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Visual contrast sensitivity of a 6-month-old infant measured by the evoked potential

THE visual contrast sensitivity of the human infant has previously been measured using behavioural methods, in which psychophysical thresholds have been inferred from visual preferences[1]. In this paper we report a preliminary investigation of contrast sensitivity, as measured by the amplitude of the evoked cortical response, in a 6-month-old infant. These results are compared with behavioural measurements on the same infant, and with adult data obtained psychophysically and from evoked cortical responses.

Campbell and Maffei[2] measured the visual evoked cortical response to a phase reversing sinusoidal grating and found that a linear relationship existed between the logarithm of contrast and the amplitude of the evoked potential. By extrapolating a regression line through such a plot to zero voltage, the psychophysical threshold could be predicted[3]. This relationship found in adult evoked potential measurements has been used in the present study to indicate thresholds for contrast in a situation where direct psychophysical methods are not possible, that is, in human infants.

The stimuli were vertical gratings of sinusoidal luminance profile, whose phase was reversed at 10 Hz. They were generated on an oscilloscope screen by established methods[4,5], with a mean luminance of 300 cd m^{-2}, and subtending an angle of 20° at 57 cm. To ensure that evoked potentials for different contrast levels were comparable in spite of possible artefactual changes over time, the various contrasts for a given spatial frequency were presented repeatedly in short blocks randomly interleaved within a particular run, which lasted about 10 min. Each block lasted 5.1 s. Control blocks, in which the contrast was set to zero, were included in each run. The infant was held sitting 57 cm from the display screen (110 cm for runs with spatial frequency higher than 5 cycles per degree). Between the infant and the display there was a 70% reflecting mirror arranged to superimpose the image of an active face on the stimuli, which served to maintain the infant's attention.

Evoked potentials were recorded from both the infant and the adult by means of 2-mm Beckmann electrodes. One electrode was placed 1 cm above the inion and the other 3 cm temporally: the signals from these were differentially amplified 100,000 times, with an earth electrode placed behind the ear. The amplified signal was filtered (by a Kemo VBF/3/J filter) with a passband of ±2 Hz centred on the second harmonic of the frequency of phase alternation (20 Hz). The filtered signal was fed into an analog input channel of a PDP-11/10 computer which maintained separate averages of the signal for each contrast level used, and also controlled the stimulus contrast and phase alternation. These averages were of a 100-ms sweep and therefore contained two cycles of the second harmonic signal. The first 100 ms of each 5.1-s block were not included in the average, to avoid the effect of initial transients due to the contrast change. The averaging could be interrupted when the infant was not attending to the screen. In general 500 sweeps were averaged at a given contrast, although for some low contrasts extra blocks were included in the program to obtain a signal of sufficient amplitude. The averaged signals, which because of the narrow passband were approximately sinusoidal, were displayed, plotted on an X–Y plotter, and the peak-to-trough amplitude was put out by the computer. Signals have only been included in the results if their peak-to-trough amplitude was at least 20% higher than that measured in the average for the zero contrast control blocks.

The subjects were tested for responses to spatial frequencies ranging from 0.1 to 15 cycles per degree, and contrasts ranging from 4% to 50% for each frequency. Psychophysical thresholds for the adult were measured with the same apparatus, using a yes–no forced choice method with a double random staircase procedure under the computer's control. The trials near to threshold were inter-

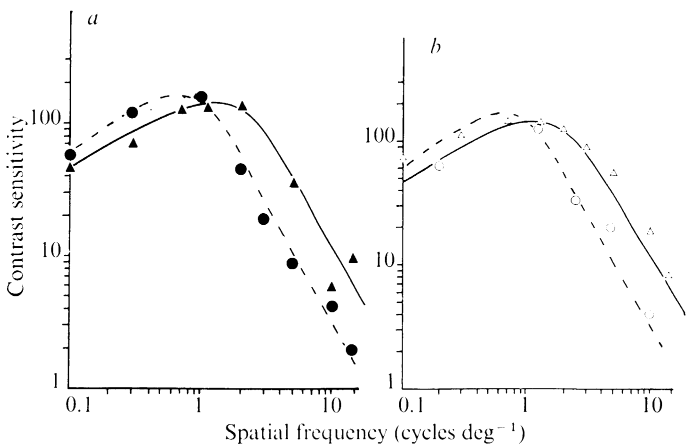

Fig. 2 *a*, Comparison of the contrast sensitivity functions for the adult (▲) and infant (●), as derived from the amplitude of the evoked potential. The curves are fitted by eye. Each point is an average of several runs. *b*, Comparison of the psychophysical contrast sensitivity for the adult (△) and the behaviourally determined contrast sensitivity function for the infant (○). The curves from Fig. 2 *a* are repeated in this figure to aid comparison between psychophysical and evoked potential measures.

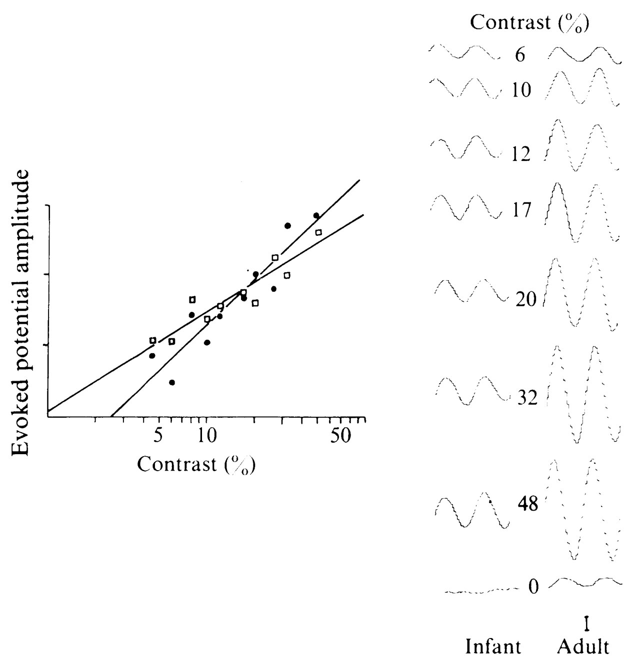

Fig. 1 Right, averaged evoked potentials (500 sweeps) for a series of contrast levels, from the infant and adult subjects. Spatial frequency: 0.3 cycles per degree. The bottom traces were obtained with no grating present. Scale: 200×10^{-9} V per sweep (adult), 50×10^{-9} V per sweep (infant). Left, plot of amplitude of these potentials against contrast (logarithmic scale). ●, Adult data; □, infant data. Regression lines are shown for each subject. The amplitudes have normalised for this plot.

leaved with high contrast displays in a similar sequence to that used for the evoked potential measurements and the screen was viewed through the 70% mirror. Behavioural data on the infant were gathered using the method of fixation preference assessed by two-alternative forced choice by a 'blind' observer[6]. Stimuli were presented on two oscilloscopes at a distance of 40 cm from the infant, subtending 15° each and separated by 9°. One screen displayed a horizontal test grating and the other a blank field matched in mean luminance. The behavioural threshold was defined as the contrast level at which the observer could make 70% correct judgements of the side to which the stimulus was presented. This was obtained by a modified staircase procedure.

Refraction of the infant subject showed that he was about 1 D hypermetropic with 0.75 D of astigmatism in each eye. He should therefore have had no difficulty accommodating to the stimulus distance. The adult subject was emmetropic.

Figure 1 shows a series of averaged signals for a single spatial frequency (0.3 cycles per degree) and increasing contrast for both the infant and adult subjects. The peak-to-trough amplitudes of the signals of each series were plotted against log contrast and the linear regression line extrapolated to give the contrast for zero amplitude. These extrapolated contrasts are plotted in Fig. 2*a* as a function of spatial frequency, for both the infant and the adult subjects. Curves have been fitted to these by eye. Plotted in Fig. 2*b* are the psychophysically or behaviourally obtained contrast sensitivities for each subject, with the curves of the evoked potential results from Fig. 2*a*.

For the adult, the extrapolated evoked potential "threshold" estimates lie close to, but in most cases slightly below, the psychophysical thresholds. This is compatible with previous findings[2,3]. The behavioural measure on the infant gives a lower limit on the estimate of sensitivity. This in fact coincided rather closely with that derived from the evoked potential measurements (Fig. 2*b*).

In the case of the low spatial-frequency stimuli, it is not possible to determine from our data whether the evoked potentials are generated by the spatial pattern, or by a frequency-doubled response to flicker[7]. When modulation is both spatial and temporal, however, psychophysical thresholds can also be distinguished by the detection of either pattern or flicker[8,9]. The uncertainty about the origin of the evoked potential does not therefore exclude a comparison with the behavioural data, but it does indicate a need for caution in extending the results to different temporal conditions, such as a static pattern.

The use of evoked potentials allows us to compare the same measure of sensitivity, employed on both infant and adult. Figure 2*a* shows that for low spatial frequencies the contrast sensitivity derived in this way is very similar for both subjects. At spatial frequencies of 2 cycles per degree and above, however, the adult is shown to be markedly more sensitive. In making these comparisons, it should be borne in mind that the infant and adult visual systems may show differences in temporal as well as spatial response.

We therefore conclude: (1) that the neural mechanisms determining contrast sensitivity at low to medium spatial frequencies have matured by 6 months of age to close to the adult level (this is consistent with the finding[10–12] that the optimum check size for checkerboard-evoked potentials is similar in the 6-month-old and the adult). However, the neural mechanisms determining high spatial-frequency sensitivity are not fully mature at this age. (2) Measurements of contrast sensitivity by means of the visual evoked potential are possible in infants and give data consistent with behavioural methods. It may prove a valuable clinical tool for the early diagnosis of visual problems.

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