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References

The Acuity Card Procedure: A Rapid Test of Infant Acuity
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Forced-choice preferential looking (FPL) and operant preferential looking (OPL) procedures for testing infant acuity typically require 15–45 min to derive an acuity estimate. This article presents a new acuity assessment technique ("acuity cards") that combines FPL/OPL stimuli with an observer's subjective assessment of an infant's looking behavior. The infant is shown a series of gray cards that contain grating targets of various spatial frequencies. An observer watches the eye movement patterns and behavior of the infant and judges whether the infant can or cannot see the grating on each card in the series. Acuity is estimated as the highest spatial frequency that the observer judges the infant to be able to see. With this technique, the binocular acuity of normal infants can be estimated with reasonable accuracy in the laboratory setting in 3–5 min. Invest Ophthalmol Vis Sci 26:1158–1162, 1985

The forced-choice preferential looking (FPL) and operant preferential looking (OPL) techniques developed in our laboratory have been valuable in documenting the development of visual acuity in normal infants and children. There is good agreement between our technique and other preferential looking (PL) techniques on acuity norms for infants and children of different ages. However, FPL/OPL techniques have been useful clinically only in the hands of a few experienced researchers, primarily because of the unavailability of simple, standardized equipment and because of the time constraints typically imposed by clinical settings.

A major reason that formal two-alternative forced-choice PL testing is time consuming is that a large number of trials must be used if standard errors are to be made acceptably small. At the same time, much of the information available in an infant's response to the gratings test stimuli is not recorded. For example, although an observer in a PL procedure might judge the location of the gratings correctly on both a trial with a relatively low spatial frequency gratings and a trial with a near-threshold frequency gratings, the infant's response to the two gratings would probably be quite different, with the infant showing a strong fixation preference for the low frequency gratings but only a slight increase in fixation for the near-threshold gratings. The goal of the present study was to test the possibility that an adult observer who was allowed to make a broadly integrative, subjective judgment about an infant's responses to gratings stimuli could produce a rapid, accurate estimate of acuity.*

* A potential problem with the present approach is that reliance on an observer's integrated judgment, rather than formal two-alternative forced-choice procedures, increases the possibility of observer bias. The possibility that a measurement can be biased in principle should be distinguished from the question of whether it can be used in an unbiased way in practice. Continuing validation of the acuity card procedure will lie in further confirmation of the results of the present study—agreement with prior acuity norms and prior estimates of variability, and high interobserver reliability—across settings, observers and infants.
Materials and Methods. Subjects were 32 full-term, normal birthweight infants, with no known neurologic or developmental abnormalities, no family history of visual deficiencies and no known ocular disorders. None of the infants had a refractive error greater than +3.00 or −2.00 dioptries (D) along any meridian or a cylindrical error greater than 2.00 D. Eight infants were tested at each of the following ages: 4, 8, 16 wk, or 6 mo.

The apparatus consisted of a large gray cardboard screen (Crescent #651, Crescent Cardboard; Wheeling, IL) and two gray side panels that shielded the infant from room distractions (Fig. 1A). The screen contained a rectangular opening behind which stimulus cards could be held. The luminance of the screen was 1.2 log cd/m².

Nine two-aperture and nine one-aperture acuity cards were used in testing (Fig. 1B). Eight cards of each type contained a black-and-white square-wave grating (82 to 84% contrast) behind one aperture. A blank gray cardboard stimulus was placed behind the other aperture of the two-aperture cards. The eight gratings on each acuity card type varied from 0.2 to 24 cycles/deg in approximately one-octave steps. The ninth acuity card of each aperture type contained only blank gray cardboard stimuli. A subset of four acuity cards, adjacent in spatial frequency, was randomly selected for use in each test run. Two additional "anchor" cards, a blank and an 0.4 cycle/deg grating, could be used as necessary to provide anchor points for the observer's judgments. The observer knew the identities of the anchor cards, the locations of the gratings on the two-aperture cards and the sequential order of the four grating stimuli, but was blind to the absolute spatial frequencies of the cards in the subset.

After procedures had been fully explained, informed consent was obtained from the parent. Infants were then tested during two 45-min sessions on consecutive days. Two-aperture and one-aperture cards were used on alternate test days. The infant's acuity was estimated up to four times on each test day, with each estimate obtained using a randomly chosen grating subset. Holder and observer roles were switched after each acuity test so that acuity estimates were obtained by two observers each day. A total of four observers participated in the study, and each tested four infants at each age.

During testing, the infant was held 36 ± 3 cm from the center of the stimulus display. The observer stood behind the apparatus, held the cards containing gratings of unknown spatial frequency to the opening. A shield suspended 36 cm in front of the screen prevented the experimenter holding the infant from seeing the stimulus card and indicated the appropriate test distance. B. Acuity cards. One- and two-aperture cards were used on alternate test days.

Fig. 1. A, Experimental apparatus. An observer stood behind the apparatus and held cards containing gratings of unknown spatial frequency to the opening. A shield suspended 36 cm in front of the screen prevented the experimenter holding the infant from seeing the stimulus card and indicated the appropriate test distance. B. Acuity cards. One- and two-aperture cards were used on alternate test days.
Results. Wilcoxon signed rank tests performed on acuity threshold estimates where threshold fell within the range of presented gratings revealed no significant differences in acuity estimates ($P < 0.01$) between card type (one- vs two-aperture), test day (first vs second day), acuity card subset (low vs high spatial frequency subsets) or observers for any of the four test ages. Data were therefore collapsed across these variables.

Acuity estimates obtained from the eight infants at each of the four ages using one- and two-aperture cards are shown in Figure 2. Rightward (leftward) pointing arrowheads on the graphs represent lower-bound (upper-bound) acuity estimates. The acuity estimates are roughly normally distributed at each age. The means of the distributions shift toward higher frequencies in older infants (Table I) and agree well with previously established PL norms (arrows on the abscissa in Fig. 2). 2,3,6,7

In addition to having similar means at each age, both the acuity card and FPL/OPL techniques have similar variability. Standard deviations of acuity card estimates for all ages (Table I) agree reasonably well with the standard deviations reported in PL studies of similar-age infants. 2,3,6,8,10 Also, the percentage of acuity card threshold estimates that fall within $\pm 1$ octave of the grating frequency nearest the mean is

† In instances where both yes and no decisions were made in the same subset, the highest spatial frequency grating with a yes decision was scored as the acuity threshold. In the 33 tests (out of a total of 215 tests) where the observer judged that the infant could see all four gratings, the highest spatial frequency in the subset was used as a lower-bound acuity estimate. In the 11 tests in which the observer judged that the infant could see none of the four test gratings, the spatial frequency one octave lower than the lowest spatial frequency test stimulus in the subset was used as an upper-bound estimate of acuity. (A value one octave lower was chosen because the difference in spatial frequency between two adjacent acuity cards was one octave.)

‡ Because of the large number of Wilcoxon signed rank tests performed ($n = 28$), $P \leq 0.01$ was used as the criterion for significance because of the high likelihood of one or more type II errors when this many tests are conducted.
close to 95% (Table 1), as has been found for previous PL acuity estimates.\textsuperscript{2,3,6,8-10}

Interobserver reliability (ie, correlation between acuity estimates of two different observers on the same day) and intraobserver reliability (ie, correlation between acuity estimates of the same observer on day 1 vs on day 2) are plotted in Figure 3. Correlation coefficients across all ages were 0.72 ($P < 0.001$) and 0.66 ($P < 0.001$), respectively.\textsuperscript{11} Average test time across all groups was 3.7 min (Table 1).

Of the 32 infants tested, one 8-week-old showed poorer-than-average acuity (as evidenced by seven acuity estimates of 0.8 cycle/deg) during testing with the cards. Standard FPL testing of this infant showed an acuity of 1.1 cycles/deg, or one octave poorer than the mean FPL acuity for the infant's age, thereby confirming the reduced acuity estimates obtained with the acuity card procedure. However, results of a thorough ophthalmic examination revealed no abnormalities to explain the acuity deficit.

**Discussion.** The results of the present study show that the acuity card procedure allows an observer to make a rapid and accurate subjective estimate of a normal 1- to 6-month-old infant's binocular visual acuity. The mean and variability of the estimates agree with previously established values and inter- and intraobserver reliabilities are high in the laboratory setting. Advantages of the procedure are: (1) the ability of the observer to lower the stimulus card and attract the attention of a noncooperative infant; (2) the speed with which an acuity estimate can be obtained; and (3) the simplicity of the apparatus and scoring procedure.

In conclusion, the present study is the initial phase in the development of a rapid technique for acuity assessment in infants in settings where the time available and the cooperation of the infant are limited. The next phases of the research involve the following: (1) the use of a smaller step size between gratings and more cards in the stimulus subsets; (2) the evaluation of the procedure as a tool for monocular acuity assessment; (3) tests of older and younger infants to define the upper and lower end of the age range over which the test is useful; (4) direct comparison of acuity card versus FPL/OPL acuity estimates in children with visual disorders; (5) use of the technique in a mass screening setting; and (6) trials of the technique in clinical settings. While the range of settings in which the procedure will be useful remains to be established, the acuity card procedure represents the first step in the development of a simple and informal, yet fast and reliable acuity

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Table 1. Summary of acuity estimate statistics for each of the four ages and all ages combined

<table>
<thead>
<tr>
<th>Age</th>
<th>Mean acuity (cycles/deg)</th>
<th>Standard deviation (octaves)</th>
<th>Percent within ±1 octave of norm</th>
<th>Test time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 wk</td>
<td>1.1</td>
<td>1.1</td>
<td>87% (39/45)</td>
<td>4.7</td>
</tr>
<tr>
<td>8 wk</td>
<td>2.1</td>
<td>0.9</td>
<td>91% (53/58)</td>
<td>3.6</td>
</tr>
<tr>
<td>16 wk</td>
<td>3.7</td>
<td>0.7</td>
<td>96% (54/56)</td>
<td>3.1</td>
</tr>
<tr>
<td>6 mo</td>
<td>4.7</td>
<td>0.8</td>
<td>95% (53/56)</td>
<td>3.6</td>
</tr>
<tr>
<td>All ages</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>93% (99/106)</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Not surprisingly, the within-age test-retest reliability was low. By limiting our subjects within an age to normal infants of the same gestational age, we virtually eliminated any within-group variation in acuity. If there is no inherent variability within a group, test-retest variability will be due only to random variations in the outcome measure, and test-retest reliability would be expected to be zero.

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Fig. 3. A. Interobserver reliability. Correlation between acuity estimates of different observers on the same test day for all test ages: ○, 4-week-olds; □, 8-week-olds; ○, 16-week-olds; and ▲, 6-month-olds. Fifty-nine of the 64 data points show a difference of one octave or less between first and second observer estimates. B. Intraobserver reliability. Correlations between acuity estimates made by the same observer on different test days for all test ages. Fifty-six of the 64 data points show a difference of one octave or less between first and second test day estimates obtained by the same observer.
assessment procedure for use with infants and other nonverbal subjects and patients.

**Key words:** infants, grating acuity, rapid test, acuity cards, preferential looking

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**References**


**Age Dependence of Freezable and Nonfreezable Water Content of Normal Human Lenses**

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The cortex, intermediate zone, and nucleus of 19 normal human lenses between the ages of 3 and 77 yr were investigated. The freezable water content of the lenses was obtained by differential scanning calorimetry. The total water content was measured by vacuum dehydration. The nonfreezable water content was calculated from these two measurements. The total water content of the nucleus and intermediate layers decrease with age, while that of the cortex does not vary appreciably. The nonfreezable water content of all three regions of normal human lenses decreases with age. Invest Ophthalmol Vis Sci 26:1162-1165, 1985

In our previous studies on the light scattering of normal human lenses we came to the conclusion that the aging process is largely due to syneresis. In syneresis, secondary and tertiary structural changes occur in the lens proteins and this is reflected in the loss of water hydration. The water lost from the hydration layer becomes bulk water. This enhances the refractive index difference between protein aggregates and their surroundings and thus contributes to an increase in turbidity. Light scattering studies provide structural parameters of protein aggregates and, therefore, only indirect evidence for the loss of water hydration. Direct evidence can be obtained from thermal studies on the freezable and nonfreezable water content of the lens. A preliminary report on using differential scanning calorimetry to measure the freezable water content of the lens has been published. In the following study, we report the age dependence of total and nonfreezable water content of normal human lenses.

**Materials and Methods.** Nineteen normal human lenses between the age of 3 and 77 yr were obtained from the New York Eye Bank via Columbia University, courtesy of Dr. A. Spector. The lenses were worked up usually less than 36 hr postmortem, during which time the lenses were either in the eyeball or after removal kept at 4°C in a moist chamber. Studies on animal lenses indicate that there are no significant changes in the total, freezable and nonfreezable water content during 48 hr storage under the above conditions.

Each lens was divided into three parts: cortex (~40%), intermediate layer (~20%), and nucleus (~40%). Separate samples from each region were taken for differential scanning calorimetry (DSC) and for vacuum dehydration.

Six to 12 mg lens sample was hermetically sealed into preweighed coated aluminum sample pans. A