VISUAL ACUITY DEVELOPMENT IN HUMAN INFANTS: EVOKED POTENTIAL MEASUREMENTS

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Reprinted from
INVESTIGATIVE OPHTHALMOLOGY
St. Louis

Vol. 15, No. 2, pp. 150-153, February, 1976

Visual acuity development in human infants: evoked potential measurements.

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Evoked potential visual acuity was measured on 16 infants on 19 different occasions when the infants were from one to seven months of age. Spatial frequency threshold values ranged from 1 to 30 cycles per degree (20/600 to 20/20) with the greatest increase occurring during the first eight weeks. Adult acuity, which is defined as 20/20, is reached during the fourth to sixth month of life.

It has been estimated that adult visual acuity, which may be defined as the resolution of one minute of arc detail, or 20/20, is reached during the development of children anywhere from 7 years to as short a time as 2 years of age. These measurements are assumed to be made without significant refractive error, and simply mirror the development of the neurovisual system. In these studies, tests of acuity depend on various kinds of preference of fixation. The wide variations of acuity from these tests could be caused by differences in methodology, as well as from variation in attention.

Optokinetic nystagmus has also been used to measure infants' visual acuity. Since the collicular pathway controlling eye movement is different from the primary sensory visual cortical routes, these values are not necessarily equivalent to psychophysical ones. Using optokinetic nystagmus, acuities have been obtained of 7.5 minarc in eight-day old neonates, and a maturation of infant acuity to about four minarc (20/80) at six months of age has been shown. Recently, it has been demonstrated, using improved pattern preference methods, that acuity was even better than four minarc in six-month-old infants.

Freeman and Marg[1] have shown very recently that the development of visual acuity in kittens measured by visual evoked potentials is completed by three to four months, which incidently coincides with the completion of their sensitive period.[1] Synaptic counts in the lateral geniculate body and visual cortex in kittens reach a maximum at about one month, the time of the fastest rise of visual acuity in kittens. Their study grew from the concept that the generation of the synaptic organization of the visual system is the basis of the development of visual resolution and that the plasticity characteristic of the sensitive period would be operative during this development.

Our goal was to determine in a similar fashion the time course of the development of human visual acuity. Because there has been such variance in measures of visual acuity in infants, we

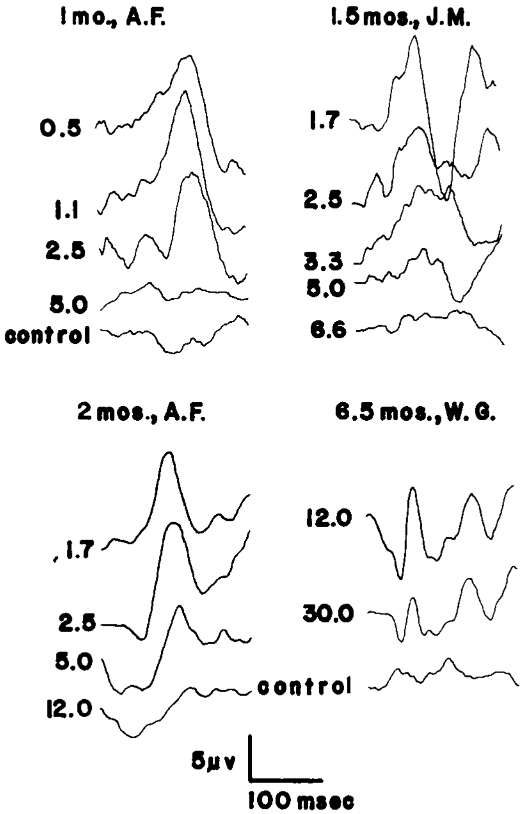

Fig. 1. Averaged visual evoked potentials in response to visual acuity gratings at the spatial frequencies indicated in cycles per degree. The control grating is a regular presentation of the 30 cycles per degree grating out of focus. The thresholds lie between the following values: Subject AF at 1 month, 2.5, and 5.0; AF at 2 months, 5.0, and 12.0; JM, 5.0 and 6.6; and WG at the maximum value of 30. The bandwidth of the recording system is 1 to 30 Hz. with a half amplitude criterion.

could not establish the time course from the literature and have therefore studied the acuity of 16 children on 19 occasions (three children were recorded twice). All of them were full-term and well-developed for their age.

Visual evoked potentials were used in an attempt to avoid the problems of behavioral or oculorotary development or attention. The responses recorded from the area of the occiput, however, do not necessarily mirror the result of cortical processing *per se*, but may represent more peripheral spatial discrimination at the lateral geniculate body or retina. However, visual evoked potential response to form has been well correlated with psychophysical threshold acuity measurements,[2-4] and it is reasonable to assume that this correlation is as valid for children as it is for adults. Our initial measurements indicated

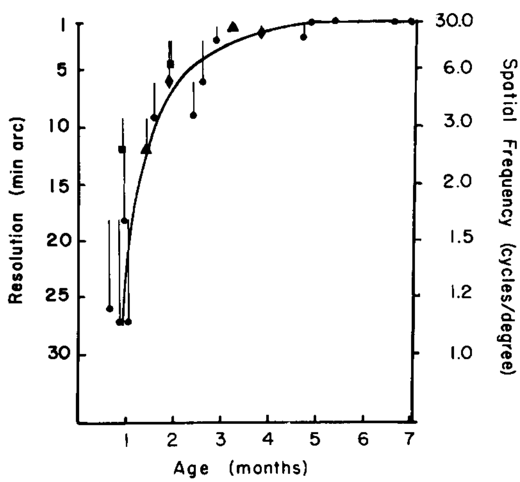

Fig. 2. The visual evoked potential acuity of 16 infants measured on 19 different occasions. The three pairs of points which represent the three infants measured at two different ages are indicated by pairs of squares, diamonds, and triangles. A curve is drawn by eye through the points which represent the highest spatial frequency (best visual acuity) of the gratings which gives a clear but minimal visual evoked potential. The vertical lines from each datum point extend up to the next higher spatial frequency tested so the actual threshold lies within the vertical lines and the curve slightly underestimates the threshold. The highest spatial frequency grating was 30 cycles per degree, or 20/20 Snellen. The right labeled ordinate refers to the fundamental spatial frequency of the square wave grating.

that all previous estimates of the time to full maturation of acuity were too high, and that we could limit the range of our infant population to seven months of age.

Each entire test sequence took 10 to 15 minutes. Beckman miniature scalp electrodes were attached over the occipital and mastoid areas with a third grounding electrode on the forehead. They showed 2 to 4 KΩ impedance at 10 Hz. For each bar grating, 75 responses were averaged on a CAT 1000 computer-averager which yielded a very satisfactory signal (Fig. 1). Rectangular bar gratings were tachistoscopically presented through a translucent screen, subtending 20°, 114 cm. from the infant who viewed it binocularly. The grating appeared for 40 msec., during which the grey uniform field was removed in a way that the average luminance remained a constant 36 cd. per square meter. The resulting visual evoked potential is basically a response to form, rather than light. The bar gratings had 65 per cent contrast and a range of spatial frequencies from 0.4 to 30 cycles per degree. The presentations of bar grating sizes were counterbalanced to minimize any ordering effect.

The appearance of the grating was triggered by the investigator when he could see by the corneal reflex that the infant, who was held on his mother's lap, was looking toward the center of the screen. Even though the room was dark and there was little other attraction, an infant's attention would wander at times. It returned with the aid of a small, hand-held, noisy, rotating, and sparking toy.

The amplitude and latency of the evoked response was found to be a function of the spatial frequency (Fig. 1), as it is in adults. To determine the threshold visual acuity, the highest spatial frequency which produced a clearly defined visual evoked potential for each of the infants is plotted as a function of age in Fig. 2 and a curve is drawn through the points. The vertical lines reach up to the next spatial frequency used which did not give an averaged response which could be distinguished on the bases of wave shape and amplitude from the control. A given symbol other than black circles indicates a single child who was tested at two different ages.

Contrary to the previous literature, the adult level of visual acuity of the infants was reached surprisingly early, by four to five months of age. We selected our infant subjects by retinoscopy for refractions of less than 1 D hyperopia to emmetropia in each eye to provide a minimal refractive error which accommodation could overcome. In the first two months after birth, acuity improves very rapidly, climbing from 20/600 at less than four weeks to 20/100 by eight weeks. This sudden improvement might reflect not only neurosensory development, but accommodation as well. At two months of age or less, infants may be unable to control their accommodation. If so, the development of the sensory visual system may occur even sooner than indicated by the acuity curve. Our measurements were to a maximum of 20/20 after five to six months.

Our visual evoked potential acuities tend to match the highest values found in psychophysical literature. For example, Atkinson, Braddick, and Braddick[5] found by behavioral methods a maximum acuity of about eight cycles per degree (20/80) in their single subject, an eight-week-old infant. This value would fit well on our curve in Fig. 2. Our observations of the infants' fundus by ophthalmoscopy confirm the generally known fact that the optical media are quite clear even at three weeks of age. In the infant, the grating dependent (as well as the flash dependent) visual evoked potentials develop in complexity. The latency of specific components shortens noticeably during the first six months, which probably indicates progressive synaptic development of the visual pathways and the visual cortex. These changes are evident from the data shown in Fig. 1. The waveforms have a longer latency and are less complex at one month than at six months.

The time it takes for visual acuity maturation is interesting in itself, but even more so because there is a therapeutic or even preventive implication in knowing the duration of the sensitive, critical, or susceptible period of the human infant during which cortical neurons show changes in response to the visual environment. This period has been variously estimated in the monkey to last (1) 12 weeks, with an especially strong portion during the first six weeks,[6, 7] and (2) from 1 to 1.5 years. (T. N. Wiesel, Berkeley lecture, February, 1975.) The duration of the sensitive period in children based on a search of patient records appears to be 4.5 to 5 years with the highest sensitivity occurring at less than six months of age.[6] It is during this period that anomalous development appears to occur from visual deprivation. Recently, it has been demonstrated in man that the selective deprivation caused by natural astigmatism, presumably during the childhood sensitive period, produces a matching amblyopia.[8]

The sensitive, susceptible, or critical period in cats is now well established as reaching a maximum at about the end of the fourth week, then decreasing and dropping off completely between the third and the fourth months.[9] Modification of the visual environment during this sensitive period can markedly affect subsequent adult visual acuity. Depressed acuity is caused by selective deprivation of light or form of visual stimuli critically influencing the laying down of synaptic pathways in the developing visual cortex.[10] Deprivation also causes degenerative changes in the lateral geniculate body.

Our finding that visual evoked potential acuity normally develops to the adult value, or 20/20, by the fourth to sixth month postpartum may have a parallel with the disclosure that in kittens the time of acuity development is the duration of the period of greatest sensitivity or susceptibility to the visual environment.[1] Eye dominance reversal experiments in kittens show that deprivation experiments which aim to balance earlier reversal are most successful if done early in the sensitive period, but largely fail if done late. These findings combined with our data point to the need for earlier examination of infants' vision than is commonly practiced to detect and correct asymmetries and other causes of stimulus deprivation.

From the School of Optometry, University of California, Berkeley, and the San Francisco General Hospital, Ward 86, Room 612. Supported by a Fight for Sight, Inc., New York City, Fellowship to D.N.F., National Science Foundation Grant BMS72-01972 A02, National Institutes of Health Training Grant NIH-EY76-03, and United States Navy No-0014-70C-0248. Submitted for publication August 28, 1975. Reprint requests: Dr. Elwin Marg, School of Optometry, University of California Berkeley, Calif. 94720.

Key words: visual acuity, infant visual acuity, visual evoked potential acuity, developmental visual acuity, critical period, sensitive period, visual maturation.

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