Original paper

Comparison between grating acuity measured by visual tracking and preferential looking in infants

Dora Lengyel[1]
Irene Gottlob[2]

[1]Department of Strabismus and Neuro-Ophthalmology, Kantonsspital, St.Gallen, Switzerland and [2]Department of Ophthalmology, University of Leicester, U.K.

Strabismus 0927-3972/03/$ 16.00

Strabismus – 2003, Vol. 11, No. 2, pp. 85–93

Accepted 23 October 2002

Abstract
BACKGROUND The aim of this study was to compare the visual acuity measured by visual tracking and by preferential looking.

METHODS We examined 51 healthy full-term infants between three and 93 days of age. Visual acuity was tested with two different methods. One method was visual tracking (smooth and saccadic pursuit), recorded with an infrared photo-oculographic technique. For stimulation of visual tracking a square of 9.4 degrees of visual angle with vertical gratings (0.1, 0.2, 0.4, 0.8 and 1.6 cycles per degree) moved at a constant velocity of 7.5 degrees/sec. for 38sec. on a surface of equal luminance. The other method was preferential looking, determined by a second examiner, where we used plates with vertical gratings (0.1, 0.2, 0.4, 0.8, 1.6, 3.2 and 6.4 cycles per degree).

RESULTS The comparison of the two methods shows a significant correlation ($p < 0.05$). Visual acuity determined by visual tracking is lower than the acuity determined by preferential looking in the first 14 weeks of age.

CONCLUSION Our study shows that visual tracking is a valid method for visual acuity testing in infants. The need of sustained attention is a possible reason for the lower values in comparison with the acuity determined by preferential looking.

Key words Grating acuity; smooth pursuit; preferential looking; visual tracking; visual acuity measurement; infants

Correspondence and reprint requests to:
Irene Gottlob, MD
Dept. Ophthalmol.
Univ. Leicester
Fac. Med. & Biol. Sci.
Robert Kilpatrick Clin. Sci. Bldg.
Leicester Royal Infirmary
P.O. Box 65
Leicester, LE2 7LX
England, U.K.
Tel.: +44 116 258 6291
Fax: +44 116 255 8810

Acknowledgements:
The work was supported by the Schweizerischer Nationalfonds (No. 32-31317-91 and No. 32-43233-95) and by the OPOS Foundation.

Introduction Different methods are employed for visual acuity measurements in infants in the first months of life. These include preferential looking (PL), visual evoked potentials (VEP) and optokinetic nystagmus (OKN).[1] The PL technique is based on the fact that infants show a greater tendency to fix on a patterned stimulus than on a homogeneous field. In this procedure, a card with black and white stripes of various spatial frequencies on one side and a blank field of matched average luminance on the other side are presented to a subject. The examiner is unaware of the target's position. The grating visual acuity is estimated by the observer according to the patient's behavioral response in the form of preferential fixation to the stimulus. A consistent preference for the grating over the blank field indicates that the infant can resolve the grating. This procedure is continued with gratings of increasing spatial frequencies until the child appears to show no preference for the target. Using this method, a poor result may be caused by the inability to generate a behavioral response rather than by impaired visual acuity.

With the OKN technique, the eye movements are elicited by a succession of stripes or objects passing across the visual field. It is a reliable test to determine visual resolution in infants.[1] The limitation is in keeping the infant's eyes fixed on the alternating black and white stripes. Failure in evoking OKN may be caused either by poor vision or by failure to attend to the stimulus. Because OKN depends on a motor response, failure to elicit a response may also be due to a defect in the oculomotor response and not to the infant's failure to see the stimulus. Direction-dependent asymmetries have been found in infants in the first months of life with earlier development of OKN to stimuli directed nasalwards versus temporalwards.[2] This asymmetry may persist with abnormal development of binocular vision.[3] Hoffman[4] hypothesizes that asymmetric OKN early in life is mediated entirely by the subcortical projections and that, once the cortical projections develop, OKN becomes symmetrical. Abnormal development of OKN in young infants and subjects with interrupted binocular vision may contribute to difficulties in estimating visual acuity by this method.

Visual acuities obtained with forced choice preferential looking are similar to those obtained with OKN during the first six months of life.[5]

For measuring the visual acuity with the VEP technique, several patterns, such as checkerboards or sinusoidal gratings, have been used.[6] Since conventional VEP measurements are time consuming and, therefore, difficult to employ in infants, the sweep VEP technique has been developed.[6] In this technique, the pattern element size is swept from large to small sizes over a range spanning the acuity limit. The sweep VEP method provides rapid sensory threshold measurements and requires less cooperation from the subject than do the other currently available VEP tests. High reliability of acuity measurements has been shown in both normal subjects and patients.[7] The VEP has the advantage of being an objective test of neural function. A disadvantage is the complex equipment, specialized personnel and the required fixation of electrodes on the scalp. In addition, only the pathway between the eye and the primary visual cortex is tested. Deficits in other visual centers are not evaluated.

These three methods have all been shown to be reliable, but the VEP technique shows a higher increase in visual acuity than the PL and OKN in the first six to eight months of life. Discrepancies between psychophysical and electrophysiological measures are partially attributable to differences in signal averaging and data scoring strategies for the techniques and partially to a presumed loss of information between the sites of generation of the VEP and the sites of initiation of a motor or behavioral response.

For eliciting responses in infants, different stimuli are used for PL, OKN and VEPs. For PL tested with acuity cards, static stimuli are used, while the stimulus for OKN is in motion. The stimuli used for VEPs have a wide variation. Possibly, these different stimuli are activating different ganglion cell pathways, i.e., the parvocellular type, which has a small receptive field and is sensitive to form vision and color and the magnocellular, large receptive field class, which is responsible for motion and luminance contrast.[8,9]

To our knowledge, visual tracking has not been used so far to evaluate grating acuity in infants.

The purpose of this study was to determine whether measurements of visual tracking can be used to determine visual acuity, and to compare visual acuity tested by visual tracking and by preferential looking in infants.

Methods We examined 51 healthy full-term infants (27 girls and 24 boys) between the postnatal ages of 3 and 93 days, with a mean postnatal age of 38.3 days (SD 27.8). Infants were recruited from the maternity ward and their families were acquainted with the research. Only infants with normal orthoptic examination were included in the study. Every infant was tested once. Visual tracking and preferential looking was performed on the same day in arbitrary order by two different examiners. The examiner of one examination was not aware of the result of the other examination. At this session, an orthoptic examination was also performed. Orthoptic evaluation included ocular alignment (Hirschberg test), fusion (4 prism diopters base-out test) and pupillary reaction. Children were examined in a state of calm wakefulness with open eyes, regular breathing and absence of gross body movements because more reliable results are obtained from infants in this behavioral state. The examiners had the flexibility to spend sufficient time with each infant, so that a complete examination in this state was possible.

The research followed the tenets of the declaration of Helsinki. Informed consent was obtained from the parents after the nature and possible consequences of the study were explained.

VISUAL TRACKING Eye movements were recorded under binocular conditions from the right eye with a photo-oculographic technique developed for examination of infants, based on the measurement of the relative position of the reflected image of an infrared source on the cornea and the pupil center. This technique has the advantage that the measurements are absolute, without drift, which is suitable for the analysis of slow eye movements.[10] The subject was seated in a reclined position in an infant car seat, the head placed between two soft cushions for lateral support, to avoid head movements, 30 cm from a cathode ray tube where stimuli for pursuit were generated. Infrared light (880 nm) was directed to the subject's right eye and the image of the eye was recorded by an infrared camera. Both infrared source and camera were placed over the infant's head without direct contact with the infant. The infrared light was reflected by a hot mirror (dichroic filter separating visible light and infrared light) positioned in the center of the cathode ray tube. The reflected image of the eye movements was automatically analyzed and stored in a computer with a sampling frequency of 30 frames/sec. For stimulation of visual pursuit, a square of 9.4 degrees of visual angle with white and black vertical gratings (contrast 95%, luminance 5 candelas/m^2, spatial frequency 0.1, 0.2, 0.4, 0.8 or 1.6 cycles/degree (cpd)) moved at a constant velocity of 7.5 deg/sec. on the screen of the cathode ray tube with identical luminance, over a range of 56 degrees.

To elicit attention, first a blinking black square was presented in the center of the screen. As soon as the infant fixated, the square with vertical gratings started to move horizontally to the right. After having reached the right margin of the screen, the stimulus automatically started in the opposite direction, from the right to the left margin of the screen. When the stimulus reached the left margin of the screen it started moving again to the right, crossed for a third time the entire screen and finally stopped in the center after a total time of 38 seconds. In the first month of life, the first stimulus used had a spatial frequency of 0.2 cpd. After 4 weeks of age, the test was started with a stimulus of spatial frequency 0.4 or 0.8 cpd. If the infant followed, targets with higher spatial frequencies were used. In the evaluation, for a target to be classified as "seen" by the infant, the infant needed to follow this target at least once over the whole screen (7 seconds). Smooth and saccadic pursuit were added for this evaluation, because we were interested in the ability of the infants to follow the target and not in the quality of eye movements with which the infants did so. The experimental setup was such that the highest spatial frequency was 1.6 cpd. If an infant reached this visual acuity, it was excluded from data analysis.

Calibration in the infrared technique is defined by the geometry of the anterior chamber.[10] This was estimated from biometry data on eyes of subjects obtained at the same age as the subjects used in our study. Sensitivity was 10 min arc.

PREFERENTIAL LOOKING Preferential looking (PL) examination was performed using Teller acuity cards with the grating acuity on one side and a gray field of equal luminance on the other side, according to the originally described procedure.[11] Briefly, the observer presented the PL cards with stripes on one side, was unaware of the location of the stimulus pattern and was not able to see the corneal reflection of the stimulus. The examiner judged, looking through a hole in the center of the card, whether the striped pattern was on the left or on the right based on the infant's direction of first fixation.

The infant was positioned on an examination table in front of the screen at a constant distance of 30 cm, measured from the infant's eyes to the hole in the cards. An assistant or one of the parents held the infant in an upright or reclined position and if required supported its head. The person holding the child was positioned behind a shield preventing her or him from seeing the test gratings and giving clues to the child. The luminance was 10 candelas/m². On one side of the acuity cards there are squares of 12.5 cm with vertical black and white stripes. In order to compare sizes of the PL method with the pursuit method, the grating sizes used for PL were 0.1, 0.2, 0.4, 0.8, 1.6, 3.2 and 6.4 cycles/deg (contrast 82–84%). The other side was a gray surface of matched luminance. After attracting the infant's attention, the examiner held the card with the 0.2 cpd grating against the opening in the screen. If the infant saw the stimulus, the card with the next higher spatial frequency was shown. If the infant did not show a preference for the pattern the card with the next lower spatial frequency was shown. The card with the highest spatial frequency eliciting a reaction was judged to correspond to the visual acuity.

The visual acuities estimated by visual tracking and preferential looking in cycles/deg were transformed into log min arc.[11] For statistical analysis, patients were grouped by one-week intervals of age. Linear regressions were calculated.

Results Examples of original recordings of the horizontal eye movements of an infant are shown in Figure 1. Figures 1A and 1B represent the pursuit at stimuli with spatial frequencies of 0.2 cpd and 0.4 cpd, respectively. Figure 1C shows the eye movement recording at a stimulus of 0.8 cpd, where the infant obviously does not follow the stimulus. For this infant, the visual acuity estimated was 0.4 cpd.

Figure 2 shows the visual acuity estimated by visual tracking during the first 14 weeks of life for 51 infants. During this time interval there was a constant decrease in the variation of the visual acuity results. For the first two weeks of life visual acuities varied over a range of four octaves. In the following seven weeks of age they varied over two octaves, and for the last five weeks of age the majority of the infants reached 0.8 cpd. The data show that the acuity improved by about one octave during the first 14 weeks of life. Regression analysis indicates that this was statistically significant ($p < 0.0005$).

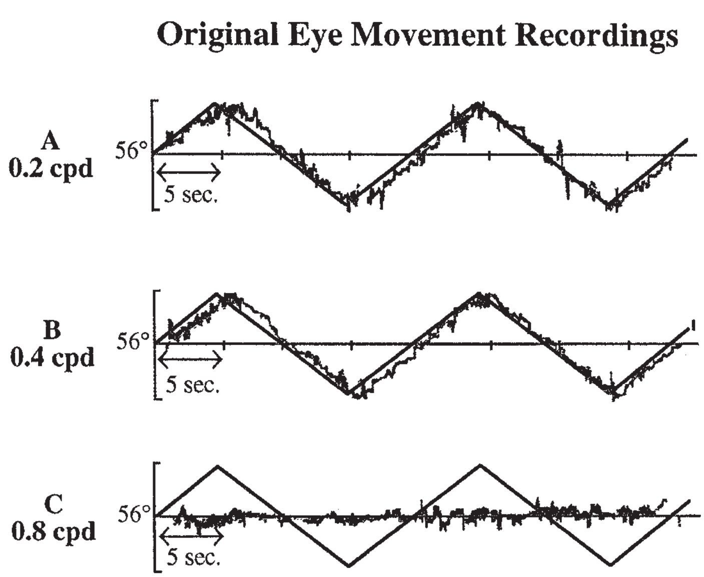

Fig. 1. Horizontal eye movement recordings of a subject at three different spatial frequencies (0.2, 0.4 and 0.8 cycles per degree) during 38 sec. of examination. Upward directions on tracings indicate eye movements to the right; downward directions indicate eye movements to the left.

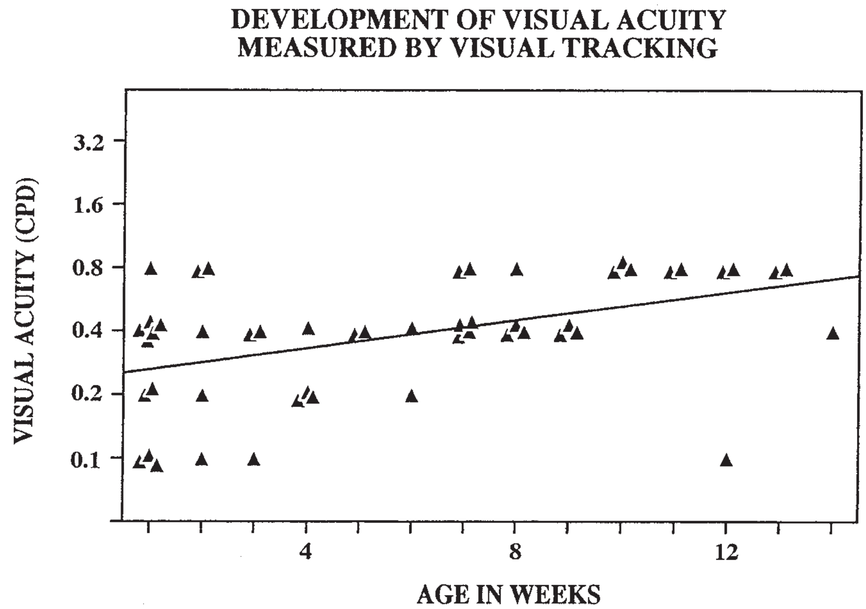

Fig. 2. Visual acuity measured by visual tracking with different spatial frequencies (0.1, 0.2, 0.4 and 0.8 cpd) in 51 infants from one to 14 weeks of age with regression line; the subjects are grouped by age in weeks.

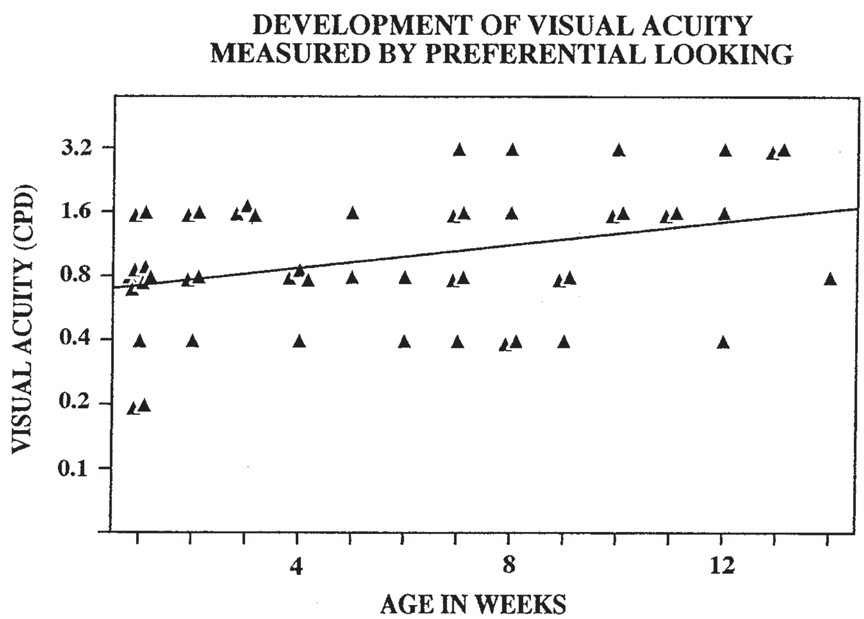

Fig. 3. Visual acuity measured by preferential looking with different spatial frequencies (0.1, 0.2, 0.4, 0.8, 1.6 and 3.2 cpd) in 51 infants from one to 14 weeks of age with regression line; the subjects are grouped by age in weeks.

Figure 3 shows the visual acuity estimated by PL during the first 14 weeks of life for 51 infants. During these 14 weeks there is a large variation in visual acuity. Within the age groups one, seven, eight and 12 weeks, acuity measurements between subjects varied over a range of four octaves. The data obtained show that the acuity improved by approximately one octave during the first 14 weeks of life. Regression analysis indicates that this was statistically significant ($p < 0.05$).

Figure 4 shows the correlation of the visual acuity in cycles per degree (cpd) measured by visual tracking and PL for the total of 51 infants. This correlation is statistically significant ($p < 0.05$). The visual acuities

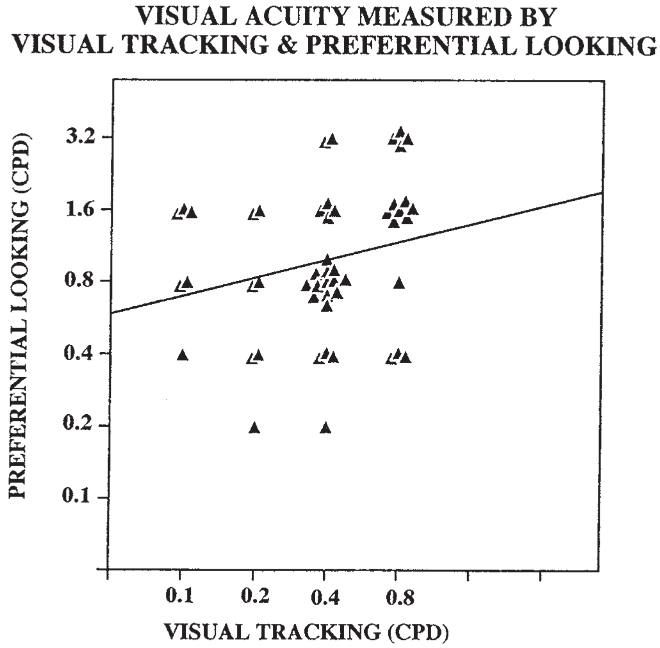

Fig. 4. Correlation of visual acuity (independent of subject age) in cycles per degree measured by visual tracking and preferential looking in 51 infants with regression line.

estimated by visual tracking were, on average, approximately 1.5 octave lower than those obtained by PL.

Discussion Our study indicates that visual tracking is a valid method for testing grating acuity in normal infants, since the acuity correlated highly with the more frequently employed and more standardized PL technique. Visual acuity values estimated by visual tracking were significantly lower than those found with the PL technique. This can be explained by the estimation criteria established in our experimental design. Whereas in PL the direction of first fixation for a short moment is taken as the criterion to determine whether a stimulus was seen or not, in visual tracking we set a requirement for a pursuit of at least 7 seconds. However, it is not clear whether pursuit or saccades are better developed in young infants.

Our PL results for the first four weeks of life are comparable to the results in the literature.[5,7,12–14] We found a slightly slower increase of mean visual acuity. However, single measurements were within the previously reported range.[6,9]

In PL, the results of visual acuity varied over three to four octaves in the whole age range tested in our study. In the literature, the acuities tested by PL varied over a smaller range: in a study by Chandna[12] this was over a range of two to three octaves, starting at 5 weeks of age; in another study by Mayer et al.[13] the youngest subjects were one month old, and here again the range was over two octaves. This age difference could be an explanation for the wider spread. Another reason could be the number of subjects. Our study included 51 subjects, whereas the former studies included 150 or even 460 infants. With the tracking method the variability of the results decreases with increasing age, which might be explained by a higher interest in a moving target than in a stationary one. Alternatively, the lower variability of the results could imply that the visual tracking test is a more objective test than PL, since the PL test relies strongly on the examiner's interpretation.

The visual acuities estimated by PL and visual tracking show approximately parallel patterns of development. This finding further underlines the validity of the visual tracking technique as an acuity testing method.

With the same experimental set up we examined the OKN in the same children by using black and white bars on the full screen of 56° × 40° corresponding to 0.5 cpd. Since we could not elicit OKN in infants less than four weeks of age,[15] the eye movements we elicited in the infants investigated in this study with the square having a size of 9.4° are pursuit movements and not OKN.

Visual tracking, PL and OKN are methods that require a combination of sensory and motor functions. This probably explains why acuities estimated with these methods are as much as to two to three octaves lower than those obtained with the VEP method.[12]

The visual acuity estimated by VEP reaches adult level at six to eight months of age,[6] which shows the maturity of the visual pathways to the visual cortex. With the PL method, the estimated visual acuity reaches the adult level only at about four to six years of age.[13,14] The visual acuity tested by the behavioral method depends, in addition, on the development of higher association centers and motor responses.

The advantage of the tracking system in comparison to the VEP method is that the former does not require placing electrodes on the infant's scalp. Another advantage of the visual tracking method compared to PL is that visual acuity can be assessed simultaneously with eye movement recordings. However, the visual tracking method, similarly to the PL method, depends on a motor response. Therefore, failure to elicit a response may be due to a defect in the oculomotor response and not to the infant's inability to see the stimulus. Interestingly, in patients with nystagmus,[16] we assessed a better visual acuity with the visual tracking method than with the PL method. The mean time for testing visual acuity with either of the methods is about the same and depends strongly on the infant's behavioral state. Both techniques are easy to learn and can be used successfully with most children.

In conclusion, we found that visual tracking is a valid method with low variability of results for visual acuity testing in infants. The need of sustained attention is a possible reason for the lower values in comparison to the acuity determined by PL. In the future, we will test whether this method is suitable in patients with various visual disorders and compare the results to those obtained by the PL method.

References

1 Dobson V, Teller D. Visual acuity in human infants: a review and comparison of behavioral and electrophysiological studies. *Vision Res.* 1978;18:1469–1483.

2 Naegele J, Held R. The post-natal development of monocular optokinetic nystagmus in infants. *Vision Res.* 1982;22:341–346.

3 Tychsen L. Motion sensitivity and origins of infantile strabismus. In: Symons K, editor. *Early visual development: normal and abnormal*. New York: Oxford University Press, 1993;364–390.

4 Hoffman K. Control of the optokinetic reflex by the nucleus of the optic tract in primates. *Prog Brain Res.* 1989;80:173–182.

5 Fulton AB, Hansen RM, Manning KA. Measuring visual acuity in infants. *Surv Ophthalmol.* 1981;25:325–332.

6 Norcia AM, Tyler CW. Spatial frequency sweep VEP: visual acuity during the first year of life. *Vision Res*. 1985;25:1399–1408.

7 Gottlob I. Infantile nystagmus: Development documented by eye movement recordings. *Invest Ophthalmol Vis Sci*. 1997;38:767–773.

8 Enroth-Cugell C, Robson JG. Functional characteristics and diversity of cat retinal ganglion cells. *Invest Ophthalmol Vis Sci.* 1984;25:250–267.

9 Wässle H, Peichl L, Boycott BB. Morphology and topography of on- and off- alpha cells in the cat retina. *Proc R Soc Lond B*. 1984,212:157–175.

10 Buquet C, Charlier JR. Quantitative assessment of the static properties of the oculomotor system with the photo-oculographic technique. *Med Biol Engin Comp*. 1994;32:197–204.

11 Westheimer G. Scaling of visual acuity measurements. *Arch Ophthalmol*. 1979;97:327–330.

12 Chandna A. Natural history of the development of visual acuity in infants. *Eye.* 1991;5:20–26.

13 Mayer DL, Beiser AS, Warner AF, et al. Monocular acuity norms for the Teller Acuity Cards between ages one month and four years. *Invest Ophthalmol Vis Sci.* 1995;36:671–685.

14 Teller DY. The development of visual function in infants. In: Cohen B, Bodis-Wollner I, editors. *Vision and the brain*. New York: Raven Press, 1990; 109–118.

15 Weinacht S, Kind C, Schulte Mönting J, Gottlob I. Visual development in pre- and fullterm infants. *Invest Ophthalmol Vis Sci*. 1999;40:346–353.

16 Gottlob I, Fendick MG, Guo S, et al. Visual acuity measurements by swept spatial frequency visual-evoked-cortical potentials (VECPs): clinical application in children with various visual disorders. *Pediatr Ophthalmol Strab*. 1990;27:40–47.