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INTRA-MODALITY SELECTIVE ATTENTION TO DIOPTICALLY- AND DICHOPTICALLY-PRESENTED PATTERNS AND VISUAL EVOKED RESPONSES IN HUMANS

by

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Human visual evoked responses (VERs) to randomly-presented dioptic and dichoptic patterns were measured in an attempt to determine whether the similarity of patterns presented to the two eyes influences S's ability to attend to one eye. In addition, an attempt was made to investigate the effects of selective attention when differential preparation and peripheral influences are reduced to a minimum. Five Ss were presented four pattern conditions in which they were to count the number of stimuli presented to one eye (relevant stimuli) and ignore stimuli presented to the other eye (irrelevant stimuli). Patterns to the two eyes were either presented dioptically (i.e., identical color and line orientation) or dichoptically (i.e., different color and/or line orientation). Differential preparation was controlled for by randomly presenting patterns to either eye at a constant fast rate (once every 550 msec.). Peripheral influences were reduced to a minimum by requiring central fixation and fusion and by maintaining constant accommodation and vergence.

Occipital and vertex VERs showed a consistent increase in amplitude (at latencies between 180 and 320 msec. after stimulation) when stimuli were relevant, as compared to VERs to the same stimuli when they were irrelevant. This effect varied with the similarity of pattern in that differences were noted only when the patterns to the two eyes were dissimilar. A color difference between the two eyes produced the largest effect.

The results were discussed in terms of the explanatory concepts of prior-preparatory states, termination of Contingent Negative Variation, reactive change, and sensory modulation. It was concluded that selective attention to a particular stimulus accounts for the increase in the late positive component of the VER. Further, these attentional differences appear to be due to sensory modulation, rather than anticipation, expectancy, or momentary relaxation.

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Introduction

For much of the past decade, electrophysiologists have been attempting to establish the existence and nature of a relationship between cortical evoked responses and various behavioral phenomena related to attention and arousal (for reviews, see Karlin, 1970; Regan, 1972; and Tecce, 1970). The resultant studies have indicated that such a relationship exists. Generally, the demonstration of this relationship has been based upon the observation of systematic latency and amplitude changes in the evoked response as the behavioral state of the subject (S) is varied. However, the origin of the relationship has remained open to question, since the underlying neurophysiological mechanisms have not yet been determined.

The usual procedure in evoked potential research involves the manipulation of behavioral state (in terms of attention, arousal, vigilance, etc.) while simultaneously recording evoked potentials to transient stimuli presented during those states. Since the evoked potentials are time-locked to the stimuli, signal-averaging techniques are generally used to segregate the evoked response from background electroencephalographic (EEG) activity. This averaging procedure involves the presentation of a number of physically-identical stimuli (usually 30 or more) while simultaneously recording and summing cortical activity for a fixed interval following stimulus onset. Since only that activity which is related to the stimulus will continue to contribute to the summation (i.e., random background EEGs will cancel out), a characteristic waveform which is dependent upon the physical parameters of the stimulus will emerge. Generally, this complex waveform has a maximum amplitude (peak to trough) of 10μv, as compared to spontaneous EEG amplitudes of 50 to 150 μV (Tecce, 1970), and a maximum duration of 500 to 750 msec. The component of the waveform most frequently investigated by attentional researchers is a positive deflection occurring between 250 and 350 msec. The amplitude of this late positive component (LPC) under different states of activation comprises the data for the majority of current research (Tecce, 1970). In the discussion to follow, reference to averaged evoked response amplitude will imply the amplitude of the LPC, unless otherwise noted.

Organismic Influences on the Evoked Response

As mentioned previously, the waveform of the evoked potential is greatly influenced by the physical characteristics of the stimulus (e.g., intensity, contour, color, etc.) (for a review, see Regan, 1972). However, the organismic state of the individual at any given moment in time has also been shown to influence the cortical potential. A number of studies have reported enhancement of various components of the evoked response with increasing activation (whether generally or specifically directed) and evoked response reduction with low arousal and/or distraction. The amplitude of the evoked response has been shown to increase with directed attention (Donchin & Cohen, 1967; Eason, Harter, & White, 1969; García-Austt, Bogacz, & Vanzulli, 1964; Gross, Begleiter, Tobin, & Kissin, 1966; Harter & Salmon, 1972; Kopell, Wittner, & Warrick, 1969; Picton, Hillyard, Galambos, & Schiff, 1971; Smith, Donchin, Cohen, & Starr, 1970; Spong, Haider, & Lindsley, 1965), vigilance (Haider, Spong, & Lindsley, 1964; Ritter & Vaughan, 1969; Spong *et al.*, 1965), task relevance (Chapman & Bragdon, 1964; Donald & Goff, 1971; Sheatz & Chapman, 1969), discrimination (Davis, 1964), and uncertainty (Sutton, Braren, Zubin, & John, 1965; Tueting, Sutton, & Zubin, 1971).

Although the above studies would appear to offer substantive evidence of a correlation between evoked potential enhancement and the significance of a stimulus to the individual, discrepant animal and human data have also been reported (Bergamini, Bergamasco, & Mombelli, 1966a, 1966b; Jane, Smirnov & Jasper, 1962; Mombelli, Bergamini, & Bergamasco, 1964; Shaw & Thompson, 1964a, 1964b; Thompson & Shaw, 1965). In these latter studies, evoked potential amplitude was found to either decrease when a significant stimulus was presented or increase during distraction. With regard to the animal studies by Shaw and his colleague (1964a, 1964b, 1965), an examination of their experimental procedure indicates that they were actually recording evoked potential reduction during the presentation of distracting stimuli. Their results, then, are not inconsistent with the above-mentioned research. Criticism may also be made of the studies conducted by Bergamini and his coworkers. They used very intense stimuli which may have resulted in asymptotic evoked potentials. Any modification in the amplitude of the evoked response due to attention may, therefore, have been impossible. Upon examination, the amplitude reduction that they reported during attention was found to be almost negligible as compared to resting level while distraction evoked potentials were markedly depressed. Finally, with regard to the study by Jane *et al.*, the authors themselves point out that their results were highly variable (two *S*s showed enhancement during distraction, while two others showed a decrement) and, therefore, were inconclusive. Although the inconsistencies between this group of data and that reported above may be due to methodological problems, the discrepancies do indicate the necessity for understanding the neurophysiological processes involved in evoked response modification.

Attention, Arousal, and the Reticular Formation

The assumption that the scalp-recorded evoked potential may reflect underlying cortical activity associated with behavioral states has, in part, been founded in the research indicating a relationship between the EEG and activation (Lindsley, 1958; Moruzzi & Magoun, 1949). Briefly, these researchers have reported characteristic EEG patterns (in frequency and amplitude) with various behavioral stages of sleep and arousal. For instance, it has been found that, during wakefulness, an alert state is characterized by fast, desynchronized cortical activity while a drowsy state is accompanied by slow, synchronized EEGs.

The neurophysiological mechanism thought to be responsible for the maintenance of these EEG patterns and for behavioral arousal is the reticular formation or, more specifically, the Ascending Reticular Activating System (ARAS) (Lindsley, 1958). Through electrical stimulation and ablation, it has been determined that the more caudal portion of the reticular formation exerts tonic inhibitory (and, possibly, facilitatory) influences which regulate the level of nonspecific general arousal of the organism. This active inhibition apparently serves to attenuate the wealth of sensory information impinging upon the individual at any one moment in time. When the organism is aroused or alerted, active inhibition is reduced to allow for the transmission of increased sensory input. Anatomically, this system appears well-suited for the control of arousal level since it has extensive connections with both the cortex and sensory afferents. More specific alerting functions are apparently mediated by the more rostral portion of the reticular formation which extends into the thalamic region of the diencephalon. This area constitutes the Diffuse Thalamic Projection System (DTPS) and seems to function primarily by "priming" (through augmenting responses) specific areas of the cortex (Gastaut, Jus, Morrell, van Leeuwen, Dongier, Naquet, Regis, Roger, Bekkering, Kamp, & Werre, 1957; Grossman, 1967; Jasper, 1949; Lindsley, 1958).

While the above conceptualization of the reticular formation is supported by a considerable amount of ablation and electrical stimulation research, a number of studies have reported data inconsistent with this formulation (for a review, see Thompson, 1967). For example, it has been reported that animals which are subjected to multistage bilateral destruction of the midbrain reticular formation usually recover some gross functioning (e.g., walking, eating) while animals which undergo one-stage bilateral lesions suffer severe coma and death. The observation that destruction of the midbrain reticular formation does not always prevent wakefulness suggests that the reticular core is not an absolutely essential structure for behavioral arousal. As Thompson points out, however, the reticular formation may normally play an important role in the regulation of arousal.

The fairly consistent demonstration of a relationship among the reticular formation, activation, and the EEG has led evoked potential investigators to postulate a similar relationship among the reticular formation, activation, and the evoked response. Although not often explicitly stated in the studies reviewed, it is generally implied that an arousing or attentive state will release the inhibitory influence of the reticular formation, thus resulting in an enhanced cortical potential to sensory stimuli. Several alternative views as to exactly how the reticular mechanisms operate to regulate activation have been suggested. Of the three hypotheses to be discussed (i.e., peripheral gating, prior-preparatory states, and reactive change), the peripheral-gating hypothesis appears to offer the most consistent explanation of evoked response enhancement and will, therefore, be presented first.

Peripheral gating. Primarily on the basis of their work with animals, Hernández-Peón and his coworkers (Hernández-Peón, 1961, 1966; Hernández-Peón, Sherrer, & Jouvet, 1956) have suggested that the reticular formation exerts tonic control through centrifugal fibers synapsing at each relay along the sensory pathways. This "peripheral gating" hypothesis maintains that sensory inputs are modulated (primarily through inhibition or release of inhibition) at all levels of the specific afferent paths to the cortex. In this conception, the receptor and subsequent relay points act as peripheral filters of sensory information; the reticular formation integrates the activity of the filters through feedback loops with both the filters and the cortex; and the cortex amplifies and further details the information.

According to this view, the phenomena of both selective attention and habituation illustrate the operation of the peripheral filters. During selective attention, only those inputs which are significant to the individual are permitted unimpeded transmission to the cortex. The focusing of attention reflects the attenuated signals of irrelevant stimuli. The filters operate in a similar manner during habituation (i.e., reduced response amplitude due to monotonous repetitive stimulation) by blocking inputs which are no longer interesting to the individual.

With regard to the selective attention process, a distinction is made between "involuntary, sensory attention" (e.g., to novel stimuli) and "voluntary, intellectual attention" (e.g., during complex discriminations). In the case of the former, attention is presumably regulated through the sensory pathways and central integrating mechanisms with or without the aid of the cortex. With voluntary attention, cortical involvement is required for thinking and remembering in conjunction with the integrating action of the reticular formation. Regardless of the type of attention, however, the final outcome of selective peripheral blockage is the same.

Support for the peripheral-gating hypothesis has been provided by data indicating that stimulation of the brainstem reticular formation reduces evoked potentials to auditory, visual, olfactory, or tactile stimuli at several levels in their respective pathways (for reviews, see Hernández-Peón, 1961, 1966; Livingston, 1959). Additional evidence from ablation studies indicates that habituation will not occur if the influence of the mesencephalic reticular formation is disrupted.

However, some evidence has also been presented which does not support the operation of a peripheral-gating mechanism, at least with regard to habituation. Using microelectrodes, Walter (1964b) found that habituation did not occur in primary visual cortical cells, whereas associative cortical cells did show habituation. Additionally, Worden and Marsh (1963) reported no habituation of auditory evoked responses at the cat's cochlear nucleus when click stimuli were continuously presented for a period of six hours. These latter data may be questioned, however, since comparisons were made between responses at the beginning of the stimulation period and subsequent responses when the cat was "alerted" (due to handling by the experimenter). Of the four records displaying both aroused and nonaroused data during stimulation, three nonaroused samples showed a reduction in response amplitude from stimulus onset to the second sampling taken two hours after onset. This reduction in response amplitude suggests that habituation of the cochlear potential may have occurred during the first two hours of stimulation.

As initially conceived, the peripheral-gating mechanism was thought to modulate attention among the various sense modalities. For example, if a significant stimulus was presented visually, all other sensory modalities would be depressed while the visual pathways would not be inhibited or would even be facilitated. Support for this idea of inter-modality selectivity has been a bit tenuous, however, since studies have indicated that photic evoked potentials may be reduced during reticular stimulation when either visual or auditory stimuli are presented (Hernández-Peón, 1966).

In order to account for these results, the proponents of sensory modulation have suggested that intra-modality selective blocking may also be a function of the peripheral filters. According to this elaboration of the hypothesis, only those neurons which are directly related to the significant stimulus would be facilitated or would not be inhibited. All other neurons in that sensory system would be selectively attenuated, as would those in other sensory systems.

This conceptualization is based, in part, upon the results of visual single unit studies by Hubel and Wiesel and DeValois (DeValois, Abramov, & Mead, 1967; Wiesel & Hubel, 1966; Hubel & Wiesel, 1968). According to these authors, their studies indicate a functional organization of the visual system in terms of cellular chromatic and spatial sensitivity. This sensitivity, or cellular specialization, would be a necessary requirement if intra-modality filtering were to occur. An example would, perhaps, best illustrate the proposed relationship. If two colors were presented (e.g., red and green) and one of the colors was made significant (e.g., red), then only cells responsive to the color red would be facilitated during transmission along the visual pathways. The activity of green-sensitive cells would be attenuated, as would other visual cells and cells in other modalities. This example was necessarily made simplistic in order to avoid an extended discussion of the various modifications and interactions that may occur. However, it does illustrate the proposed relationship.

According to this formulation, electrode placement in the pathways would be crucial in determining whether facilitation or inhibition were recorded. In order for facilitation to be recorded, the electrode would necessarily have to be near cells responsive to a relevant stimulus. Any other placement would probably result in inhibitory recordings since the majority of cells in the system would be attenuated. This line of reasoning could be used in accounting for the inter-modality results reported earlier. Since fairly gross optic pathway recordings were made, an attenuation of visual evoked responses to any type of stimulation would not be unexpected.

Several cortical evoked potential studies have reported results consistent with the peripheral-gating hypothesis. García-Austt _et al_. (1964) found visual evoked response (VER) decrements both when attention was directed to other sensory stimuli (sounds or peripheral, low-intensity flashes) and during repetitive stimulation. They also found VER enhancement during voluntary attention (counting) and with the presentation of novel stimuli during habituation (dishabituation). It should be noted that dishabituation would be predicted by the peripheral-filtering hypothesis since sensory inputs from a new or different stimulus would not be blocked during habituation.

In another study designed specifically to investigate the effects of habituation on the auditory evoked response (AER), Ritter, Vaughan, and Costa (1968) required _S_s to listen to a series of tones that were a) unexpectedly interrupted by a tone change, b) interrupted by both predictable and unpredictable tone changes, and c) interrupted by predictable and unpredictable signals to the contralateral ear (monaural presentation). In all cases, they found that the presentation of an unexpected stimulus elicited an enhanced LPC whereas an expected stimulus change did not. Again, these results are compatible with the selective-filtering hypothesis.

Eason, Harter, and White (1969) varied both attention and arousal to visual stimuli by requiring a reaction time

(RT) response or no RT response during shock threat or no shock threat. They found that attending to flashes presented in one visual field (relevant stimuli) produced an increment in the VER to those stimuli, regardless of arousal level. However, shock threat also had an enhancing effect upon the evoked potential to relevant stimuli, although the effect was not as great as that of selective attention. When attention was directed away from a stimulus (i.e., to stimuli in the other visual field), the magnitude of the potential was greatly attenuated and changes in arousal level had little influence on the evoked response. Consistent with the sensory-modulation hypothesis, the authors concluded that their results support a concept of selective attenuation of sensory inputs by an "active inhibitory neural process [p. 289]."

In another study interpreted as reflecting sensory modulation, Harter and Salmon (1972) reported VER enhancement to randomly-presented visual patterns during several selective attention tasks. _S_s were required to either count or give a RT response to one of two colors (e.g., red or blue) or patterns (e.g., vertical or horizontal bar) which were presented at a rate of either one or two per sec. An increment in the VER was observed to relevant stimuli, regardless of frequency or response task. The type of stimuli presented did influence the relationship, however, in that the largest difference in amplitude was observed for the colored stimuli. This last result may be interpreted as adding additional support to the selective-filtering hypothesis.

This conclusion is derived from the work of Hubel and Wiesel (Hubel & Wiesel, 1968; Wiesel & Hubel, 1966) which indicates that color specificity occurs at all levels of the visual pathways whereas contour specificity is first noted at the cortical level. Since the components (horizontal and vertical) of both the relevant and irrelevant bar patterns used in the Harter and Salmon study were approximately the same size, many of the same retinal and higher peripheral cells would have been stimulated by relevant and irrelevant stimuli. Cortical integration, therefore, would have been necessary to distinguish a significant patterned stimulus. Attending to one of two colors, however, could have been facilitated by selective peripheral filtering, since color coding can occur at the periphery. If the amplitude of the evoked response does reflect the operation of peripheral filters, then any attentional differences between attended and unattended patterned stimuli would, therefore, be expected to be smaller than those between colored stimuli.

In a study involving inter-modality focusing of attention, Spong, Haider, and Lindsley (1965) recorded both AERs and VERs during vigilance, key-pressing, and counting tasks. In the vigilance task, Ss were instructed to attend to stimuli in one modality in order to detect occasional weak signals and ignore stimuli concurrently presented in the other modality. In the key-pressing condition, Ss were required to press a key immediately after the presentation of stimuli in one sense modality for the first half of a condition and reverse their response for the second half. The counting condition was similar to the key-pressing condition, except that Ss were instructed to count stimuli rather than press a key. For the former two tasks, evoked responses (amplitude measure from 110 to 200 msec.) to the attended modality were enhanced as compared to the same responses when the other modality was attended. Data obtained under the counting task were equivocal, however. The authors concluded that the vigilance and key-pressing results indicate that the evoked response reflects the "attentive set" of S. The lack of consistent results in the counting condition was explained as being due to the potentially distracting requirements of a counting task. The authors' concept of "attentive set" is not incongruent with a peripheral-filtering hypothesis since the filter would reduce all unattended stimuli. As in the studies just reviewed, it would probably involve the "intellectual or voluntary attention" referred to by Hernández-Peón since cortical mechanisms may be required in the establishment of the appropriate "set."

Haider, Spong, and Lindsley (1964) investigated the effects of long-term vigilance (80 to 100 min.) on the VER. As in the previously mentioned study by Spong *et al.*, *Ss* were to detect slightly weaker signal stimuli interspersed among nonsignal flashes. Over the course of the task, a decline was noted in the amplitude (160 msec. latency) of the bipolar VER to nonsignal stimuli which was correlated with decreased detectability performance. Additionally, VERs to undetected signal stimuli were also reduced as compared to cortical responses to detected signals. Although the authors interpreted both findings in terms of attentive states, it seems more likely that VER reduction to nonsignal stimuli may have been due to habituation and reduced arousal level. However, both interpretations conform to the concept of selective blockage.

Several groups of researchers have investigated the relationship between stimulus significance and the evoked response without directly implicating peripheral mechanisms.

In a replication of the Haider *et al*. study, Ritter and Vaughan (1969) required both auditory and visual discrimination to slightly weaker signal stimuli. As in the above study, they reported that VERs (LPCs) were enhanced to detected stimuli and were reduced to undetected and nonsignal stimuli. In an effort to determine why LPC's were not prominent in some of the previous studies, they used both monopolar and bipolar recordings. It was found that LPCs were present only in the monopolar records. The authors attributed the absence of the LPC in the bipolar recording to a fairly equal representation of the LPC at both electrodes, therefore resulting in no difference (a flat line) between the two sites. Interpretation of the amplitude differences in the evoked response was in terms of a cortical template which permits routine processing of insignificant sensory information. As proposed, a mismatch between a stimulus and the template would result in a shift in attention to the stimulus while additional perceptual and cognitive mechanisms are called upon to evaluate the significance of the mismatch. The suggestion of a comparator mechanism is essentially identical to the role of the reticular formation proposed by Hernández-Peón. The only difference, then, between Ritter and Vaughan's interpretation and that of Hernández-Peón lies in the determination of the specific roles assigned the reticular formation and the cortex.

The "intellectual or voluntary attention" mentioned earlier may be involved in the discrimination task investigated by Davis (1964). In this study, subjects were required to make a difficult intensity discrimination to the third tone in a series of four signals. It was found that the AER was significantly enhanced during decision trials as compared to both a control condition in which S read a magazine and a RT condition in which S button-pressed to the stimuli. As in the Spong et al. study, the amplitude measure was taken at a fairly early latency (100 to 200 msec). However, the recording epoch may have been too short (375 msec) to observe complete later components (Ritter & Vaughan, 1969). Davis concluded that his results reflect the operation of mechanisms similar to those observed during vigilance.

In a study involving task relevance and decision, Sheatz and Chapman (1969) required Ss to make a pitch comparison between either two tones or two noise bursts when all four stimuli were alternately presented. They found that AERs were enhanced when stimuli were relevant (e.g., tones) as compared to when they were irrelevant (e.g., noise bursts). Additionally, they reported that the second presentation of stimuli (i.e., the comparison or problem-solving stimuli) showed greater amplitude differences than did the first set (i.e., the storage stimuli). The authors concluded that task relevance and possible decision processes affect the amplitude of the AER. Although this interpretation, as well as the one given by Davis, implies the operation of cortical mechanisms, it does not eliminate the possibility of selective attenuation at the periphery.

On the basis of a study involving intra-modality selective attention in cats, Horn (1960) rejected the peripheral-gating hypothesis. He found that flash VERs were attenuated upon the introduction of a mouse into the cat's line of sight, even though all non-visual stimuli were blocked by a screen. He suggested that "visual search" accounted for the amplitude decrement and was independent of the significance of the stimulus to the organism. However, as with the studies by Thompson and Shaw, the peripheral-gating hypothesis could easily account for these results. According to the hypothesis, the sight of the mouse would probably result in distraction to the flashes and, hence, an attenuation of the VERs.

Donchin and Cohen (1967) conducted a study to test the idea of "visual search" and its independence of stimulus significance. They suggested that, if the concept of visual search is accurate, then there should be no difference between VERs to a test flash when it is attended (searched for) and the same flash when another stimulus is attended. _S_s were required to respond (key press) to flashes (Flash Condition) superimposed on an alternating background (e.g., a circle versus a square) or they were to respond to the background alternations (Reversal Condition). It was found that, during the Flash Condition, VERs to the flashes were considerably larger than VERs to the same flashes during the Reversal Condition. On the basis of this evidence, Donchin and Cohen rejected the idea of "visual search" and, instead, related their results to the significance of the stimulus to the organism.

Similar results were obtained by Kopell, Wittner, and Warrick (1969) in a replication of the above study. Like Donchin and Cohen, they reported VER enhancement to flashes during the Flash Condition as compared to the Reversal Condition. However, the VERs evoked by the reversals were not affected by the attentional manipulation. These latter results were interpreted as indicating that the nature of the stimulus is an important factor in attentional research. The figure alternations used in both studies were extremely complex and may, therefore, have been difficult to attenuate.

In a later study conducted with other investigators (Smith, Donchin, Cohen, & Starr, 1970), Donchin and Cohen arrived at slightly different conclusions regarding stimulus significance. Aural intra-modality selective attention was investigated by requiring Ss to report clicks or letters that were interspersed among more frequently occurring numbers presented to one ear. Similar stimuli presented to the other ear were to be ignored. AERs to clicks were larger when those stimuli were relevant as compared to when letters were relevant. Although Ss consistently reported only those clicks to the "attended" ear, click AERs to both ears were enhanced during the click-relevant condition. These results were interpreted as indicating a relationship between the evoked response and task relevance, rather than stimulus significance. According to the authors, if only significant stimuli elicit larger responses, then clicks presented to the "unattended" ear should have been attenuated. Since clicks were "relevant" to the task, however, increments in AER amplitude were observed at both ears.

At first glance, these results appear at odds with a peripheral-gating hypothesis since there was no difference in click AERs at the "attended" and "unattended" ears. However, the peripheral-gating hypothesis does not imply that attenuation occurs as a function of suppression of one ear (or eye), although this type of suppression may occur when totally different stimuli are presented to the two receptors of the same modality (i.e., audition or vision). Rather, the hypothesis suggests that sensory inputs are selectively attenuated or facilitated according to specific channels of sensory information (i.e., in terms of cellular coding of the physical characteristics of a stimulus). Since clicks to both ears were physically identical in the Smith _et al_. study, the only distinction that could be made was in terms of ear stimulated. The only cue for selective filtering, then, would be one involving sound localization. Since localization generally requires a determination of the difference in sounds presented to the two ears (either in terms of intensity, phase, or time), sensory input from both ears would be necessary in order to determine the site of stimulation when identical physical stimuli were presented. In the above study, selective neuronal firing triggered by the clicks would be identical in either ear. Since similar neurons from either ear often synapse on the same higher-order neurons, it would be difficult, if not impossible for a peripheral filter to function with identical stimuli. Lawson (1966) has reported data consistent with this interpretation. He found that, with verbal materials presented to both ears, only one ear could be shadowed while the other was rejected. However, Ss could report the presentation of identical tone pips to either ear when they were shadowing a verbal message to one ear. If, in the Smith *et al*. study, evoked responses to the letters had been recorded (with appropriate controls for different physical characteristics), then selective attenuation at either ear may have been observed.

By simultaneously recording evoked potentials from the external auditory meatus (cochlear potential) and the scalp, Picton, Hillyard, Galambos, and Schiff (1971) attempted to test the peripheral-gating hypothesis. They postulated that, if peripheral filtering does occur, then enhancement should be observed at both the cochlea and the cortex during an attention-related task. In two portions of the experiment, S was to either read a book (control) or detect faint clicks interspersed among slightly louder clicks. In both instances, AERs increased during the signal-detection task as compared to those during reading. The cochlear potential, on the other hand, showed no significant change from the control. In the third part of the study, _S_ was to selectively attend to and record the order of single and double clicks presented to one ear while a different sequence of clicks was presented to the other ear. Again, the cochlear potential showed no change while the AER was significantly enhanced to the attended ear.

The similarity between the latter portion of this study and the experiment conducted by Smith _et al_. should be noted. The enhanced AER reported by Picton _et al_. would appear to support the peripheral-gating hypothesis. However, if the rationale used in discussing Smith _et al_.'s study is to be consistent, an AER enhancement would not be expected unless extraneous factors contaminated the results (e.g., slightly louder clicks in one ear than the other). In addition, the finding of a stable cochlear potential would appear to cast doubt on the selective-filtering hypothesis. As the authors point out, however, the cochlear potential represents the summed activity of many nerve fibers and "attention-induced alterations in the responses of some of these fibers may have passed undetected [p. 353]." This opinion is essentially the same as the one given earlier in the discussion on intra-modality selective attention.

One additional point should be made with regard to the peripheral-gating hypothesis. In the previously-reviewed studies, different researchers have reported enhancement occurring at several different latencies of the evoked response. Most frequently, attentional increments have been reported at the later components (250 to 350 msec.) of the evoked potential. However, some studies have found enhancement at fairly early latencies (100 to 200 msec.). Harter and Salmon (1972) have proposed a two-stage model that attempts to incorporate these findings. In their model, the first stage represents the coding of relevant and irrelevant afferent impulses according to "a predisposition or set of the peripheral nervous system [p. 611]." This coding (sensory modulation) is reflected in the early components of the evoked response. In the second stage, the late components of the evoked response reflect the operation of cortical association area activity that presumably mediates the interpretation and evaluation of and reaction to sensory information. Of the studies illustrating their raw data, a visual inspection reveals that many showed systematic early, as well as late, latency changes with stimulus significance (e.g., Donchin & Cohen, 1967; Eason *et al.*, 1969; García-Austt *et al.*, 1964; Harter & Salmon, 1972; Kopell *et al.*, 1969; Picton *et al.*, 1971; Ritter & Vaughan, 1969; Sheatz & Chapman, 1969; Spong *et al.*, 1965). This observation offers support for

Harter and Salmon's conceptualization and, tangentially, supports the sensory-modulation hypothesis.

The results of the studies just reviewed would seem to offer substantial support for a view that cortical evoked potentials may reflect a modulation of sensory inputs. The studies involving selective attention, habituation, vigilance, discrimination, task relevance, and stimulus significance either implicitly or explicitly suggest the existence of a peripheral-gating neural mechanism. However, with the exception of the studies by Ritter *et al*. (1968), Harter and Salmon (1972), and Eason *et al*. (1969), alternative explanations in terms of a) a more general modulation of arousal (Näätänen, 1967) or b) a reaction to (response to) significant stimuli (Karlin, 1970) have been proposed which can readily account for the results. In the discussion to follow, an attempt will be made to evaluate these alternative hypotheses in view of the results of these latter studies.

Prior preparatory arousal states. Näätänen (1967, 1969a, 1969b, 1970) has proposed that the amplitude increase observed in evoked potentials to significant stimuli is not due to a selective attenuation of irrelevant inputs. Rather, cortical activation (and arousal) induced by the ARAS influences all sensory modalities nonspecifically and independently of the direction of attention. The increment in evoked response amplitude is due to "systematic differences in cortical activation between the moments of presentation of the relevant and irrelevant stimuli [Näätänen, 1970, p. 180]." Response differences are simply due to higher arousal immediately prior to relevant stimuli as compared to irrelevant stimuli.

Näätänen's hypothesis assumes that the amplitude of the cortical evoked response would be differentially influenced only in an instance where stimuli are predictable (e.g., with regular presentations). Further, cortical responses to all modalities should be influenced in the same way, regardless of the modality stimulated. Finally, cortical activation, as reflected by the background EEG, should indicate differential preparatory states (e.g., low amplitude EEGs during high activation).

Näätänen (1967) conducted several experiments to test these predictions. In order to demonstrate that stimuli must be predictable or expected if evoked potential differences are to be noted, he randomly presented click and flash stimuli at irregular time intervals. Ss were required to respond to occasionally weak stimuli presented in the relevant modality while the intensity of the other modality was held constant. No significant differences were found between responses to relevant and irrelevant clicks, suggesting that when conditions preclude differential preparation, selective attention has no effect. However, a significant difference was found between relevant and irrelevant flashes. Näätänen postulated that the latter finding could be due to a changing precision in the operation of peripheral factors (fixation, eye movements, etc.) so that relevant flashes were more optimally controlled. However, the possibility of sensory modulation of the flashes was not eliminated. In addition, since the clicks used in this experiment were of high intensity (.6V, as reported by the author), the possibility also exists that asymptotic firing due to the intensity of the clicks resulted. If such were the case, then the physical characteristics of the stimulus would offset any reduction due to sensory modulation.

Similar click stimuli (.4V) were used in another experiment in which the question of predictability was approached in a slightly different way. In this experiment, Näätänen (1967, 1970) reasoned that if S knew when a relevant stimulus would be presented, he would be more prepared to make the necessary response. The cortical potential to that stimulus should, therefore, be larger than that for a stimulus which required no response and, consequently, no preparation. Weak and strong clicks were presented in a regularly alternating series. Depending upon which stimulus was relevant, S was to button-press to a slightly weaker (weak-relevant) or slightly stronger (strong-relevant) click which occasionally replaced a relevant stimulus. Significant enhancement in the AER was found only when the weak clicks were relevant. Unlike the previous experiment in which similar results were reported, the absence of a significant difference for the strong clicks was attributed to the relative easiness of the task. That is, very little discriminative effort was required of S when he had to attend to the loud clicks. As Karlin (1970) has pointed out, there is a conflict in the interpretation of these two experiments. The former results were interpreted as being due to the elimination of cues for differential preparation while the latter were interpreted as reflecting a failure to use the cues because of the ease of the task. With some modifications, a proponent of the peripheral-gating hypothesis would certainly support Näätänen's second interpretation, as would he accept the possibility of asymptotic firing. If the task were as easy as Näätänen implies, then very little would be gained by an active attenuation of irrelevant inputs.

In order to test the prediction of increased cortical activation during differential preparation, Näätänen (1970) also recorded background EEGs during the latter experiment. As previously noted, activation of the ARAS or the DTPS will induce a decrease in the amplitude of the EEG (Lindsley, 1958) A decrease in EEG amplitude from irrelevant to relevant stimulus presentations was found for two of five Ss in this experiment. These same two Ss also showed the most marked enhancement of the AER to relevant (weak) stimulation. Since these EEG amplitude decrements were recorded from the occiput, the vertex, and the temporal lobe, Näätänen concluded that "increased cortical activation is not concentrated in the specific sensory areas corresponding to the direction of attention but, rather is of a nonspecific nature [p. 188]." Although this result was inconsistent across Ss, this finding is damaging to a peripheral-gating hypothesis.

Cortical activation was also investigated in an experiment (Näätänen, 1967) in which irrelevant clicks were presented both within and outside an interval between a warning flash (S_1) and a signal flash (S_2). Näätänen postulated that the warning flash could alert or prepare S for the signal stimulus and should, consequently, trigger cortical activation. AERs to irrelevant clicks occurring inside the S_1-S_2 interval should, therefore, be enhanced as compared to those outside the interval. The results were consistent with this interpretation. However, Salmon (1971) has pointed out that the "inside" clicks, and not S_1, could have served as warning signals and, thereby, could have acquired relevance, resulting in enhanced cortical potentials. This latter interpretation is more consonant with a peripheral-gating hypothesis.

A review of the experiments conducted by Näätänen has not provided conclusive support for a prior-preparatory state hypothesis. Those studies designed to investigate differential preparedness yielded inconsistent findings which could be interpreted as supporting either sensory modulation or nonspecific cortical activation. Some supportive evidence was found when cortical activation was investigated more directly. However, questions were also raised as to the validity of some of these interpretations. Although Näätänen has pointed out that many of the studies mentioned earlier did not exclude the possibility of differential preparation accounting for their results, a similar criticism may be made of his studies with regard to sensory modulation.

Evidence which would seem to negate the possibility that nonspecific cortical activation completely accounts for evoked response enhancement has been presented by Ritter *et al*. (1968), Harter and Salmon (1972), and Eason *et al*. (1969). In the Ritter *et al*. study, dishabituation and enhanced cortical responses occurred when novel or unexpected stimuli were presented. Differential preparedness, therefore, could not account for the results. A similar criticism may be made with regard to the study by Harter and Salmon. Stimuli were presented randomly and peripheral factors such as eye movements and fixation were controlled. Yet, they also found enhanced cortical potentials when stimuli were attended. Finally, Eason *et al*. varied attention and arousal level independently and found that attention resulted in greater increments in the evoked response, regardless of arousal induced by shock threat. These results, coupled with the inconsistencies in Näätänen's own data, cast doubt on the sufficiency of the prior-preparatory state hypothesis.

Reactive change. In addition to supporting differential preparedness as one explanatory concept in the modification of cortical responses, Karlin (1970) has also proposed a "reactive-change" hypothesis to account for results not easily handled by the former explanation. According to Karlin's view, if S does not know when a signal stimulus will be presented, he is maintained in some heightened state of arousal, vigilance, or readiness. Irrelevant stimuli will not change this state since they do not provide information about the delivery of the next relevant stimulus. On the other hand, relevant stimuli do convey information that the next relevant stimuli will probably not occur before at least one or more nonsignal stimuli have been presented. S can therefore relax his state of vigilance in response to a given relevant stimulus. The momentary relaxation or change in arousal level associated with the task results in the LPC of the evoked response.

Due to the nature of the hypothesis, the suggestion that a "noncognitive" reaction (relaxation) to the presentation of signal stimuli accounts for cortical response enhancement is not easily open to empirical test except, perhaps, in terms of other physiological measures (e.g., background EEG). However, the nature of the response characteristics of these other measures (e.g., latency of response) makes their use unfeasible.

Although the reactive-change hypothesis could account for the results of any of the studies reporting LPC enhancement, data from those studies showing systematic early latency amplitude changes (100 to 200 msec.) do not support the concept (e.g., Davis, 1964). In order for S to relax after a signal stimulus, he would first have to recognize and discriminate that signal. The transmission and processing time required for such a discrimination would probably be much longer than the 100 msec. reported. Further, a few studies used very fast presentation rates (e.g., one per every one-half sec.) and still found LPC enhancement (Harter & Salmon, 1972). The short intervals (500 msec.) between stimuli would make it improbable that S could momentarily relax to a stimulus and then be ready for the next one. As with the prior-preparatory state explanation, however, these data do not disconfirm the reactive-change hypothesis, although they do cast doubt on its interpretive significance.

Summary

A review of the studies in which behavioral state was manipulated has indicated one consistent finding.

When the significance of a stimulus is increased, whether in terms of attention, arousal, signal detection, expectancy, task relevance, novelty, or discrimination, an enhancement is observed in the cortical response to that stimulus. Three essentially different interpretations of the mechanisms involved in the modification of the evoked response have been discussed. The peripheral-gating hypothesis maintains that evoked response increments are due to an attenuation of sensory inputs to irrelevant stimuli and/or a facilitation of inputs to relevant stimuli. The prior-preparatory state hypothesis attributes the increments to a nonspecific increase in cortical arousal to all stimuli due to a preparation for a relevant stimulus. Finally, the reactive-change hypothesis suggests that cortical (LPC) enhancement is due to a momentary relaxation in arousal following presentation of a relevant stimulus.

Data have been offered which reflect the inadequacies of all three formulations. With regard to the sensory-modulation hypothesis, EEG indicants of general cortical activation have been shown to occur during the presentation of relevant stimuli (Näätänen, 1970). Differential preparation, on the other hand, cannot account for the enhancement reported in studies that randomly presented stimuli (Harter & Salmon, 1972). And, finally, the early latency changes observed in some studies (Haider _et al_., 1964) cannot be explained by the reactive-change hypothesis.

Of the three hypotheses, however, the sensory-modulation concept has seemed the most reliable in accounting for the data. With this view in mind, a study which attempts to clarify the inconsistences and eliminate possible confounding factors (e.g., receptor changes, expectancy, etc.) would seem justified.

Purpose of the Study

The main emphasis in the present study was on establishing the influence of sensory modulation on the evoked response, even when nonspecific arousal has been eliminated. The present study was designed as a follow-up to a study conducted by Harter and Salmon (1972). In their study, the authors investigated intra-modality selective attention by requiring *S*s to attend one of two binocularly-presented stimuli. In the present study, intra-modality selective attention was investigated by requiring *S* to attend to stimuli presented to one eye and ignore stimuli presented to the other eye.

As in the first study, stimuli were presented in a single modality (vision) to eliminate the possibility of gross orienting responses toward the relevant modality (e.g., loss of fixation due to eye movements when an auditory stimulus is presented). Stimuli were presented to the same retinal areas to avoid stimulating different retinal locations (e.g., foveal or peripheral) and strong fixation cues were present at all times. In addition, stimuli were of the same size and duration and were of similar configuration so that one stimulus was not intrinsically more "interesting" than another. Again, as in the first study, stimulus presentations were randomized so that S could not accurately predict when a relevant stimulus would occur. Finally, the interstimulus interval (ISI) between relevant and irrelevant stimuli was held constant and was of short duration so that S would not have more time to prepare for one stimulus than another.

The use of this procedure should reduce the possibility that general arousal or reactive change could account for any differences observed in the evoked responses to relevant and irrelevant stimuli. Rather, any differences would be attributed to the effects of selective attention. By varying the similarity between stimuli to the two eyes (i.e., in terms of color and line orientation), the channel specificity of selective attention effects, as suggested by the sensory-modulation hypothesis, was also investigated.

Method

Subjects

Two male and three female graduate students ranging in age from 22 to 28 served as Ss. Four of the five Ss were relatively naive with regard to evoked potential experiments, although they had served as Ss in the rather extensive pilot work preceding the current study. The fifth S had had prior experience in evoked potential research.

Selective Attention Task

Each S participated in four one-hour experimental sessions (replications), given on different days. In each session, S was presented four stimulus conditions in which he was to attend to flashes presented to one eye (relevant) and ignore flashes presented to the other eye (irrelevant). Each condition required discrimination between two randomly-presented monocular stimuli occurring concomitantly but never simultaneously. The ISI between stimuli was 550 msec. with a flash duration of 10 μsec. Previous work in our laboratory indicates that this ISI is of sufficient length to permit discrimination of any systematic changes in the VER with attention (Harter & Salmon, 1972; Wilson & Harter, 1973).

Selective attention was manipulated by requiring S to count the number of relevant flashes (total of 32) and make a RT response following the thirtieth presentation. The RT response consisted of S releasing a microswitch key with the index finger of his preferred hand. Since only one response was required per run (to be discussed later), it is unlikely that any motor artifacts associated with the response would have contaminated the VERs. In order to assure that S did not relax his attention after the key release, he was also required to report the total number of relevant flashes at the end of a run. The experimenter (E) then gave S feedback as to the accuracy of his manual and verbal responses.

Dioptic and Dichoptic Stimulation

In order to determine whether the degree of similarity of stimuli presented to the two eyes influenced S's ability to attend to one eye, stimuli were either presented dioptically (i.e., same line and color patterns to both eyes) or dichoptically (i.e., different line and/or color patterns to each eye). With the line patterns, dichoptic presentation consisted of rotating the orientation of the lines presented to one eye by 90 degrees; with color, a red pattern was presented to one eye while green was presented to the other. The four pattern conditions generated were: (a) Dioptic, where the patterns to the two eyes were identical (e.g., red ///--left eye (L) and red ///--right eye (R)); (b) Orientation, where noncorresponding retinal points were stimulated by opposing line patterns (e.g., red /// (L) and red \\\ (R)); (c) Color, where stimulated retinal points were identical but hue was different (e.g., red /// (L) and green /// (R)); and Color X Orientation, where both hue and retinal points were different (e.g., red /// (L) and green \\\(R)).

Experimental Design

In order to permit comparison of responses to stimuli when they were both relevant and irrelevant, there were two attention conditions within each pattern treatment. For one half of a pattern condition, stimuli to one eye were relevant and for the other half, there was a change in relevance to the other eye. Each pattern condition, therefore, resulted in four VERs: a left eye response and a right eye response for the Attend Left run and, similarly, a left eye response and a right eye response for the Attend Right run.

In order to control for the effects of time (adaptation and habituation), flash color, and line orientation *per se* on the VERs elicited by a given attention condition, these variables were counterbalanced in obtaining each averaged VER. Within an experimental session, the four pattern treatments were presented in an ABCDDCBA order with corresponding responses for the two halves of a session being combined. This procedure counterbalanced the effects of time. Further, for the second half of a session, each initial stimulus was changed to its opponent member (e.g., red /// to green \\\ ) so that the averaged VER contained responses to both colors and both line orientations (see Appendix A for a complete representation of stimulus presentations). This latter procedure counterbalanced the effects of color and line orientation *per se* and insured that differences in VERs would reflect the similarity of stimuli flashed to the two eyes and selective attention. With regard to this summation procedure, it should be noted that earlier work in our laboratory indicated that the VERs to the two colors and two line orientations were of similar phase and polarity.

Thirty-two stimuli were presented to each eye during a run for a total of 64 stimuli to each eye under one attention condition. For example, if Color were the first pattern condition (i.e., A in the counterbalancing procedure given above), 32 stimuli were presented to each eye under both the Attend Left and Attend Right runs. The same procedure was followed for the remaining three pattern conditions, followed by a 5 min. rest period. Order of treatments was then reversed with the Color condition being presented last. The second set of 32 monocular responses to each eye under corresponding pattern-attention conditions was then combined with the first set for a total of 64 responses for each averaged VER.

To preclude any treatment order effects, the experimental conditions were arranged into four different sequences, one for each session (replication). Each order was chosen with the following restrictions: (a) across orders, no two pattern conditions were presented in sequence more than once, (b) the same pattern was not presented to an eye for more than three consecutive runs, (c) attention conditions were alternated between eyes both within and across pattern conditions, and (d) initial attention conditions were represented equally (see Appendix A for the four sequences). The presentation of the four orders to four Ss for four replications was then determined by a 4 X 4 Latin Square, with an additional presentation arrangement for the fifth S. An illustration of the Latin Square used is given in Appendix B.

Since previous attention studies have used several different electrode locations, recording site was also investigated. Two electrode placements, the occiput (O_z) and the vertex (C_z), were chosen on the basis of topological studies which indicate that O_z is a primary visual projection area and C_z reflects association area activity (for reviews, see Cohen, 1969; Regan, 1972). Since the current study involves discrimination (presumably a higher-order process), it was also felt that several levels of activity should be examined.

An abbreviated schematic representation of the two (one for each electrode site) 2 X 2 X 4 (Eye Stimulated X Eye Attended X Pattern) repeated measures designs is given in Appendix C. Statistical analyses were performed on an average of the averaged VERs that was obtained by averaging evoked potentials across the four replications for a given S under a given condition. This average measure was judged appropriate for analysis since superimposition (to be more thoroughly discussed later) of the replications revealed the consistency of the original VERs.

Prior to the first experimental session, S was informed of the stimulus presentation procedure and the RT response requirement (see Appendix D for complete instructions). In addition, he was cautioned to minimize head and eye movements, maintain central visual fixation and fusion, and remain alert. Each experimental session was initiated with a brief reminder of the instructions and with a practice run. The latter served to establish the RT response and stabilize S's EEG record and allowed E to monitor the equipment for any irregularities.

Visual Stimuli and Apparatus

Stimuli. Stimuli consisted of obliquely-oriented line-patterned transparencies (Harter, Seiple, & Salmon, 1972) that were back-illuminated by colored light flashes.

The nature of the stimulus was determined by three components of the optical system (each mounted in a 3 1/4 X 4 in. slide mount). In order of placement from S, they were a transparency containing the line patterns, a sheet of diffusing paper, and a color filter. The transparency was circular (subtending 2 degrees of arc) and consisted of black lines on a clear background (ratio of transparent elements to black elements was 1 to 7) with the distance between line centers of 18 min. of arc. For purposes of the experiment, the two line orientations could be obtained by simply reversing a transparency. A small sheet of Aquabee tracing paper (standard weight 524) was inserted behind the transparency to diffuse illumination. The color filters were Kodak Wratten Filters Number 26 (red) and Number 40 (green). Dominant wavelengths were 620.6 mμ for the former and 513.4 mμ for the latter.[1] Although these two filters transmitted different amounts of luminance (i.e., 11.6% for red and 33.6% for green in artificial daylight), different intensity settings on the photostimulators (to be more thoroughly discussed later) permitted a subjective brightness match.

Apparatus. Flashes were presented through a haploscope which permitted the stimulation of either eye

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[1] The color vision of all Ss was checked with an Ishihara color test and was found to be within the normal range in all cases.

separately. The haploscope was similar to the one described by Harter _et_ _al_. (1972). It consisted of a box-like viewing chamber approximately 50 cm. long with a partition inserted lengthwise in the chamber to separate the visual fields of the two eyes. Stimulus transparencies, diffusing screens, and color filters were inserted into three 3 1/4 in. slide trays attached to one end of the chamber. An American Optical Company 590 PC Phoropter contained the lenses (+.75 D spherical) and prisms (6.5 Δ adducting) necessary to stabilize accommodation and vergence to approximate visual fixation at one meter. The above values were varied slightly for some _S_s (depending upon interocular distance and refractive correction) in order to maintain comfortable normal vision. Artificial pupils (7 mm. in diameter) were attached to the phoropter to reduce the effects of light reflected from peripheral parts of the visual field. It should be noted that the size of the artificial pupils would not have eliminated the effects of pupillary changes. However, pupil size could not have varied systematically with the presentation of relevant and irrelevant stimuli, since these stimuli were presented randomly.

The end of the haploscope containing the slide trays was mounted flush against a small opening in one wall of the experimental room. A diffusing chamber divided into two sections and lined with aluminum foil was located immediately behind the opening. Attached to the top of the chamber was an incandescent light source mounted in such a way as to provide approximately equal constant back illumination to the two sides of the haploscope. In addition to the back illumination, constant front illumination was emitted by an incandescent source located over a small opening in the haploscope directly in front of the slide trays. This light source furnished the illumination necessary for adequate fixation and permitted S to be able to change the stimulus patterns. Total surround illumination provided by the two sources was 5.60 ml. for the right eye and 5.74 ml. for the left eye. Two Grass PS 2 Photostimulators attached to either side of the back of the diffusing chamber were used to provide the 10 μsec. stimulus flashes. In order to equalize flash intensities for the red and green filters, the intensity settings on the photostimulators were always 8 when a stimulus was green and 16 when it was red. The flash intensities (in log units above threshold) for the two colors presented to both eyes were approximately 2.30 for red and 2.05 for green.

LeHigh Valley Electronics (LVE) and Coulbourn Instruments solid state modules were used in programming stimulus events and monitoring count responses. Random stimulus presentation was programmed with a LVE 355-10 Probability Gate set at 50% probability so that both relevant and irrelevant stimuli had an equal chance of being presented until one had been presented 32 times. Then, the other was presented consecutively until it, too, had been presented 32 times.

VER Recording and Quantification

VER recording. Subjects were seated in an ophthalmologist's chair located in an electrically shielded, partially sound-proof experimental room. The chair could be raised or lowered independently of the haploscope so that S's line of sight would be horizontal to the stimulus displays. To further attenuate extraneous sounds, white noise produced by a Grason Stadler 901B Noise Generator was piped into the chamber.

Visually evoked cortical responses were recorded monopolarly with Grass gold cup scalp electrodes placed at the vertex (C_z) and 2.5 cm. above the inion (O_z) with a reference electrode attached to the right earlobe. The electrodes were held firmly in place by rubber head bands and plastic electrical tape. Skin resistance was lowered to less than 10,000 ohms with Redux Electrode Paste. Cortical activity was amplified by a Grass 7-WC Polygraph with 1/2 amplitude high and low frequency filters set at 35 and 1 Hz respectively. Electroencephalograms were monitored for muscle tension, movement, and other potential artifacts by both the polygraph pen recordings and by a Tektronix Type 545 Oscilloscope.

Evoked responses were averaged for 448 msec. following stimulus onset by a Data Com minicomputer system containing a Computer Automation Alpha 16 minicomputer. Each VER was averaged within 64 words of memory with a dwell time of 7 msec. per word. Since there were eight different stimulus conditions (Attention X Pattern) with two monocular VERs per condition, a total of 16 channels (one for each VER) was necessary for recording from one electrode site. The remaining 16 channels of the computer were similarly used for the other recording position. Solid state Coulbourn Instruments programming modules were used to sort the VERs into the appropriate channels of the computer. The ongoing averages were monitored on a Tektronix Type RM 504 Oscilloscope in order to detect any extraneous signal that could have contaminated the records. Averaged activity was permanently recorded on punched paper tape by an ASR 33TC Teletypewriter. Following completion of the experiment, the paper tape records were loaded into the computer and permanent graphic records were made with a Hewlett Packard 7035B X-Y Recorder.

VER quantification. In order to better visually illustrate any attention effects, difference potentials ($\text{VERs}_{\text{Att-Natt}}$) were obtained off-line in the computer for each replication by subtracting the unattended (Natt) from the attended (Att) response to the same eye under one pattern condition. In addition, both the original VERs and the difference potentials were averaged across the four replications to obtain average VERs (Avg VERs) for every condition. The difference potentials were also averaged across eyes to better illustrate any pattern effects. A portion of one S's (B. W.) original, difference, and averaged data is given in Fig. 1. The superimposed tracings represent the four replications and difference potentials obtained under each of the attention and pattern conditions for the right eye. Although not illustrated, similar records were also obtained for the left eye. The single dashed tracings are the average VERs from the four replications for each condition. As can be seen from Fig. 1, the replications of each condition were consistent with one another, resulting in average VERs which were representative of the original potentials. Although Fig. 1 illustrates only a portion of one S's data, approximately the same degree of consistency was observed in all Ss.

Superimposition of the original and average measures was accomplished by using the average voltage level of the first 50 msec. of activity as a baseline (see Fig. 1). After establishing reference baselines, a visual examination of the data revealed the various components of the VER to be measured (i.e., the components showing the most change with the stimulus conditions). Amplitude measures were then made with a latency bandwidth criterion of 100 msec. for each component across all Ss (220 to 320 msec. for 0_z and

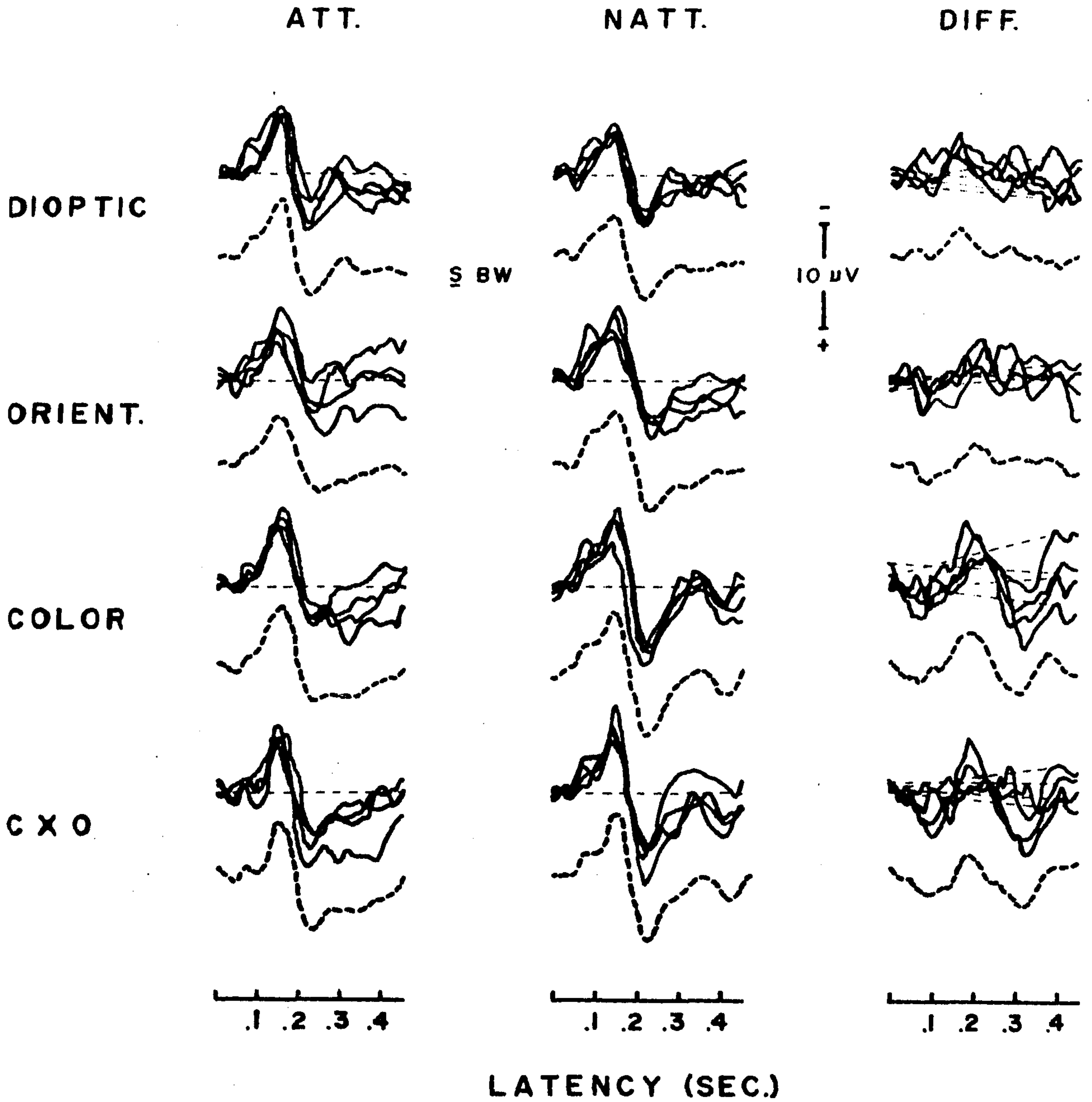

Fig. 1. Visually evoked responses recorded from the occiput of subject B. W. in response to right eye stimulation when attended (Att.) and not attended (Natt.). Difference (Diff.) responses denote differences in VER amplitude due to attention (VER$_{Att-Natt}$). Solid lines represent individual replications (average of 64 flashes); dotted lines represent average of replications (average of 256 flashes). The four pattern conditions are: Dioptic, where identical colors and orientations were presented to both eyes; Orientation (Orient.), where line orientation was varied between eyes; Color, where different colors were presented to the two eyes; and Color X Orientation (C X O), where both color and orientation differed.

180 to 280 msec. for C_z). Due to individual differences in waveform and latency, a 40 msec. window within the bandwidth was permitted each S. Measurements were made of the most negative- or positive-going portion of the component within the window (direction of measurement was dependent upon the sign of the component).

Results

The left eye average VERs and difference potentials at both electrode locations for three of the five Ss are shown in Fig. 2. Visual inspection of both measures reveals that a late positive component (LPC) occurring at a latency of approximately 300 msec. for O_z and 250 msec. for C_z was of greater magnitude to relevant than to irrelevant stimulation. For most Ss, the LPC to relevant stimulation appeared to be a continuation of a positive component occurring about 200 msec. (P200). When the stimulus was irrelevant, P200 returned to baseline much more quickly and, occasionally, went negative. It may also be noted from the average difference potentials in Fig. 2 that the enhancement of the LPC was most apparent in the Color and Color X Orientation conditions.

In order to determine whether these late amplitude changes varied significantly across attention and pattern conditions, they were quantified (as discussed in the Method section) and variance analyses (Kirk, 1969) were performed on the amplitude measures for each recording locus (see Tables 1 and 2 in Appendix E). In general, the attended or relevant stimuli elicited significantly greater amplitude VERs than the unattended or irrelevant stimuli for both O_z ($F = 14.07$ with 1, 4 df; $p < 0.05$) and C_z ($F = 24.08$ with 1, 4 df; $p < 0.01$). An interaction was found

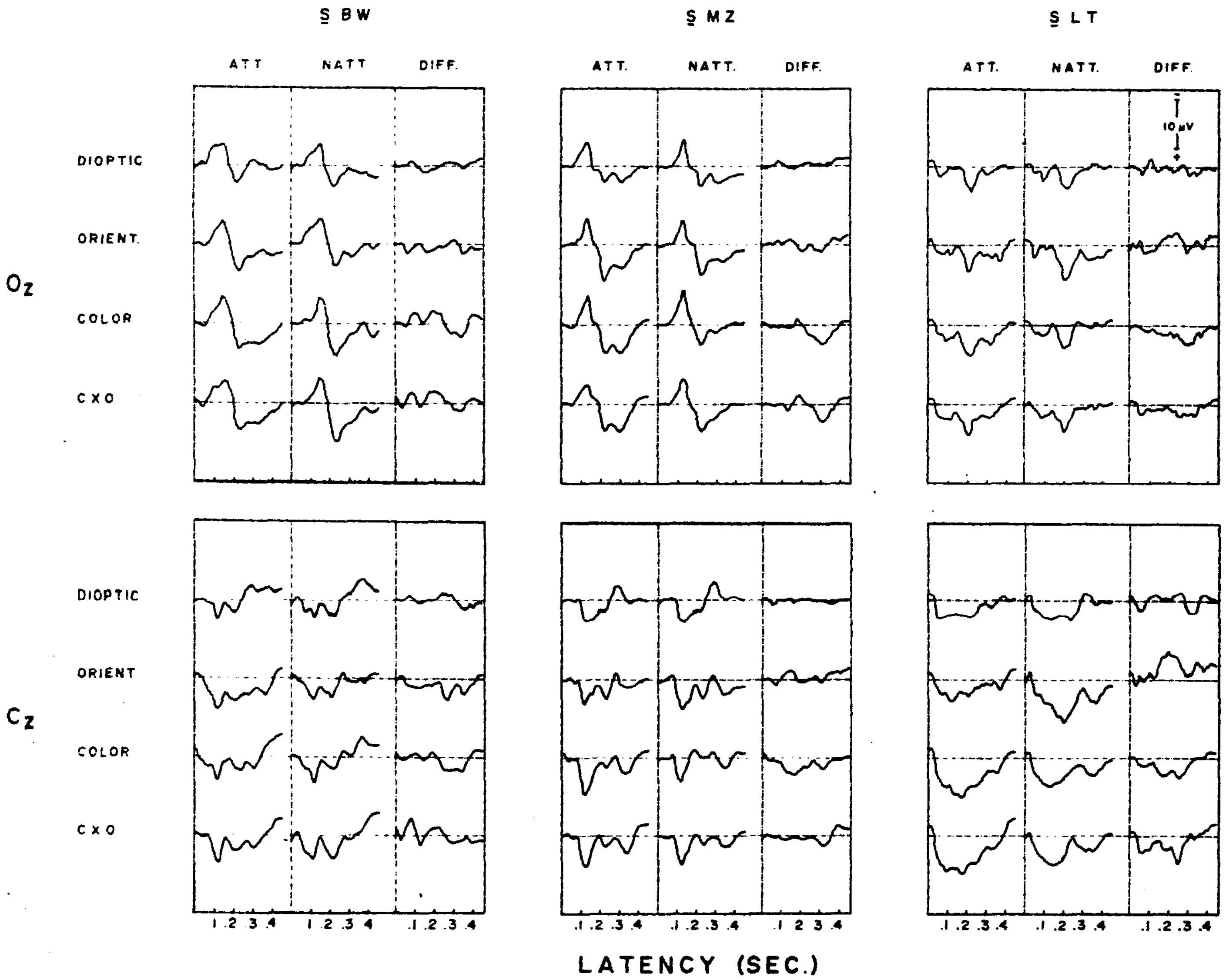

Fig. 2. Same as Fig. 1, except left eye VERs from both electrode positions (O_Z and C_Z) for three of five subjects are shown. Each tracing is an average of four replications (N = 256). Vertical line represents stimulus onset; horizontal line represents baseline determination.

between stimulus relevance and type of pattern presented to the two eyes which was statistically significant for O_z ($F = 7.76$ with 3, 12 df; $p < 0.01$). As can be seen from Fig. 3, there was essentially no difference in the late components to relevant and irrelevant stimulation when the same pattern was presented to both eyes. However, dichoptic presentation resulted in greater LPC amplitude in response to relevant stimulation. Post hoc comparisons revealed that, for O_z, the effects of attention on the LPC were significantly greater under the Color and Color X Orientation conditions than those under the Dioptic condition (Tukey HSD Test, $p < 0.01$). At C_z, the attentional effects under the Orientation condition, as well as those under the Color and Color X Orientation conditions, were significantly greater than those under the Dioptic condition (Tukey HSD Test, $p < 0.01$). Although unexpected, it was also found that Ss generally gave larger responses to stimulation of the left eye than to the right. This effect was observed at both electrode locations, but was significant only at C_z ($F = 34.60$ with 1, 4 df; $p < 0.01$).

It should be noted that, although visual inspection revealed no apparent early changes in the VER, two components (N150 and P200) were measured and analyzed (averaged data). These analyses were performed as a follow-up to a similar study conducted in our laboratory which reported early changes in the VER with changes in

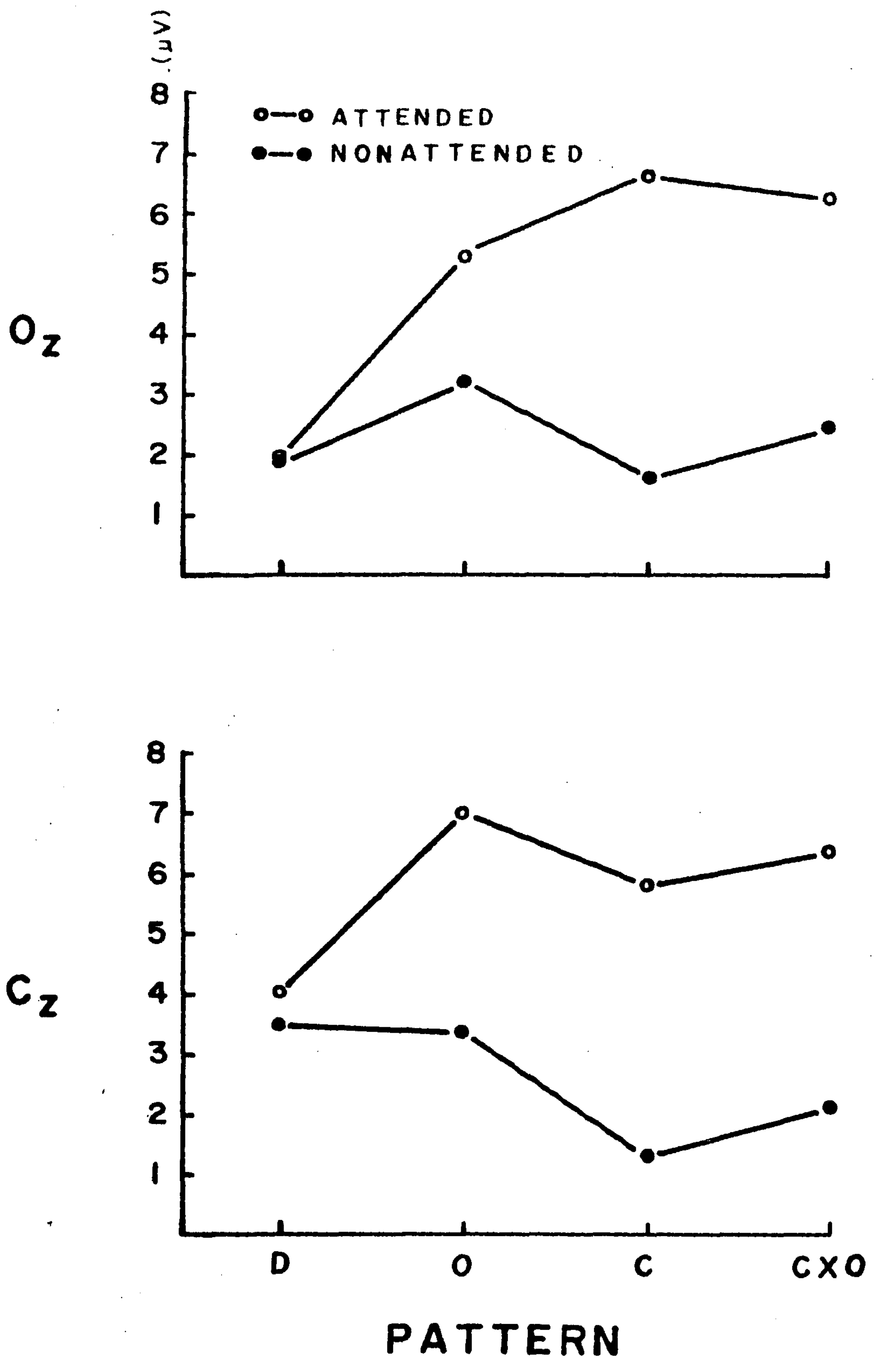

Fig. 3. Mean amplitude of attended and unattended averaged evoked responses (grouped across four replications and five subjects) for the four pattern conditions (D--Dioptic, O--Orientation, C--Color, and C X O--Color X Orientation), recorded from the occipital lobe (O_z) and the vertex (C_z).

selective attention (Harter & Salmon, 1972). Significant results were not found for either component.

Count data. Consistent with the above findings, the Count measure (i.e., the accuracy of the RT release after the thirtieth relevant flash) indicated that *S*s could only discriminate the relevant stimulus if the patterns presented to the two eyes were different (see Table 3 in Appendix E). Further, *S*s' ability to discriminate was best under the Color and Color X Orientation conditions. The percentage total correct responses under each condition were: Dioptic--6.2%; Orientation--46.2%; Color--61.2%; and Color X Orientation--63.7%. Only one of the five *S*s did not show a consistent improvement with increased disparity between the patterns. A Contingency Chi-Square Test performed on the grouped responses made prior to, during, or after the thirtieth presentation of the relevant stimulus for each of the four pattern conditions was highly significant ($\chi^2 = 85.14$ with 6 df; $p < 0.001$). Further analysis of the relationship revealed that the probability of committing an error in predicting which type of response was made would be reduced by 16.3% if the type of pattern was known. This rather low percentage was probably due to the similarity in response patterns for the Color and Color X Orientation conditions.

Subjective reports. Following completion of the study, all *S*s were asked to give their observations of the experiment. In all cases, Ss reported that, on a continuum of difficulty of discrimination, the Dioptic condition was most difficult, followed by Orientation, Color, and, finally, Color X Orientation (the easiest). Some Ss also reported that the irrelevant stimuli appeared dimmer or faded, especially in the Color X Orientation condition while unequal pulsing appeared to occur in the Dioptic condition.

Discussion

It has been shown that when S attends to stimuli presented to one eye and ignores stimuli presented to the other eye, an enhancement occurs in a late positive deflection of the VER. The patterns presented to the two eyes influence the degree of enhancement in that identical patterns result in virtually no enhancement of the LPC whereas dissimilar patterns, particularly those containing opponent colors, are accompanied by an LPC increase. This enhancement was observed at both the occiput (220 to 320 msec. latency) and the vertex (180 to 280 msec. latency), although its effect was significant only over the occipital lobe.

These differences in the LPC were observed when the possibility of differential preparation in response to relevant as compared to irrelevant flashes was reduced to a minimum. The transient changes in arousal and anticipation predicted by the prior-preparatory state hypothesis (Näätänen, 1967) were controlled for in two ways. The random presentation of stimuli reduced the predictability of relevant and irrelevant stimuli to chance level so that any transient changes in arousal due to anticipation should have influenced both types of stimuli equally. Further, the ISI between stimuli was held constant and was of short

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A similar argument may be used with regard to an interpretation in terms of expectancy and "Contingent Negative Variation" (CNV). CNV has been defined as the slow negative direct current potential associated with S's increased anticipation and expectancy of the presentation of a relevant stimulus (S_2) after a warning signal (S_1) has been paired with it (Walter, 1964a; Walter, Cooper, Aldridge, McCallum, & Winter, 1964). In studies reporting CNV, the slow negative potential shift from baseline precipitated by S_1 usually terminates with an abrupt positive deflection when S_2 is presented. Since this positive deflection generally occurs 300 to 400 msec. after the presentation of S_2, the positive after-effect has been proposed as accounting for the LPC of the evoked response. This suggestion has been based upon findings that the amplitude of the slow negative change is correlated with attention and arousal (for a review, see Tecce, 1972). However, several studies have indicated that the LPC of the evoked response and the termination of CNV are independent phenomena which may reflect the same underlying process (Donald & Goff, 1971; Salmon, 1973).

Although the 1/2 amplitude low frequency setting used in the present study (1 Hz) would reduce the amplitude of CNVs, such activity should have been evident, if present. However, no systematic slow potentials were observed in the data. As mentioned previously, the random stimulus presentations and the constant short ISIs would prevent the systematic use of irrelevant stimuli as S_1s for relevant stimuli (S_2s). The elimination of differential expectancy should, therefore, have precluded an explanation in terms of termination of CNV.

Similar criticisms may be made with regard to an interpretation in terms of "motor potentials" as an explanation of LPC enhancement (for a review, see Tecce, 1972). Like CNV, a motor potential is a slow negative potential change which ends in an abrupt positive deflection. These potential shifts are generally recorded in a paradigm involving a motor response (e.g., RT response) to a stimulus. The morphology of the motor potential consists of a slow negative shift which begins occurring one-half to one sec. prior to the presentation of the stimulus requiring the response, followed by a positive termination when the response is made. It has been suggested that these potentials reflect anticipation of and preparation for a motor response. As has been previously noted, however, anticipation cannot account for the results of the present study. In addition, only one motor response was required of S during a run (i.e., on the thirtieth trial). Even if anticipation were possible, it is unlikely that one response (out of a total of 32 presentations) would result in enhancement of the averaged LPC.

As with the differential preparation, CNV termination, and motor potential explanations, Karlin's (1970) hypothesis of reactive change cannot convincingly account for the present results. Karlin postulated that S is maintained in some heightened state of arousal which is relaxed upon presentation of a relevant stimulus. This relaxation is reflected by an enhanced LPC to that stimulus. However, the short duration of the ISIs used in the current study (550 msec.) should virtually eliminate the possibility of momentary relaxation. Any relaxation, if it did occur, would necessarily have prevented S from preparing for the next stimulus (which could have been either relevant or irrelevant) and, therefore, should have prevented consistent LPC enhancement. An additional argument which has been previously used against the reactive change hypothesis cannot be made in relation to the present study, however. Several studies (Davis, 1964; Harter & Salmon, 1972; Spong et al., 1965) have reported early-latency amplitude increments to relevant stimuli which presumably occur too early to result from momentary relaxation. The present study did not find these early latency changes, although a negative component at 150 msec. and a positive component at 200 msec. were measured and analyzed.

One additional non-attentional explanation which has been offered to account for LPC enhancement is in terms of peripheral influences. Several authors (Karlin, 1970; Näätänen, 1967, 1970) have suggested that inadequate control of peripheral factors (e.g., shifts in visual fixation) could account for LPC enhancement. In the present experiment, an attempt was made to control for any potentially confounding peripheral factors. The random presentation of stimuli to either eye should have assured that any peripheral factors occurring prior to a stimulus would have influenced attended and unattended stimuli equally. Stimuli were presented in one modality to eliminate gross orienting responses from one modality to another. Ss were emphatically instructed to avoid eye and body movements and to maintain central visual fixation and fusion. If they could not, they were to inform E to stop the experiment. Since several Ss did, in fact, halt the experiment in several preliminary sessions and since Ss were periodically reminded of these instructions in each session, it is assumed that they followed the instructions. In addition, refractive error, accommodation, and vergence were corrected for each S to approximate visual fixation at one meter. Harter and his coworkers have shown that these latter factors can greatly influence the size of the evoked response (Harter & Salmon, 1971; Harter & White, 1968). Further, stimuli presented to the two eyes were of uniform size, intensity, and pattern (i.e., when line orientations differed, the pattern to one eye was simply the opposite of that to the other eye). Although some S̲s occasionally reported that one eye appeared brighter than the other, no consistent differences were reported nor did the brightness measure indicate any noticeable difference. This observation is not consistent with the significantly larger left eye responses found at the vertex. Since there was not a significant eye effect at the occiput, this finding may not have been due to intensity differences. However, the possibility should not be eliminated since the occipital recording did show larger left eye responses for four of the five S̲s. It should be noted that any possible intensity differences could not account for the enhanced LPC to relevant stimuli, since enhancement was observed to relevant stimuli presented to either eye.

One additional peripheral factor which has been suggested as accounting for VER enhancement is pupillary dilation (Bergamini *et al.*, 1966a, 1966b; Mombelli *et al.*, 1964). Since a number of pupillometric studies have indicated that the pupil dilates when an arousing or relevant stimulus is presented (for a review, see Goldwater, 1972), it has been suggested that an increase in pupillary diameter to relevant stimuli would result in more light striking the retina and, therefore, an increase in the VER. However, in view of the randomization procedure used in the current study, pupil variation should have influenced all responses equally.

With the elimination of the above alternatives as explanations of the VER enhancement observed in the current study, an interpretation in terms of sensory modulation would seem justified. According to this hypothesis, the LPC enhancement to relevant stimuli is due to an attenuation of irrelevant inputs and/or a facilitation of relevant inputs via efferent activity originating in the reticular formation and the cortex. The interaction found between attention and pattern would seem to support this interpretation. When identical patterns were presented to the two eyes, no systematic difference was found between relevant and irrelevant stimuli. This result would be predicted by a sensory-modulation hypothesis since essentially identical neural populations from both eyes would be activated. This latter conclusion is derived from single unit studies indicating chromatic and spatial specificity in the organization of the visual system (Hubel & Wiesel, 1968; Wiesel & Hubel, 1966). Following decussation at the optic chiasm, similar cells from both eyes often synapse on the same higher-order neurons. This convergence, when combined with similar neural populations, would make discriminative attenuation (or facilitation) virtually impossible.

According to the hypothesis, when stimuli presented to the two eyes were different, however, active attenuation could occur. The degree of the attenuation should be influenced by the similarity of the patterns to the two eyes (in terms of the specificity of the underlying neural units activated). In the present study, when line orientation varied, pattern size, spatial frequency, and color were held constant. It was found that attending to lines oriented in one direction resulted in a non-significant change in the VER to that stimulus at O_z whereas a significant increase was observed at C_z. Since Hubel and Wiesel (1968) have indicated that orientation detection is a cortical phenomenon, then, systematic attenuation could not occur peripherally (e.g., at the lateral geniculate) because many of the same cells would be activated by either line pattern (same size and spatial frequency). Rather, any differences observed in the VERs to attended and unattended stimuli would be due solely to differential cortical activation of the appropriate orientation detectors. Although orientation detectors are presumably located in the occipital lobe, it has been suggested (Harter, personal communication) that the O_z electrode may reflect cortical synaptic (dendritic) activity associated with lateral geniculate fibers, rather than single unit (spike) firing of specific occipital cells.

If such is the case, then this postulate could account for the failure to find a significant orientation effect at the O_z electrode (i.e., O_z would be primarily reflecting peripheral activity). The C_z recording, on the other hand, could reflect synaptic activity from the occipital lobe (e.g., the facilitation or attenuation of orientation detectors) and would, therefore, show a large difference in VERs to attended and unattended stimuli. As previously noted, this suggestion is consistent with the current findings. When color was varied, different peripheral, as well as cortical, populations of cells would be activated (DeValois <u>et</u> <u>al</u>., 1967; Wiesel & Hubel, 1966). Therefore, a difference should be noted in the VER to an attended color at both the occipital and vertex recordings. The results are consistent with this suggestion. Attending to one color resulted in a large difference in VERs to relevant and irrelevant stimuli at both O_z and C_z. When color and line orientation were both varied, the attentional difference was approximately the same as that for color alone. This latter finding suggests that the effects were not additive, rather, many of the same processes (perhaps cortical) may have been involved when color and orientation were combined.

When reviewed in the context of present knowledge of the visual system, the results of the current study would appear to offer substantial support for a sensory modulation hypothesis. Harter and Salmon (1972) offered a similar interpretation of the VER increments found in their study. These authors further suggested that sensory modulation could be mediated by "physiological mechanisms which underlie other types of phenomenological visual suppression, and concurrent changes in cortical activity [p. 611]." Two types of visual suppression implicated were retinal rivalry (Cobb, Ettlinger, & Morton, 1968; Cobb, Morton, & Ettlinger, 1967; Kawasaki, Hirose, Jacobson, & Cordella, 1970; Lansing, 1964; van Balen, 1964) and interocular suppression (Cigánek, 1971; Lehmann & Fender, 1967, 1968; MacKay, 1968; Spekreijse, van der Tweel, & Regan, 1972; van der Tweel, Spekreijse, & Regan, 1970). As in the current study involving attention, these studies reported VER amplitude reduction when different patterns were presented to the two eyes. Since it appears that the attentional process also involves some type of suppression of the unattended stimulus (as indicated by VER reduction and Ss' phenomenological reports of "fading or dimming"), this suppression may be related to the interocular suppression observed in binocular rivalry. Although Helmholtz (1925) originally proposed that the suppression observed during binocular rivalry is strictly an attentional process, more recent studies have indicated that involuntary processes are also involved (for a review, see Check, 1968). As in the case of attention, the mechanisms responsible for rivalry and interocular suppression are, unfortunately not yet fully understood. A clarification of either of these processes could, perhaps, contribute to the understanding of the mechanisms involved in selective attention.

One additional point of view which is similar to that of the proponents of sensory modulation should be mentioned. Sokolov (1963) has suggested that when S is instructed to attend to one stimulus and ignore another one, a mental pattern or "template" for rejection may be formed. The template (which, presumably, works at a fairly low level) is patterned to match the irrelevant signal so that each time it is presented, the irrelevant signal is assimilated without further analysis. When a relevant stimulus is presented, however, a comparison indicates that it does not match the rejection pattern. The stimulus is then re-evaluated to determine its significance. The enhancement in the later components of the evoked response to the relevant stimulus may reflect this re-evaluation process. Sokolov's position is very consistent with the concept of sensory modulation. According to an interpretation in terms of the latter conceptualization, the reticular formation would perform the function of forming and matching a template. Any stimulus which matches the template would be attenuated; a stimulus which did not match the pattern would not be attenuated or would even be facilitated. Ritter and Vaughan (1969) proposed a similar explanation in interpreting the results of their vigilance study. However, they suggested that the template may be of cortical origin.

Although the results of the current study do indicate that sensory modulation may be involved in the regulation of attention, these findings do not indicate the location of the regulatory mechanism. This last observation emphasizes the weakness of most of the evoked potential studies involving attention and arousal. Although several alternative explanations have been postulated to account for evoked response enhancement to relevant stimuli, very little definitive work has been done to locate the neurophysiological mechanisms involved.

A Theoretical Model

The neurophysiological mechanism most frequently mentioned as being responsible for the modification of the evoked potential resides in the reticular formation. Lindsley (1958) has postulated that the reticular formation is involved in two essentially different systems which regulate behavioral state. The Ascending Reticular Activating System (ARAS) functions during nonspecific general arousal, while the Diffuse Thalamic Projection System (DTPS) operates during selective alerting. Although not directly implicating either system, Hernández-Peón (1966) has also emphasized the operation of the reticular formation in the modulation of sensory inputs. As Lindsley had done, Hernández-Peón felt it necessary to make a functional and physiological distinction between "involuntary, sensory attention" and "voluntary, intellectual attention." In the former, the reticular formation operates with or without the aid of the cortex to attenuate incoming signals; in the latter, the cortex is a necessary organizational component of the system.

An evaluation of these two conceptualizations indicates that they are not incompatible. An integration of the two would involve equating a) nonspecific general arousal and involuntary attention and b) specific alerting and voluntary attention. The manner in which such a system would operate could then be explained as follows. When the individual is in a generally aroused or alert state, the ARAS operates to facilitate (or disinhibit) all incoming sensory information. The amount of facilitation (or, possibly, inhibition) depends upon the nature of the arousing situation. When the situation requires specific alerting (voluntary attention), the ARAS acts in conjunction with the DTPS to maintain some optimal level of arousal while simultaneously attenuating irrelevant inputs and activating primary cortical areas. In this conceptualization, both types of alerting (attention) would result in sensory modulation and general cortical activation due to ARAS operation. Specific alerting (voluntary attention), on the other hand, would involve the additional operation of the DTPS which further activates the specific cortical projection areas relevant to the stimulus.

With regard to the current study, "voluntary" attention to one eye was required of S. According to the above formulation, then, both the ARAS and the DTPS should have been operating. Although no specific evidence was found to indicate the operation of these regulatory mechanisms, several findings do suggest a conjunctive functioning. The results from the two electrode placements offer the most convincing evidence for an integrative interpretation. Both electrodes showed attentional differences. This finding suggests that higher association cortex (and, perhaps, other cortical areas) are operating in an attentional task. Since the present task did not involve extremely complex discriminative processes, which would require a great deal of cognitive processing, the small difference found at the vertex may reflect this minimal high-level functioning. However, these results are not conclusive since they could simply reflect either activity occurring at more peripheral levels or electrical spread from other brain centers. The pronounced effect at the occipital lobe is suggestive of the "priming" effect of the DTPS, however. Again, these results are not conclusive, but they do conform to the integrative model presented earlier.

Although the differences found between evoked responses to relevant and irrelevant stimuli do not overtly indicate the operation of two regulatory mechanisms, these results do suggest a mechanism responsible for sensory modulation. Nonspecific general cortical activation cannot account for the interaction found between attention and pattern. A nonspecific arousal hypothesis would probably predict that the more similar stimuli (i.e., dioptic or line orientation) should show large cortical differences because the attentional task would be more difficult. However, the largest difference was found for the very dissimilar stimuli (i.e., color and color and orientation). As explained earlier, these results are easily interpreted in the context of a sensory-modulation hypothesis.

Finally, it should be noted that the integrative model can account for the discrepancies in the studies reviewed previously. In particular, it could explain the differences in cortical desynchronization to relevant and irrelevant stimuli reported by Näätänen (1970). Since stimuli in that study were predictable, then differential activation of the ARAS to relevant and irrelevant stimuli would be expected and would result in different levels of cortical desynchronization. This finding was the one most damaging to a sensory-modulation hypothesis. Its explanation, in terms of the model presented here, would appear to resolve the difficulties engendered by that hypothesis while maintaining the integrity of the sensory-modulation concept.

Summary

The purpose of the present study was to determine whether the degree of similarity of stimuli presented to the two eyes (i.e., dioptic or dichoptic) influences S's ability to attend to one eye and whether these attentional differences would be reflected by amplitude changes in the visually evoked cortical response. In addition, an attempt was made to investigate attentional influences on the evoked response when preparatory states and peripheral factors were controlled for.

Differential preparation was eliminated by randomly presenting relevant and irrelevant stimuli at a constant rate so that there were no cues for the presentation of a relevant stimulus. Peripheral influences were reduced to a minimum by instructing S to maintain central visual fixation and fusion of the images to the two eyes. Additionally, the effects of refractive error, accommodation, and vergence were maintained at a constant level for all Ss. The similarity of stimuli were varied in terms of stimulus color and/or line orientation.

A significant increase in amplitude of a late positive component (180 to 320 msec. in latency) was found at the occiput and the vertex when a stimulus was attended

(counted) as compared to responses to the same stimulus when it was not attended. This increase was noted only when the stimuli to the two eyes were different, particularly if they were of different hue.

These results were reviewed in terms of prior-preparatory states, termination of CNV, reactive change, and sensory modulation. It was concluded that selective attention to a particular stimulus accounts for the increase in the LPC of the VER. Further, this enhancement did not appear to be due to anticipation, expectancy, or momentary relaxation. Rather, the most consistent explanation was in terms of a modulation of sensory inputs.

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APPENDIX A

Stimulus Presentation Sequences

	Sequence I		Sequence II		Sequence III		Sequence IV	
Condition	LE	RE	LE	RE	LE	RE	LE	RE
1	$\underline{\text{R/}}$	R/	G\	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	G/	G/	$\underline{\text{R/}}$
2	G\	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	G\	R\	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	R\
3	$\underline{\text{R/}}$	G/	G/	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	R/	G\	$\underline{\text{R/}}$
4	R\	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	R\	G\	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	G\
5	$\underline{\text{G}\backslash}$	G/	G/	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	R/	R/	$\underline{\text{R/}}$
6	R\	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	R\	R/	$\underline{\text{G}\backslash}$	$\underline{\text{G}\backslash}$	G\
7	$\underline{\text{G}\backslash}$	R/	R/	$\underline{\text{R/}}$	$\underline{\text{R/}}$	G/	G/	$\underline{\text{G}\backslash}$
8	R/	$\underline{\text{G}\backslash}$	$\underline{\text{G}\backslash}$	G\	R\	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	R\
8	G\	$\underline{\text{R/}}$	$\underline{\text{R/}}$	R/	G/	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	G/
7	$\underline{\text{R/}}$	G\	G\	$\underline{\text{G}\backslash}$	$\underline{\text{G}\backslash}$	R\	R\	$\underline{\text{R/}}$
6	G/	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	G/	G\	$\underline{\text{R/}}$	$\underline{\text{R/}}$	R/
5	$\underline{\text{R/}}$	R\	R\	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	G\	G\	$\underline{\text{G}\backslash}$
4	G/	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	G/	R/	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	R/
3	$\underline{\text{G}\backslash}$	R\	R\	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	G\	R/	$\underline{\text{G}\backslash}$
2	R/	$\underline{\text{R/}}$	$\underline{\text{G}\backslash}$	R/	G/	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	G/
1	$\underline{\text{G}\backslash}$	G\	R/	$\underline{\text{G}\backslash}$	$\underline{\text{R/}}$	R\	R\	$\underline{\text{G}\backslash}$

Note.--Underlining represents relevant stimulus.

LE Left Eye   R Red   / Right Orientation

RE Right Eye   G Green   \ Left Orientation

Appendix B

Latin Square for Sequence Assignment

S	1	2	3	4
LT	I	II	III	IV
MZ	IV	III	II	I
BW	III	I	IV	II
CS	II	IV	I	III
VO	II	III	IV	I

Replications 1-4

Sequences I-IV

Appendix C

Experimental Design

Ss	D				O				C				C X O			
	Att_L		Att_R		Att_L		Att_R		Att_L		Att_R		Att_L		Att_R	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
S_1																
S_2																
S_3																
S_4																
S_5																

Patterns:
  D--Dioptic
  O--Orientation
  C--Color
  C X O--Color X Orientation

Eye Attended:
  Att_L--Attend Left
  Att_R--Attend Right

Eye Stimulated:
  L--Left
  R--Right

Subjects: Ss 1-5

Appendix D

Instructions to Ss

Your task is to attend to stimuli presented to one eye (for example, the right eye) and ignore stimuli presented to the other eye (in this case, the left). Sometimes the stimuli presented to both eyes will be the same but, more frequently, they will be different. For example, black lines oriented to the left and superimposed on a red background may be presented to the left eye while black lines oriented to the right and superimposed on a green background are being presented to the right eye. Following our pilot work together, you should be familiar with the stimulus procedure.

Please relax as much as possible and keep head and eye movements to a minimum. Always fixate the center of the display and keep the images fused. If you find that you cannot keep them fused during a run, stop the experimenter. If you need to stop, do so by simply saying "stop," do not move around. This will avoid contaminating the data collected to that point.

You will be required to change the stimulus slides after each run. You can reverse line orientation simply by turning the slide over. There are two red and two green color slides. The experimenter will always tell you which patterns to insert. In changing the slides, always push slides in as far as they will go and do so simultaneously.

In order to maintain attention, you will be required to give a reaction time response after the thirtieth presentation of the "attended" stimulus. Do so by simply releasing or tapping the microswitch key after the thirtieth presentation. The experimenter will give you feedback at the end of a run as to the accuracy of your response. After responding, continue to count the "attended" stimuli and report your count to the experimenter.

Appendix E

Table 1

Analysis of Variance: Occipital Average VERs

Source	df	MS	F
Between _S_s	4		
Within _S_s	15		
Eye Stimulated (Eye)	1	70.31	6.13
Attention (Att)	1	374.11	14.07*
Pattern (Patt)	3	68.25	3.03
Eye X Att	1	.31	
Eye X Patt	3	3.21	
Att X Patt	3	57.48	7.76**
Eye X Att X Patt	3	4.65	
Between X Within _S_s	60		
S X Eye	4	11.47	
S X Att	4	26.58	
S X Patt	12	22.51	
S X Eye X Att	4	2.09	
S X Eye X Patt	12	4.16	
S X Att X Patt	12	7.41	
S X Eye X Att X Patt	12	12.74	
Total	79		

*$p < 0.05$

**$p < 0.01$

Table 2

Analysis of Variance: Vertex Average VERs

Source	df	MS	F
Between Ss	4		
Within Ss	15		
Eye Stimulated (Eye)	1	70.31	34.60**
Attention (Att)	1	515.11	24.08**
Pattern (Patt)	3	26.61	1.54
Eye X Att	1	15.31	1.26
Eye X Patt	3	.08	
Att X Patt	3	42.35	2.67
Eye X Att X Patt	3	14.81	
Between X Within Ss	60		
S X Eye	4	2.03	
S X Att	4	21.39	
S X Patt	12	17.27	
S X Eye X Att	4	12.16	
S X Eye X Patt	12	22.63	
S X Patt X Att	12	15.88	
S X Eye X Att X Patt	12	22.74	
Total	79		

**$p < 0.01$

Table 3

Response Pattern Percentages

Resp.	D	O	C	C X O
BW ≥ + 1	-	6.25	31.25	-
0	-	56.25	68.75	81.25
≤ - 1	100.00	37.50	-	18.75
VO ≥ + 1	43.75	37.50	12.50	37.50
0	-	37.50	62.50	50.00
≤ - 1	56.25	25.00	25.00	12.50
CS ≥ + 1	18.75	31.25	-	-
0	12.50	56.25	93.75	93.75
≤ - 1	68.75	12.50	6.25	6.25
LT ≥ + 1	37.50	37.50	12.50	6.25
0	12.50	50.00	68.75	81.25
≤ - 1	50.00	12.50	18.75	12.50
MZ ≥ + 1	93.75	56.25	81.25	87.50
0	6.25	31.25	12.50	12.50
≤ - 1	-	12.50	6.25	-

Total				
≥ + 1	38.75	33.75	27.50	26.25
0	6.25	46.25	61.25	63.75
≤ - 1	55.00	20.00	11.25	10.00

≥ + 1 RT response made after the thirtieth presentation
0 RT response made at the thirtieth presentation
≤ - 1 RT response made prior to the thirtieth presentation