Infant VEP and Preferential Looking Acuity Measured with Phase Alternating Gratings

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Previously, infants' grating acuity was found to be temporally tuned, but adults' grating acuity was not. In infants, acuity was higher for gratings phase alternating at 7.5 and 14 reversals/sec than for stationary gratings and gratings alternating at 2.5 or 23 reversals/sec. Also, when preferential looking (PL) and visually evoked potential (VEP) acuity were estimated with phase alternating gratings (14 reversals/sec), the acuity difference between the two techniques was smaller than that obtained when phase alternating gratings were used to estimate VEP acuity and stationary gratings were used to estimate PL acuity. In the present study, it was determined if PL grating acuity was tuned in older children and if the smaller difference between VEP and PL acuity found when infants were tested with phase alternating gratings was independent of temporal rate. Grating acuity in infants older than 2 yr was found to be not tuned, and the smaller difference between VEP and PL grating acuity in infants when both were measured with phase-alternating gratings was not rate dependent. VEP acuity and PL acuity for phase alternating gratings developed at different rates, converging to nearly equivalent levels by 12 mo of age.

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There has been considerable interest in explaining why infant grating acuity is higher when estimated with visually evoked potential (VEP) techniques than with forced-choice preferential looking (PL) techniques. Possible reasons for this difference, which are not mutually exclusive, include: (1) criterion differences across techniques—some variant of a zero microvolt extrapolation is used to estimate VEP acuity,1-4 while 70–75% correct on the frequency of seeing curve is used to estimate PL acuity;5-6 (2) different neural substrates—PL techniques may be tapping mechanisms "downstream" from VEP mechanisms;7 and (3) temporal factors—VEP acuity is measured with temporally modulated patterns, whereas PL acuity typically is measured with stationary gratings.1

Previously,8 we studied how temporal factors contribute to this difference by measuring PL grating acuity in 2- to 10-mo-old infants with stationary gratings and gratings phase alternating at 2.5, 7.5, 14, and 23 reversals/sec. We found that the acuity functions of infants 3 mo and older were tuned. Acuity estimated with gratings alternating at 7.5 and 14 reversals/sec was one octave higher than acuity estimated with stationary gratings and gratings alternating at 2.5 and 23 reversals/sec. Adult grating acuity was tuned only for eccentrically presented targets, suggesting that the retinal region used by the infant to detect the gratings acted like the adult perifovea. Also, when both VEP and PL acuity were measured from the same infants with 14 reversals/sec phase-alternating gratings, we found that the acuity difference between the two techniques was reduced by 0.5 to 1 octaves compared to the difference found when PL acuity was measured with stationary gratings.

The purpose of this study was twofold: (1) to determine if the smaller difference between VEP and PL grating acuity, found previously at 14 reversals/sec, occurs at other temporal rates; and (2) to determine if grating acuity is tuned in toddlers and children. In the first experiment, we measured VEP and PL acuity from 2- to 13-mo-old infants using three rates of phase alternation: 10, 14, and 24 reversals/sec. In the second experiment, we measured PL grating acuity in children between 1 and 5 yr old for stationary gratings and phase alternating gratings (7.5, 15, and 24 reversals/sec).

Materials and Methods

Subjects

Experiment 1: VEP and PL estimates of acuity were obtained from 42 infants ranging in age from 2–13 mo. After the study was described to the parents, in-
formed consent was obtained. VEP estimates of acuity were obtained from six visually normal adults between 22 and 48 yr old. Each infant's VEP and PL data were collected within a 1 wk period.

Experiment 2: PL estimates of grating acuity for stationary and phase alternating gratings were obtained from 46 children between 1 and 5 yr old. Fifteen children were 12-23 mo old (mean age 17), 13 were 24-35 mo old (mean age 30), 10 were 36-47 mo old (mean age 40), and eight were 48-71 mo old (mean age 57). A complete set of data, including acuity estimates for stationary gratings and three rates of phase alternation, were obtained from each child in one or two testing sessions within a 1 mo period.

Sweep VEP Recording

Only a brief description of the VEP methods are given here. Complete details of our sweep VEP technique are found in Sokol et al.8 Phase-alternating square-wave gratings were generated on a Hewlett-Packard (Mountain View, CA) 1311B display monitor. The mean luminance of the monitor was 1.5 log cd/m² and the contrast of the gratings was 89%. The gratings were phase reversed at 10, 14, and 24 reversals/sec, with the order of presentation randomized. Physical and electronic constraints on our equipment prevented us from measuring acuity below 10 reversals/sec. The spatial frequency of the gratings was swept linearly from low to high, with a sweep duration of 13 sec. Sweep range was 0.25-10 cycles/degree at a test distance of 50 cm, 0.5-20 c/deg at 1 m, and 0.75-30 c/deg at 1.5 m. The test distance for the infants was based on each infant's age; all adults were tested at 1.5 m. The field size (7 × 6°) was constant. Fifty-two pairs of sweep VEPs and PL data were obtained at each rate.

Binocular VEPs were recorded using an electrode located at Oz and referenced to one ear; the other ear served as ground. A discrete Fourier transform was performed on the incoming electroencephalogram. An off-line routine determined the magnitude and phase of each sweep. Three sweeps were obtained for each stimulus condition, and the records were stored on a floppy disk. After each session, the three sweeps were vector averaged. VEP acuity was estimated by fitting a straight line, by eye, from the highest spatial frequency peak to zero microvolts.34

Preferential Looking Technique

The equipment used to obtain psychophysical estimates of grating acuity from the infants in experiment 1 and the toddlers and children in experiment 2 consisted of a microprocessor (Apple IIe; Apple Computer), two graphics boards with a resolution of 512 × 512 pixels, two black and white video monitors, and a control box used by the observer to initiate each trial and record the side preferentially fixated by the infants or pointed to by the older children.8

The test distance varied according to each subject's age. Infants were tested at a viewing distance of 1 m, and toddlers and older children were tested at a viewing distance of 1.5 m. At 1 m, the field size of each screen was 7 × 6°, the centers of the two screens were separated by a visual angle of 18°, and the square wave gratings ranged in spatial frequency from 0.75-35 c/deg in 0.5 octave increments. At 1.5 m, the field size of each screen was 4 × 5°, the centers of the two screens were separated by a visual angle of 12°, and the square wave gratings ranged in spatial frequency from 1.12-51.7 c/deg in 0.5 octave increments. The mean luminance of each screen was 1.5 log cd/m², and the contrast of the gratings was 89%. During the inter-trial interval, the luminance of the screens was 1.2 log cd/m².

A software algorithm ran a two-up, one-down staircase procedure. The viewing distance and starting spatial frequency was based on each child's age and was set at least one octave above threshold, which was determined from published norms.9,10 On each trial, square wave gratings ranging from 0.75-35 c/deg or 1.12-51.7 c/deg, depending on the viewing distance, appeared on the "pattern" screen and 35 c/deg or 51.7 c/deg gratings appeared on the "blank" screen. Because of the limits of acuity, no subject reached the highest spatial frequency, so 51.7 c/deg gratings never appeared on both screens. A tone from the computer indicated when the trial was ready for presentation. The observer centered the subject's gaze and initiated the stimulus presentation by pressing a button on the control box. For infants and toddlers, the observer made a forced-choice judgment as to which side contained stripes based on the child's eye and head movements. The observer was given feedback by the computer: a high frequency "beep" indicated a correct response and a low frequency "buzz" indicated an incorrect response. Older children, who could follow verbal instructions, were asked to look at the two monitors and point to the side with the grating pattern. If the child reported there was no pattern on either screen, the parent—who sat off to the side, but closer to the monitors than the child and thus was able to detect the grating—was asked where the grating was located. The observer then pressed the button corresponding to the "incorrect" side. This ensured that spatial frequency always decreased when the subject was unable to detect the grating.

If the observer's response was correct on two consecutive trials, the spatial frequency of the next trial was 0.5 octave higher; one incorrect response produced a spatial frequency that was 0.5 octave lower on the
next trial. After six (21 children) or 10 reversals (15 children) had occurred, excluding the first reversal, the program terminated and calculated the mean of the spatial frequencies at which each reversal occurred, yielding an acuity estimate. On every sixth trial, a low spatial frequency grating was presented to maintain the child’s attention.

Results

Experiment 1: A three factor (technique, age, rate) analysis of variance showed significant main effects for technique ($F_{1,244} = 211.3, P < .0001$) and age ($F_{9,244} = 26.57, P < .0001$), indicating that at all rates VEP acuity was significantly higher than PL acuity and that both improved with age (Fig. 1). Rate was nonsignificant, indicating that within each technique, acuity estimates were similar across rate. The only significant interaction was technique by age ($F_{9,244} = 3.61, P < .0003$), indicating that changes in acuity revealed by the main effect for age differed as a function of the technique used.

Because there was no rate effect, each infant’s mean PL and VEP acuity for the three rates was calculated. From these data, the mean VEP and PL acuity for each age group was determined. Within the range of data shown in Figure 2, the rate of growth of PL and

Fig. 1. Comparison of mean VEP and PL grating acuity at 10, 14, and 24 reversals/sec as a function of age. All data are paired, ie, each infant contributed data for VEP and PL measures. Vertical bars = ±1 standard error.

Fig. 2. Mean VEP and PL grating acuity as a function of age estimated with phase alternating gratings (circles, infants; closed square, adult sweep VEP acuity; open square, adult grating acuity from reference 8). Vertical bars = ±1 standard error.

Fig. 3. Mean octave difference in VEP and PL acuity as a function of age. Vertical bars = ±1 standard error.
VEP acuity decelerated with age at different rates, converging to nearly equivalent values by 12 mo of age. The average (geometric mean) change in acuity over 12 mo for VEP acuity was 2.24 min of arc/mo, while PL acuity changed at a rate of 4.83 min of arc/mo. Figure 3 shows that the mean octave difference in VEP and PL acuity as a function of age was 2 octaves at 2 mo of age, but only 0.5 octave at 12 mo.

Experiment 2: Figure 4 shows the mean grating acuity as a function of alternation rate for children between 8 mo and 5 yr old. The 8–9 and 10–11 mo groups were replotted from Sokol et al. For these subjects, acuity was significantly higher ($P < .05$) for 14 reversals/sec gratings than for stationary gratings. For the 1- to 5-yr-old children, a repeated measures analysis of variance showed a significant rate effect only for the 1- to 2-yr-old group ($F_{359} = 3.61, P < .02$). Post-hoc analysis of the 1- to 2-yr-old data, using t-tests, showed that acuity for gratings reversing at 7.5 reversals/sec was significantly higher ($P < .05$) than acuity for stationary gratings and 23 reversals/sec gratings.

Discussion

The present study shows that: (1) PL grating acuity was no longer tuned after 2 yr of age; (2) the smaller VEP/PL acuity difference, found when both are measured with phase alternating gratings, was independent of temporal rate, at least over the frequency range (5–12 Hz) we employed; and (3) from 2–12 mo...
of age, VEP and PL acuity growth was a decelerating function of age, with the growth of PL acuity decelerating by a factor of two faster than VEP acuity.

It is not clear why PL acuity was no longer temporally tuned after 2 yr of age. Previously, we had found that adult grating acuity is tuned only for targets presented perifoveally, suggesting that the retinal area used by the infant to detect the gratings acts like the adult perifovea. Possible factors that may have contributed to the drop-out of tuning include: an increase in cone density of the retinal area used by the infant to detect the gratings, increases in the number of cortical synapses, and developmental changes in temporal processing.

The absence of a rate effect for VEP acuity (Fig. 2) agrees with Norcia and Tyler, who found no difference in VEP acuity for 12 and 20 reversals/sec gratings in 4- and 6-mo-old infants. In contrast, Apkarian et al. and Gottlob et al. using a log spatial frequency sweep method rather than a linear sweep technique— which we and Norcia and Tyler used—found that acuity declined with increasing reversal rate.

It is not surprising that there was no temporal tuning for PL acuity in the present study (Fig. 2), because the range of temporal frequencies that we used (10–23 reversals/sec) was too narrow to demonstrate the effect found previously. Our previous data that showed PL grating acuity was temporally tuned was obtained over a wider range of temporal frequencies (0-23 reversals/sec), and the largest difference was found when acuity for stationary gratings and 14 reversals/sec gratings was compared.

Despite earlier reports that temporal factors have no influence on the VEP/PL acuity differences, more recent data demonstrated that temporal factors led to acuity measures within and across PL and VEP techniques. For example, within the VEP technique, Orel-Bixler and Norcia found that the slope of the acuity growth curve for pattern onset stimuli was steeper than the growth curve for pattern reversal stimuli. They suggested that one reason for these slope differences was the use of different temporal modes. Within the PL technique, rate influenced acuity up to 2 yr of age, and in the only PL study of infant temporal contrast sensitivity, Swanson and Birch found that the shape of the temporal sensitivity curve for a 1.0 c/deg spatial pattern changed from lowpass for 4-mo-old infants to bandpass for 8-mo-old infants.

One possible reason for the absolute difference between VEP and PL acuity in very young infants and the different rates of deceleration of VEP and PL acuity over the first year of life is that the development of PL acuity is subject to more constraints than VEP acuity. VEP acuity is limited primarily by structural and neural changes of the ocular media, retina, vi- sual pathways, and cortex. PL acuity also is limited by these factors, but in addition, other nonsensory factors such as attention and oculomotor development contribute to the growth of PL acuity. The convergence at 1 yr of age of acuity estimated with the two techniques may reflect the reduced influences of attention and oculomotor factors.

Key words: infant acuity, phase-alternating gratings, preferential looking, visual development, visual-evoked potentials

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References


