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Visual Fields of Infants Assessed With a New Perimetric Technique

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The visual field of normal infants was assessed using a perimeter with LED stimuli and a forced-choice observation procedure. Central fixation was elicited by four central, pulsing LEDs and maintained with the aid of auditory stimuli. Field extent was derived from the four-alternative, forced-choice judgments of an adult who observed the infant's eye movements to peripherally illuminated LEDs. The binocular visual field of infants, ages 6–7 months, was similar to that of adults tested with the same apparatus. Area of the infants' binocular field was 93% that of the adults'. However, the infants' monocular fields were smaller than those of adults, averaging 74% of the adults' monocular field area. This may have been due to the distracting effect on infant behavior of the adhesive patch used for monocular testing. The visual fields of a young patient with hydrocephalus illustrate the potential clinical utility of this new perimetric technique for infants at risk of field defects. Invest Ophthalmol Vis Sci 29:452–459, 1988

Following the introduction of quantitative assessment of visual acuity of infants into clinical settings,[1,2] interest has focused on other clinically relevant visual functions.[3] Recently, methods to study the visual field of infants have been developed and data have been reported from normal infants.[4–6]

In one of these procedures,[5–7] a white sphere is moved slowly from the periphery toward the central fixation target which is also a white sphere. The position of the peripheral stimulus to which the infant makes a directionally appropriate eye movement is an index of field extent. This method has been used to measure visual field size in both normal infants[5,6] and infants with visual or neurological abnormalities.[7] Limitations of this technique include the large object size (6 deg), the constant presence of a central fixation object, which is known to inhibit infant's responses to peripheral objects,[8–10] and the potential influence of subjective factors.

We also have developed a method to test visual fields of young subjects. It differs from the above procedure in using a hemispheric perimeter with small stimuli (LEDs), a central target that can be extinguished during presentation of the peripheral stimulus and a forced-choice procedure less influenced by subjective factors. With this method, we successfully tested visual fields of young children with normal eyes, ages 2 to 5.[11] In the present paper we describe modifications of this perimetric technique that enabled measurement of the visual fields of infants. Data on the binocular and monocular visual fields of the youngest infants we were able to test, ages 6 to 7 months, are presented. LED visual fields of one young patient with hydrocephalus illustrate the potential clinical applicability of this perimetric technique.

Materials and Methods

Subjects

Infants, ages 6 to 7 months and born ±10 days from their due dates, served as normal subjects; all were free of apparent ocular or visual abnormalities. Data are presented from ten infants tested binocularly and ten infants tested monocularly (right eye in six and left eye in four). Ophthalmological examinations of 18 of the 20 successfully tested infants indicated normal eyes; two infants did not return for the eye examination. Three additional infants were not successfully tested binocularly and five could not be tested monocularly, despite several attempts. These infants appeared wary of the testing situation and reluctant to be held by one of us and/or were intolerant of the patch. Subjects were tested in one to three sessions within a 2 week period. Parents gave informed consent to test their infants.

Monocular visual fields were also assessed in ten adults (right eye in five and left eye in five), ages 23 to

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38 years, using the LED perimeter. Binocular fields were assessed in six of these adults. All adults had corrected visual acuity of 20/20 or better and no history of ophthalmological or neurological disorders.

Visual fields were assessed in an infant born at 32 weeks gestation, who developed severe primary hydrocephalus and markedly increased ventricles of the left hemisphere in the first postnatal year. He was clinically stable after shunt insertion at postnatal age 10 months. Visual field testing was done at ages 14 and 22 months.

Apparatus

The perimeter is a 69 cm diameter, gray hemisphere. On the inner surface yellow LEDs (lambda max = 585 nm) are spaced at 7 degree intervals on 24 radii. These 24 meridia are those critical for detecting visual field losses in adults.[12,13] Four meridia are 7.5 degrees from the horizontal axis, at 7.5, 172.5, 187.5 and 352.5 degrees, and four are 5 degrees from the vertical axis, at 85, 95, 265 and 275 degrees. The other 16 meridia, divided among the four quadrants, are separated by 15 degrees. At the 33 cm test distance, LED diameter is 42 min arc. Steady-state LED luminance is 1.2 log cd/m^2 and background luminance is -0.2 log cd/m^2. An 8 mm diameter peephole is centered in the hemisphere. Central fixation is elicited by four red LEDs, pulsing at 1 Hz and spaced 2.5 degrees from the hemisphere center.

Procedures

The procedures were guided by pilot testing:

1. We wanted to assess infants as young as possible. However, we found that 3- to 5-month-olds quickly lost interest in the LED stimuli and for some, the perimeter appeared aversive. On the other hand, 6-month-old infants were interested in the perimeter LEDs, and therefore, testing procedures were developed with them.
2. Infants responded more readily when the peripheral LED was pulsed than when it was steadily illuminated; a 10 Hz pulse rate was chosen arbitrarily.
3. We wanted to measure visual field extent in the absence of a central fixation target because its presence is associated with a reduction in field extent in infants.[8-10] At the beginning of each trial, the four central, flashing LEDs were turned on to elicit fixation. When the infant was fixating centrally, the central LEDs were extinguished and the peripheral target was illuminated. However, because infants tended to lose central fixation after the central target was extinguished, an auditory stimulus ("sing-song" vocalizations) synchronized to the central flash rate remained on throughout central and peripheral target presentation.
4. Testing of the infant's visual field was limited by the finding that infants sustained interest for only 15–25 trials per session.
5. Because infants were relatively intolerant of the patch, the first group of subjects was tested binocularly.

For binocular testing, a video camera was placed behind the peephole. An adult held the infant in position 33 cm from the peephole and observed the infant's eyes in a mirror reflecting the video screen. Because the video system was not available for monocular testing, a different adult viewed the infant through the peephole, provided feedback on the infant's position to the holder, and made the forced-choice judgments required during testing. (No systematic differences were obtained when two infants, whose data are not included in this study, were tested using these different observation systems.) When the infant was judged to be fixating the central LEDs, the observer signaled another adult, the experimenter, to turn on a far peripheral LED. The experimenter illuminated the peripheral stimulus for about 2 seconds at a position and advanced the position toward the center in 7 degree steps until the observer made a judgment based on the infant's eye movement. It was assumed that if the infant looked toward the stimulus she or he detected it.

Infants were divided into two groups, each tested on eight meridia. Four meridia were orthogonal obliques (45, 135, 225, and 315 deg) and four were orthogonal, approximately horizontal-vertical meridia (either 7.5, 85, 187.5 and 265 deg, or 95, 172.5, 275 and 352.5 deg). For each infant, the two sets of meridia (obliques, horizontal-verticals) were tested in separate blocks of trials.

The observer and holder knew if the horizontal/vertical or the oblique meridia were being tested in any series of trials but were unaware of the stimulus position and meridian prior to a trial. The observer reported the direction of the stimulus from four alternatives: up, down, right or left, for the horizontal-vertical meridia, and, up-left, down-right, etc., for the oblique meridia. Infants' eye movements between the four orthogonal directions were readily discernible, even for stimuli in the paracentral field (eg 14–21 deg). The experimenter marked on perimetry paper the position of the stimulus at the moment of the observer's report and gave feedback to the observer as to the correctness of the judgement. The position of the illuminated LED at the time that the observer correctly reported stimulus direction constitutes the datum of this study.

With binocular testing it was usually possible to obtain five trials on each of the eight meridia, for a total of 40 trials from each infant. However, when infants were tested monocularly, distractibility and fussiness limited the number of trials obtained. The median number of trials for binocularly tested infants was 40 (range 18–40) and for monocularly tested infants, 32 (range 16–40). Infants who were not successfully tested provided very few test trials (median 4, range 0–8).

If the infant was distracted or failed to maintain central fixation during the trial, the trial was stopped and a new trial begun; this occurred on less than 5% of the trials. If the observer's judgment was incorrect, the trial was repeated; this occurred on 16% of binocular and 25% of monocular trials. An error analysis confirmed the informal observation that infants were reluctant to look up. Errors in monocular testing, for example, were most common for stimuli on the combined superior meridia (56%) and less common for the inferior meridia (31%) and the meridia around the horizontal (13%) (Chi-square (2) = 12.8, $P < 0.01$). In addition, a bias toward looking down was suggested by the observer's responses on blank trials (6 second duration), included at a rate of 10% of test trials. On 40% of the blank trials, the observer chose inferior stimulus locations; for 30%, the responses were distributed between superior, nasal and temporal locations and on the remaining 30%, the infants maintained central fixation.

Adults were positioned 33 cm from the central peephole using a chin rest. Adults verbally reported stimulus detection. Five trials were obtained on all 12 meridia sampled in the infant data.

Because we wanted to define the complete visual field of the young patient, single trials were presented on as many meridia as necessary to define the field defect, similar to the approach of standard clinical perimetry. Ordinarily, visual field evaluation of a patient with a postchiasmal abnormality would concentrate on the meridia on either side of the horizontal and vertical depending upon the location of the field defect. However, concentrated testing in one field sector is constrained by the multi-alternative forced-choice procedure. Therefore, in order to minimize the effect of bias on the observer's and the subject's responses, LED trials were distributed relatively equally throughout the visual field.

Data Analysis

The extent of the visual field of the infants was taken to be the median of the observer's correctly judged positions on each meridian. For the adults, the median position on each meridian reported as detected was used. Comparisons of data from infants tested binocularly and monocularly and between infants and adults were analyzed using nonparametric statistical tests.[14] Total field areas of infants and adults were compared using planimetric measurements of the planar plots connecting the group medians.

Variability, both intra- and intersubject, was analyzed separately using the range of correct responses on a meridian. No statistically significant difference between the median intrasubject ranges for right and left eye groups was found for either the infants or the adults (Mann-Whitney U test). Therefore, for both, the right and left eye intrasubject ranges were combined. Analysis of intersubject variability, defined as the range of the group medians on each meridian, excluded those meridia on which there was only one median.

Results

Figure 1 shows the median visual fields of the infants tested binocularly and monocularly. As would be expected for normal adults, the size of the infants' monocular field is smaller than the size of the binocular field (Sign test: right eye, $P = 0.006$; left eye, $P = 0.001$). Unexpectedly, the infants' median left eye field is significantly smaller than that of the right eye (median difference on a meridian, 7 deg, range 0–24.5 deg; Wilcoxon matched-pairs signed ranks test, $P = 0.05$). This difference is likely due to sampling error because of the small sample size and variability of the infant data.

Normally, an adult's nasal hemifield is less extensive than the temporal hemifield. For the infants, the nasal-temporal asymmetry was statistically significant for the median right eye field (Sign test, $P = 0.02$) but not for the median left eye field (Sign test, $P = 0.20$). However, the latter finding is probably due to the single median position on the 265 degree meridian of the left eye field (see Fig. 1). If the 265–275 meridia comparison is excluded, the nasal-temporal asymmetry of the left eye field approaches statistical significance ($P = 0.06$). Thus, it appears that infants' monocular fields are asymmetrical about the vertical, as are adults' monocular fields.

Figure 2 compares the fields of the infants to the fields of the adults. Although both the infants' median right and left eye fields are significantly smaller overall than those of the adults (Wilcoxon tests, right eye, $P = 0.05$, left eye, $P < 0.01$), the infants' median binocular field is not significantly different from the binocular field of the adults. Planimetric measurements of the field area summarize this finding. The infants' median field area relative to that of adults

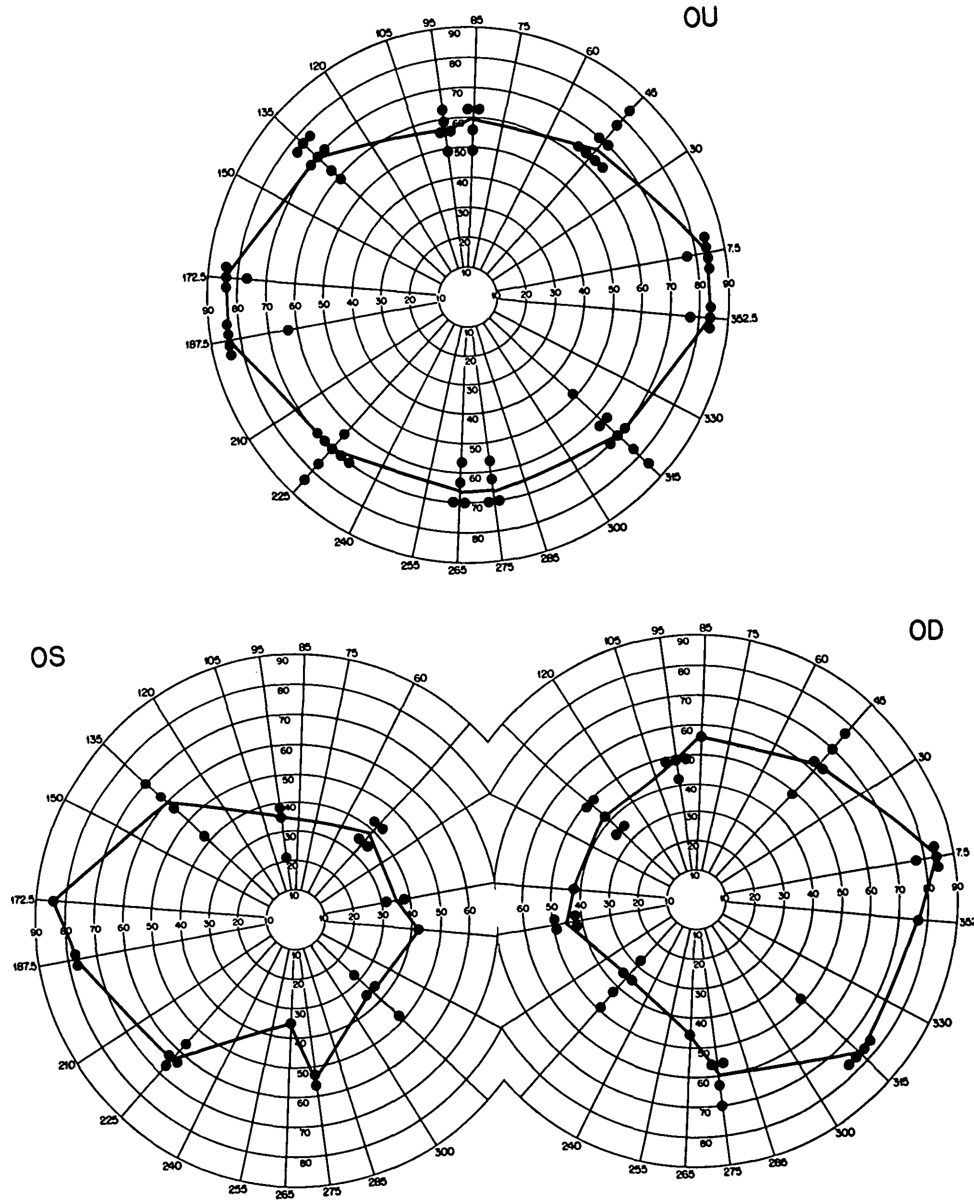

Fig. 1. Binocular and monocular visual fields of 6- to 7-month-old infants. Each point represents the median of two to five trials on a meridian from an individual infant. The median of the group medians was taken to define the field extent on a meridian. The solid line connects adjacent group medians and represents the group median visual field.

was 93% for the binocular field, 85% for the right eye and 63% for the left eye fields (mean of right and left eyes, 74%).

Intrasubject variability for the infants tested binocularly is greater than that for the infants tested monocularly (Table 1). In addition, the infants' intrasubject variability is significantly greater than that of the adults for both binocular and monocular data (Table 1). Reduced variability of the adults' data in the temporal fields may be due to the 84 degree limit of LED positions in the perimeter. Adults can detect the present stimuli out to 100 degrees temporally.

Between-subject or intersubject variability is shown in Figure 2 by the ranges of medians on each meridia. The infants' group data are more variable than those of the adults for the binocular field (Mann-Whitney U test, $P < 0.01$) and the right eye field ($P = 0.01$) but were not different for the left eye field ($P = 0.11$). The latter finding may be due to the small number of data points on several meridia in the infants' left eye field.

Visual fields of an infant at risk of a right field defect due to severe left hydrocephalus with compression of the left parietal, temporal and occipital cortical areas are shown in Figure 3. A right homonymous hemianopsia was suggested by the binocular field at age 14 months (Fig. 3A). Completeness of the hemianopsia was confirmed by monocular fields tested at age 22 months (Fig. 3B). With the limited cooperation of this patient, only 18 trials on a total of 16 meridia were obtained for binocular testing. For monocular testing, about the same number of total

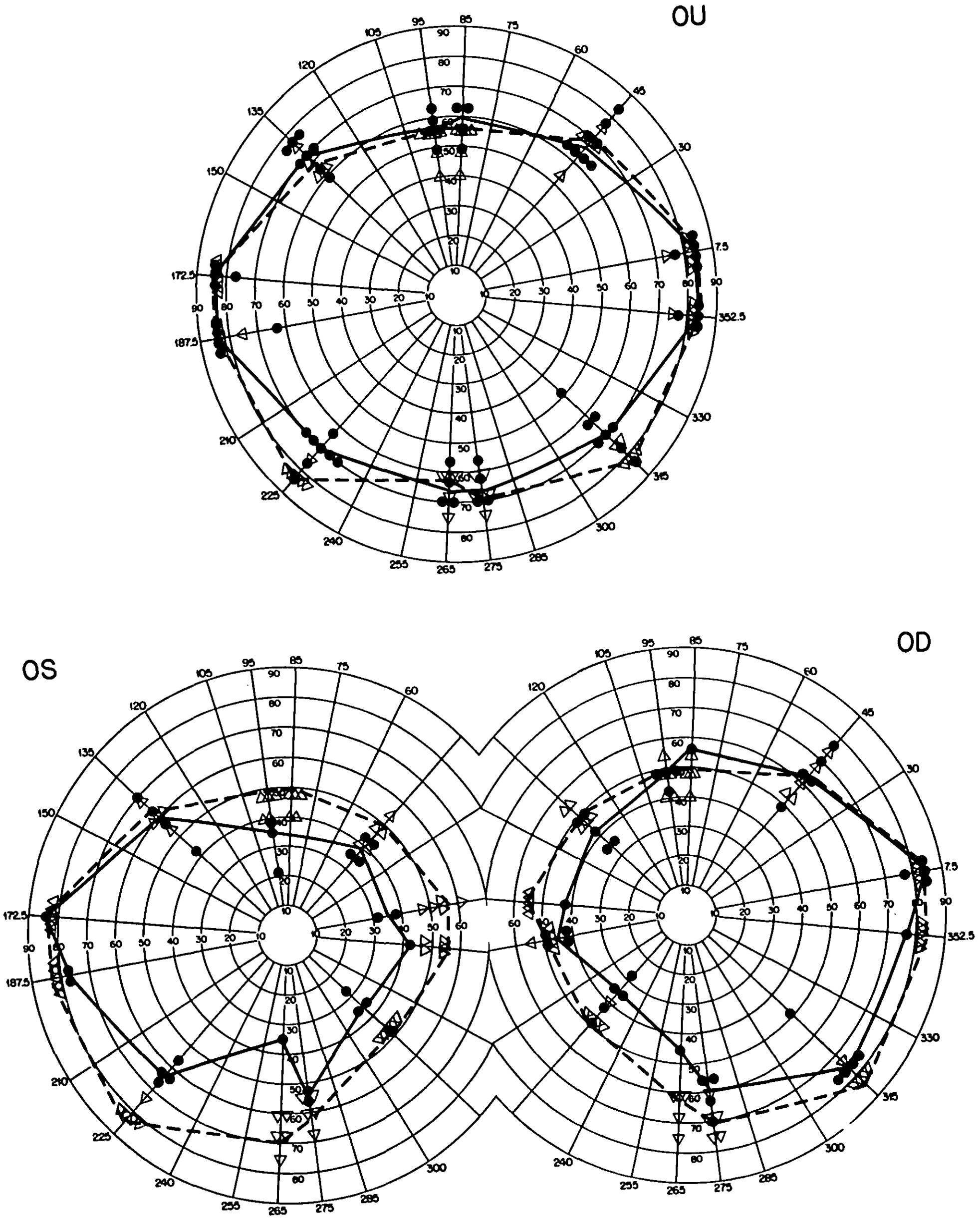

Fig. 2. Binocular and monocular visual fields of infants and adults tested on the same LED perimeter. Data from infants are as in Figure 1. The open triangles represent the medians of five trials per meridian for each adult; the dashed lines connect group medians for the adults.

trials were obtained but they were distributed over the right eye and left eye field tests; ten meridia were tested in the right eye field and eight in the left eye field. Because of the limited number of trials and the necessary constraints placed by the four-alternative forced-choice procedure on intensive testing of one field sector, the vertical meridian could not be tested as extensively as desired in this hemianopic patient. Nevertheless, despite this and the relatively few trials, LED perimetry of this patient provided clinically relevant information.

Table 1. Intrasubject variability (degrees)

	n	*Median range*	*Range of ranges*
Binocular*			
Infants†	10	7	3.5–10.5
Adults	6	0	0–7
Monocular*			
Infants†	10	14	7–24.5
Adults	10	7	0–7

* Significant difference between the infants' monocular and binocular data: Mann-Whitney U test, $P = 0.02$.

† Significant differences between the infants' and adults' data: Mann-Whitney U test, binocular: $P = 0.002$, monocular: $P = 0.05$.

Discussion

In the present study, the LED apparatus and perimetric technique first developed to assess the visual field of children[11] was successfully adapted to test the visual field of infants. Preliminary norms for binocular and monocular assessment of 6- to 7-month-old

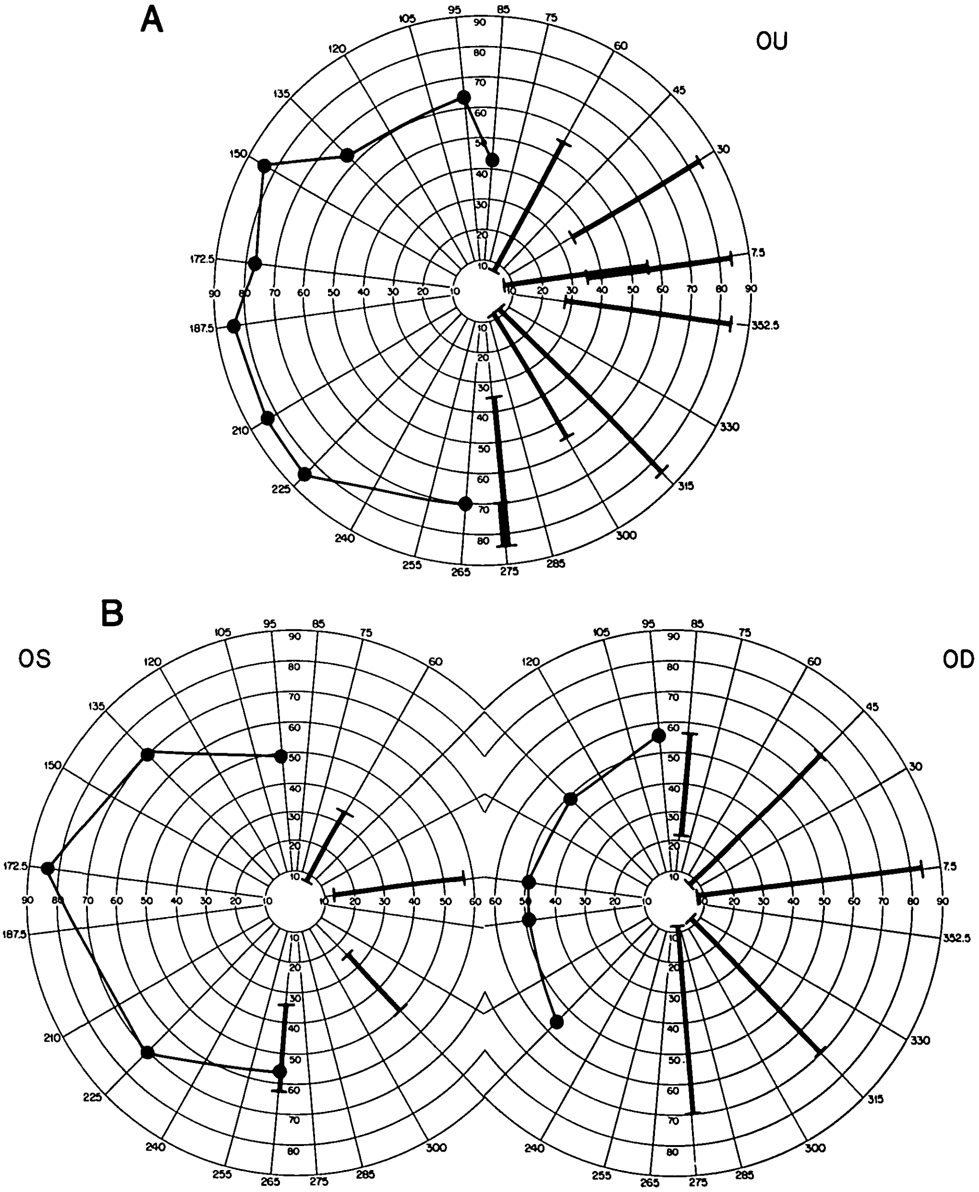

Fig. 3. Results of LED perimetry from an infant with severe hydrocephalus. Binocular testing (**A**) was done at age 14 months and monocular testing (**B**) at age 22 months. Dots represent single correct trials. Solid thick lines along a meridian represents the range of target positions that were not detected.

infants were determined. In addition, the feasibility of the procedure for clinical assessment was explored by testing an infant with a postchiasmal lesion.

The binocular visual field of normal 6- to 7-month-old infants was similar to that of adults tested in the same apparatus. The infants' binocular field area was 93% that of the adults. However, the monocular fields of the infants were significantly smaller than those of the adults, averaging 74% of the adults' field area. There is no reasonable physiological explanation for this difference and we suggest that the smaller monocular fields of the infants were caused by distraction due to the adhesive patch used during testing. Indeed, infants tested monocularly appeared more restless and irritable than those tested binocularly. Insofar as increased intrasubject variability is associated with decreased sensitivity,[15] field extent of infants may appear reduced because of the increased trial-to-trial variability resulting from distractability of the patch.*

* An explanation for greater variability of the infants' data compared to the adults' data is the potentially greater variation in eye position while testing because, unlike the adults, infants were not on a chin rest. For example, variation of the infant's eye by ±3–5 cm combined with the potential central fixation error due to the 2.5 degree eccentric position of the central fixation LEDs would result in a difference of ±3 to 5 degrees in the central field and ± 4 to 6 degrees in the peripheral field between scored and true LED positions. However, logically, an eye position error should affect monocular and binocular data similarly, whereas, in fact, intrasubject variability was greater for the infants' monocular than binocular data.

The concurrent validity of the LED perimetry technique was evaluated previously by us in older patients with chiasmal or postchiasmal lesions who could be tested by standard Goldmann perimetry.[11] In that study, field defects detected by the LED procedure were most similar to Goldmann field defects using the larger targets (III4e–V4e). In this study, the clinical potential of the LED technique for evaluating younger patients for whom standard perimetry is not suitable was illustrated by the fields obtained from an infant with hydrocephalus. Despite relatively few trials, a field defect consistent with the site of this patient's postchiasmal lesion was detected. However, to establish the LED perimeter technique for general clinical application, more efficient testing strategies must be studied and more extensive normative data obtained.

The results of this study suggest that visual fields are adult-like by age 6 months, at least for the LED stimulus size and present luminance and adaptations conditions. In contrast, Mohn and vanHof[5] reported that the visual field extent of normal infants using the moving sphere method and a large (6 deg) target was not adult-like until age 12 months. In our previous study, data obtained with the LED perimeter and similar stimulus conditions as in the present study suggested that no age-related change in the visual field occurred after age 2 years. Older studies using standard perimetric procedures reported that visual fields were not mature until age 5 years or older.[16–19]

What are the possible explanations for the discrepancies between and among studies of visual fields of infants and children? The earlier maturation of the visual field shown by recent studies may be due to these new techniques' exploitation of eye-and-head orienting responses. In the older studies that used standard perimetric methods,[16–19] the complex verbal or motor responses required may be associated with high criterion performance of young children on difficult tasks[20,21] and this could result in reduced field sensitivity and size.

Differences between the field extent of infants in the present study and infants in the same age range in the study of Mohn and vanHof[5] are likely due to the presence or absence of a central fixation target during peripheral target presentation because the stimuli in both studies were clearly suprathreshold. The present LED stimulus (42 min arc) and adaptation conditions provide fields that are comparable to those obtained with the large, bright Goldmann targets in older subjects,[11] and the stimulus in the Mohn and vanHof[5] and other studies[6,7] is a 6 degree sphere.

Stimulus size differences between the techniques is a probable explanation for the fact that younger infants can be tested by the moving sphere method[5,6] than can be tested with the LED perimeter. This need to increase stimulus size or luminance[4] in order to test the peripheral field of young infants is consistent with their poorer photopic peripheral acuity[22] and increased spatial summation[23] compared to older subjects. Future, complete delineation of the maturation of visual fields in infants awaits studies that vary stimulus size, luminance and adaptation conditions.

Possible substrates for the age-related changes of the visual field include changes in the eye's optics and neural development. As to optics, reduced field extent and sensitivity of infants may be due to an infant's smaller retinal image compared to an adult's, which is a consequence of the smaller infant than adult eye (for discussion of this issue, see reference 23). The contribution of postnatal development of the peripheral retina[24–26] and of more proximal visual system structures[27,28] to the development of the peripheral visual field may become clearer as parametric studies of infants' visual fields proceed.

Key words: visual fields, perimetry, normal infants, neuro-ophthalmology

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