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The Effects of Luminance on FPL and VEP Acuity in Human Infants

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Grating acuity was measured in 16-week-old human infants. Three measurement techniques were used: forced-choice preferential-looking (FPL), and two visual-evoked-potential (VEP) techniques. The stimuli were counterphase flickering sinewave gratings with a space-average luminance of −1.0 or 2.0 log cd/m². Slightly different luminance-dependent changes occur between FPL and VEP acuities, suggesting that some factor influences the two methods differently as stimulus luminance varies. A comparison between FPL acuities and VEP acuities within infants suggests a quantitative relationship between techniques. Infant's acuity for sinewave gratings with a space-average luminance of −2.0, −1.0, 0.0, 1.0 and 2.0 log cd/m² was also measured using a single VEP paradigm. The results are compared to the same measurements in adults and to infant and adult ideal observers. VEP acuity in this group of infants improves by about 0.5 log units between −2.0 and 0.0 log cd/m² and remains asymptotic between 0.0 and 2.0 log cd/m². This result suggests that luminance-dependent changes in infant acuity cannot be fully accounted for by immaturities in the optics and photoreceptor spacing and efficiency.

Infant visual development   Acuity   Preferential looking   Visual evoked potentials

INTRODUCTION

Visual acuity in adults improves with increasing stimulus luminance, although little improvement is observed for luminances >2.0 log cd/m² (Patel, 1966; Shlaer, 1937). Several factors contribute to this improvement, including the transition from scotopic to photopic vision at moderate luminances (Hecht, 1927) and the increase in the ratio of signal to photon noise at higher luminances (Banks, Geisler & Bennett, 1987). The state of adaptation of the eye also affects the variation of acuity with luminance (Lythgoe, 1932) so post-receptoral processes are important as well.

The visual performance of human infants at different light levels is of theoretical interest for the following reasons. It is now well established that the spatial vision of young infants is quite deficient relative to that of adults (Banks & Salapatek, 1983; Braddick & Atkinson, 1988) and that the fovea, the retinal region that supports fine resolution in adults, is distinctly immature during the first months of life (Abramov, Gordon, Hendrickson, Hainline, Dobson & LaBossiere, 1982; Youdelis & Hendrickson, 1986). A handful of investigators have pointed out recently that an important consequence of the retinal immaturity is reduced quantum catch among foveal cones (Banks & Bennett, 1988; Brown, Dobson & Maier, 1987; Wilson, 1988). The lower catch is, in a sense, similar to the effect of reducing the retinal illuminance of the stimulus by placing dark glasses in front of the eye. This is the dark glasses hypothesis (MacLeod, 1978) which, when adapted to development, states that the performance of infants and adults can be equated by increasing the light level presented to infants enough to overcome the attenuation of the theoretical glasses. According to this hypothesis, infant spatial vision at a suitably bright level should be similar to adult vision at a lower level. In the context of the current paper, the dark glasses hypothesis would predict that infant grating acuity should approach adult levels of 30–60 c/deg at high light levels.

Using the forced-choice preferential-looking (FPL) procedure, Brown *et al.* (1987) and Dobson, Salem and Carson (1983) examined this idea by measuring grating acuity in 8-week-old infants at luminances ranging from −2.6 to 1.5 log cd/m². They found that plots of acuity as a function of luminance were slightly different in shape for infants and adults and that the infant data were 1.5 log units lower than the adult. The fact that the infant data reached an asymptote at roughly the same luminance as the adult data, but at a much lower acuity

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value, is clearly inconsistent with the dark glasses hypothesis. Of course, this hypothesis is rather simplistic because it does not incorporate other known differences between infants and adults that assuredly affect resolution. For instance, age differences in eye size and photoreceptor spacing affect the sampling frequency of the eye and hence its resolution capacity. To examine the contribution of these differences as well, we compare in this paper acuity as a function of luminance in infants and in an ideal observer with neonatal optics and photoreceptors.

The acuity estimates obtained with various visual-evoked-potential (VEP) techniques are typically significantly higher than those obtained with FPL (Dobson & Teller, 1978; Norcia & Tyler, 1985). This observation raises the concern that the FPL procedure underestimates the resolution capacity of infants. Because the observation of a low asymptote in acuity vs luminance plots is crucial to rejection of the dark glasses hypothesis, it is important to use techniques that yield high acuity estimates in infants. Additionally, it is possible that this difference in acuity between techniques could be more pronounced at some luminances. Given these concerns, it seems premature to reject the dark glasses hypothesis on the basis of data obtained from FPL alone. Perhaps VEP measurements will reveal that infants' resolution performance continues to improve at high light levels. Moreover, finer acuity estimates will be important to comparisons with ideal performance.

There have been no reports of infants' VEP acuity as a function of luminance. Fiorentini, Pirchio and Spinelli (1980) recorded VEPs to sinusoidal gratings of varying contrast and spatial frequency at -1.2 and 0.8 log cd/m^2. One can extrapolate their data to estimate grating acuity. As in the behavioral studies, infants exhibited similar or less improvement in acuity compared to adults with increasing luminance. These data do not really bear on the dark glasses hypothesis, however, because the highest luminance was lower than the level at which adult acuity begins to reach an asymptote.

To test the dark glasses hypothesis more directly, we first measured acuity at two luminance levels with FPL and VEP in the same infants using nearly identical stimuli. To our knowledge, this is the first study to measure acuities in the same infants with the same stimuli using both behavioral and evoked potential techniques. We expected the absolute acuity values to differ between the two techniques, but of more interest were the relative improvements of the acuity estimates with increasing luminance. Similar relative improvements would be consistent with the hypothesis that FPL and VEP estimates of visual resolution are constrained by the same neural mechanisms. A difference in the relative improvements in acuity would suggest that the two techniques are affected differently by some factor.

We then measured acuity in a group of infants at five luminance levels spanning a 4 log-unit range and compared this to the same measurements in adults and to infant and adult ideal observer predictions of the measurements. This comparison allows one to estimate how much of the improvement in acuity can be accounted for by the pre-neural factors incorporated in the ideal observer.

METHODS

Subjects

Twenty-five infants were recruited by letter and phone from county birth records. After receiving informed consent from the parents, the infants were tested between the ages of 15 and 20 weeks. The average age was 16 weeks and 2 days. All infants were free of significant health problems, ocular pathology and strabismus. We also tested four adults with normal corrected visual acuity.

Stimuli

The stimuli were displayed on a Joyce electronics display in an otherwise dark room. The stimuli were vertical sinusoidal gratings of 80% contrast, counterphase flickered at 6 Hz. In the FPL sessions, a grating was presented on the left or right half of the display and a uniform field of the same space-average luminance was presented on the other half. In the VEP sessions, the stimulus filled the entire display. Viewing distances were 40 and 80 cm in the FPL and VEP sessions, respectively, so that equal number of cycles were presented at a given spatial frequency for both techniques.

Forced-choice preferential-looking procedure

The forced-choice preferential-looking technique has been described previously (Teller, Morse, Borton & Regal, 1974; Teller, 1979), so only a brief description is given here. Infants were tested while seated on the parent's lap. An observer monitored the infant's eye position using a Panasonic WV-1550 video camera (sensitive to 0.3 lx) and video monitor. The infant's face was illuminated by the light from the stimulus display and by an i.r. light source (60 W incandescent bulb and Wratten 87B filter). The oberver initiated a trial when the infant was judged to be fixating the center of the display. On each trial, a grating appeared on either the left or the right side of the screen. The observer guessed the location of the grating based on the infant's behavior. Feedback indicated the accuracy of the response.

At least 25 trials were presented at each of 3–5 spatial frequencies for every luminance level tested. A Probit analysis (Finney, 1971) was performed on each set of psychometric data in order to determine the best fitting cumulative normal function. Acuity was defined as the spatial frequency associated with 75% correct responding.

Visual-evoked potentials

Two VEP paradigms were used. In one, which we will call the steady-state VEP, spatial frequency remained constant during each trial. The EEG was recorded only while the observer judged the infant to be attending to the stimulus. The trial continued until 10 sec of data were accumulated. The amplitude and phase of the