Although it is now well established that a variety of ocular and systemic diseases, including diabetes, are harmful to the SWS cone pathway, causing a decrease in SW sensitivity,2-4,9 the site(s) of the loss is not well known. The loss in SW sensitivity in diabetes has been variously attributed to changes in the lens, loss of SWS cone receptors due to their greater vulnerability to insult, the reduced response range of normal SWS cones relative to LWS cones,8 and postreceptoral SWS functional losses either at the opponent site9 or beyond the opponent site.9,10

The acute and reversible nature of SW sensitivity observed in this study constrains the choice of potential sites and mechanisms to explain this effect. Clearly, the current results imply that at least part of the SWS loss in diabetes cannot be ascribed to increased lens density or photoreceptor loss, because neither of these events is likely to be reversible. The current results, however, may reflect functional changes at the receptor level or at a postreceptoral site(s) at or beyond the opponent site, but the exact locus still needs to be isolated. The results do suggest that the changes in SW sensitivity are directly related to the transient metabolic state of diabetes and immediately tied to diabetic blood glucose levels, rather than to structural damage of vascular or neural tissues presumed to be involved in the SWS pathway loss in a variety of retinal diseases.

Key Words
diabetes, blood glucose, short-wavelength sensitivity, metabolic control

Scotopic Optokinetic Nystagmus Thresholds in 10-Week-Old Infants
Ronald M. Hansen and Anne B. Fulton

Purpose. To compare psychophysical and reflexive optokinetic nystagmus (OKN) estimates of dark-adapted scotopic thresholds mediated by the posterior retina in 10-week-old infants and adults.

Methods. A staircase procedure was used to determine the stimulus intensity needed to produce an OKN response to a moving 19° × 19° grating. In the same subjects, a two-alternative, forced-choice procedure was used to obtain thresholds for detecting 10° diameter, 50 ms duration stimuli.

Results. Both OKN and psychophysical thresholds of infants are 0.9 log unit higher than those of adults.

Conclusion. The infant–adult difference in thresholds mediated by retina at the posterior pole is greater than the infant–adult difference in thresholds for full-field stimuli. It is possible that delayed maturation of the posterior retina is the primary determinant of infants’ high OKN and psychophysical thresholds.

References

The dark-adapted, rod-mediated thresholds of young human infants are significantly higher than those of adults.1,2,5 However, the magnitude of the threshold elevation is not constant across procedures. At age 10-weeks, dark-adapted infants’ scotopic ERG3,5 and VEP4 thresholds for full-field stimuli are only about
FIGURE 1. The median OKN and psychophysical thresholds of infant and adult subjects are shown. Error bars represent the range.

0.5 log units higher than those of adults, but their psychophysical\textsuperscript{1-3} thresholds for small test spots presented to the posterior retina are more than a log unit above those of adults. It has been suggested\textsuperscript{5} that relatively late maturation of the posterior rod retina\textsuperscript{6,7} explains the higher psychophysical thresholds. The psychophysical thresholds, however, depend on the infants' behavioral responses, causing one to be wary that the infantile elevation of the psychophysical threshold is, in part, an artifact. Therefore, we decided to use the optokinetic nystagmus (OKN) reflex\textsuperscript{8,9} to assess the scotopic threshold of the posterior retina in dark-adapted, 10-week-old infant and adult control subjects.

### MATERIALS AND METHODS.

The OKN stimulus, produced with a modified Nicolet (Nicolet Biomedical Instruments, Madison, WI) pattern generator and monitor (NIC 1015), was a 19° square field of 0.27 c/deg, 83% contrast, black-and-white square wave grating moving at 6°/s to the left. The space average luminance of the unattenuated stationary display, measured with a UDT S-350 photometer (United Detector Technology, Orlando, FL) positioned where the subject's eye was during testing, was 120 cd/m². For each subject, retinal illuminance at threshold was calculated taking dark-adapted pupillary diameter into account.\textsuperscript{1} Stimulus intensity was controlled by 33 × 33 cm neutral density filters.

Each infant and parent pair sat in the dark for 30 minutes to adapt to the dark before testing. A tester held the infant 50 cm from the monitor. A rattle attracted the infant's attention to the monitor. An observer watched the infant's eyes with an infrared image converter and reported when the infant was alert and looking at the monitor. A cardboard shutter was removed to expose the grating that was viewed binocularly. On every trial, the observer reported whether OKN was present or absent. Beginning with a stimulus 2 to 3 log units above the infant's psychophysical thresholds,\textsuperscript{1-3} stimulus intensity was adjusted in 0.3 log unit steps using a transformed up-down staircase that estimates 71% on the psychometric function.\textsuperscript{10} A median of 14 reversals (range, 9 to 18) was obtained from each infant. Twenty percent of trials were blanks (grating stationary) inserted randomly throughout the staircase. Additionally, subjective thresholds of adults for detecting the moving grating (yes–no task) were obtained in the same session.

At the same visit as the OKN test, the subject's psychophysical threshold for detecting 10° diameter, 50 ms, blue (Wratten 47B) stimuli presented 20° to the right or left of a flickering, red LED fixation display was determined as described previously with a two-alternative, forced-choice method.\textsuperscript{1,2} Briefly, an adult positioned the infant in front of a dark rear pro-

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Values are medians (with range in parentheses).
jection screen. A second adult observed the infant with an infrared viewer and reported when the infant was alert and looking at the fixation display. Then a stimulus was presented, and the observer reported stimulus location, right or left, based on the infant’s head and eye movements. A third adult presented the stimuli, recorded responses, and gave the observer feedback on every trial. Stimulus intensity started 2 to 3 log units above previously reported thresholds and was adjusted in 0.3 log unit steps following a transformed up-down staircase that estimates the 71% correct point of the psychometric function. A median of 12 reversals (range, 8 to 18) was obtained. Half the subjects were tested first with the OKN task and half with the psychophysical task.

Ten 10-week-old infants were tested; nine completed both OKN and psychophysical procedures. All infants were born within 10 days of their due date. Five young adults ages 18 to 23 years were also tested. Thorough ophthalmic examination of all subjects with cycloplegia demonstrated no ocular abnormalities. The study, which followed the tenets of the Declaration of Helsinki, was approved by the Children’s Hospital Committee on Clinical Investigation. Written, informed consent was obtained from adult subjects and the parents of the infants.

RESULTS. The median OKN threshold of infants is -2.9 (range, -2.7 to -3.0) compared to -3.8 (range, -3.6 to -4.0) log scot Td s for adults (Fig. 1). The median infant psychophysical threshold is -3.0 (range, -2.7 to -3.0) compared to -3.9 (range, -3.8 to -4.1) log scot Td s for adults. Both infant and adult thresholds are rod mediated at these troland values.

The difference in median thresholds of infants and adults is 0.9 log unit for the OKN test and 0.9 log unit for the psychophysical test. These are significant infant–adult differences (Mann-Whitney test, OKN, U = 0, P < 0.001; psychophysics, U = 0, P < 0.001).

There is good agreement between OKN and psychophysical thresholds for individual subjects. For infants, the median difference is 0 (range, -0.2 to +0.1) log unit. For adults, the median difference is -0.1 (range, -0.4 to +0.2) log unit. For individuals, the median difference in subjective and reflexive responses was +0.1 (range, -0.1 to +0.2) log unit. The median adult subjective threshold for detecting the moving grating was -3.8 (range, -3.5 to -4.1) log scot Td s, the same as the median threshold for the reflexive OKN response.

DISCUSSION. Infants’ dark-adapted thresholds for stimuli falling on the posterior pole are nearly a log unit above those of adults, whether measured with OKN or psychophysical procedures (Fig. 1). The OKN and psychophysical thresholds contained herein agree well with previously reported psychophysical thresholds (Table 1). As noted in previous studies, the adults’ subjective and reflexive thresholds for the OKN stimulus agree well.

Compared to the OKN and psychophysical thresholds mediated by the posterior pole, the thresholds derived from ERG and VEP responses to full-field stimuli are only about 0.5 log unit, that is, about three times, higher for infants than for adults. The rhodopsin content of the retina of young infants is about one-third that of adults. Therefore, low absorption of light by rhodopsin cannot be rejected as the explanation for infants’ elevated thresholds for full-field stimuli.

Recent anatomic studies indicate that rods at the posterior pole are slower to mature than more eccentric rods. From the perinatal period to adulthood, the posterior pole accounts for only 10% to 5% of the total retinal area. Thus, the relatively greater immaturity of the posterior pole retina appears to have little effect on thresholds for full-field stimuli.

The psychophysical and OKN thresholds mediated by the posterior retina only could be affected, however, by the relatively greater immaturity of the posterior pole retina. These thresholds are nearly ten times higher in infants than in adults. Short outer segments and low packing density of rod cells at the posterior pole of the developing retina predict a low rhodopsin content. If low quantum catch alone explained these thresholds, the rhodopsin content of an infant’s posterior retina would be one-tenth of an adult’s.

Key Words
development, human, scotopic sensitivity, optokinetic nystagmus, OKN

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References
The Rabbit Lacrimal Gland in Vitamin A Deficiency
John L. Ubels* and Jack R. Harkema†

**Purpose.** To investigate the morphology, ultrastructure, and protein secretion of the vitamin A-deficient rabbit lacrimal gland.

**Methods.** The lacrimal glands of vitamin A-deficient rabbits and age-matched controls were fixed, processed by standard methods, and examined by light and transmission electron microscopy. Protein secreted by the lacrimal gland was analyzed using gel filtration chromatography and electrophoresis.

**Results.** By light microscopy, the glands of experimental and control rabbits were indistinguishable. Electron microscopy showed little effect of vitamin A deficiency on the lacrimal acini, although occasional pyknotic nuclei were observed. The intralobular ductal epithelium was unaffected. Protein concentration and composition were essentially unchanged in lacrimal gland fluid of vitamin A-deficient rabbits compared to controls.

**Conclusions.** The rabbit lacrimal gland is minimally affected by vitamin A deficiency, suggesting species differences between rabbits and rats in the vitamin A requirements of the lacrimal gland. Normal lacrimal gland structure and function in vitamin A deficiency allow for the prompt secretion of retinol on the restoration of vitamin A to the diet. Invest Ophthalmol Vis Sci. 1994;35:1249-1253.

Among the many tissues that require vitamin A for control of cellular differentiation are the corneal and conjunctival epithelia, which become keratinized and undergo squamous metaplasia in retinoid deficiency.1,2 Because of the apparent dryness of the ocular surface epithelium in vitamin A deficiency, there has been a long-standing interest in the effects of vitamin A deficiency on tear secretion and the lacrimal gland.3 The role of vitamin A in lacrimal gland function has taken on added significance since the demonstration that the lacrimal gland secretes and metabolizes vitamin A.4,5 Bron,6 using light microscopy, demonstrated degeneration of the extraorbital lacrimal gland in the vitamin A-deficient rat. More recently, Hayashi et al8 reported ultrastructural abnormalities of the lacrimal gland in vitamin A-deficient rats. In contrast to these observations, we have observed that lacrimal gland function in the rabbit is essentially unaffected by vitamin A deficiency, as assessed by fluid and electrolyte secretion.7 Because this suggested that the structure of the vitamin A-deficient rabbit lacrimal gland should also be normal, a study was undertaken to examine the lacrimal glands of vitamin A-deficient rabbits histologically and ultrastructurally.

**MATERIALS AND METHODS.** Animals. Vitamin A-deficient New Zealand white rabbits (n = 9) were prepared as previously described.1,2 The rabbits were weighed weekly, and the eyes were examined by slit-lamp microscopy for xerophthalmia. The animals were maintained until they reached an established endpoint defined as weight plateau (mean ± SE = 2.17 ± 0.06 kg) followed by weight loss (final weight = 1.96 ± 0.08 kg) and development of stage 3 to 4 xerophthalmia1,2 in both eyes. At this point, serum retinol levels are less than 3 μg/dL. The vitamin A-deficient rabbits and four age-matched control rabbits (3.8 ± 0.12 kg) were anesthetized with intramuscular ketamine (30 mg/kg) and xylazine (5 mg/kg) and euthanized by an intravenous overdose of sodium pentobarbital. The lacrimal glands were then removed from each animal.

**Histology and Electron Microscopy.** Part of each gland was fixed in 10% neutral-buffered formalin for light microscopy, whereas the remainder was fixed in 0.2 M sodium phosphate-buffered, 8% glutaraldehyde for transmission electron microscopy. Paraffin sections of formalin-fixed glands were stained with hema-

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