Pupillary Changes During Dark Adaptation in Human Infants

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Pupillary diameter of 10 infants (age 10 weeks) and four adult subjects was measured during 30 min of dark adaptation following exposure to a full-field adapting light. Adult results confirm that, under these conditions, the course of pupillary recovery was reasonably well described by an exponential time course ($t_0 = 408$ sec; SD = 42 sec), as is rhodopsin regeneration. Pupillary recovery of infants also could be described by an exponential course (average $t_0 = 399$ sec; SD = 31 sec). These results, demonstrating similarities between adaptive functions of infants and adults, suggest that pupillographic techniques can be used to investigate dynamic processes accompanying dark adaptation in preverbal children. Invest Ophthalomol Vis Sci 27:1726-1729, 1986

Behavioral methods have been used to study human infants' scotopic retinal sensitivity, and adaptation to background lights in some steady state conditions. However, the dynamic processes accompanying dark adaptation have yet to be investigated, at least in part, because conventional adaptometry and densitometry require cooperation beyond the capabilities of infants. Recently, changes in sensitivity during the first 5 sec of dark adaptation have been studied, however, it is unlikely that preferential looking methods can be used to follow the entire course of dark adaptation in infants. Pupillographic procedures, successfully used to monitor retinal adaptation in adults, offered another approach to assessment of dynamic function in infants. We report here the course of infants' pupillary change during dark adaptation. The infants' data are compared to those of adults.

Materials and Methods

Pupillary diameter was monitored using an infrared sensitive video camera (Panasonic (Secaucus, NJ) WV 1540) with a 75 mm, f 1.4 lens and extender rings. A 15 watt tungsten source positioned behind a Wratten 88A filter (transmitting X > 720 nm) provided sufficient illumination to obtain an enlarged (approximately 5X) view of the pupil, but did not bleach a measurable amount of rhodopsin. The output of the camera was monitored on a high resolution black-and-white monitor, and recorded on a video cassette.

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Supported by National Institutes of Health (NIH) Grants EY 05325 and EY 05329.

Submitted for publication: August 5, 1985.

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The procedure was similar to that employed by previous investigators with adult subjects. At the start of each session, one of the infant's pupils was dilated with cyclopentolate hydrochloride 1% (Cyclogyl, Alcon Laboratories, Fort Worth, TX). Next, an adult holder positioned the infant so that the dilated pupil was at the opening of an integrating sphere (41 cm diameter) illuminated by a tungsten source. The unattenuated luminance of this source was 4.1 log cd/m$^2$; calibrated neutral density filters were used to attenuate this light so that it produced a retinal illumination of about 5.4 log scotopic td for all subjects. Because retinal illumination varies with pupillary diameter and inversely with the square of the posterior nodal distance, the luminance of the adapting light was decreased to about 3.8 log cd/m$^2$ (by interposing neutral density filters) to produce a retinal illumination of 5.4 log scotopic td in the smaller infant's eye. The measured diameter of the dilated pupil was also taken into account in these calculations. Consistent with previous reports, reflection retinal densitometry indicated that this exposure bleached $\geq$90% (average 92%; range: 90–93%) of the rhodopsin of the adult subjects. Although the adapting light was quite bright, previous reports indicated that exposure to more intense or longer duration sources is needed to cause retinal damage.

* Radiometric measurements made with a calibrated photodiode placed in the position of the subject's eye showed that the adapting field intensity was 36 $\mu$watts/cm$^2$. The retinal irradiance was estimated using the relation:

$$H_r = H_c(d^2/f^2)t_x,$$

where $H_c$ is the corneal irradiance, $d$ the diameter of the pupil (5 mm), and $f$ the focal length of the infant's eye (12 mm). The transmissivity of the ocular media ($t_x$) was assumed to be 1.0. The retinal irradiance ($H_r$) produced by the adapting light used in the present study was 6.2 $\mu$watts/cm$^2$. Exposures to broadband light producing retinal irradiances of 200–600 $\mu$watts/cm$^2$ for durations of 12 hr have
Fig. 1. The recovery of pupillary diameter as a function of time in the dark for four infants. Each point represents one measurement of the diameter of the pupil. Zero on the time scale corresponds to the end of the adapting light exposure and the start of dark adaptation. For each subject, the dashed line represents the best fitting exponential function through the data; the time constant $t_0$ for that function is specified on each graph.

Noises made by the experimenter, and flashing red LED’s in the integrating sphere, kept the infant alert during light adaptation. At the end of the 2 min light exposure, the holder immediately turned and positioned the infant so that a direct view of the undilated pupil was obtained with the camera. Pupillary diameter was recorded over the course of at least 30 min. The dim infrared source for the camera was visible to the subject, and served as a fixation target. Noises made by the experimenter kept the infants looking toward the camera most of the time.

After the session, pupillary and corneal diameter were measured using single frames displayed on the monitor. Frames were selected for measurement at 15–30 sec intervals following the end of the adaptation period. Only those frames in which the infant was looking straight ahead and the image of the pupil was circular and in focus were used. Corneal diameter is about 11 mm at age 10 weeks; pupillary diameter in millimeters was determined by multiplying the ratio of pupillary to corneal diameter by 11 mm. This minimized the effect of changes in image size due to variations in the subjects’ distance from the camera. The precision of measurements of the diameter of the pupil was about 0.1 mm. The total number of measurements of pupillary diameter (range: 30–55) made during one session varied, depending on the alertness and cooperation of the infant. For 10-week-old infants, the average pupillary diameter following 30 min of dark adaptation (5.2 mm; SD = 0.5 mm) was not significantly different from the average pupillary diameter 30 min after the adapting exposure (5.3 mm; SD = 0.8 mm).

Ten infants, age 10 weeks (range: 64–77 days), participated in this study. All infants were born within 7 days of their due dates. Thorough ophthalmic examination revealed no ocular abnormalities. Informed consent was obtained from parents before testing began. Four young adults were tested using the same apparatus and procedure. In a separate session, rhodopsin regeneration of the adult subjects was assessed using a reflection retinal densitometer following exposure to the same full field adapting light used in the pupillography experiments.

Results

Pupillary diameter was plotted as a function of time in the dark for each subject; representative results from four infants are shown in Figure 1. All infants yielded measurable records for at least the first 12 min (about...
3 times $t_0$ and had several measurements of pupillary diameter made about 30 min after the end of the adapting period. For the ten infants, the average maximum change in pupil diameter ($\Delta D_0$) during the 30 min following the adaptation period was 2.9 mm (SD = 0.8 mm). The best fitting exponential function through each subject’s data was determined by minimizing root mean square deviations from the function:

$$\Delta D = \Delta D_0 (1 - e^{-t/t_0}),$$

where $\Delta D$ is the difference between pupillary diameter at any time ($t$) and pupillary diameter at the end of the adaptation period, $\Delta D_0$ the maximum change in pupillary diameter, and $t_0$ the time constant. For the 10 infants tested, the average value of $t_0$ was 399 sec (SD = 31 sec; range: 346–450 sec).

The pupillary recovery of the four adults (Fig. 2) followed an exponential time course with an average 408 sec time constant (SD = 42 sec; range: 353–455 sec), that was not significantly different from the average $t_0$ found with infants. Reflection retinal densitometry, following exposure to the same adapting light as used in the pupillography session, showed that the time course of rhodopsin regeneration was similar to that of the pupillary response. For these subjects, the average time constant for rhodopsin regeneration was 396 sec (SD = 19 sec; range: 371–418 sec). Good agreement between pupillary recovery and rhodopsin regeneration is consistent with previous results. 7

**Discussion**

Infant and adult courses of increasing pupillary diameter during dark adaptation (Figs. 1, 2) are similar. These data provide some evidence that, by age 10 weeks, human visual pathways from retina to tectum to contralateral pupil have, in the conditions described, functional capacities equivalent to adults.

Pupillary recovery after 90+% bleaches of large or full field retinal areas, such as those used in the present experiments, has been previously noted to have a course similar to rod dark adaptation, 6 a rod-dominated action spectrum, 16 and to be linearly related to the fraction of unregenerated rhodopsin present. 7 These observations have led to the conclusion that pupillary responses could be used to study rhodopsin regeneration. 6,7,16 If this is the case, then the infants’ results (Fig. 1) suggest that rhodopsin regeneration kinetics at age 10 weeks are the same as adults.

Similar results have been reported in the developing rat retina. In 15-day-old infant rats, rhodopsin regeneration, assessed by measurement of extracted rhodopsin at selected times during dark adaptation, followed the same course as in adult rats. 17 (At age 15 days, rat retina is morphologically much less mature than 10-week-old human retina.) These and parallel electroretinographic data 17 led to the conclusion that at least some of the distal retinal processes underlying rat’s dark adaptation are mature in the early postnatal
days. The present results (Figs. 1, 2) suggest that the same conclusion may apply to human infants' retinal function during dark adaptation.

Thus, as in adults, pupillographic techniques should enable further study of retinal function of infants and young children. Not only can normal function be assessed, but the techniques appear feasible for the investigation of young patients.18

Key words: pupillary response, rhodopsin, retinal development, dark adaptation, infants

Acknowledgments

The authors thank Debra Leizman Kerman for help with early phases of this work and Susan Harris for meticulous technical support throughout the study. Comments of Prof. Mathew Alpern and Dr. Angela Brown on an earlier version of the manuscript are gratefully acknowledged.

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