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Steady-state pattern VEP uncorrelated with suprathreshold contrast perception

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Summary. Campell and Maffei (1970) reported a linear relationship between the logarithm of the grating pattern contrast and the amplitude of the visual evoked response (VEP). This enabled them to predict the pattern visibility by extrapolating to zero amplitude. By using a new digital fast sweep technique for acquiring and analysing steady state evoked potentials we show that, at clearly suprathreshold contrast levels, such a linear relationship only exists for certain spatial frequencies. In general, the VEP saturates with increasing contrast in a way that critically depends on stimulus spatial frequency. Such a dependency on spatial frequency is not obtained for suprathreshold contrast perception which is characterized by a remarkable contrast constancy. Thus the amplitude of the pattern VEP does not convey information about visual perception other than contrast detection thresholds.

Key words: Spatial vision – Pattern VEP – Contrast perception – Contrast sensitivity function – Spatial frequency

The correlation between electrical brain activity and perception may be investigated by relating cortical evoked responses to psychophysical detection thresholds. This was first demonstrated for the auditory system by Keidel (1965). In his technique of "objective audiology" the acoustical evoked potential (AEP) is recorded for a given sound frequency with the sound intensity being varied. Consistent with Stevens' power law (Kling and Riggs 1971), a linear relationship between the logarithm of the stimulus intensity and the logarithm of the AEP-amplitude is obtained. The repetition of this procedure for a wide variety of sound frequencies allows the construction of a 3D-amplitude surface above the sound frequency and intensity plane. The intersection of the AEP-surface with the latter plane is then determined by extrapolating the log amplitude vs. log intensity line to zero-amplitude. The resulting curve in the (horizontal) plane of stimulus determinants is the "objective audiogram" that fits the subjective, that is, the psychophysically measured, audiogram quite well.

Campbell and Maffei (1970) have used a similar approach for analysing mechanisms of spatial vision in man. These workers measured cortical evoked responses to sinusoidal gratings the spatial phase of which was altered by 180 deg at a rate of 8 Hz. The stimulus parameters being varied were contrast (i.e., maximum minus minimum pattern luminance, divided by the sum of the two values) and spatial frequency (i.e., the inverse of the spatial period length of the gratings, in cycles per degree (cpd)). Campbell and Maffei found a linear relationship between the logarithm of the grating contrast and the (linear) amplitude of the visual evoked potential (VEP). In much the same way as in the case of "objective audiology", this enabled them to predict the psychophysical detection thresholds for grating contrast. As reported by Campbell and Maffei, the slope of the regression lines in their VEP amplitude vs. log contrast plots was almost independent of the grating stimuli's spatial frequency.

The now classical findings by Campbell and Maffei have been confirmed by numerous other studies (Cannon 1983). Equally important is that a close correspondence could also be established for VEP amplitudes and behavioral grating contrast sensitivities in the cat (Campbell et al. 1973; Bisti and Maffei 1974). Moreover, it has been shown that behavioural estimates of contrast sensitivities and results from single unit recordings (Maffei and Fiorentini 1973) are consistent in the cat. This progress in investigating the mechanisms of visual contrast analysis suggested that the registration of pattern-evoked VEP is a powerful tool not only for the clinical assessment of alterations of visual perception (e.g. Arden 1973, Bodis-Wollner et al. 1977) but also for monitoring early visual development (Dobson and Teller 1978).

Given these potentials it is surprising that the paradigm of Campbell and Maffei (1970) has not achieved wide acceptance for diagnostic purposes. One reason for this is that the determination of VEP amplitude thresholds is not easily performed with standard VEP recording equipment. Another problem is that the procedure is very time consuming if used in conjunction with conventional methods of EEG acquisition. As a result of this the variability of the VEP data is considerable. To overcome these difficulties researches have usually avoided having to estimate subjective contrast sensitivities by means of the original regression procedure. They rather simply took VEP amplitude data obtained a suprathreshold contrast level as a measure of the visibility of gratings. This seemed justified as, in many cases, unimodal amplitude responses were reported that looked very much the same as contrast sensitivity functions (e.g. Armington et al. 1971; Regan and Richards 1973; Levi and Harwerth 1978; Fiorentini et al. 1980; Rentschler and Spinelli 1978). Indeed, according to Regan (1977, p. 1481), it was "well established" that the pattern evoked response is maximal at an intermediate stimulus size of 3–4 cpd. At odds with this notion, however, was the fact that other authors obtained bimodal amplitude response functions at suprathreshold contrast levels from healthy subjects with unimodal subjective contrast sensitivity functions (Harter et al. 1977; Tyler et al. 1978, 1979, 1984; Apkarian et al. 1981).

In order to investigate these inconsistencies we developed a digital sweep technique for recording and analysing VEP data. This method is comparable to the analog sweep technique used by Tyler et al. (1978) and is described in detail elsewhere (Strasburger and Rentschler 1986). Its main advantage is a considerable reduction of the time needed for data acquisition. Consequently, a complete set of data from a given subject can be obtained during a single experimental session and this improves the reliability of the results considerably. Here we report on a preliminary experiment where sine-wave gratings being sinusoidally modulated in time at a rate of 8 Hz (16 reversals per second) were used for stimulation. The time-averaged EEG signal was submitted to a Fourier analysis with the 16 Hz component being used as an indicator of the evoked response.

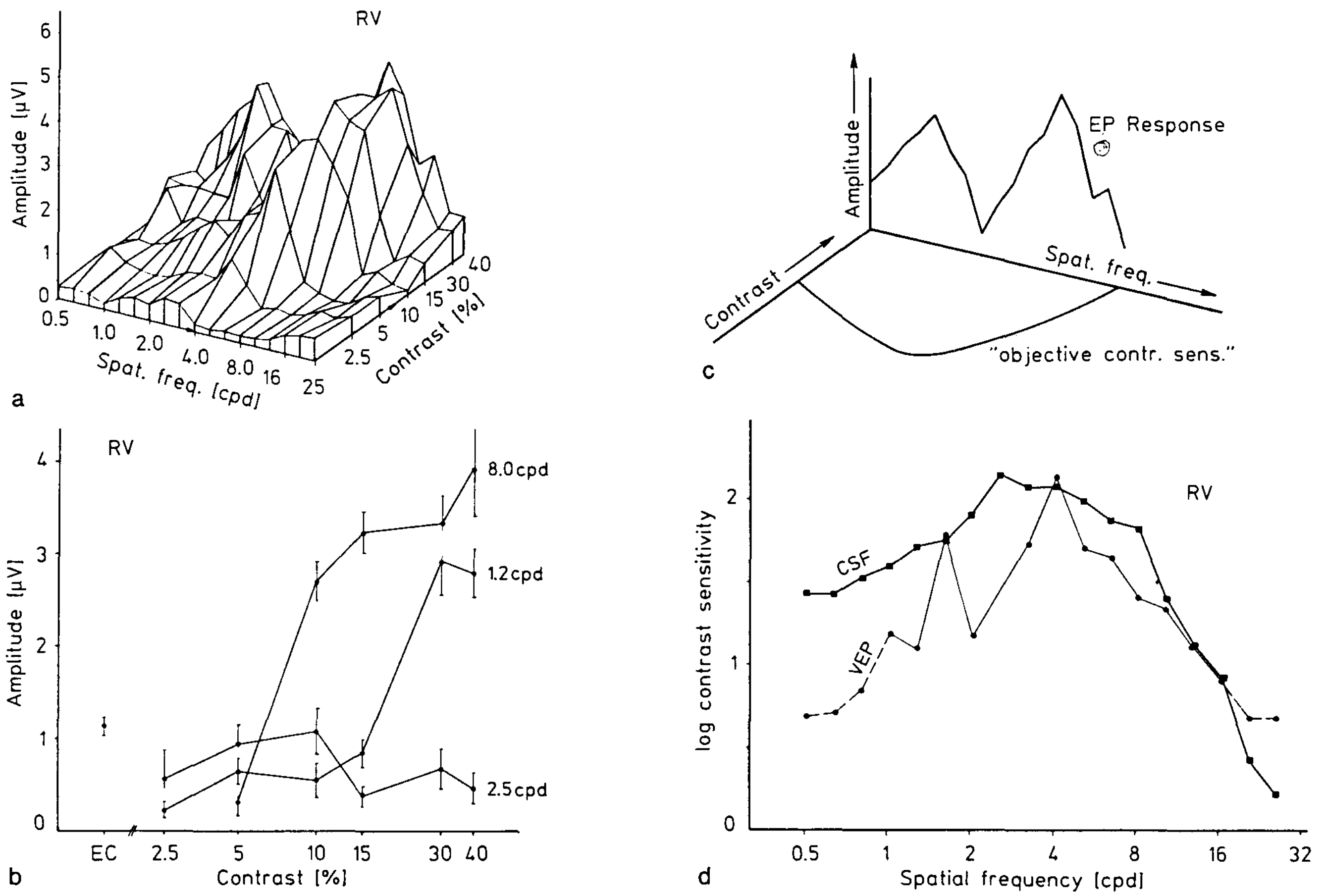

Fig. 1 a–d. Steady-state visual evoked potentials and grating contrast sensitivity. The VEP was elicited by presenting phase-alternating sine-wave gratings to the emmetropic subject R.V. (female, 28 years, 1.2 Landolt-C acuity each eye). The S viewed the stimuli binocularly at a viewing angle of 5 deg; the viewing distance was 1.28 m. The space-average luminance was 8 cd/m^2, the temporal modulation rate 8 Hz. Data points represent 12 s, net recording time. **a** VEP amplitude data as a function of grating spatial frequency and contrast. **b** Cross-sections through the 3D-amplitude surface for the spatial frequency values specified. EC denotes a data point obtained in an eyes closed situation thus providing a gross estimate of the noise-level. The actual VEP amplitude, however, attains lower values thus indicating that EEG noise during actual recording is lower than in the former condition. **c** Schematic illustration of how an objective estimate of the contrast sensitivity is obtained by fitting regression lines to the log-linear part of the curves shown in (**b**); the intersection of these lines with the horizontal plane yields the "objective contrast sensitivity". Note that the latter curve is in a plane orthogonal to the VEP-amplitude vs. spatial frequency plots. The actual result of this procedure is shown in **d** (VEP) together with the contrast-sensitivity to stationary gratings (CSF) obtained by the psychophysical method of adjustment

Figure 1 shows results obtained with the binocularly observing emmetropic subject R.V. The 3-D graph in Figure 1 a plots VEP amplitude as a function of the grating spatial frequency and contrast. These data were obtained by varying the spatial frequency with the contrast kept constant at one of the specified levels. The most significant feature of this plot is the existence of a sharp notch in VEP response midrange of spatial frequencies (around 3 cpd) in which the subjective grating visibility is maximal (see Fig. 1 d). Figure 1 b shows sections across the 3D-plot at the specified spatial frequencies. In contrast to what has been reported by Campbell and Maffei (1970) these VEP-amplitude/contrast interrelations are neither generally linear nor independent of spatial frequency. They are approximately linear over a wide contrast range for some spatial frequency values but for other frequencies they show saturation at low levels or even "over-saturation" with a non-monotonic dependency on log contrast. The presence of a notch in the 3D-surface of VEP amplitudes around 3 cpd corresponds to the onset of saturation at very low contrast levels (about 5%).

This, however, does not imply that Campbell and Maffei's (1970) claim of a direct correspondence between the extrapolated VEP response and psychophysical grating detection thresholds is not correct. Indeed, for any given grating spatial frequency we determined the regression lines for the linear range of the VEP amplitude vs. contrast plot (Fig. 1 b). As is schematically shown in Figure 1 c, a unimodal curve can be fitted to the intersection points of these lines with the (horizontal) frequency/contrast plane. This latter curve of "objective contrast sensitivity" approximates the (subjective) contrast sensitivity function (CSF) of the same subject reasonably well (Fig. 1 d). It is also important to note that the planes of the VEP response curves obtained at fixed levels of contrast as functions of spatial frequency and the contrast sensitivity curve are perpendicular (see Fig. 1 c). Thus, independent of whether the suprathreshold VEP response curves are unimodal or bimodal, they are not related to any variable of contrast perception.

In conclusion we may note that steady state evoked responses to temporally modulated gratings do not provide information about suprathreshold contrast perception, although reliable data on grating detection thresholds are obtained. One aspect of this lack of correlation is that in the range of suprathreshold contrast levels the VEP amplitude response may well show a bimodal dependency on spatial frequency, whereas such variability does not exist for the perceived contrast of gratings (see Georgeson and Sullivan 1975). The differences between suprathreshold VEP amplitude functions and subjective contrast sensitivities can be attributed to non-linearities in the VEP response occurring with increasing contrast. This discrepancy between objective and subjective data, however, does not necessarily mean that the analysis of the electrophysiological response cannot provide information of diagnostic value. A careful analysis of both the amplitude and the phase-lag of steady-state evoked potentials is needed to decide about such a possibility.

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