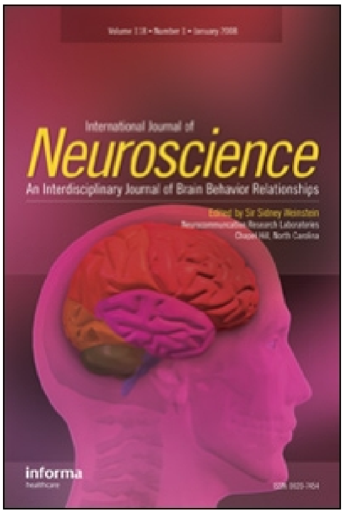


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# High-Frequency Components Of Human Visual Evoked Potentials

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# HIGH-FREQUENCY COMPONENTS OF HUMAN VISUAL EVOKED POTENTIALS

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This study was aimed to further our investigations on the high frequency components of human visual evoked potentials (VEP). By using stimulations in the form of optic step functions, we measured ($C_z$-ear lobe) VEPs with 512 real data points in a total recording time of 20.48 msec in normal adults ($N = 12$). The peaks in the transient evoked potentials occurred with approximate latencies of 0.5, 1.0, 1.5, 2.5 and 5.0 msec. Transforming the individual time responses to the frequency domain by the Fourier Transform, maxima were obtained in 200, 400, 700, 1200 and 2200 Hz positions in the amplitude frequency characteristics. The findings were compared with those of a similar study on the auditory system. It is stated that the response activities of 200 Hz and 2200 Hz are unique to the visual system.

In the last decade, there has been a growing interest in the issue of the high frequency or short latency components which exist in the evoked potentials (EP) of various sensory systems. A number of experimentally and clinically oriented studies have shown the existence of a series of short latency responses (< 10 msec) in the scalp-recorded human auditory evoked potentials (Jewett *et al.*, 1970; Jewett & Williston, 1971; Lev & Sohmer, 1972; Hecox & Galambos, 1974; Picton *et al.*, 1974). In the human somatosensory evoked potentials, the earliest peak was shown to be a small positive deflection occurring with a latency of 13–17 msec, this being recorded from the scalp (Goff *et al.*, 1962; Larson *et al.*, 1966; Cracco & Bickford, 1968; Goff *et al.*, 1969; Cracco, 1972a; Cracco, 1972b; Tamura, 1972; Halliday, 1975). Later studies indicated that, with appropriate amplificaton and electrode locations, there exist two other scalp recorded peaks preceding the abovementioned and occurring within the first 15 msec following the onset of stimulation (Cracco, 1974; Cracco & Cracco, 1976 and 1978). Short latency responses were also recorded in the visual evoked potentials (VEPs) of animals with chronically implanted electrodes. Application of electrical stimuli to the optic tract of cats was shown to evoke 4 positive potentials in the visual cortex, each potential being about 1 msec long (1000 Hz) followed by longer positive and negative potentials (Bishop & Clare, 1951; 1952; 1953; Malis & Kruger, 1956). Using bright light flashes, a series of short latency potentials were obtained from various centers and pathways of the visual systems of cats and primates. The frequency of the potentials were in the range of 100–180 Hz (Doty & Kimura, 1963; Doty *et al.*, 1964; Hughes, 1964; Steinberg, 1966). Using a frequency characteristics method, Başar and coworkers (1976a) depicted a flash evoked 900–1300 Hz component in the cat superior colliculus; and the existence of 1–1000 Hz activity in various other centers of the cat visual system (Başar *et al.*, 1977; Başar, 1980).

Reprint requests should be sent to Dr. Başar in Lübeck.

In our preliminary investigation on the high frequency components of the human visual evoked potential we used bright light flashes (light impulse functions generated from Grass Photic Stimulator) and determined the amplitude frequency characteristics from the transient data by means of Fourier Transform (Karakaş *et al.*, 1980; Başar, 1980). In the present study we used intense light step functions with a duration of 50 msec, this value being longer than the total record time, as optical stimulation, in order to avoid superimposed "on" and "off" effects which could result during the use of light flashes of very short duration. In this way we aimed to obtain more stabilized and less complex visual evoked potentials with a smaller number of high frequency components. We also intended to perform a comparative analysis of high frequency evoked potentials in visual and auditory systems in order to indicate high frequency components which should be purely originating due to optical stimulation.

## MATERIALS AND METHODS

Twelve normal volunteer adults (7 males, 5 females) were used in the study. Of these, 5 were paid volunteers and 7 were academic personnel.

A schematical block diagram of the experimental setup is presented in Figure 1. Recordings were performed with subjects lying in a supine position on a bed in an electrically isolated soundproof chamber. The optic stimulator consisted of a 40 W-commercial fluorescent lamp providing 2100 lm and driven by a general purpose DC power supply through a properly designed switching circuit, the DC source being gated by the pulses obtained from a pulse generator (Grass S48 Stimulator). Owing to this design, the light stimulation was free from any acoustical "click" artifact which is inevitable when a flash is used. The stimulating source was placed at 2 m distance at level with the subjects' eyes and centrally placed so as to expose both eyes equally to the light.

The rise time of the light step function was 10 $\mu$sec; such a rise time is short enough for analyzing response frequencies up to 10 kc/sec. The stimuli of 50 msec duration were delivered with random intervals of at least 1 sec. The subject were instructed to relax completely, to remain in a waking condition and to look directly and continuously

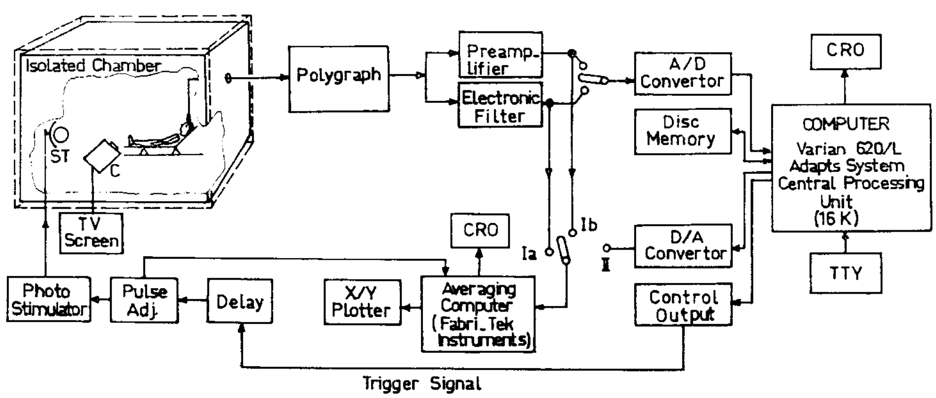


FIGURE 1 Experimental setup used for the recording of the spontaneous brain activity and VEPs and storage of data. The evaluation of averaged evoked potentials and the application of the computational methods were also carried out by means of this setup. (Modified from Başar *et al.*, 1975a).

at the stimulus source in the otherwise dark chamber. Recordings were performed with Schwarzer Type Surface Electrodes. They were placed at the midline $C_z$ location of the 10–20 system, referenced to the left ear lobe. Impedance was recorded through an electrode placed on the right ear lobe, and was maintained approximately around 5 KΩ.

Brain electrical activity was preamplified (maximum amplification $\times 10^3$, maximum output voltage 3 volts) and recorded by an EEG recorder (Schwarzer Encephysioscript E 1230). Throughout the experiments, the brain state was monitored through the polygraphic recordings and gross behavioral condition through a closed-circuit television system. In case muscle artifacts or deviations from the waking state were observed, recording was terminated. On-line filtering (low and high cut-off-frequencies of 80 Hz and 10 KC, respectively) and further preamplification were introduced to individual VEPs in order to further improve the resolution (Tektronix Type 122 preamplifier). There were 512 real data points sampled by an averaging computer (Fabritek FT-1072) with a sampling interval of 40 $\mu$sec in a total record time of 20.48 msec. The same computer was used for quasiconventional averaging of 256 VEPs ($3\times 256$ from each subject) and in the computation of the overall mean value curve.

Using a Varian 620/L computer, the amplitude frequency characteristics, $G\ (j\omega)$, were calculated from the averaged evoked potentials, c(t), through the application of the Transient Response-Frequency Characteristics Method (TRFC-Method) (for details of the method see Başar, 1976; Başar *et al.*, 1975a). The Fourier Transform that was used in the method was of the following form:

$$G(j\omega) = \int_0^\infty \frac{d\{c(t)\}}{dt} \exp(-j\omega t)dt$$

where:

$$\omega = 2\,\Pi f$$

f = frequency of the input signal

Through this application, a frequency resolution of 10 Hz and a Nyquist rate of 6250 Hz was attained. The calculations were performed for the total number of real data points (512) and on the first 320 points. The VEPs and amplitude frequency characteristics were written out by an $X$–$Y$ plotter (HP-7005B $X/Y$).

## RESULTS

### *Transient Evoked Potentials*

Figure 2 shows a typical AEP recorded from vertex-ear lobe arrangement in response to a step. Three periodicities underlie the general course of the typical curve and the major peaks. These occur with 1.5, 2.5 and 5.0 msec latencies. The fluctuations on the main peaks are given by the relatively low magnitude periodicities, occurring with 0.5 and 1.0 msec latencies.

Figure 3 represents the mean value of VEPs from 12 subjects. The general course of the curve is still given by the oscillation occurring with 5 msec latency. On the other hand, the averaging process has attenuated the influence of the periodicity which

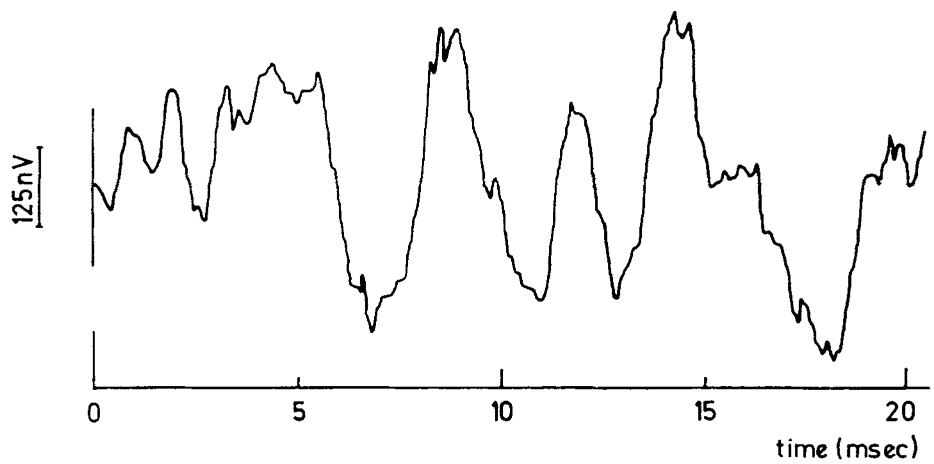


FIGURE 2 Typical quasi-conventionally averaged EP. EPs obtained from $C_z$-ear lobe location, upon visual stimulation in the form of step function. AEP calculated from 256 epochs. Direct computer plottings. Negativity upwards.

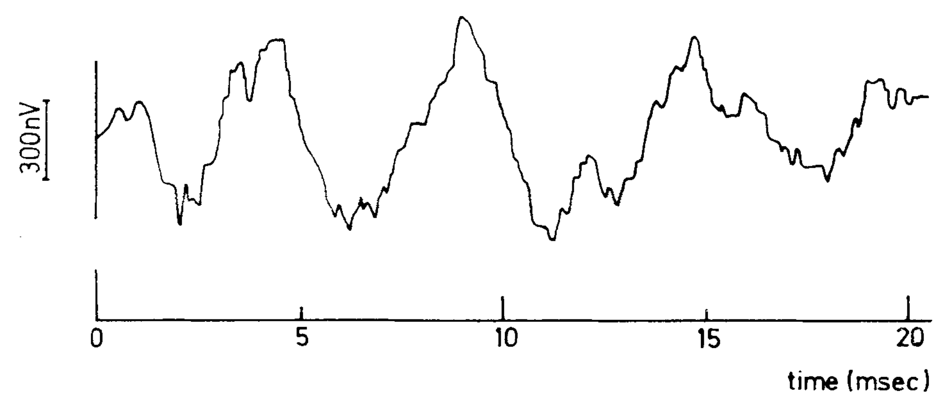


FIGURE 3 Mean value VEP. Based on 3 × 256 experiments from each of 12 subjects. Direct computer plottings. Negativity upwards.



occurs with 2.5 msec latency. As a result of this, some of the negative and positive peaks in the typical curve (Figure 2) has become insignificant; at best, the periodicity gives some of the secondary peaks and the shoulders on the primary peaks. The fluctuations on the major peaks are given by the periodicities which occur with 0.5, 1.0 and 1.5 msec latencies.

*Amplitude Frequency Characteristics*

Figure 4 shows a typical amplitude frequency characteristic computed by the Fourier Transform from the AEP illustrated in Figure 2. This curve is obtained using the first 320 real data points of the evoked potential epoch. Long or short epoch (512 and 320 real data points, respectively) analyses gave the same general results. Since short epoch analysis eliminated the masking effect of low frequency, components were, in this way, more distinctly revealed. The amplitude frequency characteristics in Figure 4 shows three distinct frequency bands extending between 150–1000 Hz, 1100–1600 Hz and 1600–3500 Hz. In the first band, there is a plateau-shaped activity at the frequency range of finding its exact counterparts in Figure 2 in the periodicities with 5.0 and 2.5 msec latencies. A less prominent maximum is observed in the same band with a projected peak at around 725 Hz; this being related to the periodicity with the 1.5 msec latency. The second band shows a clearly differentiated maximum with a peak frequency of 1200 Hz. In the third band, a bimodal activity is observed with a center peak around 2200 Hz frequency position. Considering the relative amplitudes and the peak frequencies, the last two maxima are the frequency counterparts of those periodicities in Figure 2 with latencies of 1.0 and 0.5 msec, respectively.

Figure 5 presents the mean value amplitude frequency characteristics curve calculated from all individual curves ($12 \times 3$) where 320 real data points were analyzed. The curve shows three frequency bands at 80–600 Hz, 600–1600 Hz and 1600–3500 Hz frequency ranges. The periodicity with 5 msec latency in Figure 3 finds its counterpart in the dominant 200 Hz maxima in Figure 5. In line with the status of the periodicity with 2.5 msec latency, the 400 Hz component is only a minor peaklet in the broad 80–600 Hz frequency band. There are distinct maxima at 700 Hz and 1200 Hz frequency positions. Compared with Figure 4, the component at the 1600–3500 Hz frequency band has somewhat lost its bimodal character and has a center frequency at about 2200 Hz position. The last three maxima are the counterparts of those periodicities in Figure 3 possessing 1.5, 1.0 and 0.5 msec latencies. The maxima at 200 Hz, 700 Hz, 1200 Hz and 2200 Hz frequency positions are revealed both in single and mean value amplitude frequency characteristic curves. Thus, they are the "consistent maxima or selectivities" (see Başar, 1976; Başar *et al.*, 1975b) within the limits of the present experimental design.

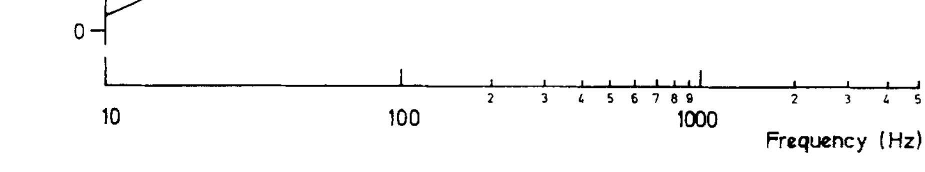


FIGURE 4 Typical amplitude frequency characteristics computed from the VEP in Figure 2 by the TRFC-Method. Direct computer plottings. Along the abscissa is the input frequency in logarithmic scale, along the ordinate the amplitude, $|G(j\omega)|$, in decibel. The curves are normalized in such a way that the amplitude at 0 Hz is equal to 1 (or $20 \log 1 = 0$).

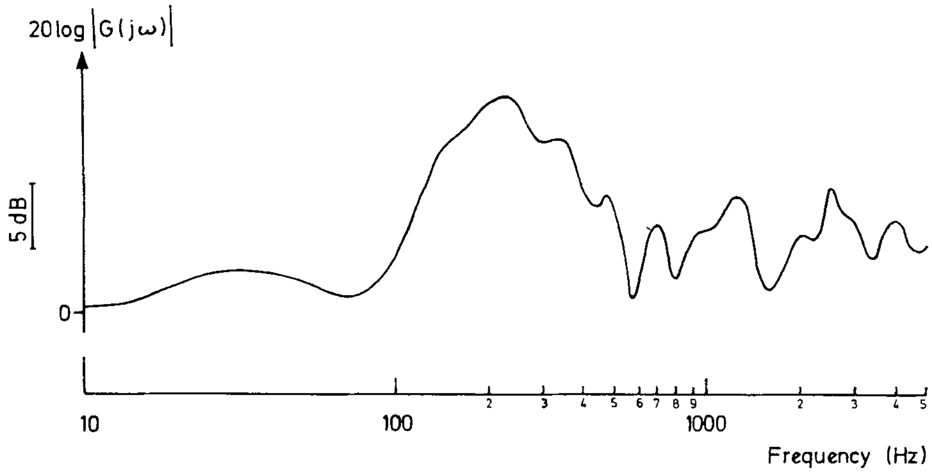


FIGURE 5 Mean value amplitude frequency characteristics from 36 experiments (based on 3 experiments from each of 12 subjects). Direct computer plottings. Along the abscissa is the input frequency in logarithmic scale, along the ordinate the mean value potential amplitude, $G|(j\omega)|$, in decibels. The curves are normalized in such a way that the amplitude at 0 Hz is equal to 1 (or 20 log 1 = 0).



## DISCUSSION

### *Transient Evoked Responses in the Time Domain*

Human VEPs were studied by many researchers by using only the transient response analysis method for various stimulus conditions and electrode locations. Of those that used bright light flashes, Ciganek's (1961) study revealed a response onset latency of 28 msec in midline parietal-occipital leads; three peaks were shown to occur in the first 80 msec, with latencies of 39, 53 and 73 msec, respectively. Recording with bipolar leads over posterior head regions, Cobb and Dawson (1960) reported an onset latency of 20–22 msec with the three peaks at 28, 40 and 65 msec time positions. Similar oscillatory potentials with onset latencies within the range of 35–90 msec have also been recorded from posterior scalp leads and from striate cortex (Vaughan & Hull, 1965; Vaughan, 1966). The earliest peak in the vertex recordings was found to have a latency of 11 msec by Hall and coworkers (1973), whereas Allison and coworkers (1977) reported a negative peak at 21.2 msec from the same electrode location. From occipital scalp electrodes, a latency of 45 msec was achieved (Ellingson *et al.*, 1973). Van Hasselt (1972) reported a visual evoked response with an onset latency of 10 msec from human auricle and mastoid process. Cracco and Cracco (1978) conducted their experiments mainly using 2/sec bright light flashes, this having been determined as the optimal for obtaining the early oscillatory potentials in animals. They applied high-pass filters to the data and summated 1024–2048 responses. Under these conditions, onset latencies of 9–17 msec and 13–24 msec were obtained from frontal and posterior scalp regions, the frequency of the oscillations being about 100 Hz.

As is evident from the above, there are diverse results on the transient response of VEP, even when these are obtained under similar experimental conditions. Today it is the contention of researchers that VEP, as a physiological phenomenon, is a multi-dimensional domain possessing a complex waveform and being greatly sensitive to variations in stimulation and recording conditions (Street *et al.*, 1976; Van der Tweel, 1977). Such characteristics are further shown to vary inter-and intraindividually (Callaway, 1966). The difficulty of assessing such phenomena with the transient response characteristics of latency, shape, magnitude and direction of peaks have been emphasized by many researchers of VEP (Ellingson *et al.*, 1973; Hall *et al.*, 1973; Praectorius *et al.*, 1977).

From a systems point of view, one should not expect all the waves of a transient response to be related to different, structurally originating resonance (Başar, 1976; 1980). Such a rule was fully confirmed by studies where the averaged evoked potentials (AEP) were interpreted through their amplitude frequency characteristics and their respectively filtered forms (Başar & Ungan, 1973; Başar *et al.*, 1975b, c; 1976a, b).

*Frequency Responses*

Employing a systems theory approach to the study of high frequency components in human VEP, Van der Tweel and Verduyn Lunel (1965) found a frequency selectivity at 35 Hz. Spekreijse (1966) proposed a short latency system of human EP, supported by findings on a 50–60 Hz selectivity. Similarly, Regan (1968) discussed a high frequency response system at VEP, with the peak amplitude occurring at 45–55 Hz. In his model for luminance systems, Van der Tweel (1977) proposed a high frequency response system, this functioning at high illuminations within a frequency range above 30 Hz. Başar (1980) classified the results of various investigators and his research group by indicating 4 to 5 selectivities in the ranges of 1–8 Hz, 8–15 Hz, 18–25 Hz, 40–60 Hz and at about 80–100 Hz.

In our previous short communication (Karakaş *et al.*, 1980; see also Başar, 1980) on the high frequency components of human VEP, we applied 1/sec bright light flashes. The electrodes were located at midline $C_z$-ear lobe. The parameters were for recording ($\Delta t = 50$ sec, $T = 25.6$ msec), for data averaging ($4 \times 64$ epochs) and for electronic filtering (high and low cut-off frequencies 80 and 2500 Hz), respectively. The amplitude frequency characteristics calculated from the VEPs showed maxima centering around 200, 400, 500, 700, 900 and 1200 Hz frequency positions. Here it should be noted that, in our study, the prominent 100 Hz activity that Cracco and Cracco (1978) observed was not evident. This is due to the fact that the chosen total record time ($T = 25.6$ msec) is too short in order to realize the perfect analysis of the 100 Hz mechanism. On the other hand, they varied inter-and intraindividually, although the respective VEPs showed several peaks in the range of 1–25 msec. In accordance with the foregoing statement the peaks were complex and unstable. Occurring in 80% of the cases, a consistent band was observed at 1400–2500 Hz frequency range, but it showed varied maxima and submaxima.

The above stated results are supporting evidences for the high frequency responses in human VEP, the "high" in the study denoting frequencies much higher than those stated in the literature until then. Likewise, in similar studies on the auditory evoked potentials, the amplitude frequency characteristics revealed prominent high frequency maxima approximately at 1000 Hz and variable ones at 80–120 Hz, 150–300 Hz and 400–650 Hz frequency ranges (Ungan *et al.*, 1978; Başar, 1980). These results depict a high frequency mechanism in the functioning of the two sensory systems. Moreover, comparing the results on the auditory and visual evoked potentials (Karakaş, 1978; Karakaş *et al.*, 1980) we tentatively stated that the frequency selectivities at around 200 Hz and 2000 Hz positions are specific to the VEPs.

*The High Frequency Response of Purely Visual Origin*

Our concern in the visual evoked potential studies (Karakaş *et al.*, 1980) were the unstable pattern of the VEPs and the variable activity in the highest frequency range of 1400–2500 Hz. In our earlier analysis we indicated that the underlying factor might be an auditory artifact generated by the gas discharge of the popularly used flashbulb. Performing control recordings, Cracco and Cracco (1978) showed that the "clicks" evoke a postauricular response with an onset latency of 15–20 msec. These researchers also noted that when the stroboscope was encased, the "click" evoked potential was not observed. But in our unpublished observations, the effect on AEP was persistent when the stroboscope was encased, when it was placed 3 m away from the subject or even when it was placed outside the experimental chamber. The effects of polysensory stimulation on EPs was handled in Grey Walter's (1965) concept of idiodromic projection. Here, Walter proposed that when signals from two different modalities are presented with ever-decreasing temporal intervals, the evoked response produces a potential derived from the sums and differences of the two responses to the associated stimuli. Thus, the variability and complexity that we observed in the VEPs in our previous studies (Karakaş, 1978; Karakaş *et al.*, 1980) might be due to the effects of a probable polysensory integration.

When the step evoked visual potentials of the present study are compared with the flash evoked potentials of our previous studies (Karakaş, 1978; Karakaş *et al.*, 1980), we see that the number of periodicities were decreased in number. This fact gives *the step evoked potentials a simpler and noise-free appearance.* The reduction in inter- and intraindividual variations plus the advantages of the averaging process is reflected in the stable waveform of the mean value VEPs. The amplitude frequency characteristic of the potentials depicts frequency bands and activities that are generally similar to those obtained from the flash evoked potentials. Only, the maxima in the present study are more distinct, clearly differentiated and fewer in number. The effect is especially pronounced for frequencies above 700 Hz; the variable maximum and submaximum that were observed in the previous studies in the 1400–2500 Hz frequency region were replaced, in the present study, by a consistent maximum at around 2200 Hz.

Figure 6 illustrates, comparatively, the amplitude frequency characteristics of human visual and auditory evoked potentials. (For detailed analysis of the amplitude characteristics of auditory evoked potentials, see Başar, 1980; & Ungan *et al.*, 1978). As Figure 6 reveals, the acoustic stimuli elicit maxima of potentials at around 600–700 Hz and 1000–1200 Hz frequency positions. Since similar amplitude maxima are observed upon application of the step-light (which is a stimulus free from the contamination of auditory signals), we can conclude that 600–700 Hz and 1000–1200 Hz maxima are responses common to both visual and auditory systems. Further, we can now definitely conclude that the 200 Hz and 2200 Hz components are response signals having purely visual origin. We also want to point out that Gönder and Başar (1978) measured a marked selectivity in the frequency channel of 600–1000 Hz, a frequency channel in which Başar (1980) measured an important selectivity of the cat superior colliculus upon visual stimulation.

*Adaptive Filtering of High Frequency Visual Evoked Responses*

Figure 7 illustrates band-pass filtered components of the averaged human visual evoked potential which is analyzed by using a digital adaptive filtering technique described by Başar and Ungan (1973). The band limits of the filters are chosen

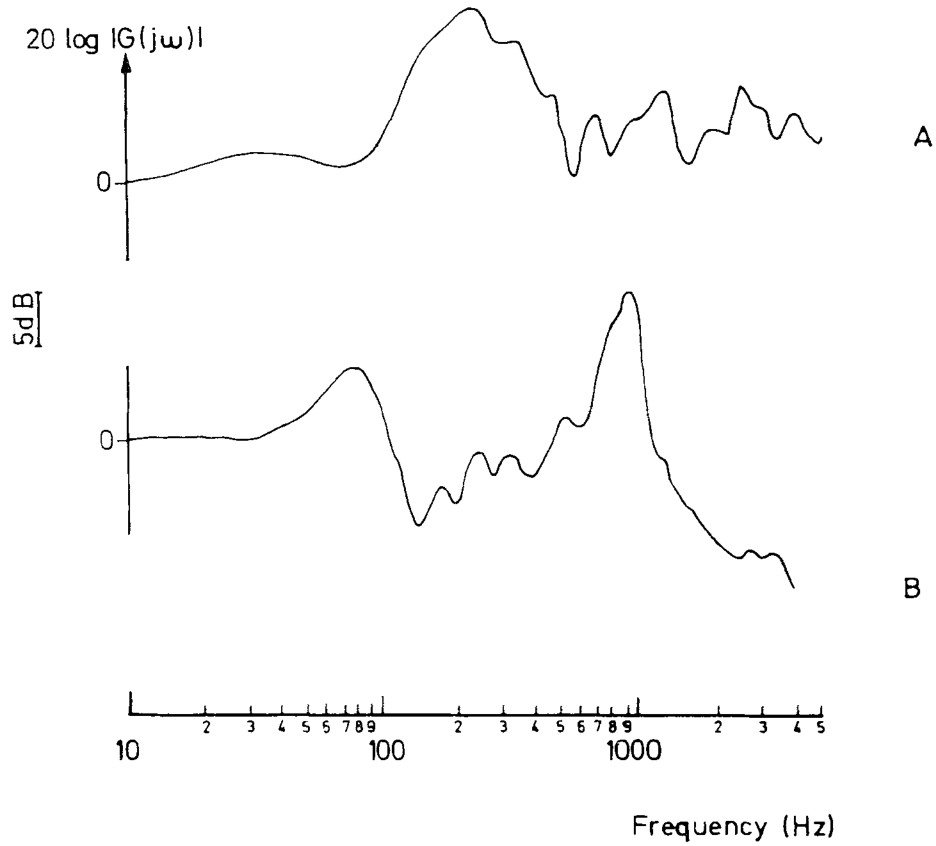


FIGURE 6 Mean value amplitude frequency characteristics based on visually and acoustically elicited AEPs obtained from vertex electrodes on human scalp. (A) based on 36 experiments (3 experiments from each of 12 subjects); (B) based on 60 experiments (10 experiments from each of 6 subjects). High-pass filters with 80 Hz cutoff frequency applied. Direct computer plottings. Along the abscissa is the input frequency in logarithmic scale, a long the ordinate the mean value potential amplitude, $|G(j\omega)|$, in decibels. The curves are normalized in such a way that the amplitude at 0 Hz is equal to 1 (or 20 log 1 = 0). (After Başar, 1980).



according to the mean value amplitude characteristic of Figure 5. Although in this study we do not aim to analyze in detail the results of this methodology, we want to describe approximately the correspondence between frequency responses and latencies of the peaks in transient VEPs. According to systems theory criteria (see Başar & Ungan, 1973 and Başar 1980) it can be approximately stated that the frequency responses of frequencies higher than 1000 Hz are reflected in peaks of smaller latencies (0.5, 1.0 and 1.5 msec) whereas the lower frequency responses of 700 Hz and 200 Hz are reflected in waves (or peaks) of around 2.5 msec and 5 msec.

*The Advantage of the Step-Light Stimulation*

By concluding, we want to emphasize that the step-light response has two big advantages in comparison to flash stimulation: firstly, the click contamination originating from flash bulbs is definitely eliminated. Secondly, the evoked potentials contain only the response characteristics of neurons (and/or neural systems) which are sensitive to "on" stimulation signals and that supplementary response components resulting from "off-effects" are excluded. Therefore, we assume that the use of step-light responses enables the investigator to perform a more optimal analysis of visual evoked responses.

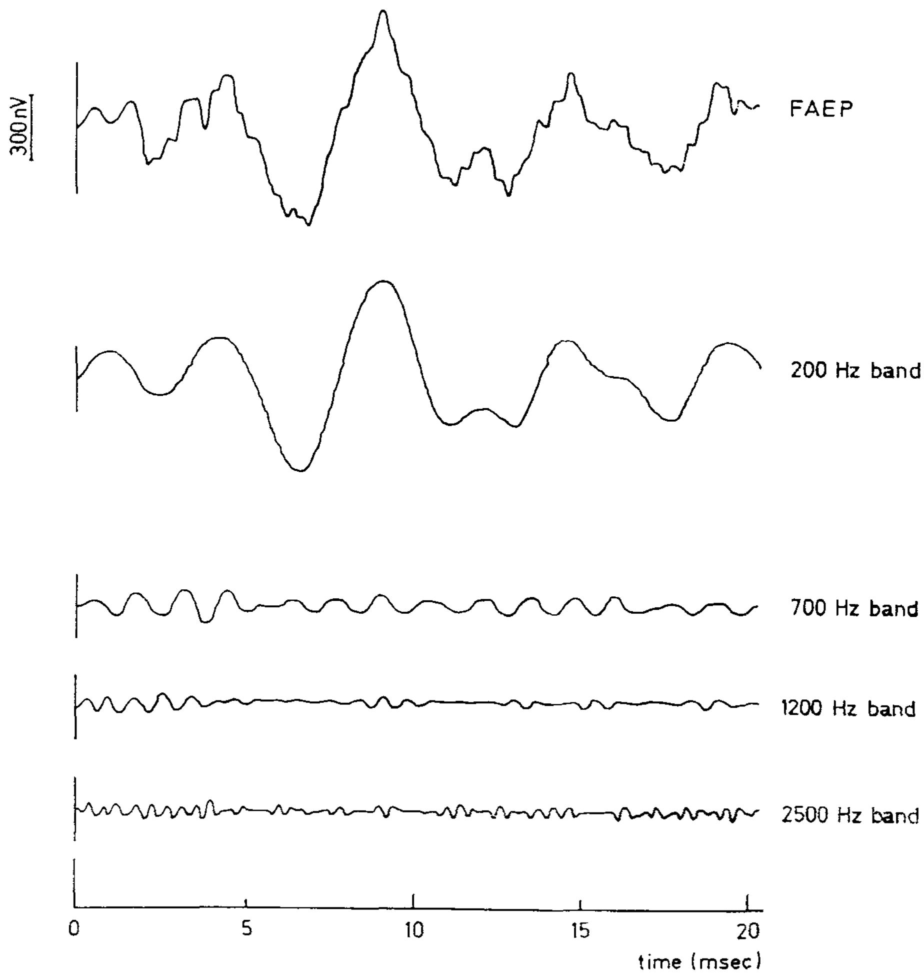


FIGURE 7 Filtered averaged evoked potential from 36 experiments (3 experiments from each of 12 subjects) filtered with ideal band-pass filters with the specified values. Direct computer plottings. Negativity upwards.



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