10%), the subject was judged to see a particular stimulus on some trials but not on others. In those cases, the observer was allowed to take into account whether the infant was equally alert throughout the experiment and how many attempts were necessary before the infant looked at the stimulus. In those cases, the result of either the preliminary or the control test was taken as the visual acuity.

The tester timed the test from the moment the first card was presented until the observer judged the visibility of the last card. Tests were scored as "attempts" if the clock was started and as "successes" if the test was completed and a final visual acuity estimate was made.

Results

The two types of one-stimulus card used on the normal newborn infants did not produce significantly different visual acuity (t = 0.134; P>.5), population standard deviation (F = 1.86; d.f. = (9,13); P>.1), or test duration (t = 0.577; P>.5). Because none of these comparisons was significant, the data on normal newborns have been pooled across those two card types.

We were not successful with the two-stimulus card and we stopped using it after a few attempts.

The success rate for normal newborns was 83% (24 successes in 29 attempts). Of the 93 tests done on the full-term infant patients, including retests, 87 (94%) were successful; 43 of the 52 tests (83%) on preterm infants were successful. The average success rate for all subjects in Kobe Children's Hospital was 80% on the first attempt (49 of 59). Of the 52 infants tested two or more times, 51 (98%) were successfully tested on the first or second attempt. Therefore, if it is important for some reason to test the visual acuity of a particular healthy infant, that test can almost surely be done if several attempts are made. The problem seems to be that finding the infant really awake is partly a matter of luck, even when testing takes place at the optimal time in the feeding schedule, and perseverance is sometimes necessary for success.

Average durations of the timed, completed tests, ±1 S.D., appear in Table 1. The test took longer on the youngest infants because their direction of gaze was not well controlled and repeated attempts were necessary for confident judgments.[17] The duration of the test for the oldest infants was similar to that for the grating

TABLE 1
AVERAGE DURATION OF TESTS

	Kobe Children's Hospital		Ohta Community Hospital	
Gestational Age at Test (wks)	No.*	Mean (± S.D.) Test Duration (min)†	No.*	Mean (± S.D.) Test Duration (min)†
32 to 33	1	4.25	—	—
34 to 35	6	8.86 ± 2.7	—	—
36 to 37	8	8.67 ± 3.3	—	—
38 to 39	7	7.52 ± 2.9	9	6.25 ± 2.5
40 to 41	18	6.02 ± 1.9	11	6.19 ± 2.2
42 to 43	6	5.51 ± 2.2	1	6.18
44 to 45	4	6.23 ± 2.6	—	—
46 to 47	3	6.03 ± 1.3	—	—

*No. for whom data are available. Data for preterm and full-term infants at the Kobe Children's Hospital are pooled. Each infant contributed no more than a single data point.

†Standard deviation is undefined when No. = 1.

acuity cards used by McDonald and associates[12] on infants of comparable ages.

The average visual acuity of the normal newborn infants tested at 39 or 40 weeks of gestational age was 20/815. The average visual acuities of the preterm and full-term infant patients in the same age range were 20/872 and 20/951, respectively. These mean values did not differ significantly from one another (P>.05 by one-way analysis of variance).

Visual acuities of all infants successfully tested are shown in Table 2 and Figure 2. Each infant contributed no more than one measurement to each data point in Figure 2 or to each cell in Table 2: when an infant had been tested several times within a two-week gestational-age grouping (for example, by different observers), one of the tests was chosen for inclusion in this analysis by consulting a random number table. Each data point is the average of data for no fewer than four infants. The error bars are ±1 S.E. Published data for older infants taken

TABLE 2
AVERAGE VISUAL ACUITIES

	Kobe Children's Hospital				Ohta Community Hospital (Full-Term Infants)	
	Preterm Infants		Full-Term Infants			
Gestational Age at Test (wks)	No.*	Mean (± S.D.) Visual Acuity (cpd)†	No.*	Mean (± S.D.) Visual Acuity (cpd)†	No.*	Mean (± S.D.) Acuity (cpd)†
32 to 33	2	0.27 ± 0.71	—	—	—	—
34 to 35	9	0.41 ± 0.78	—	—	—	—
36 to 37	9	0.47 ± 0.71	—	—	—	—
38 to 39	4	0.63 ± 0.50	7	0.56 ± 0.79	9	0.75 ± 0.00
40 to 41	4	0.63 ± 0.50	20	0.59 ± 0.59	12	0.73 ± 0.40
42 to 43	2	0.75 ± 0.00	8	0.82 ± 0.64	3	0.53 ± 0.71
44 to 45	1	0.75	4	0.94 ± 0.58	—	—
46 to 47	—	—	3	0.94 ± 0.58	—	—
48	—	—	1	0.75	—	—

*Each infant contributed no more than a single data point to each cell.

†Standard deviation in octaves is undefined when No. = 1 and is equal to zero when the visual acuities of infants in the cell are equal.

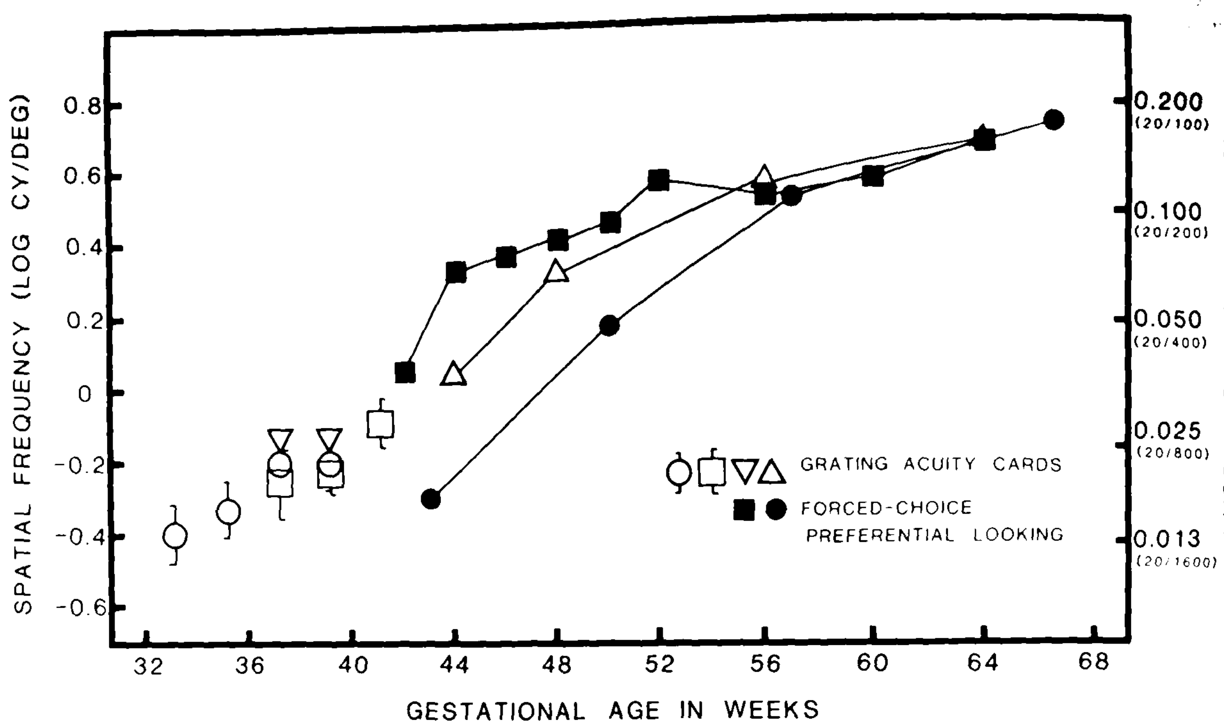

Fig. 2 (Brown and Yamamoto). Visual acuity as a function of gestational age. Data are shown for three groups of infants. Open circles, preterm infants; open squares, full-term infant patients; open inverted triangles, normal newborns. Error bars are ±1 S.E. Representative data for older infants are also shown: solid squares, Allen[15]; solid circles, Gwiazda and associates[19]; open triangles, McDonald and associates.[12]

binocularly using the forced-choice preferential-looking technique[15,19] and the grating acuity cards[12] are also shown.

The correlation between gestational age at time of test and visual acuity was 0.53, which was highly significant (F = 36.32; d.f. = (1,92); P<.001) for all the infants in Kobe Children's Hospital, including both preterm infants and full-term infant patients. Visual acuity improved at the rate of about 0.46 octaves per month of gestational age. For those same data, the correlation between age since birth and visual acuity was 0.14, which was not significant (F = 1.78; d.f. = (1,92); .10<P<.25).

In 30 cases, tests on the infants in Kobe Children's Hospital were carried out twice within five days with each of us serving once as observer and once as tester. In 27 of the 30 test-retest pairs (90%), the two observers agreed to within 1 octave. The average visual acuity estimates of the two observers were not significantly different (t = .856; P>.2) for these test-retest pairs. They also did not differ overall (t = .745; P>.2).

All successful tests included at least two different control cards for which the observer did not know the stripe widths during testing. There were four possible outcomes of this part of the test. The observer could judge both control cards as seen or neither as seen; the relative frequencies of these outcomes depended on which cards were arbitrarily chosen as control cards by the tester, and is not of interest here. The other two possibilities were that the broader stripes could be judged resolvable and the narrower ones not, or the narrower ones could be judged resolvable and the broader ones not. The relative frequencies of the latter two possibilities were informative. If the observer arbitrarily assigns a plausible visual acuity to each infant, then the narrower stripes should be judged visible and the broader ones not just as often as the other way around. On the other hand, an observer who is correctly assessing the visibility of the cards should only rarely declare the narrower but not the broader stripes to be visible.

In only three cases were the narrower stripes judged to be visible but not the broader stripes, whereas in 52 tests the wider stripes were judged to be visible but not the narrower ones. The "arbitrary observer" hypothesis outlined above can therefore be rejected beyond the .001 level by a likelihood ratio test ($\chi^2 = 25.2$; d.f. = 1).

Discussion

This new technique was highly successful for measuring the visual acuity of newborn and preterm infants. Average binocular visual acuity of normal infants was 20/815 at 39 to 40 weeks of gestation. The preterm and full-term infant patients in the same age range, hospitalized in the nursery of the intensive care unit but free of neurologic or ophthalmologic diseases, had visual acuities near 20/872 and 20/951, respectively. The test was fast (about six minutes on the average) and noninvasive, so it shows promise for use on a more widespread basis.

This technique is convenient to use in a clinical setting. The test requires the participation of three adults: the nurse who holds the infant, the tester, and the observer. Of these, only the observer needs any training, and that training can be short, as the task is easy for a physician or anyone else with experience observing visual behavior. Medical training per se does not appear to be important, however, as an ophthalmologist (M.Y.) and a psychologist (A.M.B.) generally agreed to within 1 octave in their visual acuity estimates. The nurse has no responsibility other than holding the infant and keeping it alert. The role of tester was occasionally carried out by an orthoptist, with good success. These tests could easily be done by a physician in the course of an examination without additional personnel being required other than the nurses on duty. This is important for crowded and busy hospital wards.

The cards themselves fit in a large briefcase and no additional apparatus is required. This is a big advantage in a hospital setting where space is at a premium. Infants more than approximately 44 weeks of gestational age, on the other hand, seem more interested in other things in the environment, and testing them with hand-held cards is difficult. For these older infants, the use of a large screen to block visible distractions, as suggested by others,[8,12] would undoubtedly result in a much better test.

Early attempts at using the cards with two stimulus windows (Fig. 1, bottom) were not successful. The problem was that the infants did not spontaneously turn to fixate the stripes even when the stripes were very broad. However, other investigators[14,15] reported good success with the two-stimulus cards. The difference seems to be that when two-stimulus cards are used, the nurse must turn the infant to show him or her the stimulus windows on both sides of the card before preferential looking can occur. This required more training of the nurses and better communication between the observer and the nurse than was possible in our situation. With our technique, the observer started the trial by placing the stimulus directly in the infant's line of sight, which worked reliably without requiring coordination between the nurse and the observer.

It is important to consider whether this test (or any new test) actually measures visual acuity.

The data themselves are good evidence that this technique measures something that depends on visual resolution. All successful tests included at least one card that the infants did not refixate. Therefore, the card itself (and the slight space-averaged reflectance mismatch between the stripes and the gray card) was not sufficient to produce refixation if the stripes were too small. Furthermore, if the infants were not responding differentially to gratings of different stripe widths, observers should be unable to tell which stimuli had wide stripes and which ones had narrow stripes by observing the infants' looking behavior. Actually it was quite easy to do this when the widths of the stripes straddled the visual acuity limit, and the observers rarely made mistakes. Therefore, this technique measures a visually mediated differential response to the stripes.

It is also a reasonable conclusion that the present technique, which uses cards with a single stimulus window, measures the same thing as other behavioral studies of visual acuity, which use a left-right stimulus configuration. The observed data fell nicely on an extrapolated curve from the published data on older infants (Fig. 2) and agreed rather well with other psychophysical estimates of visual acuity in newborns.[1-8] In particular, the visual acuities of infants under 6 weeks of age tested with one-stimulus cards and two-stimulus cards also agreed with one another and with the present data.[14,15] This overall agreement is consistent with the view that this test for newborns measures the same visual acuity as other behavioral tests for use on infants.

While the results of this test are reliable and clearly depend on visual resolution, it is less clear that they are limited by immaturities located in the distal visual pathways: other parts of the nervous system, notably the oculomotor system, are necessary for successful refixation of the displaced grating, and immaturities there could certainly limit performance. All infants in this study refixated at least one stimulus successfully, so it would be hard to argue that the critical maturation is purely motor. However, these data are certainly consistent with the hypothesis that the effectiveness of the gratings in producing differential responses in the optic nerve (for example) is relatively well developed in newborn infants. Maturation of the visual sensitivity or acuity of the central visual nervous system could then account for the improvement of behaviorally measured visual acuity with age. This view is consistent with the finding of Norcia and Tyler[11] that visual acuity in young infants measured by visual-evoked potential is somewhat higher than that found in any behavioral experiment (however, other investigators using visual-evoked potentials reported visual acuities closer to those reported here[3, 5,9,10]). Further research is necessary to trace the course of maturation of function in the different parts of the visual nervous system.

There are several reasons that it may be important to be able to assess the visual acuity of newborn infants. First, it is possible that behavioral assessment could disclose visual disorders not apparent from ocular examination, just as behavioral assessment is necessary for the diagnosis of amblyopia in adults and young children. Evidence for this can only become available if clinicians have a technique suitable for measuring visual acuity in newborns. The present report provides the first technique that is really adequate for investigating this question. Second, it has been reported that behaviorally assessed visual performance is correlated with neurologic status[5,20] and that visual performance is a sensitive predictor of intelligence.[21] This suggests that it may be useful to include a measure of visual function as part of the neurologic examination of the neonate. Once these uses can be established, routine screening may benefit individual patients and would also allow the development of good epidemiologic data on a worldwide basis. Finally, even in cases in which the cause of poor visual function is not well understood or effective treatment is not possible, knowledge of the extent of impairment may be valuable for genetic counseling and for early planning of the education of the handicapped infant. All of these require a convenient technique for measuring the visual acuity of infants. This technique and ones like it will allow these and other issues in the vision of newborns to be explored.

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