Development of VEP Vernier Acuity and Grating Acuity in Human Infants

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Purpose. To compare the developmental sequences of two basic measures of pattern vision, Vernier acuity and grating acuity, using steady state visual-evoked potentials (VEPs) and an analysis designed to isolate pattern-specific responses from those due to motion in the Vernier stimulus.

Methods. The authors recorded VEPs from 57 healthy full-term infants and 4 adults. The grating acuity stimulus was a sinusoidal grating, temporally modulated (appearance-disappearance) at a rate of 3 Hz, with spatial frequency decreasing in linear steps during each 10-second trial. The Vernier acuity stimulus was a vertical square-wave grating with portions of each bar temporally modulated to make offsets appear and disappear at a rate of 3 Hz. Vernier offset size changed in log steps from small to large offsets. The authors recorded each observer's electroencephalogram (EEG) during multiple presentations of each stimulus type, and the EEG was digitized and filtered to obtain the amplitude and phase of the response at the first two harmonics of the stimulus temporal frequency. Thresholds were estimated with an extrapolation technique that took into account the signal-to-noise ratio and phase of the response.

Results. VEP Vernier acuity and grating acuity develop at different rates, with grating acuity approaching adult levels earlier than Vernier acuity. The within-subject relationship between VEP Vernier acuity and grating acuity follows the same developmental trajectory established by previous psychophysical studies of humans and monkeys.

Conclusions. This VEP technique provides a rapid estimate of Vernier acuity in infants. VEP Vernier acuity remains strikingly immature throughout the first year of life, similar to behavioral Vernier acuity. Because Vernier acuity is a sensitive measure of amblyopia, this VEP test may be useful in the future to identify amblyopia and to follow its treatment progress in pediatric patients. (*Invest Ophthalmol Vis Sci.* 1999;40:2411–2417)

Most aspects of spatial vision are quite immature in the human neonate, and different visual functions have different developmental time courses. For example, grating acuity, a measure of the finest resolvable detail, and Vernier acuity, a measure of sensitivity to the relative position of pattern elements, develop at different rates during infancy, according to preferential-looking measures.[1–4] One conclusion that may be drawn from these behavioral studies is that grating acuity and Vernier acuity are limited by different mechanisms. This conclusion is consistent with adult data and theories suggesting that grating acuity is limited by retinal factors, whereas Vernier acuity is further limited by cortical factors.[5]

In the present study, we wished to establish the normal developmental sequence of a new visual-evoked potential (VEP) Vernier acuity measure as a prelude to future clinical applications. Vernier acuity has been shown in adults to be a more sensitive indicator of amblyopia than grating acuity,[6] and thus a rapid and reliable technique for measuring Vernier acuity in infants could provide a valuable tool for evaluating the progress and treatment of infants and children at risk for the development of amblyopia.

The measurement technique we used relies on the observation that modulation between nonequivalent asymmetrical pattern states (e.g., a square-wave grating versus a grating containing Vernier offsets) produces odd as well as even harmonics in steady state VEP responses. A previous study of adults has exploited these separate Fourier components to differentiate between pattern-specific responses and motion responses in the steady state VEP.[7] The even- and odd-harmonic components in the VEP reflect symmetrical and asymmetrical "spatial" aspects of the stimulus modulation, respectively.[8] The odd-harmonic component of the steady state VEP response to Vernier onset-offset is consistent with the response to an alignment/misalignment transition being different in amplitude than the misalignment/alignment transition as has been reported for the transient Vernier VEP.[9] Odd harmonics are thus produced when the stimulus changes spatial configuration during each cycle of modulation, as opposed to translating or reversing in polarity. Even harmonics are produced in response to the symmetrical properties of the offset motion, such as those

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caused by a change in the "spatial phase spectrum" caused by motion of the stimulus, rather than by changes in spatial configuration.

Methods

Observers

VEPs were measured in 57 healthy full-term (±3 weeks gestation) infants, ranging in age from 8 to 80 weeks postnatal, and in 4 adults with normal vision. These infants were recruited from parent education classes in the San Francisco Bay area and from the nursery at California Pacific Medical Center in San Francisco, and written informed consent was obtained from one or both parents. This research conformed to the tenets of the Declaration of Helsinki, and the research protocol was approved by the Institutional Review Board of the California Pacific Medical Center.

Stimulus Conditions

Stimulus generation and signal analysis were performed by version 1.3 of the DIVA-i (Digital Instrumentation for Visual Assessment) system, controlled by an Apple II+ microcomputer, and stimuli were presented on a TECO 12-inch composite video monitor. This apparatus, along with the general procedure and signal analysis, has been previously described[10,11]; thus, here we describe the attributes unique to the present study. For all stimuli, space average luminance was 64 candela/square meters (cd/m^2); Michelson contrast was 0.80 [calculated by the equation $(L_{max} - L_{min})/(L_{max} + L_{min})$]; and the stimulus field size was 16 cm (height) by 24 cm (width). Viewing distance was 69 or 100 cm for infants and 138 cm for adults. Schematic examples of the Vernier acuity and grating acuity VEP stimuli are shown in Figure 1.

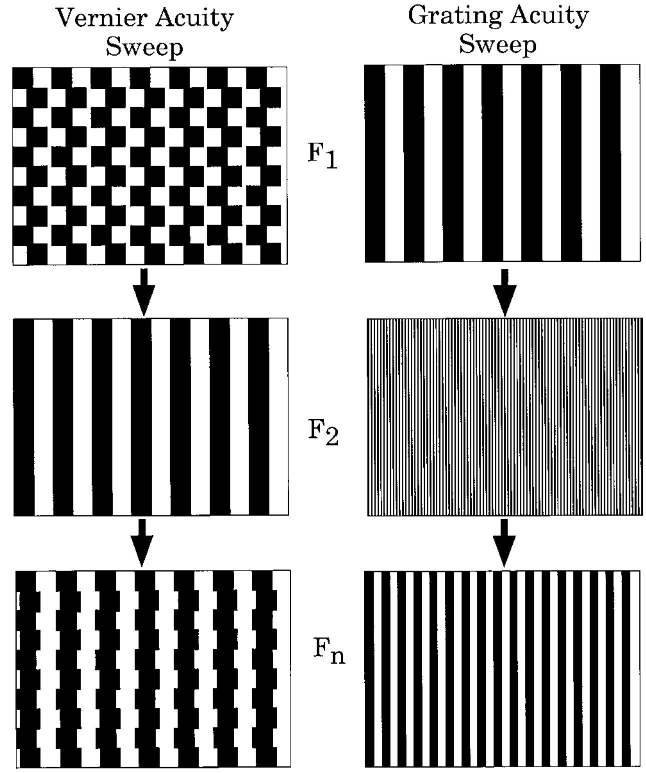

Figure 1. Schematic examples of the two stimulus conditions. Each row shows a schematic drawing of one video frame of stimulus presentation (labeled from top to bottom as F_1, F_2, and F_n) to indicate the spatiotemporal characteristics of each stimulus. *Left column*, The Vernier acuity stimulus was a high-contrast (0.64) square-wave grating that alternated between states containing offsets (F_1, F_n) and a colinear state (F_2). Alternation occurred at a rate of 3Hz, and throughout each 10-second trial the offset size changed in logarithmic steps from small to large offsets. *Right column*, The grating acuity stimulus was a high-contrast (0.64) sine-wave grating (shown here as square wave, F_1 and F_n), which alternated with a matched-luminance blank field (F_2), at a rate of 3 Hz. During each 10-second trial, the spatial frequency of the grating changed in linear steps from high to low.

The Vernier acuity stimuli consisted of vertical square-wave bars that alternated at a fixed temporal frequency between a fully colinear grating and a grating containing Vernier offsets (see Fig. 1, left). Offsets were periodic along the vertical extent of the bar, and offset height (and vertical spacing) ranged from approximately 0.5° to 2° of visual angle, depending on viewing distance. The fundamental spatial frequency of the grating was 0.5 cyc/deg for infants aged 5 to 35 weeks postnatal, 1.0 cyc/deg for infants aged 36 to 75 weeks, and 2.0 cyc/deg for adult observers. These spatial frequencies were chosen to control for the visibility of the carrier grating at different ages, by placing it at (or just below) the approximate peak of the contrast sensitivity function for different ages, based on previous VEP data.[12] The temporal frequency was the same for all observers, 3 Hz (3 cycles of alternation per second).

The grating acuity stimulus consisted of a vertical sine wave grating that alternated with a matched space-average luminance field, at a rate of 3 Hz (see Fig. 1, right). The spatial frequency range varied with age: 1 to 10 cyc/deg for infants 2 months and younger, 2 to 20 cyc/deg for those aged 2 to 8 months, and 3 to 30 cyc/deg for older infants and adults. We used an appearance-disappearance modulation state, rather than phase-reversal modulation, to observe responses at the same response frequency (3 Hz) being analyzed for the Vernier stimulus.

EEG Data Acquisition and VEP Spectrum Analysis

Grass E-6H gold-cup surface electrodes were used to collect EEG data. The electrode montage was bipolar with a common reference at Oz, and ground was placed 3 cm left of the reference. Differential voltages were measured between the reference and each of two electrodes placed according to the International Ten-Twenty System[13]: one at Pz, 3 cm above the reference, in line with the reference and the inion; and the other at O2, 3 cm to the right of the reference.

The EEG was digitized to 8-bits accuracy over a 1- to 100-Hz bandwidth at a sampling rate of 180 Hz. Preamplifier gain was set to 20,000 for infants and 50,000 for adults. We used a self-ranging amplifier stage between the EEG preamplifier and the analog/digital (A/D) converter. This stage was under computer control and continuously adjusted the system gain between trials to maximize the A/D converter range. A series of discrete short-time Fourier transforms was performed at the end of each 10-second trial. This analysis provided response amplitude functions at the fundamental and second harmonic components of the stimulus temporal frequency (e.g., a 3-Hz stimulus resulted in a 3-Hz first harmonic response and a 6-Hz second harmonic response). The amplitude function was smoothed by analyzing the signal in 17 separate bins, each with a 2-second sweep duration and a 1.5-second overlap between bins.

To estimate baseline EEG activity (or noise), response amplitudes at two frequencies, 2 Hz higher and 2 Hz lower than the response frequency, were measured in each analysis bin and used as a comparison to the visually-driven signal. This allowed a signal-to-noise ratio (SNR) to be computed for each analysis bin. Norcia and Tyler[11] demonstrated that a SNR of 3:1 reduces the single bin false alarm rate to 0.003, thus it was used as the amplitude criterion for estimating threshold.

Experimental Protocol and VEP Threshold Estimation

During an experimental session, the infant was held by his or her parent. The infant's attention was attracted to the stimulus monitor by an experimenter who dangled a small toy in the central portion of the screen and sang or spoke to the infant during each trial. The experimenter could interrupt a trial if the infant looked away from the stimulus display screen and resume the trial when the infant looked back at the screen. When interruptions occurred, the program interrupted the sweep but not the stimulus appearance or modulation. When the trial resumed after an interruption, data collection began with the stimulus set to its value at 0.5 seconds before the interruption.

For estimation of Vernier acuity, evoked potentials were recorded while offset size was swept from below threshold to above threshold in 17 equally spaced logarithmic increments throughout a 10-second trial duration. Beginning and ending Vernier offset sizes were chosen on the basis of the infant's age and previous psychophysical estimates of infant Vernier acuity[1–4] scaled by a factor consistent with the relationship between psychophysical and electrophysiological estimates of infant visual thresholds.[14] Grating acuity estimates were obtained by measuring VEPs while sweeping the grating spatial frequency from a value below threshold to one above threshold, in 17 equally spaced steps on a linear scale.

Thresholds were estimated by the scoring algorithm described by Norcia et al.[10] Briefly, the algorithm searched the sweep record for a range of data values that exceeded SNR and phase consistency criteria, starting at the low-visibility end of the data record. Once a range of acceptable data values was found, threshold was estimated by linear extrapolation to zero microvolts. The two stimulus conditions yielded three separate acuity estimates: Vernier acuity, from the first harmonic response to the Vernier stimulus; motion acuity, from the second harmonic response to the Vernier stimulus; and grating acuity, from the first harmonic response to the grating stimulus. Sixty-five percent of infant observers provided Vernier acuity data, 85% provided motion acuity data, and 90% provided grating acuity data. All cases for which data were not provided were because of a failure to meet the SNR criterion.

Results

Specificity of First Harmonic Response to Vernier Offset Appearance

A previous study of adults[7] has shown that the first harmonic response component of the Vernier onset-offset stimulus is a specific response to pattern changes caused by the appearance and disappearance of the offsets. By contrast, one study of infants in which nonquantitative analysis of transient VEP data was used suggested that infant transient VEP responses were not selective for offset appearance/disappearance.[15] We conducted a similar control experiment to determine whether our steady state VEP technique yields responses in infant observers that quantitatively demonstrate a first harmonic response specific to asymmetrical pattern differences created by offset appearance/disappearance. These data are shown in Figure 2.

We tested seven infants (and one adult; for comparison, see also Ref. 7) in two conditions: in the first, fixed-size offsets appeared and disappeared in a 0.8 cyc/deg square wave grating at a rate of 3Hz (alignment/misalignment condition); in the second, offsets alternated at 3 Hz between two misaligned states (misalignment/misalignment condition). Thus, the first condition contained two asymmetrical pattern states, a grating with offsets and a grating without offsets. The second condition contained two equivalent mirror-symmetrical pattern states with Vernier offsets always present and moving symmetrically about the grating reference bars. Schematic representations of these stimuli are shown as insets in Figure 2. The magnitude of offset displacement was 30 arc minutes in both conditions. If both responses were evoked simply by the motion of the offsets, we would expect to see evidence of both response harmonics in both stimulus conditions. If, however, the first harmonic response was specific to the discrimination of the pattern states with and without Vernier offsets present, we expected to observe it in the alignment/misalignment condition but not in the misalignment/misalignment condition. This is exactly what we observed in 7 of 7 infants tested, as well as the adult. Response spectra for two infants are shown in the top portion of Figure 2. These data illustrate the strong first harmonic response to the alignment/misalignment condition, and the lack of first harmonic response in the misalignment/misalignment condition (upper panels, indicated by the shaded bar). Strong second harmonic responses (as well as higher even harmonics) are present in both conditions and are likely a response to the motion of the offsets.[7] The bar chart in the lower panel of Figure 2 shows first harmonic amplitude and standard errors for all eight observers. All observers had a significant first harmonic response in the alignment/misalignment condition ($t = 3.59$, $df = 7$, $P < 0.01$), whereas none had a significant first harmonic response in the misalignment/misalignment condition ($t = 0.64$, $df = 7$, $P > 0.05$). Based on these results, we used the first harmonic VEP response to estimate Vernier acuity and the second harmonic response to measure a motion threshold.

Displacement and Grating Acuity Thresholds

Figure 3 shows displacement thresholds for the asymmetrical (3 Hz) and symmetrical (6 Hz) components of the Vernier onset-offset response for 8- to 80-week-old infants along with grating acuity, measured with pattern appearance/disappearance targets. Resolution on each response measure increased linearly over the age range of the study. Based on regression lines fit to each data set, Vernier acuity increased most rapidly, by a factor of 4.5 between 10 and 100 weeks, whereas motion and grating acuity improved by factors of 1.9 and 2.3, respectively. The slopes (and confidence limits) describing the developmental rates of the three data sets were as follows: Vernier acuity, 0.72 (0.051); motion acuity, 0.32 (0.055); and grating acuity, 0.41 (0.031). At any age, there is a substantial range of

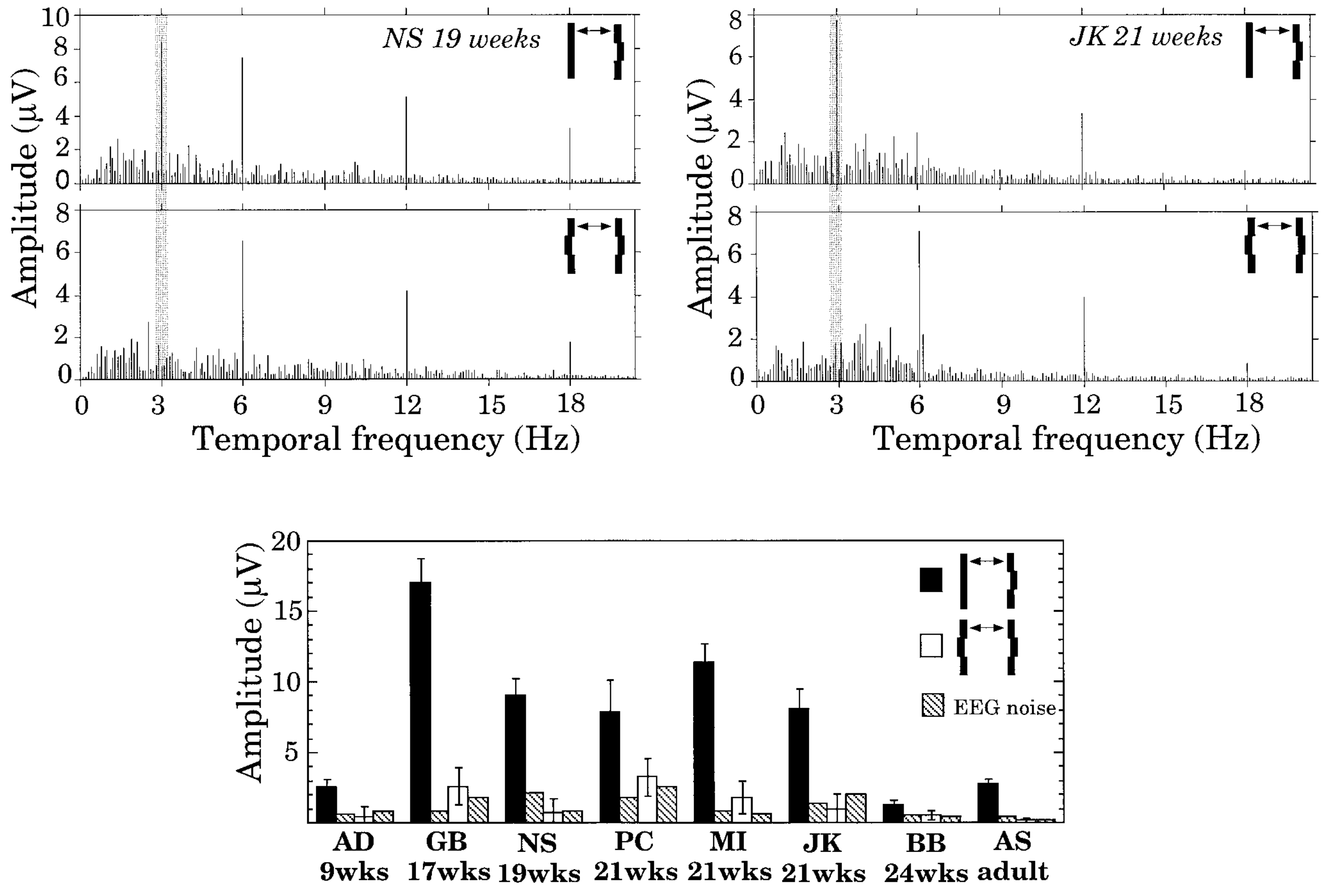

Figure 2. Infant data demonstrating the specificity of the first harmonic VEP response to stimulus configuration. (*Top*) VEP response amplitude as a function of temporal frequency from two infants: NS (*left*) and JK (*right*). The *upper panels* show each infant's response to fixed Vernier offsets alternating between alignment and misalignment (*stimulus shown in insert*). This produces a strong first harmonic 3-Hz response (*in shaded area*) as well as strong responses at the even harmonics of 6, 12, and 18 Hz. By contrast, the *lower panels* show the same infants' responses to Vernier offsets undergoing mirror-symmetrical pattern motion. In this case, no first harmonic response occurs (*shaded box*), although the responses at even harmonics are strong. (*Bottom*) First harmonic responses of seven infants and one adult to alignment/misalignment alternation (*solid bars*) and misalignment/misalignment alternation (*hatched bars*), with SE bars. For comparison, the hatched bar to the right of each solid bar shows the amplitude of the background EEG noise for that condition. For all observers, the alignment/misalignment condition produced a significant first harmonic response, whereas the misalignment/misalignment condition did not.

variation in measured resolution, especially for the motion measure.

Figure 4 shows the data from Figure 3 plotted as age-binned averages, along with adult data taken on the same apparatus. This figure contains double *y* axes to represent the units for grating acuity (right axis, cyc/deg), Vernier acuity (left axis, 1/min), and motion (left axis, 1/min). These axes are aligned according to asymptotic (adult) performance, which is shown by the line at the top of the graph (with the shaded area showing confidence limits). This format illustrates the "relative maturity" of the three types of acuity, although the different units of measure preclude a comparison on absolute terms between grating acuity and Vernier or motion acuity. Vernier and motion acuity, which are measured in the same units, can be directly compared. Vernier acuity is lower than motion acuity at 10 weeks, equal to it at 20 to 22 weeks, and higher at 50 weeks. Both Vernier and motion acuities were markedly inferior to adult values at 50 weeks (0.3 and 0.2 inverse minutes versus 2.3 inverse minutes for the adults). In contrast, grating acuity at 50 weeks was within about a factor of 2 of adult values as previously reported.[11]

Discussion

Displacement thresholds measured in response to Vernier onset-offset targets are markedly immature throughout the first year of life. Although considerable improvement occurred, especially in the Vernier-related component of the response, thresholds for both the Vernier and motion responses at 50 weeks were approximately 10 times lower than adult values. Vernier acuity and motion acuity develop at different rates through the age range that we tested. This suggests that the two types of acuity, measured from different response components in the same stimulus condition, may have different underlying mechanisms (*c.f.* Ref. 7). The marked immaturity of the displacement thresholds contrasts with grating acuity, which is within a factor of two of adult values at 50 weeks of age.

In previous behavioral studies,[1–4] preferential looking was used to determine whether infants could discriminate a single bar or grating containing offsets from a bar or grating without offsets. In the present study, the evoked response indicated a discrimination between a grating with Vernier offsets periodi-

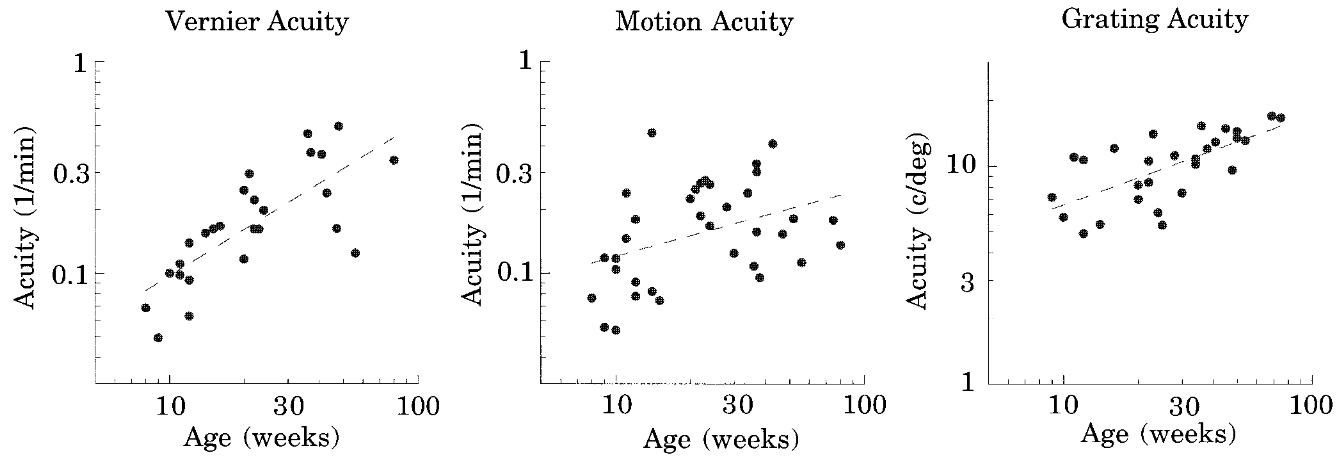

FIGURE 3. Three types of acuity as a function of age. Each data point represents acuity for an individual infant. Vernier acuity was measured by extrapolating thresholds from the first harmonic response to the Vernier stimulus; motion acuity was measured by extrapolating thresholds from the second harmonic response to the Vernier stimulus; and grating acuity was measured by extrapolating thresholds from the first harmonic of the grating stimulus. The *dotted line* in each graph shows a regression line (power fit) for the data set, to illustrate the age trend. Slopes (and confidence limits) for these regressions are as follows: Vernier acuity, 0.72 (0.051); motion acuity, 0.32 (0.055); grating acuity, 0.41 (0.031).

cally alternating with a grating without offsets. A first harmonic response component was present when the two stimulus states differed in their form but not when the two states were mirror reflections. All infant Vernier acuity tests, including the presently reported data, are different in a critical way from adult psychophysical tests of vernier acuity. Adults are asked to judge the left-right (or up-down) direction of the Vernier offset(s) with respect to the reference bar(s). Because this type of response is impossible for infants, some type of form discrimination measure is used instead. The logical conclusion in all

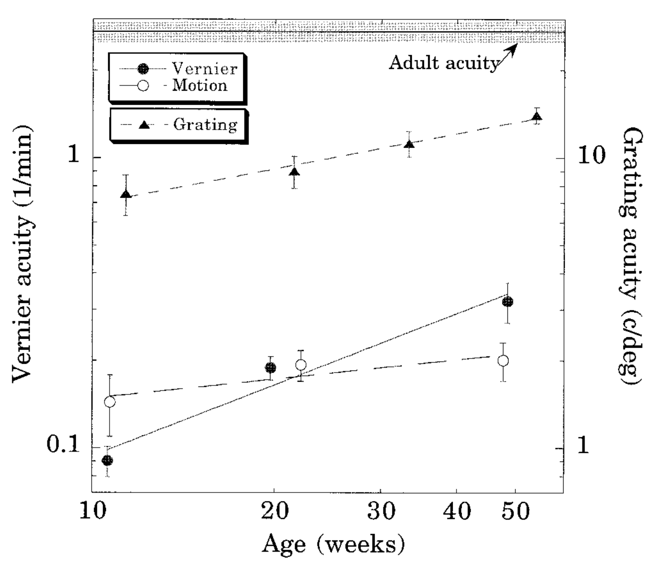

FIGURE 4. Average data: Vernier acuity (*filled circles*), motion acuity (*open circles*), and grating acuity (*filled triangles*) as a function of age. Infant data from Figure 3 are shown as averages, along with adult data. The left axis indicates units (inverse minutes) for Vernier acuity and motion acuity, and the right axis indicates units for grating acuity (cycles per degree). Although these units cannot be compared on absolute terms, the axes extend the same number of octaves and have been aligned according to adult performance (*top*), to show the maturity of each type of acuity.

infant studies, including the present one, is that if infants can discriminate the two pattern states, they can detect the Vernier offsets that define the difference in the pattern states. Successful discrimination in any infant measure does not necessarily imply an adult-like ability to encode offset direction.

Several previous behavioral studies have examined the relationship between Vernier and grating acuity.[1–4,6] The earliest studies[1–3] attempted to equate the units of Vernier acuity and grating acuity to directly compare them during infant development. Based on these comparisons, it was suggested that hyperacuity emerges relatively early: Vernier acuity was superior to grating acuity by 4 to 5 months of age. However, these three earliest studies[1–3] used temporal cues in the Vernier acuity task and stationary stimuli in the grating acuity task. Because temporal modulation can enhance preferential-looking grating acuity[16] as well as Vernier acuity,[17,18] it is possible that these studies maximized Vernier acuity estimates and minimized grating acuity estimates. Zanker et al.[4] overcame this confound by using stationary stimuli to measure both types of acuity in infants and young children and found results that disagreed with the previous infant behavioral data but agree with the present study: Vernier acuity was worse than or equal to grating acuity throughout infancy, and only became significantly superior to grating acuity at 4 years of age. More recent studies[6,19] have tested toddlers and children and have compared the relative maturity of Vernier and grating acuities (that is, how close each measure is to adult levels at different ages). There is general agreement in these studies that Vernier acuity reaches adult levels substantially later than grating acuity.[4,6,19] Carkeet, Levi, and Manny[19] reanalyzed several studies in which both Vernier and resolution (grating) acuity were measured, calculating the age at which threshold would be within a factor of 2 of adult performance. They found these ages to range between 5.7 and 8.7 years for Vernier acuity and 1.4 to 2.2 years for resolution.

The most comprehensive longitudinal developmental data relating Vernier and grating acuity come from infant macaque monkeys.[20] These data are plotted in Figure 5 (filled triangles) along with our VEP data (open circles) and human infant behav-

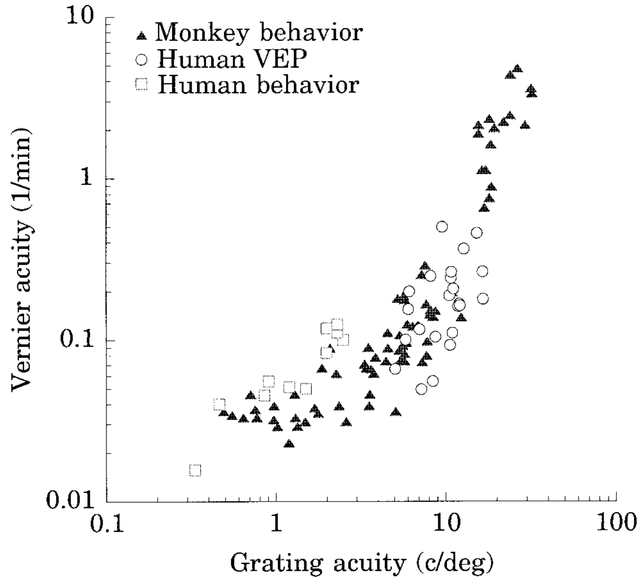

FIGURE 5. The relationship between Vernier acuity and grating acuity during development. This graph shows individual data for monkeys tested behaviorally (*triangles*, from Kiorpes[20]) and humans tested with VEPs (*open circles*, present study), as well as average data for humans tested behaviorally (*open squares*, from Manny and Klein[1]). Age is not explicitly shown here, but the range of ages for each data set was as follows: 2 to 60 weeks for monkeys, 2 to 24 weeks for humans tested behaviorally, and 8 to 80 weeks for humans tested with VEPs.

ioral data (open squares, from Manny and Klein[1]) Figure 5 shows a within-subject comparison for individual infants from the present study and Kiorpes' monkey data,[20] and average data from the human behavioral study. Our human VEP data lie along the developmental trajectory defined by the macaque data. Human behavioral data also fall along the macaque developmental trajectory, although they are placed lower down on the curve than our human VEP data. Although age is not explicitly represented on a plot of Vernier versus grating acuities, it is implicitly represented by increasing acuity. The human behavioral data were obtained over the age range 2 to 24 weeks postnatal, and the monkey data were obtained over an approximate age range of 2 to 60 weeks. Although the absolute values of human data obtained with the VEP are better than those obtained behaviorally, the relationship between Vernier and grating acuities appears to be similar.

To a first approximation, Vernier acuity and grating acuity development covary in the same way across species and across different measurement techniques (behavioral versus electrophysiological, temporally modulated versus static targets). What mechanism(s) could bind Vernier and grating acuities together in a stereotypical relationship? Kiorpes and Movshon[21] suggest that a single mechanism early in the visual pathway could be responsible for the development of Vernier acuity and grating acuity in young monkeys. The strongest argument in favor of this view is that Vernier acuity and grating acuity reach adults levels at about the same age in monkeys. This is not the case for humans, however. The present study shows that grating acuity is substantially closer to adult levels than is Vernier acuity by the end of the first postnatal year. Carkeet, Levi, and Manny[19] have also demonstrated that Vernier and grating acuities reach asymptotic levels at substantially different ages during early to middle childhood.

Levi and Carkeet[6] have proposed a model that relates Vernier/grating acuity ratios to performance on these tasks in the normal periphery. In their model, the fovea at a given age during infancy resembles the adult periphery at a certain eccentricity. At that eccentricity, retinal sampling density and variability pose a fundamental limit on the precision of positional acuity, which is then reflected in the cortex. As development proceeds, changes in receptor size, spacing, and regularity in the infant fovea provide finer and finer positional information to the cortex, and Vernier and grating acuity improve. The improvement is not 1:1, because Vernier and grating acuities have different dependencies on peripheral sampling and photon efficiency.[22,23] On this view, early retinal factors must combine with central limitations, such as position uncertainty, to predict the stereotypical relationship between Vernier and grating acuity.

Although the form of the relationship between Vernier acuity and grating acuity in the adult periphery is similar to the observed developmental relationship shown in Figure 5, there is a significant quantitative shift between the Levi and Carkeet model[6] and experimental data. Most notably, previous studies have shown that Vernier acuity is always better than grating acuity in the adult periphery.[5,24] Hyperacuity (Vernier acuity superior to grating acuity) was not seen reliably in the present study, nor is it seen in infant macaques with grating acuities comparable to those measured in the present study. Hyperacuity is only seen in the macaque data from the oldest animals. Hyperacuity on the order of 2 times grating acuity has been reported in the human infant literature (see Fig. 5, open squares). However, it is only after about four years of age that Vernier acuity is substantially superior to grating acuity.[19] It thus appears that an additional central factor not affecting the adult periphery may be needed to explain why our infants failed to show hyperacuity.

One candidate central factor that has been suggested and supported by data is a reduction of neural blur, possibly associated with synapse elimination during later development.[25] Another possibility is that additional specialized cortical mechanisms are needed to extract fine grain positional information provided by the retina. Srebro and Osetinsky[26] have suggested that extra-striate mechanisms make a substantial, if not dominant, contribution to Vernier-VEPs. It is possible that hyperacuity-level visual processing can be achieved only after postnatal development at the level of extra-striate cortex. Our results suggest that although distal factors may constrain the shape of the developmental trajectory, they are not sufficient to explain the normal relationship between human infant Vernier and grating acuity, central factors clearly act as well.

SUMMARY

We used a VEP technique to measure Vernier acuity in human infants and to demonstrate that the Vernier response is distinct from a motion response that can be measured with the same stimulus. We observed different rates of development for VEP Vernier acuity and grating acuity. This result converges with previous human developmental data to suggest that Vernier acuity and grating acuity are limited by different mechanisms during development. Our data show that Vernier acuity has a prolonged developmental sequence compared with grating acuity, suggesting that the critical period for the development of mature Vernier acuity extends well beyond the first year of life. This may explain why Vernier acuity is more affected than grating acuity by developmental vision disorders, such as amblyopia.[6] Because Vernier acuity is a sensitive measure of amblyopia, this VEP measure may be useful in the future to identify and follow the treatment progress of pediatric amblyopia.

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