

EFFECTS OF CONTRAST, ORIENTATION AND BINOCULARITY IN THE PATTERN EVOKED POTENTIAL*

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(Received 25 August 1983; in final revised form 29 October 1984)

Abstract—Monocular and binocular visual evoked potentials were studied as a function of modulation depth (contrast) of a counterphase sinusoidal grating stimulus. A range of spatial and temporal frequencies of stimulation were used. The contrast functions showed many different forms, and were in some cases nonmonotonic. The binocular response usually had a steeper slope than the monocular response. Extrapolating the slope to the zero intercept gave electrophysiological thresholds which did not correspond with psychophysical threshold at any spatial or temporal frequency used. The binocular response was reduced to the monocular level when the orientation difference between the two eyes exceeded about 20°. The data show that the pattern evoked potential is highly specific to many stimulus variables.

Pattern Contrast Binocular Orientation VEP

INTRODUCTION

An important variable determining the amplitude of the visual evoked potential (VEP) is the depth of modulation (i.e. contrast) of the stimulating pattern. Under some conditions the VEP amplitude is a linear function of log modulation depth in sinusoidal counterphase grating stimuli (Campbell and Kulikowski, 1972; Fiorentini and Maffei, 1973; Kulikowski, 1977). Under other conditions, the contrast function may show two limbs as demonstrated in human by Campbell and Maffei (1970) and in monkey by Nakayama (1982). The high contrast limb may have either a steeper slope than the low contrast limb (acceleration) or a shallower slope (saturation). A saturation type of response has also been described by Regan (1973) and Spekreijse *et al.* (1977).

The specificity of pattern responses also extends into the domain of binocular interactions. Apkarian *et al.* (1981) have reported that the summation ratio, defined as the ratio of the binocular response (B) to the mean of the two monocular responses (M) under each condition, varies markedly with the precise spatial and temporal frequency of counterphase grating stimulation. The evidence suggested that the spatio-temporal tuning of binocular responses was different from that of monocular responses.—This raises the question of how the response varies with increasing contrast in regions of different types of binocular/monocular response ratio.

To examine the effects of contrast in the VEP responses to sinusoidal patterns in more detail, we performed a study of the effects of spatial and temporal frequency, ocularity and orientation on the pattern evoked potential (PEP) as a function of contrast. The complex interactions across these variables provide further support for the separability of local luminance and multiple pattern response mechanisms from the scalp VEP.

METHODS

Stimulus

Stimulus patterns were presented on the face of a Hewlett-Packard cathode ray tube (CRT) display (Model 1332A, P31-Phosphor) following a modification of the method employed by Campbell and Green (1965). Either a flickering homogeneous field or a sinusoidal grating flickering in counterphase with a range of stimulus dimensions could be generated.

Linearity of the intensity modulation was determined by plotting luminance as a function of Z-axis voltage. A selenium photocell was used in all light measures, including those of contrast. The mean luminance of the 10 × 12° display screen was set at the midpoint of the measured linear operating range (40 cd/m²). In view of the extensive nonlinearities in the behavior of the PEP with contrast described in Results, it was important to establish the linearity of the grating contrast modulation. Figure 1 shows the display characteristics to be highly linear over the full

*Supported by NIH Grants EY 2124, EY 3622, RR 5566, and The Smith-Kettlewell Eye Research Foundation.

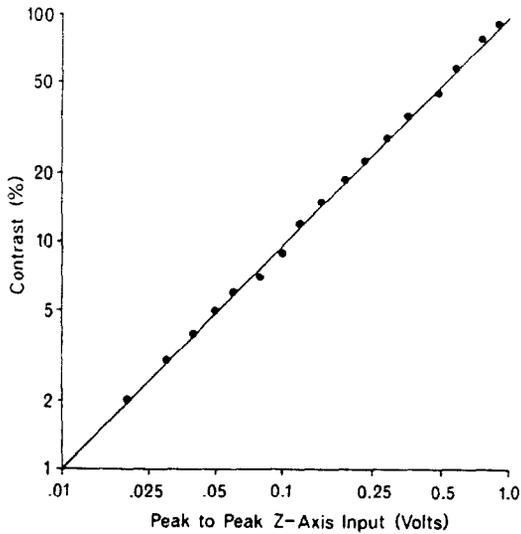


Fig. 1. Linearity of luminance as a function of input voltage for the stimulus display.

tested range (2–90% contrast), when measured according to the standard Michelson (1927) definition. Contrast could be adjusted in 0.1 log unit steps.

Dichoptic orientation was varied by viewing the stimulus to one eye through a rotatable Dove prism, while the other viewed it directly.

Recording and data analysis

Steady-state visually evoked potentials were recorded with a bipolar electrode placement based on the optimum position for pattern-evoked potentials determined by many previous authors (e.g. Cobb *et al.*, 1967; Jeffreys and Axford, 1972; Tyler *et al.*, 1978, 1980). The recording electrodes were placed 3 cm above the inion and 3 cm above and lateral; the ear served as ground. This electrode configuration may be more selective than a monopolar derivation for the narrowly-tuned responses which are the subject of this paper.

To improve the signal-to-noise ratio of the steady state evoked potential, the EEG was analyzed by means of the 0.3 Hz bandwidth, synchronous narrow-band filtering technique previously described (Tyler *et al.*, 1978). Amplitude and phase of the second harmonic response were derived from sine and cosine components for each stimulus condition.

*In view of the large number of conditions required to compare, for example, the detailed forms of monocular vs binocular contrast functions, we performed extensive studies on two observers rather than replications across many observers. Our previous work (Tyler *et al.*, 1978, 1980; Apkarian *et al.*, 1981) has indicated that most features concerning the steady-state VEP amplitude vary unpredictably both between observers and between electrode locations in a given observer, as well as with many stimulus attributes such as spatial and temporal frequency. The results are considered to have generality only in the occurrence of the features discussed, not in the specific conditions under which those features were obtained.

To distinguish between the stimulus frequency and the stimulus alternation rate (= analysis frequency), cycles per second (Hz) are used to denote the former while reversals per second (rps) are used to denote the latter.

One of the authors (CWT) and another practised observer (DL) served in the experiments*, fully corrected for refractive errors. They were required to fixate a 10' spot at the center of the display.

Each plotted point is based on at least three readings, or more if the data showed unusual variability.

In our own and much other previous work, it has been found that amplitude variability is proportional to signal amplitude when responses are substantial greater (more than 2×) the noise level. To avoid cluttering the already complex figures, variability is shown in terms of log standard error of the mean (σ_e) by the error bars on the spatial frequency tunings, but are omitted for the contrast functions where they were similar. Amplitude differences were regarded as significant when they exceeded $3 \times \sigma_e$ (or a signal-to-noise ratio difference of 40%) corresponding to $P = 0.001$.

Noise analysis

We felt it important always to distinguish carefully the neural activity evoked by the stimulus from the uncorrelated background activity at the stimulus frequency. The evoked potential amplitudes are therefore expressed in signal-to-noise ratios. The average level of the noise (uncorrelated background activity) was obtained by recording the response to a homogeneous stationary field at random intervals during each recording session. The ratio of the mean signal amplitude for each stimulus condition to this noise amplitude was then taken as the response measure. Thus, in the figures, the horizontal line at a ratio of 1 represents the average noise level.

RESULTS

Variation in contrast functions

To investigate the change in form of the contrast function with spatial frequency, we selected a region of interest from the spatio-temporal response map of observer CWT (Tyler *et al.*, 1978). At 16 rps (or 8 Hz, an often used temporal frequency for VEP studies), the spatial frequency tunings at 0.8 and 0.65 contrast for this observer and electrode placement [Fig. 2(F) and (G)] showed a sharp peak in response at 7.3 c/deg, with a subsidiary peak at 2.7 c/deg and a large low spatial frequency response. [Figure 2(G) is replotted from the earlier study.] Contrast functions were therefore obtained at each of these peaks and at the two intervening dips (1 and 4 c/deg) under similar conditions. Figure 2(A–E) show that underlying the multiple peaked spatial frequency tuning lie a wide variety of contrast functions, from the linearly in-

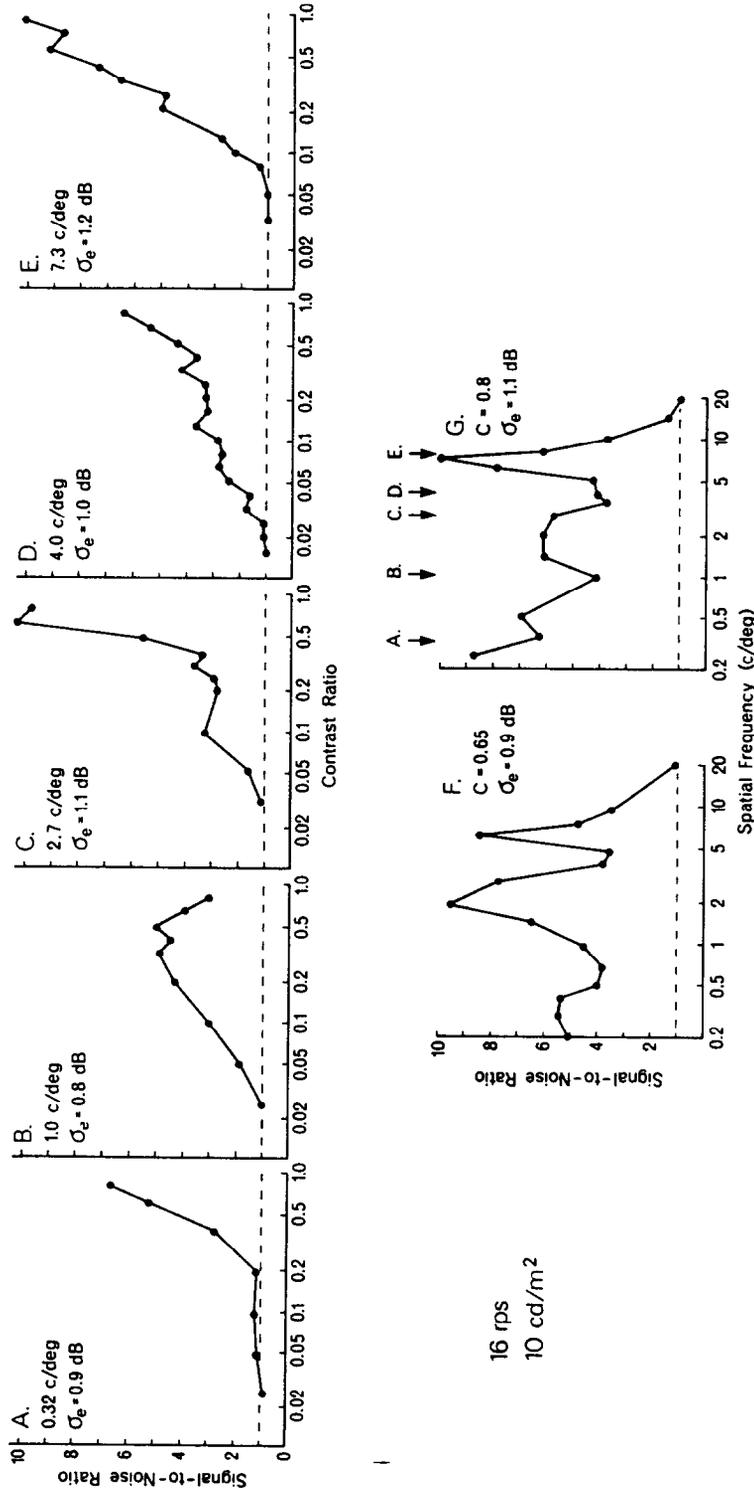


Fig. 2. Evoked potential amplitude at a stimulus reversal rate of 16 rps for observer CWT. (A-E) Contrast functions at the spatial frequencies indicated in (G). (F-G) Spatial frequency tunings at a fixed stimulus contrast of 0.65 and 0.8. Signal-to-noise ratio variability for these conditions is given in terms of the mean log standard error (σ_e) in each panel.

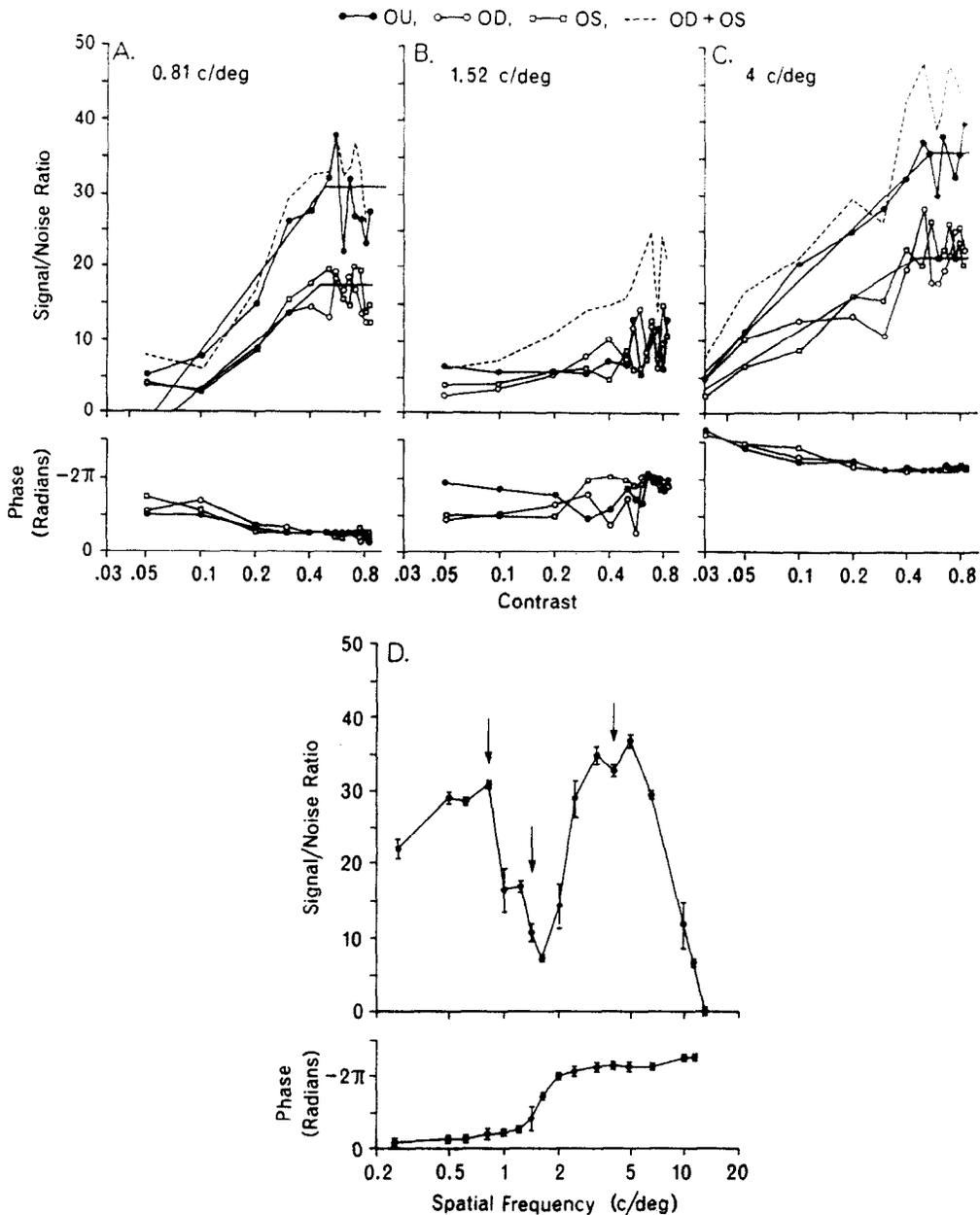


Fig. 3. Contrast functions (A-C) and spatial frequency tuning (D) with temporal phase lag (lower panels) at 16 rps for observer D.L. Solid circles—binocular response. Open symbols—monocular responses. Dashed line—sum of monocular responses. Full straight lines—threshold extrapolation lines. Standard deviations for individual points are shown for the spatial frequency tunings. Average σ_c for contrast functions was ± 1.3 dB.

creasing ones at 0.32 and 7.3 c/deg to those with several changes of slope at both low and high contrasts. The spatial frequency tuning will therefore depend radically on the contrast chosen for its measurement, as is illustrated by the difference between tunings at the 0.8 and 0.65 contrast levels [Figs 2(F) and (G)].

In order to clarify the analysis of such contrast functions, some terminology needs to be discussed at this point. The evoked potentials to pattern reversal will be called pattern evoked potentials (PEP). A segment of the PEP contrast function will be called

“log-linear” when it conforms to a straight line on the logarithmic contrast/linear amplitude coordinates commonly used for such functions. When the contrast function departs from such log-linearity to become approximately constant as contrast increases, it will be said to have “saturated”, following Spekreijse (1966). If it then decreases with a further increase in contrast as in Fig. 2(B), it will be described as “oversaturated” or “metatropic”, a term implying that the response has turned beyond the saturation point to a lower response level. Furthermore, as seen in Fig. 2(C), a second “increasing phase” often

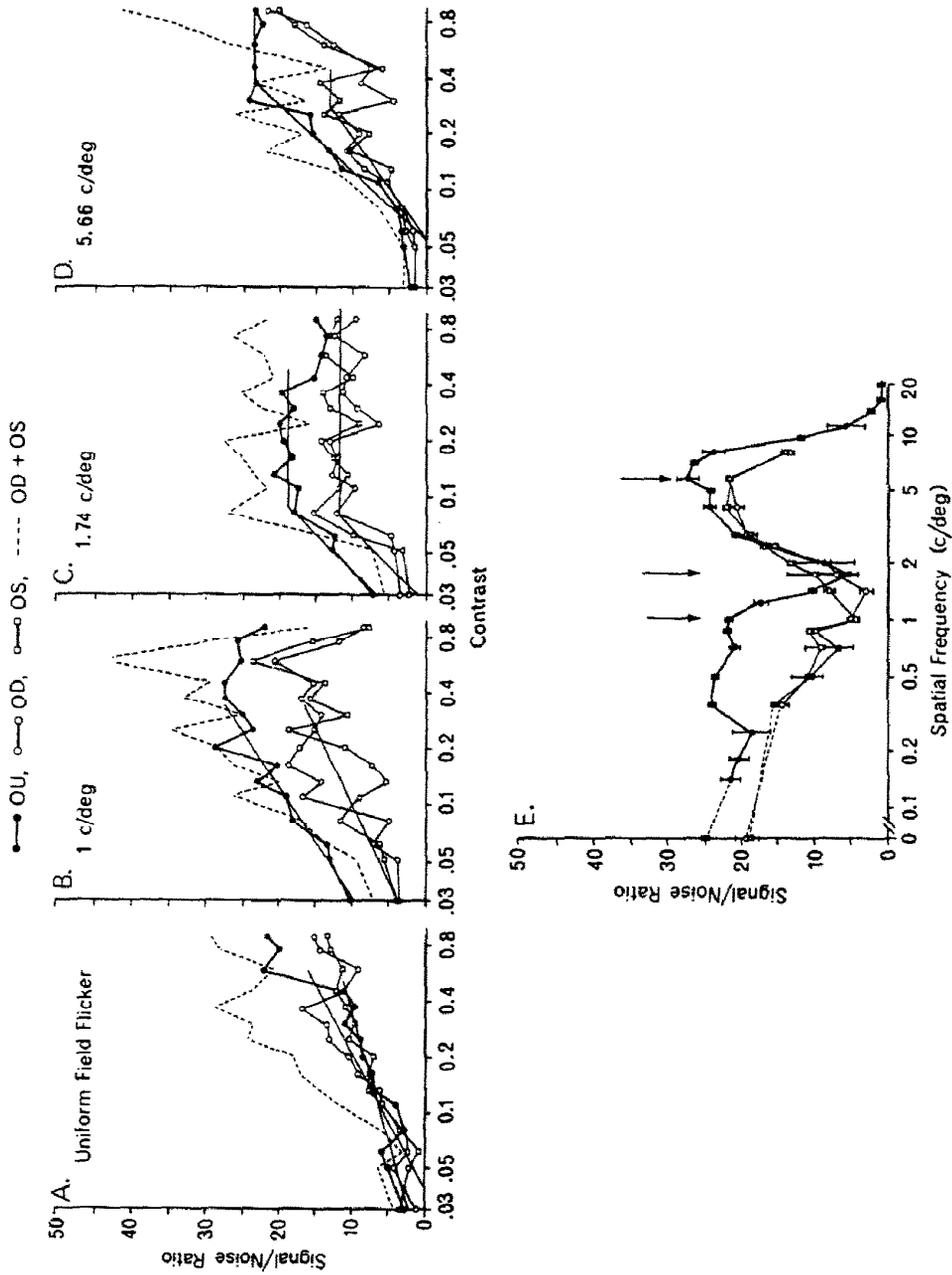


Fig. 4. Contrast functions (A-D) and spatial frequency tunings (E) at 24 rps. Solid circles—binocular response. Open symbols—monocular responses. Dashed line—sum of monocular responses. Full straight lines—threshold extrapolation lines. Standard deviations for individual points are shown for the spatial frequency tunings. Average σ for contrast functions was ± 1.3 dB.

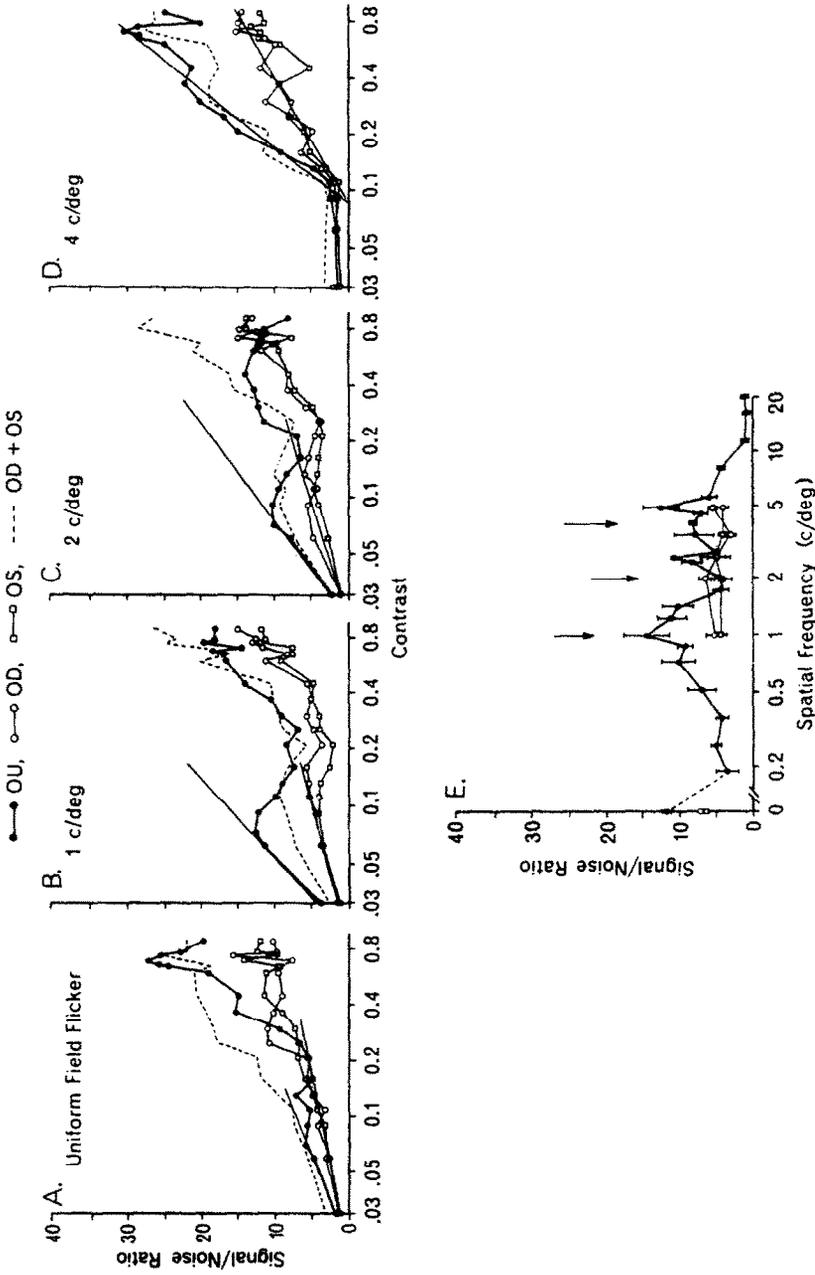


Fig. 5. Contrast functions (A-D) and spatial frequency tunings (E) at 32 rps. Filled circles—binocular response. Open symbols—monocular responses. Dashed line—sum of monocular responses. Full straight lines—threshold extrapolation lines. Standard deviations for individual points are shown for the spatial frequency tunings. Average σ_c for contrast functions was ± 1.5 dB.

followed by a metatropic drop in response can sometimes occur at high contrast. The sharpness of the reversal suggests a different type of mechanism from simple saturation, which is why a new term has been employed.

Binocular interactions

Binocular and monocular contrast functions at four different temporal frequencies for another observer (D.L.; Figs 3-6) show further examples of the more complex contrast functions which can be obtained. Below each series of contrast functions are spatial frequency tuning functions obtained at $C = 0.8$ for each temporal frequency. The occurrence of multiple spatial frequency peaks and the change in peak response as a function of temporal frequency have been described in more detail elsewhere (Tyler *et al.*, 1978). Binocular and corresponding monocular contrast functions for each temporal frequency were obtained at the spatial frequencies indicated by the arrows above each tuning curve. The spatial frequencies were selected, when possible, at the peaks and troughs of the spatial frequency tunings.

Binocular and monocular temporal phase of the

sinusoidal response has been included for three contrast functions (Fig. 3). The left and right eye phase plots are similar and the binocular phase is usually comparable with the monocular phase under the same stimulus conditions. Variation in temporal phase with contrast is most clearly shown with contrast functions obtained at the peak spatial frequencies [Fig. 3(A, C)]. Here, the phase lag decreases by about π radians (180°) as contrast increases. However, phase at the trough spatial frequency [Fig. 3(B)] is variable and difficult to determine because of the low responses in this region.

Figures 3-6 also show the binocular functions (B) to be expected if full summation (2 M) of the monocular responses (M) had occurred (dashed lines). In most cases, the binocular responses (solid symbols) fall somewhere between the mean monocular level ($B = M$) and full summation ($B = 2 M$). In one region, below 0.1 contrast in Fig. 5(B), the summation ratio (B/M) reaches about 3, corresponding to substantial facilitation of the binocular response in this particular case. At another point, 0.9 contrast in Fig. 5(C), the ratio drops to 0.5, probably as a result of nonlinear oversaturation of the binocular response.

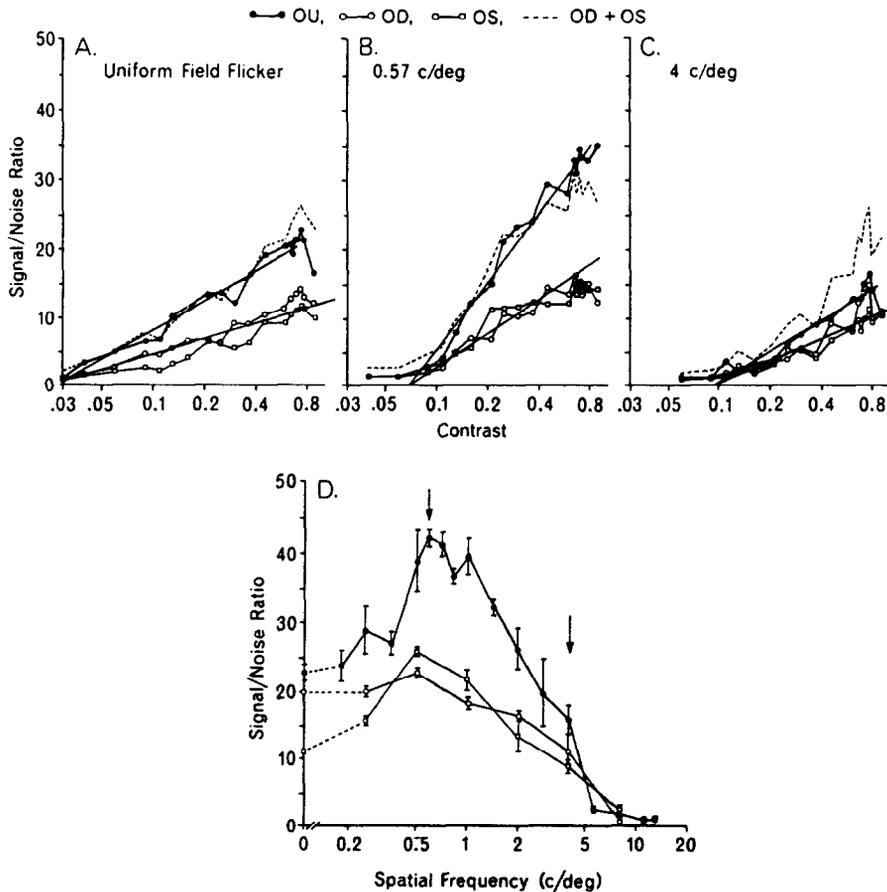


Fig. 6. Contrast functions (A-C) and spatial frequency tunings (D) at 48 rps. Solid circles—binocular response. Open symbols—monocular responses. Dashed line—sum of monocular responses. Full straight lines—threshold extrapolation lines. Standard deviations for individual points are shown for the spatial frequency tunings. Average σ_c for contrast functions was ± 0.9 dB.

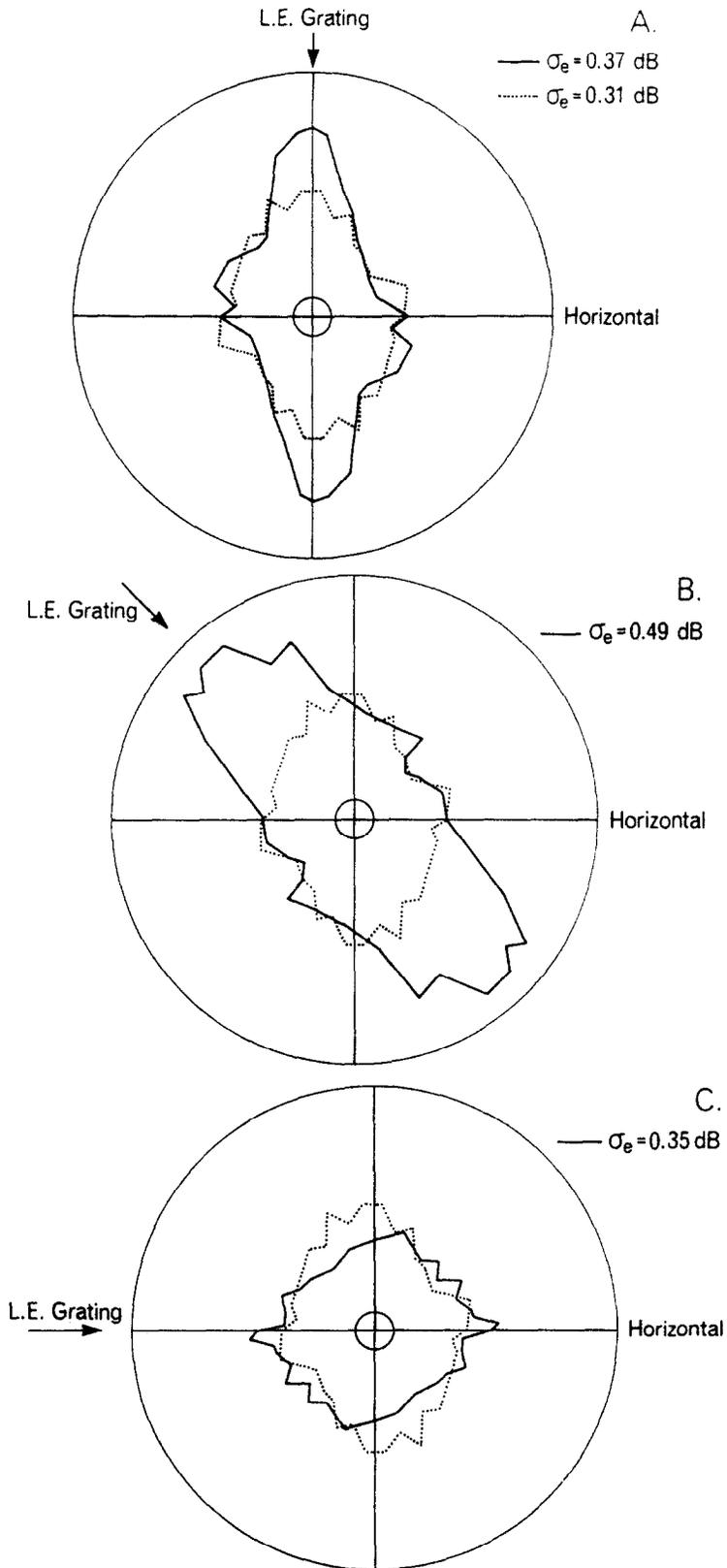


Fig. 7. Dichoptic orientation tunings at 28 rps for observer C.W.T. plotted with centric symmetry (i.e. responses at opposite orientations are identical). Dashed lines (A-C)—left eye response as a function of grating orientation. Full lines—dichoptic response as a function of orientation of the left eye stimulus while the right eye viewed a vertical (A), oblique (B) or horizontal (C) counterphase grating. Central circle represents a SNR of 1. Outer circle shows SNR of 13. Average variability of SNR is given in terms of log standard error in each panel.

Orientation

A further study was made of the effects of orientation on binocular interactions. Apkarian *et al.* (1981) have shown that a region of binocular facilitation with vertical gratings in each eye may exhibit merely summation when the gratings are rotated to horizontal, and lack of summation if the gratings are placed in rivalrous orientations. We therefore studied the effect of relative binocular orientation for one of the same observers in more detail.

First the monocular orientation tuning was measured at 4 c/deg and 28 rps with one eye viewing the stimulus through a rotatable Dove prism and the other eye occluded. The dotted lines in Fig. 7(A-C) show the response of the left eye as a function of orientation on a polar plot with reflected symmetry. Although there is some variation of response amplitude as the grating was rotated, the range is only a factor of two. It is roughly consonant with the pattern to be expected from the oblique effect (Mitchell *et al.*, 1967). Next the response was measured while the right eye viewed the same alternating stimulus in a vertical orientation, to determine the orientation tuning of the binocular interaction. The dichoptic response [full lines, Fig. 7(A)] lies close to the monocular response for orientations up to 75° away from the horizontal (when the gratings were seen in binocular rivalry), but then shows a narrow (30°) region of greater response around the vertical orientation. This corresponds to a similar range in which the grating was perceived as tilted in depth. Thus the increased dichoptic response appears to be specific to the stimulus orientation, as well as its contrast and spatiotemporal frequency.

The same experiment was repeated with the right eye stimulus at an orientation of -45° (left oblique) and then horizontal. In the left oblique case [Fig. 7(B)], tilting in depth was visible when the rotating grating was within about 20° of the fixed orientation. The PEP shows full binocular summation in a similar range.

Finally, when the fixed grating was in a horizontal orientation, the dichoptic response hovers at the level of the monocular response [Fig. 7(C)], with a tendency to increase somewhat when the dichoptic gratings coincide at the horizontal orientation. This is consistent with the fact that no stereoscopic tilt was seen in this condition, and that binocular rivalry occurred except when the gratings were close to the point of coincidence.

We conclude from this study that in this observer the mechanism of binocular summation has an orientation tuning similar to that seen in studies of orientation adaptation (Campbell and Maffei, 1970). The strongest degree of dichoptic summation occurred when stereoscopic depth tilt was seen, supporting our previous conclusion (Apkarian *et al.*, 1981) that the increased response is produced by disparity selective neurons.

DISCUSSION

This study of the specificity of steady-state VEP amplitudes used a wide range of stimulus variables for single electrode locations in two observers. The major aim was to provide a description of the types of contrast function that can be obtained in such conditions, and it is this typology, rather than the specific stimulus conditions involved, that is considered to have any generality to other recording conditions [1]. In addition, we investigated the summation effects of ocularity on the contrast and orientation tuning of the responses. We also compared the extrapolated VEP contrast thresholds with those obtained psychophysically to extend the results of previous workers to high temporal frequencies.

The data of Figs 2-6 generally exhibit partial and complete summation, rather than facilitation, but they emphasize the complicated nature of the VEP contrast response and binocular interactions. Seven points of interest in our data may be noted.

1. The early VEP saturation at relatively low contrasts and for comparable luminance levels reported by Spekreijse *et al.* (1973) are not always apparent in the data of Figs 2-6. Instead, some of the contrast functions presented here, particularly at high temporal frequencies, increase monotonically to high contrast before showing sudden oversaturation. This dramatic response reduction appears at contrasts from 0.50 to 0.75 and can result in a response decrease of as much as 50% without change in the temporal phase. Such metatropic attenuation can occur in both the binocular and corresponding monocular contrast functions [e.g. Figs 3(A), 6(A)], in the binocular function alone [e.g. Fig. 5(A, C, D)], or primarily in the monocular function [e.g. Fig. 4(B)]. The sharpness of the metatropic attenuation means that a change of 25% (or 0.1 log units) in the contrast can affect the response amplitude by a factor of 2 [e.g. open circles, Fig. 4(B)]. Thus one needs to be extraordinarily careful with calibration of contrast to obtain replicable results.

2. The slope of the log-linear regression lines (fitted by eye to the contrast data when possible) can markedly increase when two eyes rather than one are stimulated [e.g. Figs 3(A, C); 4(D); 5(A-D), 6(A-C)]. The doubling of slope with binocular viewing conditions is consistent with the view that the responses of the two eyes are independent and are summing together in binocular conditions, although more complex interpretations are possible. Some conditions can be found in which the binocular and monocular slopes are not significantly different [Fig. 4(B, C)]. Nevertheless, it is important to note that the log contrast intercepts of the monocular and binocular zero voltage extrapolations are frequently similar. Thus, it is clear in a wide variety of cases that the $\sqrt{2}$ difference between binocular and monocular thresholds described by Campbell and Maffei (1970) is probably the exception rather than the rule.

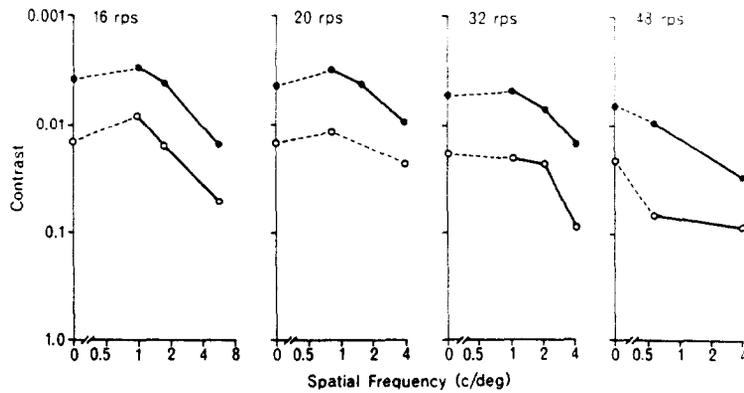


Fig. 8. Binocular contrast threshold as a function of spatial frequency at 4 temporal frequencies. Solid symbols—psychophysical thresholds. Open symbols—evoked potential threshold extrapolations, as shown in Figs 2–6.

3. Campbell and Maffei further suggest that for their data, extrapolating the log-linear regression to zero gives a contrast value which is a good match to psychophysical threshold, although van der Tweel (1964) has reported some failures of this relationship. Extrapolation lines are fitted to the low contrast portions of the data by inspection (since any statistical procedure requires unwieldy assumptions). For our recording conditions, zero voltage extrapolation of the evoked potential amplitude underestimates psychophysical threshold, although the data do not go below 3% contrast. Psychophysical threshold values were obtained by the method of adjustment and under the same counterphase flickering spatial and temporal frequency conditions as those employed to obtain extrapolated PEP contrast thresholds. The flicker was visible psychophysically about half a log unit below the contrast of the extrapolated VEP threshold under all conditions we tested (Fig. 8). A similar discrepancy is reported across all spatial frequencies by Cannon (1983) with counterphase gratings at 13, 20 and 40 rps.

4. Contrast functions sometimes have more than one rising phase. For example, in Figs 2(C), 4(A, D) and 5(B, C), the PEP amplitude peaks at a low contrast modulation depth, appears to saturate or even become metatropic, and then peaks again at a higher modulation depth. Results similar to these have been reported by Regan and Beverley (1973) for a homogeneous field. According to Campbell and Maffei, two regression lines best fit contrast data obtained with large stimulus fields ($50^\circ \times 40^\circ$) and with low spatial frequencies (< 3 c/deg). Although we present examples of complex contrast functions, we have also recorded several monotonic functions [e.g. Figs 2(E), 3(C), 4(D), 5(D), 6(C), solid circles]. That these functions can be fitted with a single log-linear regression line prior to saturation is, however, contrary to the results of Campbell and Maffei, as they can be obtained under large field ($20^\circ \times 15^\circ$) and low spatial frequency conditions [Figs 2(A), 3(A), 4(B), 6(A, B)].

The second rising phase at high contrasts can be

very steep [Figs 2(C), 4(A), 5(A)], with the response doubling from a 0.1 log unit increase in contrast or less. Since the response is highly specific to both spatial and temporal frequency, a small change in contrast may have dramatic effects on spatiotemporal response profiles.

5. The nature of the substantial notches at intermediate spatial frequencies is addressed by the contrast functions in Figs 2, 3, 4 and 5. In each case, the mid-frequency response was as strong at medium contrasts as that for the peak spatial frequencies on either side, but rapidly saturated so as to produce a notch at high contrasts. This seems to explain why such notches are not apparent in threshold extrapolation studies. They seem to be relatively high contrast phenomena. Note that even the spatial frequency of the notch can shift with a change in ocularity [Fig. 4(E)], in this case apparently as a result of the metatropic 1 c/deg monocular response above a contrast of 0.6.

6. Contrast functions for homogeneous fields in Figs 4–6(A) are substantially different from those at 1 or 0.57 c/deg, both in slope and binocular summation properties. For the homogeneous field at 20 rps [Fig. 4(A)] there was zero binocular summation up to 0.5 contrast, while by 1 c/deg full summation is approximated. Similar differences are evident at 32 rps, while the reverse is the case at 48 rps. Such radical changes in ocularity support the contention (Tyler *et al.*, 1978) that pattern reversal responses for gratings as low as 0.5 c/deg and homogeneous field responses are produced by separate mechanisms.

7. There is previous evidence that more than one mechanism may contribute to the pattern specificity of the PEP beyond the region apparently governed by the homogeneous field mechanism. Kulikowski (1977), Bain and Kulikowski (1976) and Parker and Salzen (1977) have implicated two mechanisms contributing to the form of the contrast and spatial frequency functions. Tyler *et al.* (1978) invoke a larger number to account for the multiple spatiotemporal tuning peaks in the PEP. Apkarian *et al.*

(1981) show that a further differentiation is required between monocular- and binocular-specific mechanisms.

The present data support the concept of multiple pattern-specific mechanisms. Figures 2(F) and (G) show two spatial frequency peaks (at 2.7 and 7.3 c/deg) in addition to an increase in amplitude below about 0.7 c/deg. The contrast function at 2.7 c/deg has two distinct slopes [Fig. 2(C)], suggesting a further sub-division, while that at 7.3 c/deg is unitary [Fig. 2(E)]. The implication that the peaks correspond to separate mechanisms is supported by the fact that the small change in contrast from 0.65 to 0.8 (within the region of the high contrast limb of the contrast functions) increases the high frequency response but reduces the 2.7 c/deg response.

The operation of separate monocular and binocular mechanisms within each spatial frequency peak is indicated by the differing response to closure of one eye. In Fig. 4(E) the lower frequency peak is much more attenuated (at 0.8 contrast) than either the high frequency peak or the uniform field response. The contrast functions of Fig. 4(A–D) show that the reverse is the case at a contrast of 0.6, and the picture is again reversed for contrasts below 0.3. Similar contrast/spatial frequency specificity (but different in detail) in the effects of ocularity is evident at other temporal frequencies, particularly 32 rps (Fig. 5). The orientation tuning difference provide another example of differences between monocular and binocular responses. As in Apkarian *et al.* (1981), the binocular response is interpreted as a combination of monocular and purely binocular (stereoscopic) responses.

If it may be assumed that each single mechanism maintains a fixed equivalent dipole position in the brain, as its response amplitude varies with contrast and spatial frequency, a minimum number of mechanisms are required to account for the data at each temporal frequency in the absence of complex, non-linear interactions. In addition to a uniform field mechanism, at least two spatial frequency regions each give rise to at least two contrast limbs with different monocular and binocular characteristics. This implies at least eight pattern-specific mechanisms responding selectively with spatial frequency contrast and ocularity. (Furthermore, they must either change their characteristics across temporal frequency or have additional counterparts at more than one temporal frequency.) What is known from neurophysiology is easily complex enough for such a multiplicity of simple mechanisms to be plausible. This view of multiple independent mechanisms has the virtue of parsimony relative to a model based on unknown nonlinear interactions between fewer, more complex mechanisms.

CONCLUSION

We conclude that the steady state VEP to counter-phase grating stimuli shows a complex response

pattern both monocularly and binocularly. The data (particularly Figs 5 and 6) show that the contrast functions above 0.5 c/deg differ markedly from those for uniform-field flicker, and also from each other. As has been previously demonstrated, there are some conditions under which the VEP response to pattern stimulation can be attributed to local luminance mechanisms (Spekreijse *et al.*, 1973; Regan, 1978). A local luminance mechanism is taken to correspond to a cortical neuron with a retinal receptive field that has a limited size, but no other spatial structure such as an inhibitory surround. In earlier papers (Tyler *et al.*, 1978, 1980), the evidence suggested that local luminance mechanisms make little contribution to the pattern response above about 0.5–1 c/deg. The structure in responses above this spatial frequency range is attributable to the presence of pattern-specific mechanisms.

The specificity of the contrast and orientation functions suggests that the VEP taps several kinds of pattern-specific mechanism. Each mechanism may have a different response characteristic, not only in spatial and temporal frequency, but also in ocularity, orientation tuning, and amplitude as a function of contrast. In many cases, the contrast functions may be described as having two separate ascending limbs, sometimes with a decreased response between them. Neurophysiologically, it has been shown that there are two populations of neurons with substantially different contrast thresholds. Neurons in the magnocellular layer of the LGN, which project to layer IV α of the cortex, have low contrast thresholds, while parvocellular LGN cells projecting to cortical layer IV β have higher thresholds (Kaplan and Shapley, 1982). If these characteristic differences are maintained at the higher processing levels, contrast functions recorded from the overall neural population (as in the VEP) might therefore be expected to show a double-limbed form, as has been reported for the monkey VEP (Nakayama, 1982). The present findings open the possibility of characterizing the responses from two narrowly-defined cortical laminae from the human evoked response.

Note added in proof—Underestimation of psychophysical thresholds by estimation of the zero point of the VEP, similar to that of Fig. 8, was recently reported by Seiple *et al.* (1984, *Invest. Ophthalmol. Vis. Sci.*, 25, pp. 627–631), who used real time sweeps of increasing contrast. Inspection of both their curves and the threshold region of the well defined data on Figs 2–6 suggests that a log-linear relation may not strictly hold near threshold, and that perhaps the extrapolation should be performed after some other transform of the near threshold data. Other factors, such as inability to ensure that the neurons mediating psychophysical threshold are contributing to the PEP, may also contribute to the underestimation of threshold.

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