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Human cortical visually evoked responses (VERs) to pairs of stimuli presented in rapid succession were investigated in an attempt to assess the electrophysiological nature of temporal visual processing as a function of the spatial frequency of the stimuli involved. Four stimuli, all of which were of an equal mean luminance level, consisted of a diffuse flash and square checkerboard patterns of three spatial frequencies: 0.5, 1.0, and 4.0 cycles/degree (check-sizes subtending 60, 30, and 7.5 min of arc visual angle). Stimuli were presented both singly and in all 16 possible pairwise combinations with a 40 msec interflash interval interposed between the pairs. Both the psychophysical reports and the VERs to the various stimulus configurations were analyzed in order to test whether the existence of visual information channels selectively tuned to a specific range of spatial frequencies would be revealed in terms of selective masking effects among the various stimulus combinations.

Analysis of the VER data was based primarily on the magnitude of variability of the VERs, resulting from variations in the pattern stimulation from the first or second flash. The variability measure indicated the degree to which stimulus pattern processing of one flash of the pair was impaired by the nature of pattern in the preceding or following flash (forward and backward masking effects respectively). When

stimuli were presented singly, the VER changes attributable to differential stimulus pattern processing occurred maximally at the same latency (110 msec) for all four subjects. The contribution of the stimulus to the VER was reduced when the stimulus was either preceeded or followed by another stimulus as indicated by the variability measures, indicating the presence of both forward and backward masking. The contribution of the second flash was always less than the first, forward masking being most pronounced.

The psychophysical data did not indicate either forward or backward masking when both flashes of the pair contained pattern. When one of the flashes contained diffuse light, however, the pattern stimulus masked the diffuse flash regardless of sequential order, as also indicated by the electrophysiological indicant.

At the electrophysiological level, it was observed that the 7.5 and 30 min patterns elicited the largest negative amplitude potentials at the 110 msec latency after flash onset, whether presented alone, or in pairwise sequence in either the first or second position. In addition, these two stimuli were found to be the most effective forward maskers of the four stimuli.

Further, it was found that forward masking was specific to the spatial frequency of the pattern in the first (masking) stimulus, electrophysiological masking being greatest when identical as compared to dissimilar spatial frequencies were presented in the flash pair. This finding of selective masking lends support to the notion that visual channels are selectively sensitive to a limited range of spatial frequencies.

VISUAL EVOKED CORTICAL RESPONSES AND SELECTIVE DIOPTIC MASKING WITH PATTERN FLASHES OF DIFFERENT SPATIAL FREQUENCIES

by

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Introduction

The purpose of this study was to measure both perceptually and electrophysiologically the human nervous system processes spatial and temporal visual information. Spatial information, which refers to the distribution of contrast gradients as a function of location, accounts for stimulus pattern, shape, and size. Temporal information, which entails the sequencing of sensory input, accounts for the duration and ordering in time of sensory events. In essence, all visual information can be characterized in terms of these two parameters. This study will investigate the question of whether these two variables interact when the limits of temporal processing are approached in a visual masking paradigm. When two stimuli are presented in rapid temporal succession, does the pattern size of the two stimuli influence their perceptual and electrophysiological processing?

Before this question can be formulated methodologically and explicitly in terms of the parameters of this study, a review of the literature and experimental findings related to this topic will be offered. While considerable data have been collected in the areas of both spatial and temporal information processing, comparatively little work has been done on the interaction between these variables. Therefore, in the sections which follow the findings related to the perceptual and electrophysiological processing of spatial and temporal information will be first considered separately. In the first section data will be presented which suggests that spatial information is coded in terms of the spatial frequency composition of the stimulus and is processed over neural channels selectively sensitive to a particular range of these spatial frequencies. Next, a discussion of temporal coding of visual information will follow which will provide perceptual and physiological data indicating that there is a limit on just how fast the visual system can sequentially process information. The third section of this review will discuss some of the studies which either directly or indirectly have researched the spatial-temporal processing of visual information under various perceptual phenomena. The final section will attempt to summarize the conclusions drawn from the previous sections in addition to providing justification for conducting the present investigation.

Spatial Information Coding

Single and multiple channel models have been offered to explain how the visual system differentially processes spatial information. The single channel model (SC), which has been proposed by several individuals (Graham, Brown, and Mote, 1939; von Bekesy, 1960; and Ratliff, 1965), accounts for the processing of patterned visual information in terms of a single spatial-luminance transformation function wherein there is a single integrated linear summation of neural excitation. Despite the size and form of a given stimulus, this transformation is performed by the same neural network. At any point of stimulation on the retina, a two dimensional spatial-luminance transformation is encoded and processed to represent the perceived luminance and form of the stimulus. The SC model would predict that the perception of the given stimulus is a function of the overall integrated summation of neural excitation, rather than the specific size and form of the stimulus.

The multiple channel model (MC) of visual processing (Thomas, 1970; Campbell and Robson, 1968; and Blakemore and Campbell, 1969) proposes that the visual system is composed of neural networks, each of which is sensitive to only a certain range of stimulus sizes. The processing of a given stimulus is carried out by the channel most sensitive to the size of that particular stimulus. Since there are differentially sensitive channels, the response of a given channel will depend on the size of the stimulus. While the SC model maintains that altering the sensitivity of a particular channel will change the effectiveness of processing of stimuli of all sizes, the MC model predicts that only the stimuli whose size falls within the range of that particular size tuned channel would be effected, while all other size stimuli would be processed unaffected by channels to which they were more appropriately tuned.

What the MC model proposes, then, is that there exist in the visual system independently operating channels, each of which is selectively tuned to a limited range of spatial frequencies. The spatial frequency composition of a patterned stimulus, which is a means of specifying both the size and Fourier spectral composition of a stimulus, refers to the various frequencies (cycles/unit distance) of spatial sinusoids that compose that stimulus and relate luminance level to linear direction (Graham and Nachmias, 1971). The MC model maintains that the visual system spectrally analyzes a stimulus of complex form into its component sinusoidal gradients of various spatial frequencies, and in turn each of these sinusoidal components are conveyed via channels selectively tuned to the respective specific spatial frequencies of the various components. While the exact nature of the neural mechanisms involved in the coding and processing of patterned visual information has yet to be completely understood, there has been a considerable accumulation of both psychophysical and electrophysiological evidence which tends to support a MC interpretation of visual processing.

An experimental paradigm, utilizing selective adaptation phenomena, has provided substantial psychophysical evidence in support of the MC model (Blakemore and Campbell, 1969; Pantle and Sekular, 1968). After exposure to a high contrast grating of sinusoidally modulated luminance for a period of time, it was observed that the visual sensitivity for a low contrast grating of a similar spatial frequency and orientation was substantially reduced, while there was little effect on stimuli of more discrepant spatial frequency and orientation. The rationale for using this type of paradigm is that the response characteristics of the neural channels to stimulus parameters common to both the adapting and the subsequent test stimulus will be reflected.

When the similarity of spatial frequencies presented in the adapting and test stimulus are varied, both the psychophysical and electrophysiological measures of the adaptation effect support the MC interpretation of information processing. That is, multiple neural channels exist each of which is tuned selectively to a certain range of spatial frequencies.

Blakemore and Campbell (1969) obtained psychophysical threshold measures of contrast sensitivity to horizontal gratings of various spatial frequencies before and after exposure to a high contrast adapting grating. Threshold for contrast sensitivity were established by increasing the modulation voltage of the sinusoidal grating projected on the oscilliscope screen until the grating was perceptible. For each adapting stimulus of a given spatial frequency, a contrast sensitivity function was established across a wide range of spatial frequencies of the test stimuli. They found a rise in threshold across only a limited range of spatial frequencies centered around the frequency of the adapting stimulus. For spatial frequencies ranging from 3 to 14 cycles/degree of visual angle, the effect was limited to approximately a bandwidth of one octave around the center adapting frequency. At higher spatial frequencies (20 to 28 cycles/degree) the adaptation effect was more evident and had a narrower bandwidth. For low spatial frequencies the effect reportedly asymptoted a 3 cycles/degree. This latter effect, however, could reflect a procedural artifact. A relatively small projection screen (1.5^{o}) was employed which limited the presentation of stimuli of smaller spatial frequencies. It may be noted that the specificity of the adaptation effect was in direct discordance with the predictions of the SC model of visual information processing. The SC model would predict that the adaptation effect should be independent of the similarity of spatial frequencies in the adapting and test stimuli.

Campbell and Robson (1968) have stated contrast sensitivity thresholds, in response to gratings of various complexities and sizes, indicate the visual system performs some type of Fourier analysis in analyzing spatially patterned stimuli. They observed that gratings of a complex waveform, consisting of the additive combination of various sinusoidal components, cannot be identified until the contrast levels of the individual components reach their independent thresholds. For example, Fourier analysis may be used to demonstrate that a square wave is the sum of the sine waves whose frequencies are 1, 3, 5,...times the frequency of the square wave with amplitudes $4/\pi$, $4/3\pi$, $4/5\pi$,...respectively, times the amplitude of the square wave. A square wave was not perceived any differently from the sine wave grating of the fundemental frequency until the third harmonic had reached its own threshold. These factors imply that the analysis of a complex visual form entails, first, the spectral decomposition of the stimulus into its spatial frequency components and, second, the independent transmission of these various spatial frequencies over appropriately tuned channels.

Using the selective adaptation effect in conjunction with two different detection tasks, Carpenter and Ganz (1972) also concluded that the visual system spectrally analyzed the separate harmonic components of a square wave before it was perceived as such. In one detection task where the subject was to indicate the presence or absence of a square wave grating, it was observed that preadaptation of a sine wave of the same fundamental frequency as the square wave was more effective in elevating the detection threshold to the square wave. In another task which required the discrimination between a square and sine wave grating of the same fundamental frequency, pre-exposure to an adaptation sine wave three times the fundamental frequency of the test stimuli was most effective in elevating the discrimination threshold. Note that the higher harmonics of a square wave are what account for the edges of the wave and would, thus, provide the cues for discriminating a square and sine wave grating of the same fundamental frequency.

In line with this research, Graham and Nachmias (1971) directly tested the predictions of the SC and MC models' interpretations of visual analysis. Contrast thresholds were obtained for gratings containing two superimposed sinusoidal components with the frequency of one always three times that of the other. The components were presented in two different ways: peaks adding and peaks subtracting, thereby having the ratio of contrasts of the composite stimuli taking on several values. In terms of detecting these various stimuli, an SC model would predict that the complex patterns containing both components would be identified even though the contrast level in each component was substantially below its threshold value when presented alone. In addition, the phase in which the components were added would have an effect on the ease of detectability. On the other hand, the MC model would predict that the complex pattern would be above threshold only if the individual components have reached their independent threshold levels, regardless of the phase relation between them. Psychophysical functions obtained from stimuli presented over a 6^{o} foveal area and consisting of spatial frequencies ranging from .9 to 6.3 cycles/degree fully supported the MC model predictions.

Sachs, Nachmias, and Robson (1971) conducted a subsequent study to further substantiate both the independence and bandwidth characteristics of these frequency specific channels. Psychophysical functions of the contrast thresholds for simple sinusoidal gratings and complex gratings consisting of the sum of two sinusoidal components of various spatial frequencies (f and f') were obtained. With f always equal to 14 cycles/degree, the two components were independently detected as long as the ratio (f/f') of the two components' spatial frequencies lie outside the range of 4/5 to 5/4.

Stromeyer and Julesz (1972) also collected psychophysical data supporting the spatial frequency notion of visual analysis. Subjects were required to detect the presence of a sinusoidal vertical grating which was masked by vertical gratings of many spatial frequencies. Both the test and masking stimuli were presented simultaneously on an oscilloscope screen; contrast sensitivity functions for the test stimuli were established by determining the percentage modulation required for detection. When a one octave bandwidth of masking noise was presented with stimuli of different spatial frequencies, masking functions were obtained which closely resemble the sensitivity functions obtained in the adaptation experiments. Test stimuli whose frequency fell within the bandwidth of masking noise were optimally masked as indicated by their increased detection thresholds. However, there was little effect when their spatial frequency fell outside the masking noise bandwidth. Masking was also measured as a function of the bandwidth of the masking noise centered around the test stimulus. Masking increased up to the point where the bandwidth was ± 1 octave of the of the test stimulus' spatial frequency, after which point the function asymptoted.

Stromeyer and Julesz (1972) also showed frequency specific masking functions at low spatial frequencies which disagree with the Blakemore and Campbell (1969) findings which were based on the utilization of the selective adaptation paradigm. Stromeyer and Julesz accounted for these differences in terms of the differences in the area of stimulation and the size of the stimuli used in the two studies. In the masking noise paradigm of Stromeyer and Julesz, stimuli displayed on the oscilloscope were very dynamic, giving the impression that broad bands of noise were moving about rapidly. Unlike the adaptation paradigm, the same set of neural units were not necessarily being stimulated, and therefore, one cannot account for the findings in terms of stabilized image phenomena. Otherwise, the findings presented by Stromeyer and Julesz (1972) corroborate previous findings that different spatial frequencies are neurally transmitted over different spatial frequency selective channels, the bandwidth of which is centered approximately one octave around the center frequency.

Bagrash (1972) has conducted a series of psychophysical observations which point out some of the limitations and shortcomings entailed in using the selective adaptation paradigm to test the validity of the MC model of visual processing. One such criticism is that edge detector channels really may be affected rather than spatial frequency channels. Bagrash tested this alternative explanation by using a disc and annulus, whose respective outer and inner diameters coincided, as a test and adapting stimuli respectively in the typical selective adaptation paradigm. While the disc and annulus were of different spatial frequencies, their inner and outer diameters coincided and would thus demonstrate edge-detecting adaptation, if it does exist. While the annulus did not have as great an adapting effect on the disc as did another disc of the same size, the annulus did play some appreciable role in decreasing the sensitivity of the perception of the disc. It was, thus, concluded that the multiple size tuned channel explanation is plausible, but such a neural model should also include some sort of edge-detection mechanism.

This explanation seems somewhat tenuous for two reasons. First, there is considerable psychophysical evidence (Graham and Nachmias, 1971; Campbell and Robson, 1968; Nachmias and Robson, 1971; and Stromeyer and Julesz, 1972) which is not based on the adaptation paradigm nor allows for stabilized images, supporting a spatial frequency rather than an edge-detector mechanism. Secondly, the distinction between an edge-detector mechanism and a spatial frequency mechanism may be questionable since an edge-detection analysis may entail the spectral analysis into component spatial frequencies. For example, in the experimental manipulation of the

Bagrash (1972) study, there were, undoubtedly, many spatial frequency components common to both the annulus and the disc stimuli.

A second limitation of the adaptation experiments which Bagrash (1972) demonstrated was that there was no simple relationship between the intensity of the adapting stimulus and the decrement in visual sensitivity. By varying the size and intensity of the adapting stimulus, a complex interaction between the adapting stimulus size and intensity level was obtained, as reflected in the sensitivity functions. The fact that this nonlinearity between area and intensity of adapting stimulus existed, discredits both a SC and MC interpretation. Bagrash, thus concludes that while the majority of findings obtained from the selective adaptation studies support a MC model interpretation, one cannot, in fact, use this adaptation paradigm to distinguish between the two models of visual mechanisms. Nevertheless, since a number of additional studies have supplied data which substantiates a MC interpretation, without the limitations imposed by the adaptation paradigm, the MC model appears most plausible in viewing the psychophysical evidence.

Considerable physiological data may be cited in support of the MC model of the visual system. Hubel and Wiesel (1960a; 1960b; 1966), using microelectrode recording techniques, have shown retinal ganglion cells of both the monkey and the cat, and lateral geniculate (LGN) cells of the monkey to be selectively sensitive to an optimal size stimulus of a particular contrast value. This size was equivalent to the diameter of the inner excitatory center of the receptive field. If stimuli were smaller, they do not cover the entire excitatory center, thus resulting in a less than optimal neural summation. If the stimuli were larger than the excitatory center, they impinged on the inhibitory surround, resulting in a less than optimal response. Hubel and Wiesel (1968; 1972) also found cortical cells in the cat and monkey optimally sensitive to a certain size and orientation of stimuli. Since the original work of Hubel and Wiesel, there has been a number of physiological studies at the single unit level demonstrating the existence of receptive fields at various levels of the visual system optimally responsive to a particular range of stimulus parameters (size, orientation, rate, direction of movement, etc.).

While size is one of the major stimulus parameters to which single unit activity is very sensitive, other stimulus parameters may interact with the size parameter in determining how a neural unit will respond. For example, Ikeda and Wright (1972) showed that in cats the activity of ganglion cells, with receptive fields in the central retina (within 5^o of area centralis) was inhibited when an optimal size stimulus was defocused by inducing a refractive error. Maffei, Cervetto, and Fiorentini (1970) have demonstrated the effect of luminance level on the processing of stimulus size. Recording from the cat's retinal ganglion cells, they reported that under different levels of illumination the size of the inhibitory surround of the receptive field will change, thus changing the range of stimulus sizes to which the ganglion cell is responsive. These findings suggest the existence of either a certain degree of plasticity in the receptive field size or a more complex notion of the concept of receptive field than presently prevails.

Graham (1972) has attempted to relate and replicate the electrophysiological findings of Maffei _et_. _al_. (1970) with a psychophysical measure of spatial selectivity using the selective adaptation paradigm under different levels of illumination. The psychophysical data indicated no difference in the sensitivity functions under different levels of illumination, suggesting that the neural channels do not change their spatial frequency selectivity over different luminance levels. The discrepancy between the psychophysical and retinal ganglion cell data may be accounted for by cells higher in the visual system than the ganglion cells which make the range of each spatial frequency channel narrower than observed at the peripheral ganglion level.

Maffei and Fiorentini (1973) have presented electrophysiological single unit data supporting this possible explanation. When recording single unit activity of ganglion, LGN, and simple and complex cortical cells level to stimuli of various spatial frequencies, a narrowing of the sensitivity range from the ganglion to the simple cortical cell level was observed.

A number of other physiological studies may be related to the effects of spatial frequency on psychophysical thresholds. Enroth-Cugell and Robson (1966), Campbell, Cooper, and Enroth-Cugell (1969), and Maffei and Fiorentini (1973) have presented sinusoidally modulated stimuli of various spatial frequencies, analogous to the psychophysical study of Campbell and Robson (1968), while recording single unit activity at various levels of the cats' visual system. Enroth-Cugell and Robson (1966) recorded retinal ganglion cell activity to the various grating stimuli in order to establish individual cell contrast sensitivity functions in terms of unit activity as a function of spatial frequency, mean luminance level, and contrast level of the grating pattern. While the ganglion cells were selectively sensitive to a limited range of spatial frequencies, like the Maffei _et_. _al_. findings (1970), reducing the illumination level produced changes in the sensitivity functions of a number of the ganglion cells. Campbell _et_. _al_. (1969) conducted essentially the same investigation but recorded single unit activity from cortical and LGN fibers of the cat. Units, whose responses were measured in terms of the frequency of impulses, were found to be selectively sensitive to a limited range of spatial frequencies. Maffei and Fiorentini (1973) who found the range of spatial frequency sensitivity to be the narrowest at the simple cortical cell level, concluded that the simple cells of the cortex were primarily responsible for coding spatial frequency, while the complex cortical cells which did not have the resolving power of the simple cells were believed to be involved in the coding of movement.

A number of human electrophysiological studies have been conducted by observing the visual evoked response (VER) to stimuli of various spatial frequency characteristics. Several studies (Rietveld, Tordoir, Hagenovw, Lubbers, and Spoor, 1967; Harter and White, 1968; Harter and White, 1970; Eason, White, and Bartlett, 1970; and Harter, 1970) have shown that the human VER is differentially sensitive to the size of a patterned stimulus. When stimuli are presented foveally, patterns with intercontour distances of 10 to 20 minutes of visual arc appear to give the largest amplitude VER. As the size of the stimuli becomes larger or smaller the VER amplitude declines. However, Harter (1970) has shown that optimal stimulus pattern size varies as a function of retinal eccentricity, with a 60 minute pattern being the optimal size in terms of VER amplitude when stimuli were presented 7.5^{o} in the peripheral retina. This suggests that there are different size tuned channels which are differentially distributed across the retina.

Blakemore and Campbell (1968; 1969) have recorded human evoked potentials to sinusoidal gratings used in the selective adaptation studies to assess the relationship between the VER amplitude and the perceived contrast level of the gratings. It was reported that there was reduction of evoked potential amplitude concommitant with the psychophysical fading of the low contrast grating after preadaptation with a 30 second exposure to a high contrast grating of the same spatial frequency. Suppression of the VER amplitude and an increase in the psychophysical threshold did not occur if the high contrast adapting grating had a different orientation or if its spatial frequency differed by more than one octave from the test grating. While the electrophysiological data reported in these studies was very cursory and not subjected to statistical analysis, it would seem very fruitful to conduct a parametric investigation of spatial frequency selectivity using a preadaptation paradigm in conjunction with collecting both psychophysical and VER data concommitantly.

Campbell and Maffei (1970) collected human VERs to the presentation of stimuli of various spatial frequencies and contrast levels. The existance of different spatial frequency channels was demonstrated by dividing the stimulus screen into upper and lower halves. On the upper half a gradient whose spatial frequency remained constant was displayed, while on the lower half gradients of various spatial frequencies were presented. This manipulation was based on the premise that as the spatial frequencies of the two gradients became more discrepant, more neural channels would be utilized than if the stimuli were more similar. It was first observed that there was, indeed, a linear relationship between VER amplitude and the log of the stimulus contrast level. The psychophysical threshold value agreed with the theoretical value obtained from extrapolating the regression line of the VER amplitude function to the zero voltage value. While the slope of this regression line was independent of the spatial frequency of the stimulus grating, the slope could be augmented by using stimuli in the two halves of the screen with discrepant spatial frequencies. In other words, a relatively larger VER amplitude is observed across all contrast levels to a stimulus possessing two separate spatial frequencies as compared to an equal size stimulus possessing only one spatial frequency. Again this increase was most pronounced when the stimuli's spatial frequencies differed by more than one octave, at which point there would be little overlap in the bandwidth sensitivity of the stimulated channels.

In the preceeding discussion considerable evidence of both a psychophysical and physiological nature has been presented which supports a MC interpretation of visual processing. Stimulus pattern and size are encoded and processed in terms of sinusoidal spatial frequency components. This spatial information is transmitted over neural channels, independently operating, which have a limited selective sensitivity to stimuli which fall within ±1 octave around the center frequency. One is thus led to conclude that the visual system is composed of multiple neural channels each selectively responsive to a particular range of spatial frequencies.

Temporal Information Coding

It has been well substantiated that the speed of sequential sensory information processing by the nervous system is limited. Most investigations on the limitations of temporal processing have followed two general lines of research. One deals with the phenomena of visual masking, wherein both psychophysical and physiological data have been related to the interference of one visual stimulus by another of close temporal proximity. Formally, visual masking can be defined as a class of situations in which some measure of effectiveness of the visual stimulus (test stimulus) is reduced by the presentation of another visual stimulus (masking stimulus) in close temporal proximity, either prior to the test stimulus (forward masking) or subsequent to the test stimulus (backward masking) (Kahnaman, 1968). The other line of investigation deals with the notion of cortical excitability cycles and temporal numerosity. This type of research investigates the effects of trains of sequential stimuli on the psychophysical measure of perceived number and the physiological indicants of the recovery rates of the various neural structures. Temporal numerosity is related to the more classical studies of critical flicker-fusion (CFF) wherein the frequency of intermittant photic stimulation becomes so high that the stimulation is perceived as a steady fused light. All these areas of research, masking, temporal numerosity, and CFF are related in the sense that they offer both perceptual and concommitant physiological data on how the visual system sequentially processes information, and how when the system approaches its limit of temporal acuity, temporal processing deteriorates.

Both psychophysical and physiological data dealing with temporal numerosity and cortical excitability cycles suggests that the nervous sytem groups or samples in time incoming sensory information. The duration of this unit of time, the psychological moment, has been cited as ranging from 50 to 200 msec depending on the stimulus and the type of perceptual task entailed. Harter (1967) reviewed two theories which attempted to explain how this sensory input is grouped. The cortical excitability theory, stemming from the data on varying sensory thresholds as a function of the cyclic EEG activity, states that the excitability cycles serve as gating or tuning devices for the incoming sense data. The cortical scanning theory, based on histological and neurophysiological evidence, states that a cortical scanning mechanism scans the sensory projection areas and temporally groups data into psychological moments. Both of these theories assume a central cortical mechanism is limiting the sensory input. These two explanations may prove to be only partial explanations of temporal coding in light of data in which there is temporal interference due to rapid sequential stimulation at the most peripheral levels of sensory input (as discussed below). While these hypothetical central mechanisms may modulate the temporal responsiveness of the peripheral neural structures via efferent control, this has yet to be ascertained.

White (1963) reports that when a train of diffuse light flashes are presented in rapid succession, the number of flashes perceived depends not on the number of stimuli in the sequence but on the time it took to present the stimulus train. This again suggests that some neural mechanism is limiting the number of perceived events over a given unit of time. Harter and White (1967) related this perceptual phenomena to the human cortical VER, showing that when trains of flashes were presented at 33.3 flashes/sec of various train lengths (1-14 flashes) the number of perceived flashes was directly related to the number of successive components of the VER. The duration of these successive components was 50 to 100 msec depending on the subject, corresponding to the time duration attributed to the psychological moment. After reviewing the physiological data pertaining to temporal numerosity and the VER, White and Eason (1967) also concluded that a close relationship exists between the temporal numerosity phenomena and the VER pattern. Again, the rate at which each successive perceived flash was added depended on the addition of a successive VER component. This relationship suggests that the VER could be used as a physiological measure or an indicant of the temporal processing of visual information.

In an attempt to assess the nature of the steady state evoked potentials as a function of stimulation rate, Kinney, McKay, Mensch, and Luria (1973) have investigated the waveform of the VER to either diffuse flash or striped pattern stimuli. Using several rates of stimulus presentation (4, 8, 12, and 20 hz.) and analyzing peak to trough amplitudes, they found that the mean amplitude decreased and variability increased as the rate of stimulation increased for both diffuse and pattern stimuli. This implies that subjects are unable to respond independently to each stimulus as the interstimulus interval (ISI) is decreased. At higher flash rates there was no difference in wave form between the diffuse and pattern stimuli, which suggests that at high presentation rates there is a loss of information due to the temporal restraint imposed by the visual system.

A number of studies have attempted to relate both perceptual and electrophysiological responses to the discrimination of one versus two flashes of diffuse light under progressively shortened ISIs. Andreassi, Mayzner, Davidovic, and Beyda (1971) found that the presence and amplitude of a positive component of the human VER was directly related to the subject's ability to perceive two discrete flashes. This agrees with the findings of Harter and White (1967) which found the perception of additional flashes depends on the addition of successive VER components.

Donchin, Wicke, and Lindsley (1963) and Donchin and Lindsley (1965) have recorded VERs to a pair of stimuli presented at various ISIs while human subjects were asked to detect both the presence and orientation of the test stimulus. The test stimulus was a semicircular shaped diffuse flash, 1°22' in diameter and having a luminance level of 0.25 mlam.; while the subsequent masking stimulus consisted of a circular shaped diffuse flash 2°26' in diameter and having a luminance level of 260 mlam. With the two stimuli centered on the same retinal location, as the ISI was shortened, backward masking occurred wherein the deterioration of the perception of the test flash occured due to the subsequent presentation of the masking stimulus, which eventually becomes the only stimulus phenomenally present. There was a close relationship between the perceptual events and the VERs to the stimulus pairs. At ISI longer than 100 msec when the two stimuli were always perceived as two, there was no overlap in the early VER components of the two stimuli. At intermediate ISIs (25-100 msec), as the interval was shortened, there was an increase in the apparent brightness of the test flash until eventually it was abruptly masked. At the same time there was a progressive overlapping of the VER components of the two stimuli. At short ISIs (less than 25 msec.), when only the masking stimulus was perceived, the VER to the test flash was obliterated and the VER to the pair of stimuli at these short ISIs resembled the VER to the masking stimulus alone.

In these studies, it was assumed that the VER to a pair of flashes reflected the algebraic neural summation of the neural response to each individual flash. By subtracting the VER to the blanking flash when it is presented alone from the VER to the conjoint presentation of the test and blanking flash, a residual VER was obtained representing the electrophysiological activity in response to the test stimulus in the blanking conditions. It was found that the amplitude of this residual VER was directly related to the perceptual detection of the test stimulus.

Lindsley (1961) has indicated that cortical processes, in conjunction with the reticular formation, may be imposing the temporal gate in terms of how fast stimuli are processed. While both the optic tract and LGN electrophysiological activity in cats seems to follow rapid stimulus presentation rates far beyond the perceptual CFF, cortical responses are not able to follow stimulation rates much beyond the CFF. Schneider (1968a; 1968b) has recorded evoked potentials at the cortical level to different rates of intermittent photic stimulation in rabbits to which behavioral CFF thresholds had been previously determined. While there was following (a discrete identifiable response is given to each stimulus) of the VER beyond the CFF (about 19 cps above CFF threshold), it was noted that at the CFF level, the VER had been attenuated 10-20 percent of its maximal amplitude.

A number of subsequent studies have been conducted since Lindsley's statement implicating the cortical areas as being the limiting gate of temporal sensory input. Fehmi, Adkins and Lindsley (1969) had monkeys perform a perceptual operant task, entailing the discrimination between a tachiscoptically presented square or triangle followed by a more intense blanking flash of diffuse light at various ISIs, while evoked potentials were recorded from the optic tract, the LGN, and the cortex. When discriminations were at chance level due to the masking effects of the blanking flash, a VER characteristic of the blanking flash alone was observed at all recording sites. When the test stimuli could be detected, early portions of the VER attributable to the test could be discerned at all recording sites. Residual VERs, derived in the same manner as in the Donchin, Wicke, and Lindsley (1963) study, to the test stimuli were obtained which revealed a relationship between discrimination performance and amplitude of the residual response at all three levels of the visual system. This suggests that temporal interference of sensory input occurs as far in the periphery as the retinal ganglion fibers of the optic tract.

Peck and Lindsley (1972) conducted a similar study with cats trained to make an operant discrimination between one and two flashes of diffuse light. Evoked potentials were recorded at the optic tract, the LGN, and the cortical levels to the presentation of either one or two equal luminance light flashes at various ISIs. A decrement in discrimination performance and a concommitant overlapping of the VERs to the two stimuli of the pair was observed as the ISI was shortened. At short ISIs (below 20 msec) where performance was at a chance level, the evoked potential to the pair of flashes resembled a response to a single flash. While there appeared to be temporal interference at all levels of the visual system, (temporal interference being defined as the overlapping of the individual electrophysiological responses to the individual stimuli of the pair) analysis of residual VERs to the second stimulus of the pair indicated relatively greater postchiasmal influences. As the ISI was shortened below 60 msec, there appeared to be latency and amplitude changes in the residual VER at the LGN level and above. However, the validity of the residual VER in this study is questionable, since changes in the latency and amplitude of the residual response waveform did not parallel the behavioral performance, as was the case in previous studies where the residual VER closely corresponded to the perceptual responses.

It may be concluded from these two studies (Fehmi, Adkins, Lindsley, 1969; Peck and Lindsley, 1972) that the evoked potential data indicates that electrophysiological temporal interference exists as far in the periphery as the retinal ganglion cells of the optic tract in the monkey and cat. But because evoked potentials reflect activity generated from a mass of neural units, temporal integrity may possibly exist at the single cellular level, yet go undetected in the gross VER. For example, two rapidly presented sequential stimuli may be processed over two separate parallel neural paths. Yet, because one is recording from a mass of neural units the evoked potential, which reflects the average sum of all individual unit activity, would not necessarily indicate such temporal integrity.

In a subsequent study, therefore, Peck and Lindsley (1973) looked at both single unit activity and evoked potentials at the optic tract level in acutely prepared cats under the same stimulus conditions of the previous study (Peck and Lindsley, 1972) in which behavioral data had been collected. Neural activity was measured under both light and dark adaptation conditions. It was observed that the activity of only half of the units recorded under light adaptation and only one third of the units recorded under dark adaptation demonstrated activity parallel to the evoked potential responses, wherein two discrete responses from a given unit would be given to the pair of stimuli until the ISI was shortened to the point where perceptual and electrophysiological fusion would have occurred. In light of the small proportion of units that gave temporal responses, the authors rejected the notion that only a small, fixed number of units are specialized for temporal discrimination in favor of the interpretation that under a different set of stimulus conditions there are different sets of neural units that are optimally sensitive to making temporal discriminations in terms of their fast recovery rates. This interpretation is based on the observation that there was a difference in the percentage of units that would respond temporally under light and dark adaptation conditions.

In a study by Cenen and Eijkman (1972), single unit activity was recorded from the optic tract and LGN fibers of cats to the presentation of stimuli which, if shown to a human subject, would result in either backward or forward masking. The results suggest that temporal interference may be localized in retinal mechanisms. They found that the processing of a single photic stimulus at the unit level may be characterized by the firing of an on-center cell followed by the firing of an off-center unit, while the processing of two discrete stimuli is characterized by this alternate unit activity occurring twice. The backward masking condition in this experiment consisted of a short, 2 msec in duration test flash being followed by a longer 40 msec in duration masking flash of equal luminance. It was observed that the response duration of the on-center units, in conjunction with the combined behavior of the on- and off-center units, was responsible for the backward masking. So when only one flash is perceived while two are presented, the on-center unit fires only once followed by the firing of the off-center unit. It was concluded that backward masking appeared to be due to two effects: a) the long latency of the on-response excitation of the on-unit to the test flash which results in an overlapping of the on-response with the second, masking stimulus as the ISI is shortened and b) the off-response activity is suppressed as the two on-center excitations begin to overlap.

In the forward masking condition, the long duration masking stimulus preceeded the short duration test stimulus. Lateral inhibition seemed to account for the suppression of the activity attributable to the test stimulus. There was a suppression of the on-center excitability to the second, test stimulus through inhibition attributable to the first stimulus. In both forward and backward masking, therefore, the important factor that determines whether temporal integrity will be maintained is the alternating activity of the on-center and off-center units for each separable unit in time.

Schiller (1968) also investigated masking phenomena in the single LGN units of cats and demonstrated how the antagonistic center-surround organization of the receptive fields may play a role in determining temporal interaction. It was observed that the interaction varied as a function of both how the test and masking stimuli were presented to different parts of the receptive field and the relative intensity of the test and masking stimuli. When a 1° disc, test stimulus followed by a 2° disc of a higher relative intensity are presented within the 3° center of an on-center receptive field, backward masking resulted. The unit activity attributable to the masking stimulus progressively infringed on the activity due to the test stimulus as the ISI was shortened, until, eventually, the response to both stimuli resembled that to the masking stimulus alone. When the two stimuli were equal in intensity, however, reduction of the ISI ultimately resulted in temporal summation. That is, the response to both stimuli was greater than the response to the masking stimulus alone.

When the two stimuli were presented to the center of an off-center receptive field, the relative intensity of the test and masking stimulus was less important. The response to the first stimulus was decreased as the ISI was decreased until it was completely absent. Such backward masking was reported regardless of the relative intensities of the test and masking stimuli.

When the test and masking stimuli were presented within the on-center and over the entire portions of the receptive field, respectively, and were of the same intensity, backward masking also resulted. In this situation, however, near complete masking was found at ISIs longer than those obtained when both stimuli were presented within the center of the field. It was speculated that this effect was primarily due to lateral inhibition effects. It, therefore, appears that electrophysiological masking phenomena at the

LGN and retinal level can be attributed both to the temporal overlapping of unit activity and to the antagonistic activity of the center and surround of the receptive fields.

A number of studies have been directed toward ascertaining the contribution of both peripheral and central factors in temporal processing by investigating masking conditions where both the test and masking stimuli are presented to the same eye (monoptic conditions) or where the test stimulus is presented to one eye and the masking stimulus to the other (dichoptic conditions). In the former situation, both central and peripheral factors would presumably be involved, whereas in the latter situation, mechanisms central to the optic chiasm would be involved. Kietzman, Boyle, and Lindsley (1971) psychophysically examined both forward and backward masking under both monoptic and dichoptic conditions in order to separate central from peripheral effects. Under the monoptic conditions in which the test flash and the more intense masking flash fall on the same retinal location, both forward and backward masking were observed. Under the dichoptic conditions in which the test flash is presented to one eye and the masking stimulus is presented to the other, only partial backward and no forward masking was observed. This suggests that forward masking is due to peripheral processes, while backward masking may encompass both central and peripheral processes.

Sturr and Battersby (1966) have recorded evoked potentials at both the LGN and the cortex of cats while presenting, either monoptically or dichoptically, a test flash followed by a more intense blanking flash. While both forms of stimulation depressed cortical excitability, monoptic stimulation elicited greater and longer lasting effects in comparison to dichoptic stimulation. With monoptic stimulation, increasing the blanking flash duration or intensity prolonged the recovery cycle at both LGN and cortex. With dichoptic presentation, the recovery was relatively shorter and did not reflect the blanking flash parameters. Interocular interactions could not be observed at the LGN. These data also suggest that both peripheral and central processes may be separately involved in temporal processing of visual information.

Schiller (1965) and Schiller and Weiner (1963) have conducted several psychophysical studies using both pattern and diffuse stimuli as masking stimuli under both monoptic and dichoptic stimulation conditions. Masking of letters of the alphabet by diffuse light occurred primarily under monoptic conditions only, while masking with a checkerboard pattern occurred both monoptically and dichoptically. It was concluded that two different processes may be involved in pattern as opposed to diffuse stimulus masking, since a) decreasing the ISI seemed to increase pattern masking more than diffuse masking, and b) the magnitude of the pattern masking seemed to be more susceptible to practice effects than diffuse masking.

Turvey (1973) who has conducted a series of extensive psychophysical studies to ascertain the nature of central and peripheral factors in masking situations has also concluded that several distinct processes may be involved in the different masking situations. Peripheral forward and backward masking are related to energy parameters such as test stimulus size and intensity and ISI. Peripheral forward masking is more pronounced than peripheral backward masking. While energy variables significantly effect the direction and extent of peripheral masking they had relatively small effects on cortical contributions to masking as evidenced under the dichoptic presentation conditions. In comparing central forward and backward masking, forward masking was relatively weak compared to backward masking and tended to delay rather than impair the perception of the target stimulus. Backward masking of a central nature seemed to be related more to temporal rather than energy factors with onset-onset time of the test and masking stimuli being the important variable.

In summarizing the experimental findings on temporal visual processing, one must conclude that there is a limitation on how rapidly the nervous system can process visual information. From an electrophysiological perspective, this limitation is based on the fact that the electrophysiological response to a given stimulus is longer in duration than the stimulus itself (Brown, 1968; Bartley and Bishop, 1933). Therefore, as two stimuli are brought in close temporal proximity, the electrophysiological response of the two stimuli will start to overlap, resulting in temporal interference. The infringing of responses to two discrete stimuli has been correlated with perceptual fusion and masking in a number of studies. Temporal interference has been observed at all levels of the visual system through evoked potential and single unit activity. In order to assess how other stimulus parameters (intensity, spatial frequency, etc.) influence temporal processing, it appears judicious to investigate and view temporal processing in terms of the response latencies and recovery cycles of the individual neural structures responsible for processing a given stimulus.

Spatial-Temporal Coding

The metacontrast paradigm has provided a convenient tool for investigating the nature of spatial-temporal aspects of visual coding. Metacontrast entails the sequential presentation of two stimuli at two distinct retinal locations. Usually this involves the presentation of a test stimulus disc followed by the presentation of an annulus whose inner circumference coincides with the outer circumference of the disc. There has been some controversy over the lack of correspondence between the perceptual reports and the physiological responses as the interval between the two stimuli is varied.

Psychophysical measures of metacontrast typically reflect an inverted U-shaped function between ISI and visual threshold. For example, Schiller and Chorover (1966) reported an inverted U-shaped function relating the perceptual brightness of the disc to the length of the ISI interval. At short ISIs (0-10 msec.) the disc and annulus appear equally bright, while at intermediate ISIs (40-100 msec.) the disc is completely masked and only the annulus is perceptible. At long ISIs (200-250 msec.) the disc retains its equal brightness to the annulus. The difference between the effects of metacontrast and masking on the visual threshold is quite apparent. While under the metacontrast situation there is the inverted U-shaped function between ISI length and temporal interference, the relationship is linear with the usual masking paradigm. This difference is most probably due to differences in the interaction between temporal and spatial factors in the two procedures.

Under the metacontrast paradigm, Schiller et. al. (1966) collected both human psychophysical responses and VERs as a function of the ISI length. No change in the initial components of the VER attributable to the disc was reported which would correspond to the perceptual fading of the disc under the various ISIs. Schiller (1968), in an attempt to demonstrate that the effect may be due to lateral inhibition effects, found no electrophysiological correspondence at the single unit level of the LGN in the cat when the disc and annulus were centered respectively on the center and surround portions of an on-center unit's receptive field. Lawwill (1973) recording VERs, in both normal and amblyobic subjects, also found that the VER to the target stimulus in the metacontrast paradigm did not reflect the perceptual reports. The VER to the target stimulus was present at both the occipital and parietal areas despite the fact that it was phenomenally absent.

The findings of Schiller _et_. _al_. (1966) have been called into question by Vaughn and Silverstein (1968) who found a modification to the VER in a metacontrast phenomena by utilizing a different analysis technique. By measuring the area under the 150-275 msec positive VER component, there was a correlation between magnitude of this area and perceptual brightness of the test stimulus. These authors also claim that the reason Schiller and Chorover did not observe a perceptual-electrophysiological correlation was that their stimuli were presented to the parafoveal visual field and the VER may have been contaminated by scattered light falling on the fovea. However, Lawwill exercized procedural controls to prevent this possibility and still replicated the Schiller and Chorover findings. Lawwill has criticized Vaughn and Silverstein's data analysis technique, claiming that an increase in the area under the positive VER component may be due to changes in the baseline due to changing the temporal proximity of the masking stimulus. The neural processes involved in metacontrast and the locus of this form of temporal interference have yet to be clearly established.

Weisstein and Bisaha (1972) have investigated spatial-temporal coding by using a temporal visual masking paradigm to demonstrate that the processing of stimulus size entails a spatial frequency analysis. Bars and square wave gratings of the same width and orientation were used as both test and masking stimuli, while psychophysical measures of the contrast sensitivity to the test stimulus were collected. Results of this study lend credence to a spatial frequency interpretation of visual processing, since it was found that, when a bar preceeding a grating by a short period of time (5-30 msec.), the apparent contrast of the grating was degraded over the entire grating field (forward masking). It was also observed that a grating did not mask a bar as effectively as another bar would. This suggests that the visual system is not merely coding the size of a stimulus. If size coding alone were responsible for the neural processing, the bar should have had little effect on the grating except at the point on the stimulus display where the bar and grating coincided. Likewise, a grating should have masked a bar as effectively as another bar would, if stimuli were processed according to size.

Besides offering additional evidence in support of the spatial frequency analysis of visual processing, the Weisstein and Bisaha (1972) study offers an approach to investigating the processing of visual information in light of both spatial and temporal characteristics. The results of their study seem to suggest that it is possible to investigate the existence and characteristics of spatial frequency channels by interfering selectively with the temporal processing of a limited group of these channels. In other words, in the Weisstein and Bisaha (1972) study it was observed that more temporal interference in terms of visual masking occurred when the spatial frequency composition of the two stimuli were more similar. This suggests that both spatial frequency and temporal processing is channel specific.

Conclusions

The above review has presented both psychophysical and physiological findings related to how the visual system processes stimuli in terms of their spatial size and temporal integrity. From this discussion, it appears that the visual system is composed of channels which are limited in their responsiveness in two respects: a) the range of spatial frequencies to which they can respond, and b) the rate at which they can respond to the sequential presentation of stimuli. The primary purpose of this study is to examine how limitations on temporal processing of visual input influence the neural processing of spatial information. The spatial size selectivity of the visual system will be investigated by interfering with the temporal integrity of spatial information using a masking paradigm. It is assumed that temporal interference is channel specific and that channels are spatial frequency selective. On the basis of these assumptions, it is predicted that more temporal interference, and, thus, greater masking effects, will be obtained as the spatial frequency of two rapidly presented sequential stimuli becomes more similar. If two stimuli are composed of disparate spatial frequencies and, thus, are processed in different channels, there should be less temporal interference and masking; if the spatial frequency components of the stimuli are identical and, thus, are processed in the same channel, there should be more temporal interference and masking.

The present study will investigate visual masking at both the psychophysical and electrophysiological level as a function of the spatial pattern of the two stimuli involved. Previous work has shown that the wave-form and amplitude of the VER components are sensitive to pattern size (Harter and White, 1970). This differential response of the VER to pattern size will be used as an indicant of pattern information processing as a function of the masking paradigm parameters.

The controversy over the perceptual-electrophysiological relationship in the metacontrast experiments mentioned above brings forth a secondary problem which exists in all electrophysiological studies of sequential temporal processing. How does one go about analyzing and discriminating the responses to two successive stimuli when the responses are in such close temporal proximity that one response overlaps in time with the other? This problem becomes particularly difficult when one is concerned with VERs to multiple stimuli in close temporal proximity. This difficulty partially explains the various analytic techniques used in different studies. Some authors have looked at the addition of successive VER components with the addition of successive stimuli (Harter and White, 1967; Andreassi, _et_. _al_., 1971), some have looked at excitability cycles in response to successive stimuli (Bergamasco, 1966; Sturr and Battersby, 1967), some have assumed an additive model of VERs and looked at residual responses to portions of the stimulus sequence (Donchin and Lindsley, 1965; Donchin, _et_. _al_., 1963; Fehmi, _et_. _al_., 1969), and still others have assumed such an additive model, yet have found weak relationships between residual responses and perceptual events (Peck and Lindsley, 1972).

It thus becomes apparent that in order to use the VER as a measure of spatial-temporal coding, it is necessary to establish an analytical approach which will overcome the difficulties attributable a) to the multidimensional nature of the stimulus configuration employed, b) to the complex topographical nature of the VER, and c) to individual differences in the VER waveform. A secondary purpose of the present study will be to describe such a technique wherein measures of variability, which are indicative of effectiveness of electrophysiological stimulus processing, will be obtained and quantified for successive latencies of the VER.

Method

Experimental Design

Visually evoked responses were obtained to a pair of light flashes (interflash interval fixed at 40 msec). The effects of the pattern within each flash of the pair and the order of presentation of the various patterns was investigated. Both diffuse light and checkerboard patterns were used as stimuli. Patterns were reproduced on transparency film and consisted of white and black squares, with the ratio of white and black being equal. Three check-sizes were used, subtending a visual arc of 7.5,30, and 60 min. The fourth stimulus was a diffuse transparency with luminance transmittance equal to the checkerboards.

Given four different stimuli and that each stimulus was presented singly (four control conditions) and in all possible pairwise combinations (16 experimental conditions) a total of 20 different stimulus configurations or conditions were used. Since the stimulus projector could hold only eight stimulus slides at any one time, only four pairs of stimuli could be presented on a given trial. It, thus, became necessary to group the twenty different stimulus configurations into five groups of four pairs each.

Each subject participated in four experimental sessions conducted on four different days, each session consisted of a full replication of each of the 20 stimulus configurations. While the 20 configurations were grouped into five groups, no subject received the same group of four more than once. Configurations were grouped using a Latin square design (Winer, 1971) and groups were counterbalanced within subjects, so that the position of configurations was not confounded with time in the experimental session. Therefore, a given experimental session consisted of five blocks of trials. Each block consisted of four stimulus configurations, each configuration being presented 32 times in random order.

Subjects

Four subjects between the ages of 25 and 28 participated in the experiment. All subjects had corrected visual acuities of 20/20 or better and were previously familiar with data collecting procedures in the lab. All subjects were informed to keep movement at a minimum, to maintain visual fixation, and to remain alert during the experiment. Since subjects had no previous experience with psychophysical visual masking experiments and since it has been reported that psychophysical reports in visual masking studies are very susceptible to early experiental changes (Schiller, 1965), all subjects were exposed to several trial runs prior to the experiment.

Visual Stimuli and Psychophysical Task

Stimuli were presented using a multiple stimulus projector which consisted of a disc on whose periphery eight

3¼" x 4" stimulus transparencies were mounted. The disc was rotated by a variable speed motor. The slides were back-illuminated (strobed) by a 10 μ sec flash from a Grass PS 2 photostimulator as they passed in front of the viewing window. The photostimulator was synchronized with the rotating disc by means of photo-transistors in conjunction with Lehigh Valley solid state equipment. The stimulator allowed stimuli to be presented either one at a time or in rapid pairwise succession. The rate of sequential stimulus presentation or the inter-flash interval (IFI) for the stimulus pair was controlled by the speed of the rotating disc. In this experiment stimulus pairs were presented with a 40 msec IFI. This IFI value was chosen both because previous psychophysical studies indicated temporal interference of pattern stimuli at this interval and pilot psychophysical data in the present conditions resulted in temporal effects. The IFI was monitored via a Dumont 708A two channel oscilliscope and found to be stable over the entire experimental session. For all stimulus configurations, a 2.5 sec interval was placed between each presentation. Stimuli were also presented in random order to maintain a high attentional state throughout the experimental session.

The illumination of the stimulus display and visual fixation was controlled in the following manner. The subjects foveally viewed the light flashes through an American Optical Phoropter which was used to hold artificial pupils (2mm) and to control the eye to stimulus distance (74.2 cm). A black screen was placed immediately in front of the rotating disc. A 3.85^{o} window, bordered by a white circular frame, was cut in the screen through which the strobed transparency was viewed. The window frame was constantly illuminated with a 1 log unit above threshold light source so that the subjects could fixate the center of the window. The luminance of the light flash was 3.5 log units above ambient level of illumination.

A psychophysical report was taken during the experimental session by having the subjects verbally identify the stimulus or stimuli presented. Verbal responses were heard over an intercom and recorded by the experimenter. When two stimuli were presented and identified as two, the subjects were asked to verbally report the most "vivid or perceptible" of the two first. The study was designed around the VER data collection procedures, and the sensitivity of the psychophysical measure was limited to a dichotomous response. By responding to each stimulus presentation, attention to all stimuli was kept consistent over the entire experimental session.

Visual Evoked Responses

Evoked cortical responses to the visual stimuli were recorded monopolarly by means of a gold cup scalp electrode placed 2.5 cm above the inion on the midline. The reference electrode was attached to the right earlobe and resistance between the two electrodes was kept below 10,000 ohms by means of Redux electrode paste. Cortical activity was amplified with a Grass Model 7wc polygraph through a wide band Model 7P5A AC EEG preamplifier with ½ amplitude high and low frequency filters set at 35 and 1 Hz, respectively.

A Datacom Alpha 16 computer system was used to average cortical activity for 500 msec after stimulus onset. One-hundred data points, each having a dwell time of 5 msec were allocated to each VER. The summation average of 32 responses to each of the 20 stimulus configurations was stored and then recorded on binary tape via an ASR-33 teletype tape punch for future data analysis.

Electroencephalograms were monitored for movement and other artifacts by visual inspection of the polygraph chart record and the Hewlett Packard 141A variable persistent oscilliscope. The experiment was conducted in an electrically shielded, sound-attenuated room into which a sufficient level of white noise was piped to mask any extraneous sounds generated by the experimental equipment.

VER Data Analysis

A modification of a variance analysis procedure described by Harter, Seiple, and Salmon (1973) was used to quantify the degree of stimulus size and neural masking effect on VERs as a function of the different stimulus conditions. When the four stimuli (D, 7.5, 30, and 60 min checkerboards) were presented alone for the control conditions, the variability (V_c) in the resulting VERs reflect the stimulus size effect per se, there being no temporal interference. The magnitude of the stimulus size effect was measured by computing the variance of the four VERs (to the four stimuli) about their mean ($V_c = \Sigma X^2 - (\Sigma X)^2 /4$, where X is amplitude of a given data point). This variance measure was obtained for each of the 100 data points composing the averaged VER.

The same procedure was followed in order to assess the effects of stimulus size and order when pairs of stimuli were presented except the variance, due to changing the pattern size presented in one flash was obtained when the pattern presented to the other eye was held constant. The variance measures in the paired flash situation, therefore, reflected the responsiveness of the VER to different sized checks flashed on one temporal position as a function of a given pattern flash either before or after the variable stimulus. When the first flash was fixed and the second flash variable (D-v, 7.5-v, 30-v, and 60-v), changes in the magnitude of the variance measure would reflect forward masking--that is, the change in the magnitude of pattern-size effect as a function of the preceeding flash. When the first flash was varied and the second flash fixed (v-D, v-7.5, v-30, and v-60) changes in the magnitude of variance measures would reflect backward masking. For example, in order to assess the extent to which a first diffuse flash (D) masked the second flash, the variance due to D-v (D-D, D-7.5, D-30, and D-60) was computed. If there was complete forward masking, the variance due to D-v would equal zero. A complete description of the stimulus configurations used to obtain the eight variance measures is given in Table 1.

Results

Visual Evoked Responses

In analyzing the electrophysiological data, first it was demonstrated that the different size stimuli, when presented singly in the control conditions, elicited differential VERs. The VER to each of the four control stimuli for each subject and the variability measure(V_c) indicating variations in responses to the four control stimuli about their mean are presented in Figure 1. For all four subjects, check-size had the greatest effect on VER activity 110 msec after stimulation as evidence by the prominant V_c peak at this latency. The variability was due to the inversion and change in amplitude of this portion of the VER as the stimuli were varied from D, 15, 30, to 60 min of arc. An inverted "U-shaped" function between the pattern size and the amplitude of the activity of the VER at the 110 msec latency was observed, with the 7.5' and 30' check-size patterns eliciting the largest potentials ($P<0.005$).

It should be noted that while the wave-form of the individual subject's VERs differed to some extent, the latency is fairly uniform at which variability due to stimulus size

TABLE 1

DERIVATION OF VARIANCE MEASURES USED TO ASSESS FORWARD AND BACKWARD MASKING OF DIFFERENT SIZE STIMULI

		Forward Masking		Backward Masking	
Stimulus Size (min. of arc)	D	Dv	D-D D-7½ D-30 D-60	vD	D-D 7½-D 30-D 60-D
	7½	7½v	7½-D 7½-7½ 7½-30 7½-60	v7½	D-7½ 7½-7½ 30-7½ 60-7½
	30	30v	30-D 30-7½ 30-30 30-60	v30	D-30 7½-30 30-30 60-30
	60	60v	60-D 60-7½ 60-30 60-60	v60	D-60 7½-60 30-60 60-60

processing occurred. The VERs, therefore, were combined and averaged across the four subjects and are displayed in the right column of Figure 1. The wave-form of these average responses, while not exactly resembling any one particular subject, do reflect the significant and characteristic changes in the VERs of individual subjects as the stimulus was varied from diffuse to patterned light.

The variability reflecting the effects of check-size in the first and second flash in pairs of stimuli for both individual subjects and for the average across the four subjects, indicate two major variability peaks, one at 110 msec and the other at 150 msec (Figure 2). The VER data (grouped across subjects and replications), from which the average variability measures shown in the right column of Figure 2 were obtained, are shown in Figure 3 and discussed below. The fact that the two stimuli of the pair were presented 40 msec apart and that when stimuli were presented alone there was a peak variability at 110 msec, makes it reasonable to assume that the second variability peak 40 msec later at a 150 msec latency reflects the variability in response to the second stimulus of the pair.

In order to assess the origin of variability, it was necessary to conduct two analyses on the raw VERs measuring the maximum VER amplitude of negative deflection at latency windows of 110 ± 10 msec. The size of checks in the first

FIGURE I

The effects of checkerboard pattern size (D, 7.5', 30' and 60') on the VERs from each of the four subjects (JK, LS, LW, and GF) and the average response across the four subjects (AVE.). Each VER tracing is the average response to 128 single stimulus presentations. The bottom row represents the variability, V_c, in the VER at successive 5 msec latencies attributable to the differential responses to the four pattern stimuli. Negativity up.

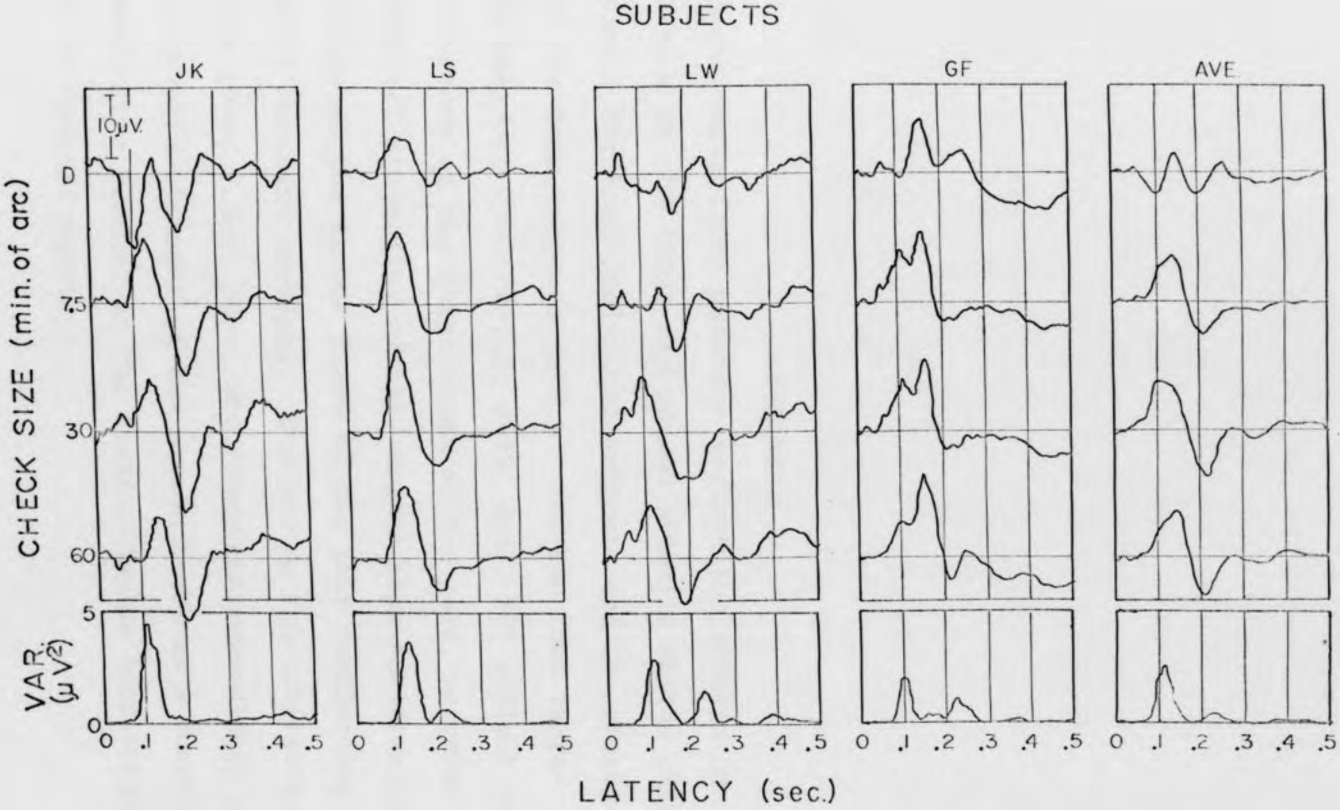

SUBJECTS
JK
LS
LW
GF
AVE.
10μV.
CHECK SIZE (min. of arc)
D
7.5
30
60
VAR. (μV²)
5
0
0 .1 .2 .3 .4 .5
LATENCY (sec.)

FIGURE 2

The eight variability measures reflect the effects of check-size in the first and second stimulus in the pairs of stimuli for both individual subjects and the average across the four subjects (AVE.). The top four variability measures (v-D, v-7.5, v-30, and v-60) reflect the effectiveness of the first flash of the pair, in terms of differential processing of the various size patterns, as a function of the second flash of the pair (reflecting degree of backward masking). The bottom four variability measures (D-v, 7.5-v, 30-v, and 60-v) correspondingly reflect the effectiveness of the second flash as a function of the check-size flashed in the first stimulus (reflecting degree of forward masking).

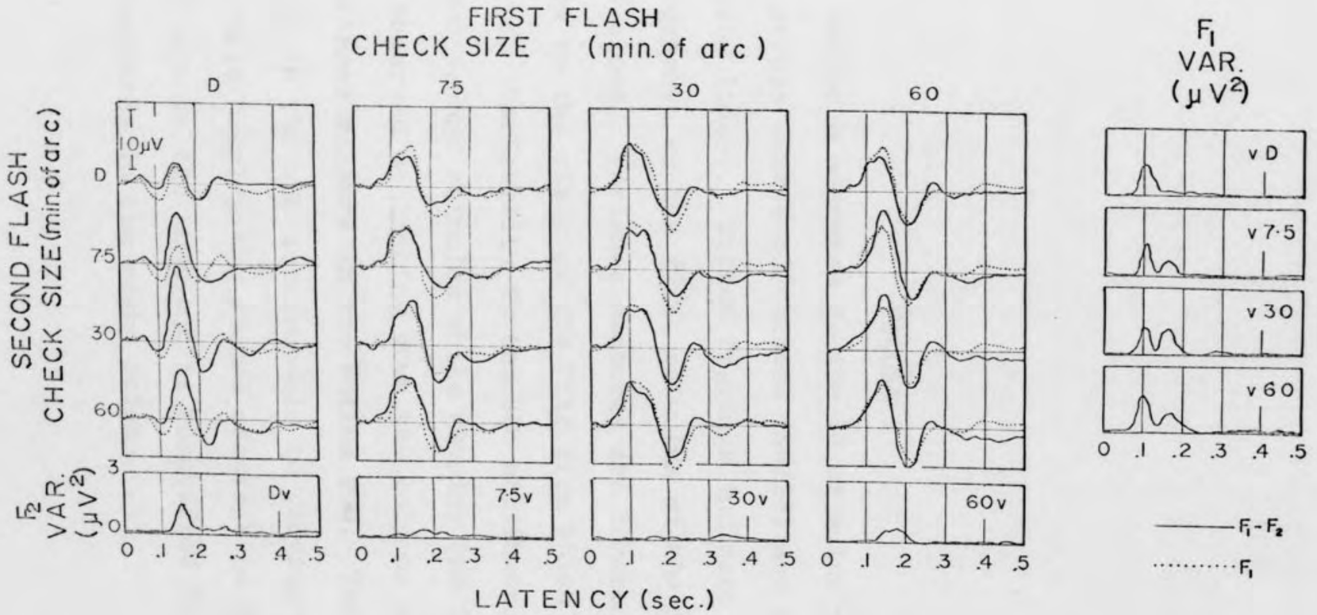
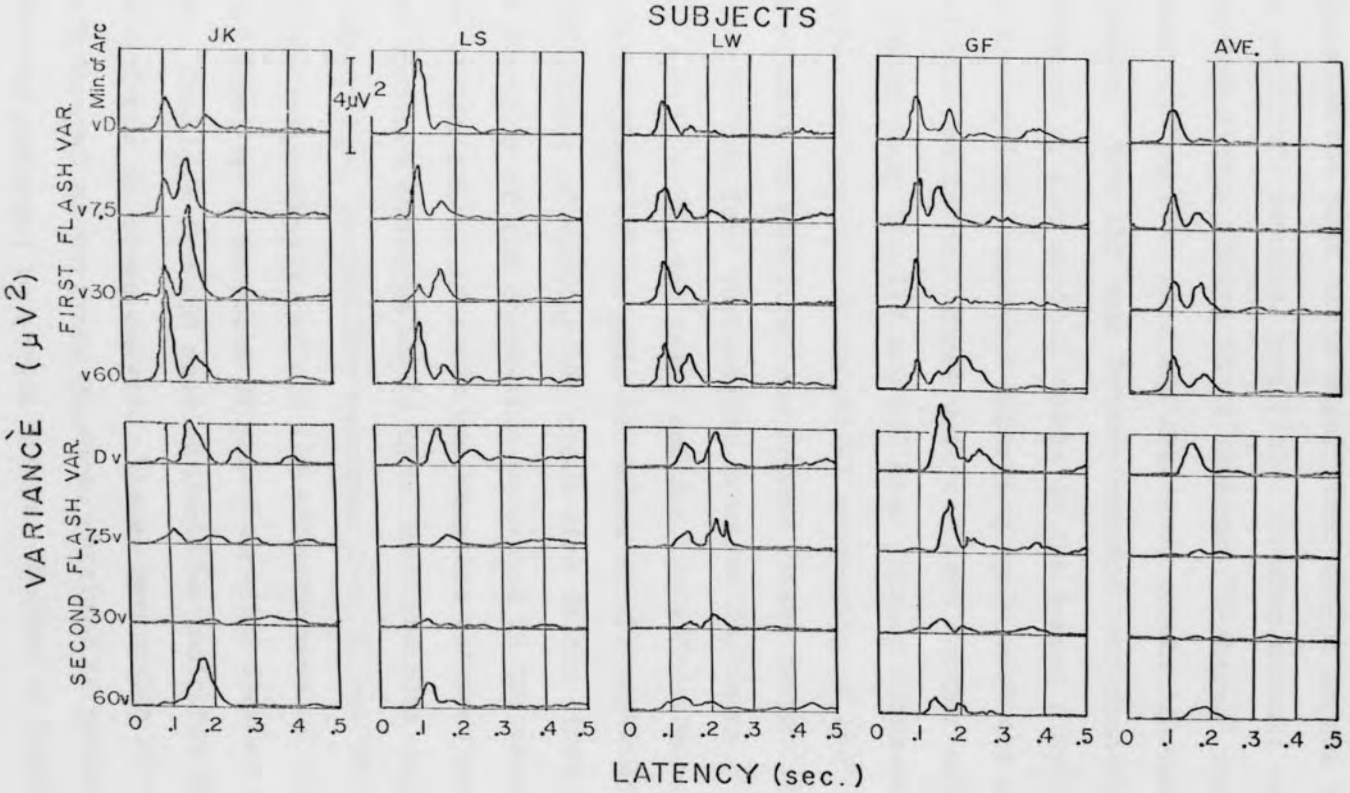

FIRST FLASH
CHECK SIZE (min. of arc)
D
7·5
30
60
SECOND FLASH
CHECK SIZE (min.of arc)
D
7·5
30
60
10μV
F_2 VAR. (μV^2)
3
0
Dv
7·5v
30v
60v
0 .1 .2 .3 .4 .5
LATENCY (sec.)
F_1 VAR. (μV^2)
v D
v 7·5
v 30
v 60
$F_1 - F_2$
F_1

FIGURE 3

VERs and variance measures to the 16 stimulus pairs, averaged across four replications (N=128) and four subjects (solid lines). Dotted tracings indicate the average response to the first stimulus of the pair when presented alone. Variance measures are located at the bottom and to the right of the VERs from which they are derived. Variability in the VER attributable to varying the second stimulus while keeping the first constant is observed by looking down the columns and quantified in the variance measure in the bottom row. The variability in the VER attributable to varying the first stimulus while keeping the second constant is observed by looking across the rows and is quantified in the variance measures in the right column.


SUBJECTS
JK
LS
LW
GF
AVE.
Min. of Arc
4μV^2
vD
v7.5
v30
v60
Dv
7.5v
30v
60v
FIRST FLASH VAR.
SECOND FLASH VAR.
VARIANCE (μV^2)
0 .1 .2 .3 .4 .5
LATENCY (sec.)

stimulus of the pair had a significant effect on the 110 msec amplitude measure ($p<0.025$). As when stimuli are presented singly, there is an inverted "U-shaped" function between the pattern size and amplitude of the 110 msec VER component. The 150 msec latency measure correspondingly was influenced by the size of checks in the second flash ($p<0.01$), with the maximum responses occurring again with the more modal size patterns. These analyses lend further support to the notion that the 110 and 150 msec latency variance measures reflect the differential processing of the various size stimuli in the first and second flash, respectively.

The top four variability measures in Figure 2 (v-D, v-7.5, v-30, and v-60) reflect the effectiveness of the first flash of the pair (in terms of the magnitude of the effect of varying the check-size in the first flash) as a function of the check-size presented in the second flash of the pair. If there was complete backward masking, these variance measures would equal zero (be flat lines). The bottom four variability measures (D-v, 7.5-v, 30-v, and 60-v) correspondingly reflect the effectiveness of the second flash as a function of the check-size flashed in the first. Complete forward masking would be indicated by zero variance in these curves. Visual inspection of the data indicated a) variance measures obtained to pairs of flashes as compared to single flashes (bottom of Figure 1) were generally reduced, thus, indicating both forward and backward masking, and b) variance measures were greater when the first as compared to the second flash was varied, thus indicating greater forward masking.

In order to statistically assess the relative effectiveness of each of the four stimuli as both a forward and backward masker, paired comparison t-tests were conducted on the following variance pairs for peak variability amplitudes at the 150 and 110 msec latencies respectively: D-v and v-D; 7.5-v and v-7.5; 30-v and v-30; and 60-v and v-60. It was found when pattern stimuli were used, the electrophysiological effects of the first stimulus were relatively greater than the effects of the second stimulus (7.5-v vs. v-7.5, 30-v vs. v-30, and 60-v vs. v-60 significantly different at $p < 0.025$); whereas when diffuse light was used there was no difference between the degree of forward as compared to backward masking (v-D vs. D-v did not differ significantly, $p > 0.05$). Therefore, under the present stimulus conditions, when two pattern stimuli of mean equal luminance are presented 40 msec apart, forward masking at the electrophysiological level seemed to prevail. Observing the variability measures associated with the diffuse stimulus, D-v and v-D, it is apparent that the diffuse stimulus had little effect in suppressing the processing of pattern stimuli in either the forward or backward masking conditions.

An analysis of variance on D-v, 7.5-v, 30-v, and 60-v variability measures (at the 150 msec latency) indicated that the four stimuli were differentially effective as forward maskers ($p < 0.05$). The 30' pattern was most effective in suppressing the effects of the second stimulus as indicated in the bottom portion of Figure 2.

Looking at the variability measures, v-D, v-7.5, v-30, and v-60, which indicate the effectiveness of the first flash of the pair as a function of the second flash of the pair (backward masking), there was a certain degree of variability for all subjects at the 150 msec latency. If variability at this latency reflects the processing of the second stimulus and the second stimulus is being held constant under these conditions, variations in this measure at the 150 msec latency could be due to interaction effects between the first stimulus of the pair and the second stimulus which remains constant. Two subjects, JK and LS, showed an interesting relationship between the magnitude of the variabilities at the 110 and 150 msec latencies as a function of the second stimulus. Both subjects showed a decrement in variability at the 110 msec latency and a concommitant increase in variability at the 150 msec latency when the second stimulus was either the 7.5 or 30 min pattern. The exact nature of this interaction is yet to be ascertained, but it may be in some way related to the effective nature of these size pattern stimuli as backward maskers. For example, the decrement in the 110 msec latency variability suggests backward masking of the first stimuli of the pair, and the 150 msec latency variability could be due to the differential interaction effects between the first stimuli of the pair and the second stimulus (7.5 or 30 min).

In Figure 3, VERs and variance measures to the 16 stimulus pairs, averaged across four replications and four subjects, are shown. Variability in the VERs attributable to varying the second stimulus while keeping the first constant may be observed by looking down the columns. Variability in the VERs attributable to varying the first stimulus and keeping the second constant may be observed by looking across the rows. This variability, quantified as variability measures as described above, are presented at the bottom and to the right of the present figure. The VERs and the variability measures demonstrate that when the first stimulus is patterned, there seems to be little difference in the VERs as a function of the second stimulus.

Forward masking and electrophysiological predominance of the first stimulus of the pair, when patterned, may be directly observed by comparing the VER to pairs and single flashes (solid and dotted lines in Figure 3). When the first stimulus of the pair was patterned, there was a close resemblance between the VERs to the first stimulus presented singly and presented in conjunction with a subsequent stimulus. However, when the first stimulus was diffuse, the VER to the pair of stimuli take on characteristics which are more indicative of the second patterned stimulus, suggesting little forward masking.

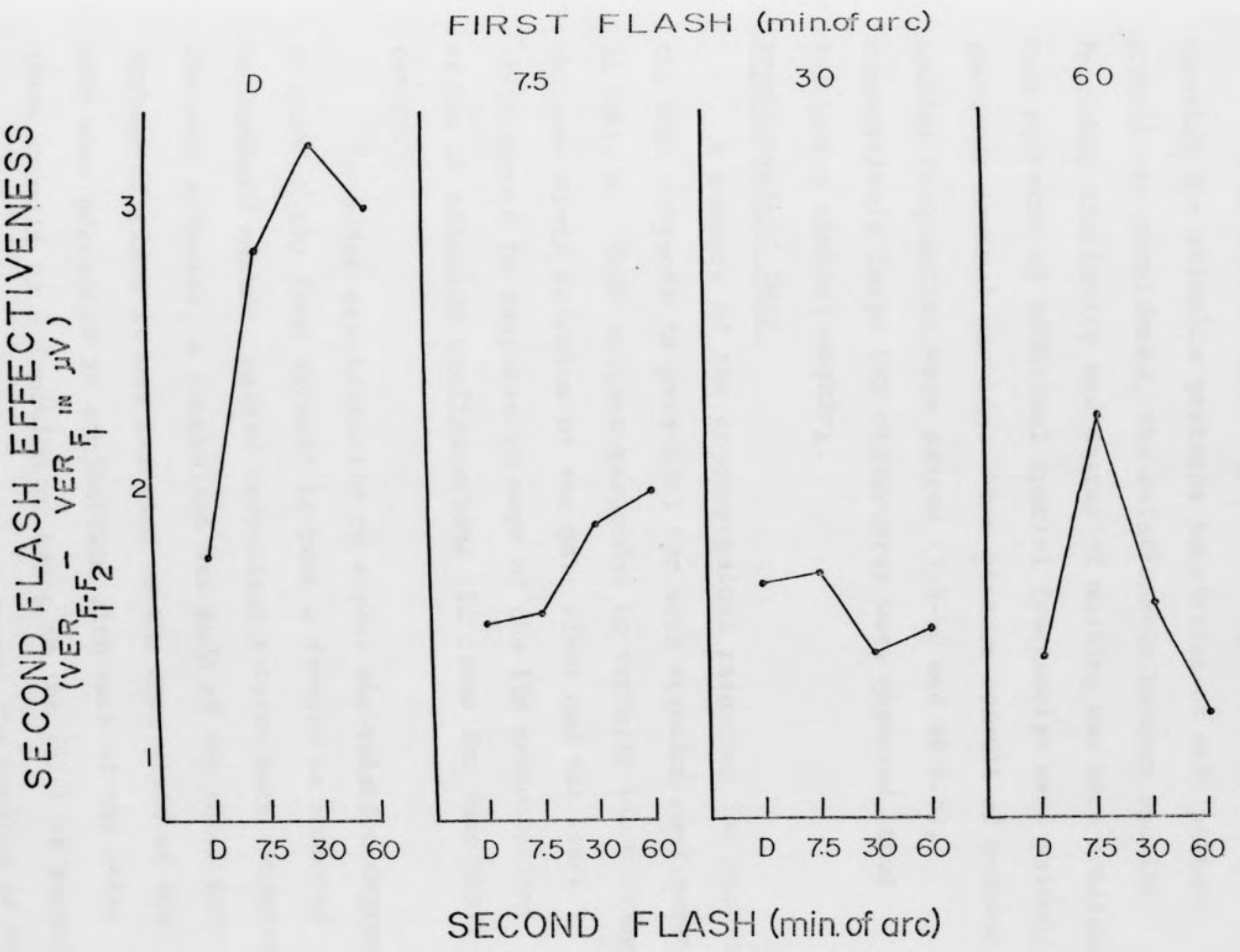
In order to more directly quantify the degree of forward masking and to assess the question of channel specificity in terms of spatial frequency selectivity, the following analytical steps were taken. Given that forward masking tends to dominate in this stimulus situation and the electrophysiological response is largely determined by the first stimulus of the pair, one may assume that any differences between the VER to the pair of stimuli and to the first stimulus when it is presented alone (See Figure 3) would be due to processing of the second stimulus. If visual masking is spatial frequency selective, the magnitude of this difference between the VERs should be influenced by the similarity of the spatial frequencies in the two stimuli composing the pair. When the two stimuli have discrepant spatial frequencies, thus bringing separate neural channels into play, in processing the first and second flash, there should be less forward masking and the magnitude of the difference in the VERs should be greater due to the contribution of the second flash. The greatest degree of forward masking and the smallest difference in the VERs would be expected when the two stimuli presented in the pair have identical spatial frequencies.

To quantify the magnitude of these differences, the average absolute difference in microvolts between the VERs to the pair of stimuli and to the first stimulus presented alone was integrated over the first 300 msec after stimulus onset. The average difference across all four subjects is illustrated in Figure 4 which shows both the relative forward masking efficiency of each of the four stimuli and the selective nature of this masking as a function of the second stimulus. These differences were computed for each subject across all 16 stimulus pairs and an analysis of variance was conducted. The effectiveness of the second flash, as indicated by the magnitude of the differences in the VERs to the flash pairs and to the first flash by itself, varied as a function of the check-size flashed in the first stimulus of the pair (interaction significant $p < 0.025$).

In all cases but one (7.5-D) the magnitude of the VER difference was smallest, thus indicating maximal masking, when the two stimuli were identical in spatial frequency. The fact that a comparatively small difference score resulted when the diffuse flash followed either the 7.5 or 60 min pattern possibly suggests that the diffuse stimulus does not belong on a linear scale with the pattern sizes. This is also evidenced by the observation that in both cases where diffuse and 60 min patterns were paired (D-60 and 60-D) there was a relatively small difference score, indicating some similarity between these two stimuli. In other words, diffuse stimulation may be more similar in electrophysiological consequences both to the smaller and larger size patterns than to the more modal size when stimulation is directed on the fovea in the present experimental situation.

FIGURE 4

The effectiveness of the second stimulus as a function of the check-size of the first was quantified by computing the average absolute difference in microvolts between the VERs to the pair of stimuli and the first stimulus of the pair when presented alone. This difference was integrated over the first 300 msec of stimulus onset and averaged across the four subjects.


FIRST FLASH (min.of arc)
D
7.5
30
60
SECOND FLASH EFFECTIVENESS
(VER F1-F2 − VER F1 IN µV)
3
2
1
D 7.5 30 60
D 7.5 30 60
D 7.5 30 60
D 7.5 30 60
SECOND FLASH (min. of arc)

If in assessing the spatial frequency selectivity question the stimulus patterns consisting of only pattern stimuli are considered, the relationship between spatial frequency similarity and degree of masking was very consistent. When patterns of identical spatial frequencies were paired, there was maximal masking. When pattern stimuli of extreme spatial frequencies were paired (7.5-60 and 60-7.5), comparatively large VER differences were observed, thus indicating minimal masking.

Psychophysical Data

A summary of the psychophysical responses for each of the four subjects is presented for each stimulus configuration in Table 2. Each subject responded by verbally identifying the most vivid stimulus of the pair first and the least vivid second in response to each of the 128 presentations of the 20 stimulus configurations (32 times for four replications).

In order statistically to assess the relative degree of each of the four stimuli as both a forward as compared to backward masker, paired comparison t-tests were conducted. For each stimulus, a comparison was made of the total percentage of times it was reported as the most vivid of the pair when presented in conjunction with each of the other three stimuli as a function of being in the first or second position of the sequence, e.g., to assess the masking of the "D" flash comparison (D-7.5) + (D-30) + (D-60) vs. (7.5-D) +

TABLE 2

SUMMARY OF PSYCHOPHYSICAL RESPONSES

Stimulus Configuration	Subjects JK	Subjects LS	Subjects LW
D	D(128)	D(128)	D(128)
7.5	7.5(128)	7.5(128)	7.5(128)
30	30(128)	30(128)	30(128)
60	60(128)	60(128)	60(128)
D-D	D(128)	D(128)	D(128)
D-7.5	7.5(128)	7.5(128)	7.5(128)
D-30	30(110); 30-D(18)	30(128)	30(96); 30-D(32)
D-60	60-D(108); 60(20)	60(128)	60(128)
7.5-D	7.5-D(76); 7.5(52)	7.5-7.5(126); D-7.5(2)	7.5(128)
7.5-7.5	7.5(128)	7.5-7.5(82); 7.5(9) 7.5-D(37)	7.5(92); 7.5-7.5(36)
7.5-30	30-7.5(128)	30-7.5(128)	30-7.5(127) 30-30(1)
7.5-60	60-7.5(126); 7.5-60(2)	60-7.5(128)	60-7.5(128)
30-D	30-D(69); 30(59)	D-30(45); 30-D(47) 30-30(16); 30(20)	30-D(91); 30(37)
30-7.5	7.5-30(128)	7.5-30(128)	7.5-30(128)
30-30	30-30(105); 30(9) 30-60(13); 30-7.5(1)	30-30(128)	30-30(128)
30-60	60-30(118); 30-60(10)	30-30(128)	60-30(126); 30-30(2)
60-D	60-D(127); 60(1)	D-60(71); 60-D(57)	60-D(128)
60-7.5	7.5-60(128)	7.5-60(128)	60-7.5(128)
60-30	30-60(40); 30-30(42) 30(46)	30-30(128)	30-60(128)
60-60	60-60(124); 60(4)	60-60(128)	60-60(128)

(continued)

TABLE 2
(Continued)

Stimulus Configuration	Subjects	
	GF	AVE.
D	D(128)	D(128)
7.5	7.5(128)	7.5(128)
30	30(128)	30(128)
60	60(128)	60(128)
D-D	D(128)	D(128)
D-7.5	7.5(128)	7.5(128)
D-30	30(125); 30-D(3)	30(115); 30-D(13)
D-60	60(128)	60(101); 60-D(27)
7.5-D	7.5-D(118); 7.5(10)	7.5-D(49); 7.5(47) 7.5-7.5(31); D-7.5(1)
7.5-7.5	7.5(60); 7.5-7.5(68)	7.5(72); 7.5-7.5(47) 7.5(9)
7.5-30	30-7.5(128)	30-7.5(128)
7.5-60	60-7.5(128)	60-7.5(127) 7.5-60(1)
30-D	30-D(123) 30(5)	30-D(83); 30(29) 30-30(4); D-30(12)
30-7.5	30-7.5(116); 7.5-30(12)	30-7.5(29) 7.5-30(99)
30-30	30-30(128)	30-30(122); 30-60(3) 30(3)
30-60	30-60(76); 30-D(32) 60-30(32)	60-30(66); 30-30(32) 30-60(22); 30-D(8)
60-D	60-D(94); 60(34)	60-D(102) 60(9) D-60(17)
60-7.5	60-7.5(92) 7.5-60(36)	7.5-60(73); 60-7.5(55)
60-30	30-60(121); 30-30(6) 30(1)	30-60(72); 30-30(44) 30(12)
60-60	60-60(128)	60-60(127); 60(1)

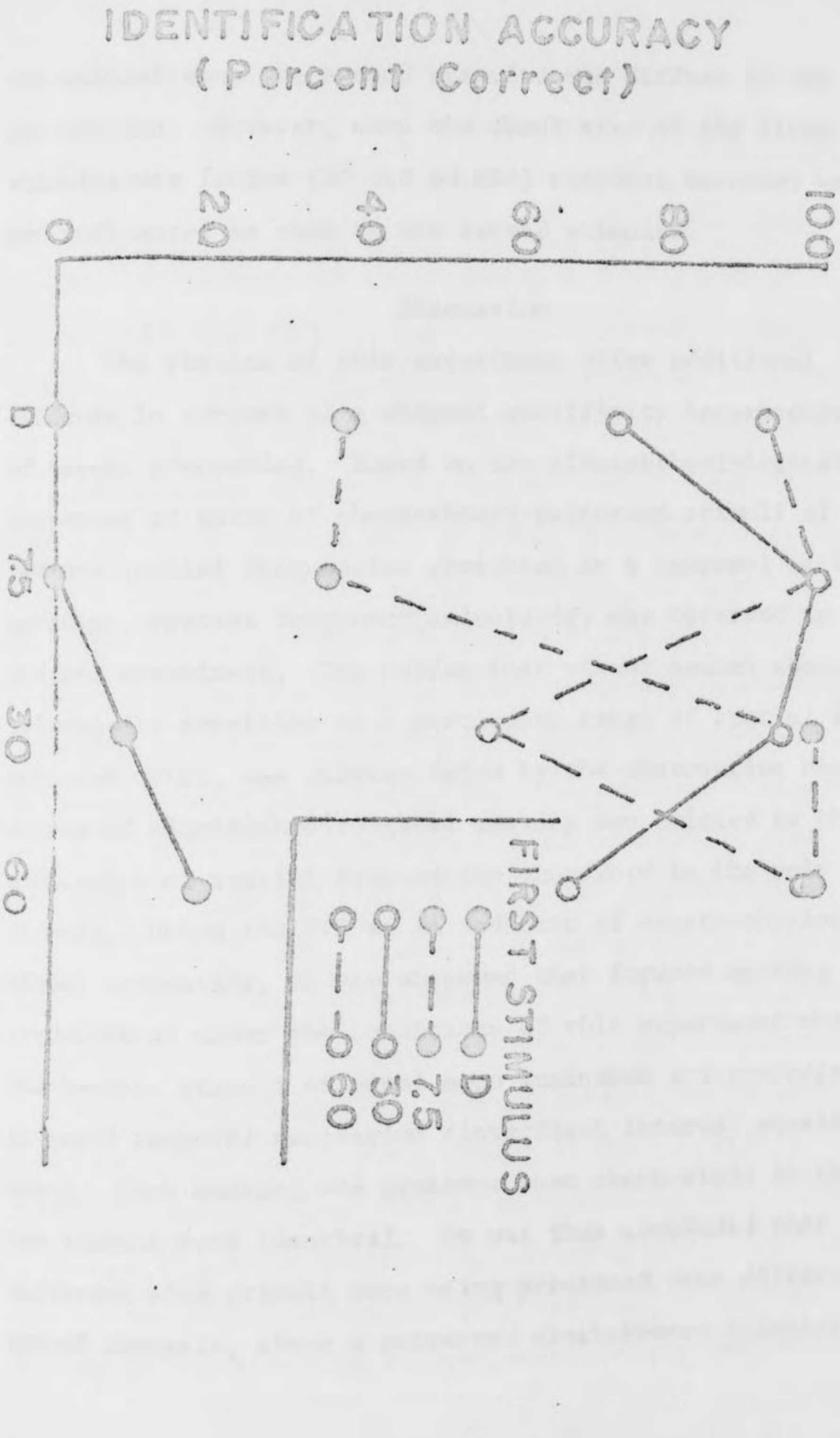
N.B. Symbols preceeding parentheses indicate reported stimuli (most "vivid" first) and number in parentheses indicates number reported out of 128.

(30-D) + (60-D). All four comparisons indicated that the order of presentation did not influence the "vividness" of the stimuli and thus, that psychophysically forward and backward masking did not differ significantly for any one of the four stimuli ($p > 0.05$). The lack of significance was primarily due to the large intersubject variability across the various stimulus conditions.

In order to assess the masking effectiveness of specific stimuli composing the pair in light of the finding that there was no consistent directional masking, an analysis of variance was conducted on the percent correct responses (correctly reporting both stimuli in the pair) for each pair as a function of the check size in the first and second stimulus of the pair. It was found that the check size of the first stimulus of the pair had a significant effect on the accuracy of identification ($p < 0.001$) and that the effect of the first flash depended on the check size of the second flash ($p < 0.01$). The effect of check size of the first flash was primarily due to the fact that when the first stimulus of the pair was diffuse it was identified on only 10 per cent of the trials, whereas when the first stimulus was patterned it was identified on more than 99 per cent of the trials. The significant interaction effect between the check size in the first and second stimulus is illustrated in Figure 5. When the first stimulus of the pair was either diffuse or the 7.5 min pattern selective masking occurred. Response accuracy

FIGURE 5

Psychophysical data. The response accuracy in terms of the correct identification of both stimuli in the pair for each of the four stimuli (D, 7.5, 30, and 60 min) in the first position as a function of the pattern in the second stimulus. Response accuracy is expressed in terms of per cent correct responses out of a total of 128 and is averaged across four subjects.


IDENTIFICATION ACCURACY
(Percent Correct)
0
20
40
60
80
100
D
7.5
30
60
SECOND STIMULUS (Min. Arc)
FIRST STIMULUS
D
7.5
30
60

was minimal when the second stimulus was diffuse or the 7.5 min pattern. However, when the check size of the first stimulus was larger (30 and 60 min) response accuracy was not influenced as such by the second stimulus.

Discussion

The results of this experiment offer additional evidence in support of a channel specificity interpretation of visual processing. Based on the electrophysiological responses to pairs of checkerboard patterned stimuli of various spatial frequencies presented in a temporal masking paradigm, spatial frequency selectivity was observed in the present experiment. The notion that visual neural channels selectively sensitive to a particular range of spatial frequencies exist, was substantiated by the observation that the degree of electrophysiological masking was related to the similarity of spatial frequencies contained in the pair of stimuli. Using the VER as an indicant of electrophysiological visual processing, it was observed that forward masking predominated under the conditions of this experiment where two pattern stimuli of equal mean luminance are presented in rapid temporal succession (interflash interval equals 40 msec). Such masking was greatest when check-sizes in the two stimuli were identical. It was thus concluded that different size stimuli were being processed over different neural channels, since a patterned checkerboard stimulus would more effectively interfere with the processing of another checkerboard stimulus of the same spatial frequency than one of a more dissimilar composition.

Since only three checkerboard stimuli of quite discrepant spatial frequencies (0.5, 1.0, and 4.0 cycles/ degree) were employed, it was not possible to describe precisely the bandwidth characteristics of the various spatial frequency channels. However, the findings of this investigation suggest that if further electrophysiological data had been collected over a wider range of spatial frequencies, physiological masking functions analogous to the psychophysical sensitivity functions obtained in other studies (Campbell and Robson, 1968; Blakemore and Campbell, 1969; and Stromeyer and Julesz, 1972) would have been obtained. The masking functions derived from the present experiment and illustrated in Figure 4 revealed that masking efficiency was greatest when the first and second stimulus of the pair were identical in spatial frequency and diminished as the spatial frequencies became less similar. Therefore, the electrophysiological data indicated that the relationship between spatial frequencies of the patterns of the stimulus pair had an influence on the degree of visual masking. This selective masking relationship is consistent with a spatial frequency interpretation of channel specificity.

The visual masking paradigm employed in this study, in addition to supplying corroborating data in support of spatial frequency selectivity, which previously has been derived from studies utilizing the selective adaptation paradigm, is of more methodological value than the pre-adaptation technique for several reasons. First, since the masking paradigm involves the presentation of two transient stimuli, it is possible to record physiological responses to each of the two stimuli. This is not possible with the adaptation paradigm where long duration exposure of both stimuli are entailed. Second, twice as much information can be observed per trial with the masking paradigm. Both the effects of the spatial frequency of the first stimulus on the spatial frequency of the second stimulus and, likewise, the effects of the second on the first can be evaluated on a given trial. With the adaptation paradigm, only the effects of the adapting stimulus on the test stimulus can be evaluated. Third, the masking paradigm appears to be a more naturalistic type of experimental manipulation than the adaptation paradigm. Temporal sequential processing is an ever occurring sensory process across all sense modalities. Also, the masking situation is not so limiting in the sense that two discrepant stimuli, one high (adapting) and one low (test) contrast stimulus must not always be employed; but equal contrast stimuli at various levels of illumination may be employed. So while both visual masking and preadaptation seem to be effecting similarly the neural processes responsible for spatial frequency selectivity the masking paradigm may prove to be the more powerful technique to investigate further the psychophysical and physiological aspects of channel specificity.

In terms of temporal processing at the electrophysiological level, while both forward and backward masking were observed, forward masking was the most dominant. This is in accordance with previous psychophysical (Kahnamen, 1968; Turvey, 1973) and physiological (Peck and Lindsley, 1972; 1973; Andreassi, et. al., 1971, Cenen, et. al., 1972; Donchin et. al., 1963; Donchin et. al., 1965; Fehmi, et. al., 1969) studies which found forward masking when two stimuli of equal energy levels (intensity, duration, etc.) were brought into close temporal proximity. These same studies reported backward masking when the stimuli were of discrepant energy levels. Backward masking may be interpreted physiologically in terms of the neural response to the second stimulus overtaking the response to the first due to the fact that the higher energy level of the second stimulus results in a shorter response latency. Forward masking with two equal energy stimuli may be interpreted in light of the temporal numerosity investigations (Harter and White, 1967) where VER wave-form was similar for both single flashes and trains of flashes. This implies that the onset of the first stimulus initiates a process which will have an effect on subsequent stimulation. Therefore, if the first stimulus initiates the physiological processing, it is reasonable to assume that this stimulus will dominate over the second equal energy stimulus, as was the case in this experiment.

The 7.5 and 30 min patterns were found to be the most effective forward maskers in terms of suppressing the electrophysiological effects of the second stimulus. This observation is related to previous findings (Harter, 1971) which found that patterns with more modal sized elements (15 min) elicited the largest amplitude VERs when stimuli are presented foveally. The optimal sized stimulus, however, changed as a function of retinal eccentricity. The more effective nature of these intermediate check sizes (7.5 and 30 min), in terms of a greater proportion of neural channels located in the fovea which are sensitive to these spatial frequencies, may account for their more effective masking.

Although the spatial-temporal interactions were not investigated parametrically in this study, since only one interflash interval was employed, several observations about such interactions still can be made by comparing the physiological responses to stimuli presented in pairs (IFI = 40 msec) and singly (IFI infinitely large). First, there was a general decrement in VER differentiation to pattern size, as reflected by the variability measures, when stimuli were paired in temporal succession. This finding is in accordance with the results of Kinney _et_. _al_. (1973) who found a loss in information content in the VER as the rate of presentation was increased. Also, the decrement in response differentiation was greater for the second as compared to the first stimulus of the pair (forward masking was more predominant than backward masking). In addition the VER characteristics attributable to the diffuse stimulus were suppressed more, as compared to the other three patterned stimuli, when paired with another stimulus. It, therefore, appears that there is a loss in information content of the VER as reflected by a decrement in response differentiation a) when pairs of stimuli are brought into close temporal proximity, b) being greater for diffuse as compared to patterned stimuli, and c) being greater for stimuli in the second as compared to the first position of the pair.

A limitation of this study was the inability to compare more extensively the electrophysiological and psychophysical data due to the insensitivity of the psychophysical measure. While the physiological data agreed with the psychophysical whenever a significant perceptual effect was observed (e.g., dominance of the diffuse stimulus by a pattern stimulus), few corrallary observations were possible. Possible explanations for the absence of perceptual masking and the lack of correspondence between the psychophysical and physiological responses are that the psychophysical measure employed in this study was not as sensitive as or did not reflect the same processes as the VERs. In comparing the electrophysiological and psychophysical measures, regardless of their sensitivity, they are respectively absolute and relative indicants of stimulus effectiveness. The VER, in conjunction with the variability measure indicated the absolute effectiveness of each stimulus as a masker, while the psychophysical measure indicated the relative perceptual effect of each stimulus in the pair in relationship to its paired mate. The psychophysical measure used in the present study was not as sensitive as the VER measure for several reasons. Resolution of measurement was limited due to the fact that the psychophysical report was a dichotomous decision in terms of degree and direction of masking (more or less "vivid"). Secondly, the psychophysical report was susceptible to response set variables with the redundant nature of the psychophysical task. It thus becomes imperative that in future studies, a more sensitive psychophysical indicant of the perceptual phenomena must be utilized if electrophysiological perceptual comparisons are to be made.

A secondary purpose of this study was to demonstrate the utility of a variance analysis technique for assessing the contribution of stimulus parameters on the VER. It was observed that the variability in the VER across the various stimulus conditions in the present study corroborated the findings of previous research assessing the VER to pattern stimuli (Harter and White 1968; Harter and White, 1970; Eason, White and Bartlett, 1970; and Harter, 1971). The peak VER variability, attributable to differential pattern size processing, was reflected for all four subjects at the 110 msec latency and to a lesser extent at the 220 msec latency in three of the subjects. The fact that the VER changes as a function of stimulus pattern at the same latency for all subjects may have pervasive implications for evoked potential research investigating other stimulus parameters. In the history of evoked potential research there has been considerable controversy and indecision in regard to quantifying this complex analog response which tends to be unique in its wave-form for each individual subject. One of the recurring issues is the search for adequate analytic techniques in addition to visual inspection to distinguish between signal and noise. It seems quite feasible that the variability measurement technique would help resolve this problem by indicating the latencies at which the evoked potential is changing as a function of the stimulus parameter under investigation.

In summary, it can be concluded from the electrophysiological data that masking is influenced by the sequential order of the stimuli, the size of the stimulus pattern, and the relationship between the size of the patterns contained in the two stimuli composing the pair. Forward electrophysiological masking predominated when two pattern stimuli composed the pair. As found in previous studies (Harter and White, 1970; Eason, White and Bartlett, 1970; and Harter, 1971) the more modal size stimulus patterns (7.5 and 30 min) elicited the largest VER whether presented singly or in conjunction with other stimuli. The modal sizes also were the most effective forward maskers. And finally, the extent of forward masking was directly related to the similarity in size of the patterns contained in the pair, thus supporting a spatial frequency analysis interpretation of stimulus pattern processing.

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