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VISUAL EVENT-RELATED POTENTIALS TO COLORED PATTERNS AND COLOR NAMES: ATTENTION TO FEATURE, DIMENSION, AND MEANING

The University of North Carolina at Greensboro PH.D. 1983

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VISUAL EVENT-RELATED POTENTIALS TO COLORED PATTERNS AND COLOR NAMES:

ATTENTION TO FEATURE, DIMENSION, AND MEANING

by

Cheryl Janice Aine

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Approved by

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APPROVAL PAGE

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ABSTRACT

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The present study utilized visual event-related brain responses to investigate the nature of representation of colors and color names in the nervous system. It was hypothesized that the initial processing of sensory colors and linguistic stimuli occurs at different levels of the brain, while later in time, these features may be synthesized into a unitary representation (e.g. sensory color along with its linguistic label) in central cortical regions. A final prediction was that the processing of sensory colors would elicit greater responses over the right hemisphere while the processing of word stimuli would elicit greater enhancement of the brain response over the left hemisphere.

Pairs of stimuli were presented to the central retina. The first stimulus of a pair (S1) consisted of either a circular red or blue diffuse flash. The second stimulus of a pair (S2) was either a red or blue pattern or the words "red" or "blue" printed in black against a white surround. Selective attention to either the color or word dimension was manipulated by instructing the subjects (four right-handed males and four right-handed females) to respond to the S2 (reaction-time

task) when it matched S1 in terms of the relevant dimension. Brain responses were obtained from both S1 and S2 stimuli and were recorded from over the left and right hemispheres of occipital, central, and frontal cortical regions.

The results indicate the following: 1) The time-course and scalp distribution of a relatively early component of the brain response suggests different source generators or brain regions mediating the processing of colors and words; 2) The selection of a specific dimension (colors versus words) was evident relatively early in time (172 msec) over occipital regions and was followed by the selection within the relevant dimension--a specific color (229 msec) or a specific word (370 msec); 3) The earliest attention effect associated with the processing of specific words was evident over frontal regions (274 msec); 4) An enhancement of the brain response to task irrelevant but semantically related stimuli was evident very early in time (229-274 msec) and in different cortical regions for colors versus words; and 5) Selective attention to a specific color resulted in greater enhancement of the brain response over the right hemisphere while attention to a specific word resulted in a greater enhancement over the left hemisphere.

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CHAPTER I

INTRODUCTION

An aspect of perception which has long been a theoretical stumbling block for theories of perception is an account of how objects and events become meaningful (Neisser, 1976). The British Associationists of the seventeenth century believed that all mental life could be analyzed into specific ideas (the elements of mind) and the association between these ideas (Boring, 1957; Lowry, 1971). Associations, as expressed by Aristotle and maintained by the associationists, develop when events or objects occur in the same time or space (Doctrine of Association by Contiguity), when events or objects are similar (Doctrine of Association by Similarity), and when objects and events are opposites (Doctrine of Association by Contrast).

William James rejected the elementarism of associationism (Watson, 1968). Similar to the associationists, James proposed that objects experienced together tend to become associated by law of neural habit; elementary brain processes occurring in immediate succession or simultaneously tend to propagate excitement into one another. However, analyses of mind which treat the mind as mere congeries of elements fail to consider the global processes such as the innate capacity of the mind to perceive relations and categories. Consciousness is a continuous affair, not discrete elements or ideas (Boring, 1957; Watson, 1968).

The Gestalt movement, subsequent to James and the Functionalists, also rejected the notion that our perceptions are mere aggregations of sensations. Perceptions are organized as meaningful wholes through the Principle of Isomorphism; the form of experience corresponds to the form or configuration of the stimulus pattern (i.e., Gestalten). Gestalten are not photographic copies of the physical word but are true representations of the physical world. Kohler has suggested that Gestalten develop via electrical fields in visual cortex which are isomorphic with stimulus configurations (Chaplin and Krawiec, 1974).

In contemporary psychological theories of perception and cognition, this controversy takes the form of "data driven" or "bottom-up" processing versus "conceptually driven" or "top-down" processing. Is meaning added to a representation of the stimulus configuration after the features have been analyzed (data driven) or before the stimulus details have been processed (conceptually driven)? "Data driven" processing is initiated by the arrival of sensory data at the receptor which then proceeds through successive stages of analysis until "meaning" becomes attached at some higher level of processing (e.g., after contact is made with memory). "Conceptually driven" processing begins with a general knowledge of events that are being experienced and with specific expectations which guide the stages of analysis at all levels (Lachman, Lachman, and Butterfield, 1979; Lindsay and Norman, 1977; Treisman and Gelade, 1980).

The controversy between "bottom-up" and "top-down" processing also has its counterparts in the neuroscience literature. It is unlikely that neural processes resemble "bottom-up" processing in absolute terms since attention, for example, has been shown to influence neural processing of afferent information at all levels of the visual system including the retinal level (Eason, Oakley, and Flowers 1983). However, these terms suggest basic differences in the organization of the visual system. "Bottom-up" processing implies that complex processes result from the integration of afferent information as if information is processed in a serial and/or hierarchical fashion. "Top-down" processing, on the other hand, does not presuppose that higher-order processes are dependent upon lower-order processes. In fact, it implies the opposite. From a neurophysiological perspective, "top-down" processing suggests that complex processes such as the processing of "meaning" can occur very early in time and in parallel with lower-order processes.

The work of Hubel and Wiesel on cats has led to the classical conception of the geniculostriate system as being a serial and hierarchical pathway from retinal through striate and extrastriate regions (Hubel and Wiesel, 1965; Kuffler and Nicholls, 1976, pp. 61-73). This conceptualization is reminiscent of "bottom-up" processing where information processing is carried out in hierarchically arranged levels, proceeding from one functionally related group of cells to the next. Some researchers (Gross, 1973, pp. 451-482)) consider inferotemporal cortex as the highest level of the serial and hierarchical pathway. In general, there is a trend for the receptive-fields to increase in size from striate to extrastriate regions; this progressive increase in size appears to correlate with higher levels of visual cortex (Zeki, 1978). Inferotemporal cortex, for example, has larger receptive-fields and generally has more converging inputs than striate and prestriate areas (Gross, Rocha-Miranda and Bender, 1972; Rocha-Miranda, Bender, Gross, and Mishkin, 1975). Its receptive-fields are sensitive to complex stimulus features in comparison to receptive-fields in occipital cortex (Gross, 1973). This region has been implicated in higher forms of information processing such as the categorization of information, object representation, retrieval of visual information, discrimination learning, and selective attention (Bagshaw, Mackworth, and Pribram, 1972; Butter, 1969; Gross, Rocha-Miranda, and Bender, 1972; Sahgal and Iversen, 1978).

The adequacy of this serial hierarchical conceptualization may be, in part, questioned in light of recent neurophysiological and neuroanatomical data on parallel visual pathways and areas. Lieb and Karmel (1974) have utilized ERPs in the rhesus monkey (via implanted electrodes) to show that the earliest and most significant signs of sensitivity to checkerboard patterns of varying sizes was evident in parafoveal striate cortex (70 msec poststimulus) rather than foveal striate cortex. Subsequent changes in the ERPs were noted in foveal striate, foveal prestriate, and inferotemporal cortex, respectively (190-400 msec).

Data on neuroanatomical pathways, in general, suggest that there are several visual pathways from the retina to cortex with many subcortical feedback loops as well as cortical feedback loops (Graybiel, 1974; Lund and Boothe, 1975; Macko, Jarvis, Kennedy, Miyaoka, Shinohara, Sokoloff, and Mishkin, 1982; Singer, Tretter, and Cynader, 1975; Sprague, Levy, Diberardino, and Berlucchi, 1977; Wilson, 1978; Zeki, 1978). At the cortical level there are many different visual areas which are not arranged in a strict serial order (Van Essen, 1979). Each visual area in primates receives input from more than one cortical area and projects to more than one cortical target. Zeki (1978) suggests that these different visual areas perform a simultaneous analysis of different types of visual information which is why a visual field must be represented separately in each of the different areas.

Consequently, the role of the parallel tectopulvinar and geniculostriate systems in perception has been questioned. The tectopulvinar system may provide the first stage of simple coarse pattern perception rather than striate cortex (Sprague, Levy, Diberardino, and Berlucchi, 1977). Parietal areas are another likely candidate for providing the first stage of analysis given the large multimodal cells in this region which are highly interconnected with other regions (Mountcastle, Lynch, Georgepoulos, Sakata, and Acunia, 1975; Yin and Mountcastle, 1977). Striate cortex may be necessary only for limited aspects of perception such as rapid learning, selective attention, and fine stereopsis (Cowey, 1981; Berlucchi and Sprague, 1981; Rodieck, 1979).

In addition to the early single-unit data of Hubel and Wiesel, Geschwind's neuropsychological model of the representation of language (1972) also favors a hierarchical conceptualization of the nervous system. Geschwind hypothesized that the angular gyrus integrates sensory information from various modalities to form an abstract or symbolic representation of this sensory information. Clinical studies on anomic aphasia (i.e., difficulty in finding names of objects) support the notion that such deficits result from lesions in the angular gyrus or parietal-occipital regions (Geschwind, 1967; Luria, 1973). Ojemann (in press), in contrast, has presented a model of cortical organization of language, derived from stimulation mapping techniques, which stresses parallel processes. Association cortex is organized in discrete mosaics or columns each of which seems to be related to a distinct language function. A particular language function, however, is re-represented from frontal to parietal-temporal areas.

The asymmetry of neural responses associated with various types of processing has yielded additional information related to the serial versus parallel nature of the visual system and the temporal sequence in which different types of information (e.g., processes of varying levels of complexity) are processed. Harter, Aine and Schroeder (1982) reported an early (172 msec) enhancement of a negative component in occipitally recorded event-related potentials over the hemisphere contralateral to the visual field of the attended stimulus. This enhancement was associated with attention to the location of the evoking flash. Later in time, an enhancement of the brain response over occipital regions (N272) was greater over the right hemisphere regardless of the location of the evoking flash. Differences in the time-course (i.e., temporal sequence) of asymmetries associated with various types of processing and the cortical regions in which these asymmetries were evident, were interpreted as reflecting different underlying mechanisms and suggests both the serial and parallel nature of different processes.

The primary purpose of this study is to address the following questions related to the serial verus parallel nature of different types of neural information processing at the cortical level: Are verbal and nonverbal information processed serially in the same system or in parallel in different systems? Does the labeling of percepts (i.e., linguistic and nonlinguistic) occur in the same or different cortical regions? At what point in time is the "meaning" of a stimulus reflected in the brain response? Is there an interaction between the sensory and linguistic representations of information? Furthermore, is one hemisphere better suited for the processing of one type of information than another (e.g. colors versus words)?

ERPs as a Measure of Neural Processing

These questions are addressed in the present study by utilizing the ERP (event-related potential) methodology. The ERP methodology has a potential advantage over behavioral measures of processing (e.g., reaction-times) in that it may reflect the temporal sequence of information processing, the general brain regions involved in such processing, and whether this processing is occurring in series or in parallel with other processes.

The present study tested a number of hypotheses related to the neural processing of colors and color names which were based on the neural specificity model of selective attention proposed by Harter and Aine (in press). This model proposes that selective neural processing due to attention is mediated by the efferent modulation of neural channels. Neural channels are defined as an aggregate of neurons with similar receptive-field properties. Selective processing is indicated by enhanced neural activity to a stimulus when it does versus does not have features in common with the relevant stimulus. This negative enhancement was termed "selection negativity" by Harter and colleagues and was used as a measure of <u>neural processing</u>. The specificity of selection is determined by the information-processing properties of each neural channel subjected to modulation. This theoretical framework allows one to predict the relative time-course and scalp distribution of enhanced neural responses associated with processing different features and conjunction of features defining the relevant stimulus.

In support of this model, Harter and colleagues present ERP data which they interpret as indicating that attention to spatial location is mediated, in part, by activity in the tectopulvinar-parietal system (Harter, Aine and Schroeder, 1982), whereas, attention to spatial orientation is mediated by activity in the geniculostriate projection system (Harter and Guido, 1980). Within the geniculostriate system, Harter and Previc (1978) have shown that selective attention to a specific check size modulates a negative component in the ERP which was interpreted as resulting from the modulation of the neural channels responsible for the processing of the attended check size. Similarly, Harter and Guido (1980) have suggested that selective attention to pattern orientation modulates the activity of orientation-specific channels.

Color and word processing.--It follows from the above neurophysiological model that colors may be processed before words. In this context, "processing" refers to the increased activation of the neuronal aggregates responsive to features of a relevant stimulus. Data indicate that color is represented in the visual system as early as the retinal level and through parietal and inferotemporal cortical regions (De Valois and De Valois, 1975; Fuster and Jervey, 1981; Gross, Rocha-Miranda, and Bender, 1973; Zeki, 1973, 1978, 1980). Single-unit studies on Rhesus monkeys indicate that receptive-fields in Area V4 (occipital-parietal regions) contain the central 20-30 degrees of the retina and are specialized for the analysis of color (Zeki, 1973, 1978, 1980). The foveal prestriate areas also project to inferotemporal cortex, an area apparently necessary for the discrimination and selection of essential cues from a visual stimulus (Cowey and Weiskrantz, 1967; Gross, 1973; Kolb and Whishaw, 1980, pp. 273; Manning, Gross, and Cowey, 1971; Sahgal and Iversen, 1978; Wilson, 1978). The receptive-fields in this region usually include the central retina and are sensitive to color, contrast, shape and orientation (Gross, Bender, and Rocha-Miranda, 1974; Gross, Rocha-Miranda, and Bender, 1972). Fuster and Jervey (1981) found that the reaction of some cells in inferotemporal cortex depend critically on whether the animal paid attention to the colored stimulus. Furthermore, a substantial number of cells showed differences in frequency of discharge when monkeys were required to retain information on the colored stimulus.

Words, in contrast, should be processed later in time since they presumably are represented in parietal-temporal cortical regions (Geschwind, 1972). The integration of sensory information from various modalities to form an abstract or symbolic representation presumably takes time. Similarly, Ojemann (in press) has found a cluster of cortical sites in the posterior temporal lobe which appears to mediate "naming" of common objects. Ojemann suggests that parietal-temporal sites most likely contain the store of neural representations of words ("engrams"?).

Several studies have assessed color and word processing using ERPs. Early ERP studies investigating the effects of color on ERPs revealed color specific changes around 150-300 msec over occipital areas (Eason, Oden, and White, 1967; Shipley, Jones, and Fry, 1965). These studies utilized simple color flashes rather than color embedded in pattern or color/word stimuli and reported changes in the ERP as a function of wavelength, intensity, and retinal location. Harter and Salmon (1972) demonstrated ERP changes as a function of attention to colors (i.e., changes in the ERP to one color flash when it was attended versus ignored).

Neville (1980) attempted to investigate the nature of linguistic processing utilizing ERPs as a measure. She instructed subjects to recall either dichotically presented words (verbal-auditory task), 4-letter words presented visually (verbal-visual task), or to recall melodies or line drawings (nonverbal auditory and visual tasks). ERPs were recorded over both hemispheres of parietal and central cortex. The results indicated a greater left hemisphere effect for linguistic tasks over parietal regions.

Her study, however, contained a number of methodological problems. First, the linguistic and nonlinguistic stimuli varied in their physical characteristics. Such variations are known to influence the ERP; one cannot be sure whether the differences reported above were due to nonlinguistic versus linguistic processing or due to stimulus differences per se. Secondly, the nature of stimulus presentation (i.e., sequential versus simultaneous) and the nature of the tasks (i.e., recognition versus recall) were confounded with the type of stimuli. These methodological problems are commonly found in ERP studies on Linguistic processing (Donchin, Kutas, and McCarthy, 1977).

Aine and Harter (A and B, in press) investigated the neural processing of colors and words in a series of studies while controlling for stimulus differences and other confounds. The nature of the selection process was assessed by investigating the effects due to attending either a single dimension (i.e., the sensory color or word--Study A) or both dimensions (i.e., a particular conjunction of colors and words or the stimulus per se--Study B) of color/word stimuli.

ERPs were recorded to the same physical stimulus (Stroop and Nonstroop color/word stimuli) and compared under these different task instructions; therefore, resultant changes in the ERP were due to the task instruction and not the nature of stimulation per se. This change in ERP waveform, associated with task relevance, consisted of an early enhanced negativity (termed selection negativity) followed by a later enhanced positivity (termed P300).

Aine and Harter (Study A) predicted that the effects of selective attention to colors would be associated with earlier neural processing than attention to words and would be most prominent over occipital regions. In contrast, they predicted that effects due to attending words would be most prominent over the left central electrode. In support of the predictions, the results indicated that enhanced color processing over occipital regions, as indicated by selection negativity, began sooner in time (onset latency=150 msec, peak latency=273 msec) than enhanced word processing (onset latency=273 msec, peak latency=326 msec). Reaction-time data also supported this trend; RTs to colors (386 msec) were faster than RTs to words (420 msec). The second prediction was not supported, however, in that the central data did not show effects due to attending words.

Aine and Harter (Study B) reported that the selection negativity during the processing of colors, began sooner in time than the selection negativity associated with the processing of words (225 msec versus 273 msec poststimulus) at both occipital and central electrode locations. The selection negativity, associated with color processing continued for the duration of the neural processing of words (peak=326 msec).

The data from central regions indicated that the selection negativity associated with word processing was dependent on attention to the color dimension. If the evoking stimulus shared the same color as the task relevant stimulus, then the ERP showed an enhanced response to the word dimension of the color/word stimulus. This result was interpreted as indicating that the left central electrode was recording activity primarily associated with the processing of a conjunction of features which defined the relevant stimulus. The behavioral data were consistent with this interpretation. The mean RT of 428 msec, when responding to both dimensions of conjunction stimuli, paralleled the mean RT to words when responding to a single dimension of conjunction stimuli (Study A). The occipital electrodes, in contrast, showed an enhanced negativity to the relevant word dimension regardless of whether or not the color of the stimulus was relevant.

The results of Aine and Harter (Studies A and B) suggest that color and word processing were initiated in a serial order, but once initiated, they continued in parallel. When the word dimension was relevant, ERPs to stimuli recorded from central regions did not show an enhancement of the selection negativity unless the color dimension was also relevant. This dependency of the word effect on the processing of the relevant color implies a serial and hierarchical organization. This interpretation is consistent with the view that representations of complex stimuli are a result of the integration of sensory information from various cortical areas.

It is proposed here that the failure of obtaining a word processing effect from central regions in the first Aine and Harter study was a result of the conjunction stimuli having been perceived as a single dimension--that is, a word. Perhaps activation of central regions is associated only with attention to multiple dimensions and/or relevant stimulus per se. If central regions are activated by attention to the relevant stimulus per se then "meaning" of these conjunctions may also be represented in this region. The relationship between the processing of features versus "meaning" is examined in the present study along with an examination of the serial or parallel nature of these processes.

The Stroop Phenomenon. The Stroop effect is a delay in color naming of incongruent as compared to congruent color/word stimuli. This effect has provided considerable information on color and word processing (see reviews by Dyer, 1973; Jensen and Rohwer, 1966). A thorough understanding of color and word processing should account for Stroop interference effects. The Stroop effect generally is viewed as the competition between a reading response to the irrelevant word aspect of incongruent color/word stimuli and a color naming response to the relevant aspect of the stimulus. The reading response is presumably stronger than the color naming response and acts to delay color naming. Several studies have, in fact, shown that naming colors takes more time than reading words (Fraisse, 1969; Lund, 1927; Stroop, 1935).

Variants of the Stroop test, however, have shown Stroop interference effects when the reading of words and naming of colors were not required. Interference effects were reported with card-sorting tasks (Treisman and

Fearnley, 1969), a Sternberg paradigm (Hock and Egeth, 1970), and when responding with keypresses (Aine and Harter, C; Pritchatt, 1968; Schmit and Davis, 1974). These studies point to the generality of the phenomenon which needs to be taken into consideration. An interpretation based solely on the notion of competing vocal responses cannot account for the interference effects noted in the variants of the Stroop test.

Color naming may take longer than reading a color name, but color processing per se does not take longer than the processing of words. Speed of recognition is faster for colors than for words when the task involves finding colors versus words in a display (Lund, 1927) and when giving reaction-times to colors versus words (Aine and Harter, A; Schmit and Davis, 1974). If this is the case, then word meaning must interfere with color processing in the later stages of processing (i.e., after the word is processed). This prediction is a major concern in the present study.

Logan (1980) and Marscharck (1982) have treated the Stroop paradigm as a subset of the priming paradigm in general, where one dimension cues another. Logan stated that the relation between the two sources of information (i.e., the physical color and word in color/word stimuli) is influenced by three factors: 1) the nature and strength of prior associations between the two features; 2) the nature and strength of current predictive relations between the two features; and 3) the temporal factors between the two features.

The nature of prior associations (to be addressed in Hypothesis III) is considered by this author to be of primary importance since interference effects are reported in the psychological literature whenever highly associative stimuli are involved (i.e., semantically related). Interference effects are not unique to colors and words; they have been demonstrated for other associative stimuli such as directions (e.g., an arrow pointing upwards associated with the word "south"; the word "north" placed in an incongruent position within a square) and are not unique to one modality (Cohen and Martin, 1975; Logan and Zbrodoff, 1979; Seymour, 1977; Shor, 1970; White, 1969). From a physiological perspective, relatedness between stimuli implies that they are processed at similar points in time and/or share the same neuronal space.

Two studies have utilized the ERP methodology for investigating Stroop interference effects and have reported insignificant results (Duncan-Johnson and Kopell, 1981; Warren and Marsh, 1979). ERPs to Stroop and Nonstroop stimuli did not differ when subjects responded to the color of the stimuli. These failures may be attributed to methodological difficulties. For example, Duncan-Johnson and Kopell utilized P300 latency as a measure of Stroop effects. According to the neural specificity model, the selection negativity (between 300-400 msec) should reveal a difference in the ERPs to Stroop versus Nonstroop stimuli during the neural processing of words. The interference effect may result from one parallel channel inhibiting another (e.g., neural channels mediating word processing may inhibit neural channels mediating color processing when activated) or when the color and color name are processed in the same brain region.

Aine and Harter (A) did show that ERPs can reflect Stroop interference effects; the amplitude of the selection negativity to Stroop stimuli was smaller at 225 msec over occipital regions when compared with the amplitude of the selection negativity to Nonstroop stimuli. Their paradigm, however, was not a Stroop paradigm in that subjects did not respond to a color on every trial. In addition, subjects were required to respond as quickly to Stroop stimuli as Nonstroop stimuli; therefore, the RTs did not vary and a behavioral Stroop effect was precluded.

Consequently, Aine and Harter (Study C, in preparation) addressed the above methodological concerns in a third study. It was hypothesized that the negative results in Study A was due to the emphasis on response speed. Requiring subjects to respond quickly to the color of Stroop stimuli may not have provided sufficient time for processing the word aspect of the stimulus and thus precluded the Stroop effect. In Study C, therefore, response speed was manipulated as an independent variable.

The results of Study C can be summarized as follows. The two RT intervals in which subjects were required to respond (i.e., 300-500 msec and 550-750 msec) influenced the behavioral Stroop effect; but, contrary to the hypothesis, responding quickly did not lessen this effect. Both Stroop and the Reverse Stroop (i.e., the color influences the word response) effects were evident in the behavioral data during the short RT interval. Only the Stroop effect was noticeable at the long RT interval. Interestingly, the majority of studies on the Stroop effect did not report a Reverse Stroop effect (see review by Dyer, 1973). In most of these studies, however, subjects were not required to respond rapidly, which may account for the lack of obtaining the Reverse Stroop effect. In general, the amplitude of the late selection negativity over central cortical regions correlated highly with the behavioral results.

In summary, the results of two of the Aine and Harter studies (A and C) indicate that the selection negativity reflected an interference effect at 225-250 msec poststimulus when subjects responded to the colors. The ERP enhancement associated with attending color was less for Stroop stimuli than for Nonstroop stimuli. This result was interpreted as reflecting either a decrease or delay in processing the color of Stroop stimuli. The early onset of the Stroop effect suggests a paradox, however, since the onset of word processing was not evident in the ERP at this early latency (225-250 msec). How could word meaning influence color processing as early as 225 msec when the onset of word processing was first reflected in the ERP at 273 msec (Aine and Harter, A)? This paradox has served to direct the kinds of questions asked in the present study concerning color and word processing in general. It suggests that word meaning was processed earlier in time than indicated by the ERP data in these studies. One possibility is that the earliest effects of word processing may not be reflected by the occipital electrodes or regions. Ojemann (in press) has shown that frontal regions are involved in many different language functions. Frontal regions, therefore, could reflect the word processing effects very early in time. Another possibility is that words may be processed "automatically", as suggested by some psychological investigators (Shiffrin, Dumais, and Schneider, 1981). If so, the processing of word stimuli may not require sustained attention. These two alternative possibilities will be addressed in the present study.

The preceding discussion was a review of the studies investigating the processing of color and word information from the psychological, neurophysiological, and neuropsychological perspectives. The present study is a continuation in the examination of color and word processing with an emphasis on the serial versus parallel nature of color and word processing. In addition, an attempt to relate previous and present findings on color and word processing to current psychological constructs will be made when there appears to be a correlation between the ERP and the behavioral measures.

Hypothesis I. The internal representation of colors and color names is considered as the activation of different neuronal aggregates responsive to individual color or word features or conjunctions of features. The general hypothesis tested is that the initial internal representation of linguistic versus nonlinguistic stimuli are not located in the same brain region, but rather, are represented at different levels of the brain depending on the location of neuronal aggregates responsive to that particular feature or dimension of the stimulus (e.g., colors).

On the basis of the above discussion, it is hypothesized that colors are represented more peripherally than words. The modulation of the ERP due to processing colors should be evident first over occipital regions; the modulation of the ERP associated with the processing of words should be localized in occipital-parietal or temporal regions. Central cortical regions, in contrast, should reflect the processing of complex features, the conjunction of features, or the "meaning" of the stimulus. Activity associated with processing complex features or "meaning" should be evident later in time when compared with occipital regions. The prediction that activity in occipital regions will precede activity in central regions is based on the conceptualization of the visual system as having some hierarchical organization. If the visual pathway is organized in a serial fashion, then the processing occurring in central regions (presumably representing complex processes) should occur later in time than the processing in occipital regions. This conceptualization is consistent with Geschwind's model of language representation and "bottom-up" theories of information processing in the psychological literature.

The predictions for ERP measures (e.g., selection negativity) over occipital regions are as follows. The early portion of the ERP associated with the onset of color and word processing should show different time-courses and scalp distributions. Previous data (Aine and Harter, A) suggest that the enhancement of the ERP negativity associated with color processing should be evident between 200-300 msec poststimulus. The enhancement of the ERP negativity associated with the processing of words should be evident between 300-400 msec poststimulus. It was suggested that the processing of color/word conjunctions may be more localized to left central regions (Aine and Harter, B). Given the results of Aine and Harter (B) and Geschwind's model of the representation of language, it is possible that a color (a single feature) becomes synthesized with its appropriate linguistic label (i.e., its color name) due to an automatic neural association between the two representations at higher levels of the nervous system. In other words, perhaps the neural association between the representation of a sensory color and its name occurs in central regions ("meaning"?). This hypothesis presupposes that colors and words are processed both physically and linguistically at the same brain region. This suggestion is consistent, in part, with Geschwind's view that the angular gyrus integrates "sensory" information from different areas of the cortex. A different time-course for the late portion of the ERP negativity (at 300-400 msec) reflecting color and word processing, therefore, would indicate that colors and word meaning were not synthesized in the same brain region.

Hemispheric Asymmetries

The study of aphasic disorders (i.e., disorders of language resulting from cortical damage) has demonstrated that lesions in the left frontal lobe (Broca's area) and lesions in the left temporal lobe (Wernicke's area) account for most of the aphasic disorders. This association between disorders of language with left hemisphere lesions has been a basis for the concept of cerebral dominance of language in the left hemisphere. Anatomical differences between the hemispheres (e.g., the planum temporale is larger in the left brain) has provided further support for the concept of laterality of language function in the left hemisphere (see Kolb and Whishaw, 1980, pp. 153-183).

Tachistoscopic studies, in the psychological literature, have also been successful in attempts to demonstrate cerebral laterality for language. In general, individuals who are left-hemisphere dominant tend to exhibit shorter RTs to linguistic stimuli presented to the right visual field or to the right ear (Hines, 1978; Kimura, 1961, 1966; Pirozzolo, 1977).

Neville (1980) utilized ERPs to show a left-hemisphere effect (i.e., the amplitude of the "raw" ERP was greater over the left hemisphere) when subjects were engaged in the processing of linguistic stimuli. A right-hemisphere effect was noted when subjects were attending to line drawings. However, the methodological difficulties associated with this study (as mentioned in a previous section) may suggest an alternative interpretation.

Several studies have investigated the possibility that color processing is lateralized to the right hemisphere. Reaction-time studies (Davidoff, 1976; Pennal, 1977; Pirot, Pulton, and Sutken, 1977; Schmit and Davis, 1974) have shown that subjects typically give shorter responses when colored stimuli are presented in the left visual field. However, this finding has not always been replicable (Guiard, 1981). Clinical studies have also yielded inconsistent results; it is not clear as to which lesion sites produce the various color deficits (e.g., color matching, color memory, or color naming) or which hemisphere may be implicated in these deficits of color perception (Critchley, 1965; De Renzi, and Spinnler, 1967; Oxbury, Oxbury, and Humphrey, 1969).

Harter, Aine, and Schroeder (1982) and Aine and Harter (A) utilized the ERP methodology and reported a left-hemisphere effect when attending to one of many features presented to one point in space. It is unclear, however, whether this effect was associated with attending a conjunction of features (a particular feature at a particular location), associated with attention to one of many stimuli sequentially presented to one location in space, or whether this effect was associated with particular types of processing per se (e.g., processing of linguistic stimuli). In Aine and Harter (A), effects due to attending color were greater over the left hemisphere which may have been a consequence of color being embedded within linguistic stimuli. Therefore, the present study utilized color stimuli consisting of a conjunction of color embedded within a nonlinguistic pattern.

Hypothesis II. It is hypothesized that attention to colored patterns will result in greater amplitude of the ERP (e.g., selection negativity) recorded from the right hemisphere of occipital cortex. This prediction is based on psychological and neuropsychological studies which suggest that the right hemisphere is more responsive than the left hemisphere to the processing of colors. The asymmetry should be evident in the ERP around 200-300 msec which is when color processing effects have been noted previously. Conversely, a greater enhancement of the ERP should be evident over the left occipital hemisphere when subjects are engaged in the processing of linguistic stimuli. This interaction between the asymmetry of the neural responses when processing linguistic versus color stimuli would yield further support for the hypothesis that different neural generators are mediating the effects associated with color and word processing.

Separate Versus Unitary Coding Systems--Meaning

This aspect of the study focuses on when and where the "meaning" of a stimulus is reflected in the ERP. In this study, "meaning" will be operationally defined in a behavioral classification paradigm. The paradox of how word meaning can influence color processing (as reflected in the ERPs) when the onset of word processing occurs later than the onset of the interference effect, needs to be reconciled.

The present study attempts to address this issue in three ways. First, according to the Geschwind model of language representation, one might expect that later activity over central regions may be comparable in terms of time-course for both color and word-processing effects. This may imply that both the physical and semantic aspects of the stimulus are represented in this region. This model resembles "bottom-up" processing where sensory aspects are synthesized into a "meaningful" percept. This possibility was already discussed under Hypothesis I.

Secondly, it is conceivable that occipital regions may not be suitable for recording activity associated with word meaning per se. Perhaps occipital regions are more sensitive to the physical characteristics of the words, whereas, the processing of "meaning" may occur in parallel with the occipital activation and be localized in more frontal regions. Previous results have already shown that central locations were not sensitive to neural activity associated with the processing of words (Aine and Harter, A and B). Frontal electrodes will be used in the present study in order to provide additional information about the neural generators mediating word processing or word meaning.

Johnston and Chesney (1974) and Kutas and Hillyard (1980) provide support for the position that neural activity associated with the "meaning" of a stimulus may be more localized to central-frontal cortical regions. Johnston and Chesney have shown that neural activity correlated with the "meaning" of the stimulus, started as early as 160 msec and was reflected over frontal, not occipital, areas. They recorded ERPs from an ambiguous stimulus (13) when it was to be perceived as a "13" or a "B". It was concluded that visual cortex is more concerned with the representation of physical characteristics of the stimuli and that frontal areas may be more involved in the subsequent representation of "meaning".

Kutas and Hillyard reported a late negativity in the ERP which was evident when subjects performed higher-order linguistic tasks. Subjects were instructed to read 160 different seven-word sentences presented one at a time. The seventh word of each sentence was either semantically appropriate or semantically inappropriate (i.e., out of context with the general meaning of the sentence). Semantically deviant words elicited a late selection negativity occurring around 400 msec which was greater in amplitude over central regions; whereas, physically aberrant stimuli (i.e., the seventh word was larger in size) elicited a late positivity (P3) showing a slightly larger effect over parietal regions.

Although "meaning" in both of these studies was reflected in the ERP over central-frontal regions, the time-course of these effects are not comparable (i.e., 160 msec versus 400 msec). "Meaning" was not clearly defined in these two studies. For example, perhaps the late negativity over central regions in Kutas and Hillyard was an orienting reaction of some kind due to the presentation of a novel stimulus (e.g., an inverted P3).

A final way in which "meaning" can be examined in the present study is to record ERPs to irrelevant stimuli (i.e., they do not require a behavioral response) that are semantically related to the target stimulus (e.g., the color red versus the word "red"). If subjects are instructed to respond to a particular color of a colored flash will the ERP show an enhancement to the related color name? If such enhancement is reflected in the ERP then it says something about the neural association between the processing of two dimensions (linguistic and nonlinguistic) of highly associative stimuli. This enhancement in the ERP would be considered as reflecting the "meaning" of a stimulus per se (e.g., "redness" or "blueness").

The relationship between the processing of colors versus words and the "meaning" of a stimulus can be assessed by examining the time-course and scalp distribution of these effects. For example, is color and its "meaning" processed in the same cortical channel or is the "meaning" of a color flash processed in a separate but parallel cortical channel from the processing of the feature?

Hypothesis III. If the "meaning" of an object or a word becomes attached (i.e., neural association) in some way after the stimulus features have been processed (e.g., "bottom-up" theories of perception or theories based on a hierarchical visual pathway), then the time-course of color processing, for example, and the effect associated with the "meaning" of the colored stimulus should differ. Effects in the ERP associated with the "meaning" of the stimulus should be evident later in time than effects associated with color processes. A hierarchical model would also suggest a difference in the source of origin of this effect. For example, an enhancement of the ERPs associated with the "meaning" of a colored stimulus would most likely be more pronounced over central or frontal regions than occipital regions. Effects associated with the processing of particular words may correspond more in terms of time-course and scalp distribution with the effects in the ERP associated with word "meaning" if words are assumed to reflect higher-order processes.

CHAPTER II

METHOD

Subjects

Four right-handed males and four right-handed females ranging in age from 26 to 40 years participated in the study. All of the subjects either were college graduates or were currently graduate students. Seven of the subjects had had prior experience in an ERP laboratory and all of the subjects had had practice in the experimental conditions.

Several Stroop studies have shown that females are better at naming colors (i.e., shorter naming latencies) than males (Jorgenson, Davis, Opella, and Angerstein, 1980; Stroop, 1935). Jorgenson et al. also have demonstrated shorter reading latencies for males. Although sex differences were not the focus of this study, the design enabled such differences to be assessed with the limitation of small group sizes.

Stimuli

The S1 stimuli consisted of two colored diffuse flashes (red and blue). The four S2 stimuli were two colored patterns (red and blue) against a white background, and two words ("red" and "blue") printed in black against a white background. The color of the flashes was determined by Kodak Wratten color filters (No. 45-blue and No. 29-red). The words were flashed randomly in upper and lower case; ERPs to both the upper and lower case print of a particular word were averaged together. As an additional control for pattern differences, the letter

"E" was left off the word "blue" so that both words were three letters in length. ERPs to one color were averaged across the two patterns.

The stimuli were presented on a 25 mm in diameter rear projection screen (Lehigh Valley Electronics Model 1346) subtending 1.92 degrees at the viewing distance of 75 cm. The circular screen was placed in a salmon-colored surround. The words subtended a vertical visual angle of .69 degrees and a horizontal visual angle of 1.69 degrees. Flash intensities were equated at threshold by adding Kodak neutral density filters to the stimuli when necessary. The resulting flash intensities were 2.3-2.8 log units above the background luminance of .06 mL. Stimulus duration was 40 msec (20 msec rise and fall time).

Pairs of stimuli (S1 and S2) were presented foveally at a rate of one pair per 1200 msec. The S1-S2 interval was 500 msec. A total of eight equiprobable pairs of stimuli were presented randomly.

Experimental Design and Procedure

Subjects were seated in a dimly lit, electrically shielded room and binocularly fixated the centrally located stimuli. White noise was utilized to mask any noise extraneous to the experimental setting. Subjects were instructed to respond (i.e., by pushing both thumbs down on a switch box) to one of two possible matches between S1 and S2: 1) match for sensory color and 2) match for word meaning. The subjects were informed as to the nature of the match condition before the beginning of each trial-block (i.e., color-color or color-word). The first flash (either red or blue) determined which S2 was relevant (i.e., which S2 was to be responded to behaviorally). For example, if the task was to "match for word meaning" and the randomly determined S1 was a red flash, then the subject was required to respond bimanually to S2 only if it was the word "red". Similarly, if S1 was a blue flash, then the word "blu" was the relevant S2.

A trial-block consisted of presenting at least 200 pairs and resulted in four averaged ERPs (to each of the four possible S2s), each of which were based on 50 individual neural responses. There were a total of 24 trial-blocks for each subject: all combinations of two match conditions (color-color or color-word), three electrode locations (occipital, central, and frontal), two hemispheres (left and right), and two replications. The order of presentation of the two match conditions and electrode locations were counterbalanced across replications and subjects.

All the subjects were verbally informed before the first testing session (during a practice session) on how to start and stop the stimuli when necessary. Control of stimulus presentation was provided to the subjects in case they needed to blink, swallow or adjust their position. The experimenter also had control over stimulus presentation. The actual running time for one replication took approximately 2.0-2.5 hours. This time was extended somewhat in order for the experimenter to record the ERP and behavioral data after each trial-block. This also provided the subjects with a few minutes of rest between trial-blocks.

Selective Attention and Task Relevance

Attention was manipulated by having subjects make either a color or word match as signaled by a response to relevant (matches) S2s. To insure that subjects were selectively attending to the appropriate stimuli, criteria were imposed on the behavioral responses. Reaction-times occurring before and after 440 msec to relevant S2s were counted as "Hits" and "Misses", respectively. Subjects were informed of a "Miss" immediately by a negative feed-back tone. The value of 440 msec was chosen since the mean RT to words from a previous study was 428 msec. Subsequent pilot data indicated that matching responses (present study) were faster than RTs in an attention paradigm (previous study). Additional criteria of attaining a minimum percentage of "Hits" and a maximum percentage of "False Alarms" were also imposed. If these criteria were not met, the data from that trial-block were discarded and the condition was repeated. Different criteria (percentage of "Hits" and "False Alarms") were set for the match "color-word" versus "color-color" conditions. These criteria were based on speed and accuracy data obtained in a practice session with each subject (to be discussed later). The percentage of "Hits" and "False Alarms" were adjusted in an effort to hold subjective task difficulty constant: a minimum of 85% "Hits" and a maximum of 15% "False Alarms" in the color-color condition and a minimum of 75% "Hits" and a maximum of 25% "False Alarms" in the color-word condition.

To control for handedness effects, subjects were required to respond bimanually. Reaction-time was recorded from the slower of the two thumb responses. Mean RTs consisted of an average of individual RTs to the total number of relevant stimulus presentations (approximately 50 responses) during a single trial-block.

A practice session was mandatory for each subject to aid in controlling for practice effects and setting criteria. This was especially important for the "match color-color" conditions. Since one aspect of the study was to look at the nature of associations between colors and words, it was necessary to look at pure perceptual matches (if at all possible). An attempt was made to train subjects not to label the color flashes as "red" or "blue" but to make perceptual matches in this condition. A total of six conditions (three color-color matches and three color-word matches) were practiced. This training session was scheduled on a day different from an actual experimental session.

Visual Event-related Responses

Electrical activity was recorded monopolarly from six electrode positions (O1, O2; C3, C4; F7, F8) as defined by the International 10-20 System. All electrodes were referenced to linked ears. Grass gold-cup electrodes were held to the scalp with Grass electrode cream. Skin resistances were below 15K ohms. A ground electrode was placed on the left mastoid. Electrical activity was amplified with a Grass AC differential amplifier (7P5A pre-amplifier and 7DAC driver amplifier). The low and high frequency filters were set on 0.3 Hz and 35.0 Hz, respectively.

Cortical ERPs to task relevant and task irrelevant stimuli were recorded on-line with a Fabri-Tek Instruments signal averager (Model 1062). Cortical activity was measured for a duration of one second following S1 onset; therefore, one sweep of the computer encompassed ERPs to both S1 and S2. Each pair of stimuli was presented until all of the pairs had been presented 50 times. When one pair had been presented 50 times, for example, the averaging of ERPs to that pair was stopped even though that particular pair may have been presented again.

During a single trial-block, the ERPs to eight pairs of stimuli were sorted into the four computer channels according to the degree of similarity between the S2 ERP and the task relevant stimulus (i.e., same feature, same dimension, semantically related-different dimension, unrelated-different dimension). If the task instruction was "match sensory colors", then the ERPs to the two appropriate color-color matches (i.e., the task relevant S2 stimuli) were averaged together into one of the four channels (e.g., blue-blue plus red-red). Similarly, ERPs to the task irrelevant color matches (i.e., the S2 stimuli shared the same dimension as the task relevant S2) were also averaged together into one channel of the computer (e.g., blue-red plus red-blue). The remaining two channels were utilized for recording 1) the ERPs to task irrelevant but semantically related color-word combinations (e.g., red-"red" plus blue-"blue") and 2) the ERPs to the task irrelevant and semantically unrelated color-word combinations (e.g., red-"blue" plus blue-"red"). A similar recording procedure was implemented for the "match word meaning" conditions (See Table 1).

Averaged ERPs were recorded on graph paper with a Hewlett-Packard X-Y Plotter (Model 7035B). Difference potentials, showing the difference in ERP waveform due to the four types of "similarity" conditions, were obtained electronically with the signal averager.

Quantification and Statistical Analysis of ERP and RT Data

The mean voltage level of the first 75 msec following the presentation of both S1 and S2 was utilized as a baseline from which all amplitude measures were taken. The latency of the first S1 amplitude measure was defined for each subject as the maximum positivity occurring after 100 msec poststimulus over occipital cortical regions. Amplitude was measured every 40 msec thereafter up to the maximum late positivity occurring after 350 msec (measure 8). S2 ERP amplitudes were also measured at specified latencies for each subject, including N2 selection negativity which is known to reflect effects due to attention. The difference potentials referred to above, along with data from previous studies and the "raw" ERP waveforms of the present study aided in determining the latencies of all the S2 amplitude measures. The latencies of all amplitude measures, although comparable across subjects (+/- 40 msec from the mean), were not identical for all subjects due to individual differences. The S1 and S2 amplitude measures for each subject are displayed in Table 2.

TABLE 1

Procedure for Recording ERPs to S2 Stimuli

TASK	CHANNEL	(S1-S2)	+	(S1-S2)	S2	TASK RELEVANCE	SIMILARITY BETWEEN S2 AND TASK RELEVANT STIMULUS
Match Color	1	(red-red)	+	(blue-blue)	C	Rel	Same Feature
	2	(red-blue)	+	(blue-red)	C	Irr	Same Dimension
	3	(red-"red")	+	(blue-"blue")	W	Irr	Semantic (Different Dimension)
	4	(red-"blue")	+	(blue-"red")	W	Irr	Unrelated (Different Dimension)
Match Word Meaning	1	(red-"red")	+	(blue-"blue")	W	Rel	Same Feature
	2	(red-"blue")	+	(blue-"red")	W	Irr	Same Dimension
	3	(red-red)	+	(blue-blue)	C	Irr	Semantic (Different Dimension)
	4	(red-blue)	+	(blue-red)	C	Irr	Unrelated (Different Dimension)

Note: S2 ERPs were sorted into four channels during a single trial-block according to the similarity between the S2 stimulus and the task relevant S2 stimulus. One of the S2 stimuli was task relevant. The other three S2 stimuli were irrelevant to the behavioral task but shared either the attended dimension (i.e. color or word), semantic meaning, or was totally unrelated to the task relevant stimulus.

TABLE 2

S1 and S2 Amplitude Measures for Each of Eight Subjects

	S1 AMPLITUDE MEASURES (msec)								
SUBJ.	1	2	3	4	5	6	7	8	9
CA	130	170	210	250	290	330	370	380	500
KL	150	190	230	270	310	350	390	430	500
MM	140	180	220	260	300	340	380	460	500
VJ	140	180	220	260	300	340	380	440	500
GM	140	180	220	260	300	340	380	400	500
RB	130	170	210	250	290	330	370	400	500
TM	150	190	230	270	310	350	390	410	500
RP	150	190	230	270	310	350	390	440	500
MEAN LAT. (msec)	141	181	221	261	301	341	381	420	500

	S2 AMPLITUDE MEASURES (msec)							
SUBJ.	1	2	3	4	5	6	7	8
CA	140	220	270	300	360	410	460	480
KL	180	230	270	320	380	420	450	480
MM	170	220	280	320	390	420	450	480
VJ	190	230	270	330	390	420	460	480
GM	170	240	280	320	370	420	450	480
RB	180	220	250	280	320	360	430	480
TM	170	230	270	320	360	390	420	480
RP	180	240	300	350	390	450	460	480
MEAN LAT. (msec)	172	229	274	318	370	411	450	480

Note: Nine latencies were designated for each individual at which all measures of S1 amplitude were taken. S2 amplitudes were measured at eight designated latencies for each subject. Mean latency of each S1 and S2 amplitude measure is shown below the individual latencies.

Repeated measures analysis of variance (ANOVA) was performed on each dependent measure (i.e., the amplitude measures at each designated latency) for the three electrode locations (occipital, central, and frontal). Therefore, each ANOVA for S1 amplitude measures consisted of the following factors: 1) match conditions (color versus word), 2) hemisphere (left versus right), 3) replications (8), and 4) four subjects nested under each group (male versus female). Each ANOVA for S2 amplitude measures consisted of the following factors: 1) match conditions (color versus word), 2) similarity to the task relevant stimulus (related versus unrelated), 3) hemisphere (left versus right), 4) evoking flash (color or word), 5) replication (2), and 6) four subjects nested under each group (male versus female).

Mean RTs were computed for the two match conditions and subjected to an ANOVA consisting of the following factors: 1) match condition, 2) evoking flash, 3) replication (12), and 4) four subjects nested under each group (male versus females). Separate analyses were performed on the "Hits" and "False Alarm" data.

CHAPTER III

RESULTS

General Effects of Selective Attention and Definition of Effects

The terms Interdimension (Direct) and Intradimension (Direct and Indirect) effects are utilized to describe changes in the ERP as a function of task instruction (i.e., match colors versus words), similarity of the evoking flash to the task relevant S2 (i.e., related versus unrelated), and the dimension of the evoking flash (i.e., color versus word). If the above interaction was statistically significant for an amplitude measure, then portions of these data were analyzed separately to partition out the statistical significance of each of these effects.

Interdimension effects of attention reflect changes in ERP waveform to task-irrelevant stimuli when the task dimension (match colors versus words) interacted with the dimension of the evoking flash. For example, ERPs to S2 colors were compared when colors versus words were being matched. Intradimension Direct effects of attention reflects changes in ERP waveform when task dimension was held constant and the task relevance of S2 (relevant versus irrelevant) interacted with the nature of the evoking flash. For example, if subjects were instructed to match colors then ERPs to S2 colors were compared when the S2 color was task relevant (i.e., the S2 color matched the color of S1) versus when the S2 color was not task relevant (i.e., the S2 color did not match the color of S1). Intradimension Indirect effects of attention reflect changes in ERP waveform when task dimension and task relevance (i.e., ERPs were to task irrelevant S2s) were held constant but the semantic similarity between the task-irrelevant evoking flash and the task relevant stimulus varied. For example, if the task instruction was to match colors then ERPs to S2 words were compared when the S2 word was semantically related to the S1 color versus when the S2 word was semantically unrelated to the S1 color. See Table 3 for a summary of how these different attention effects were derived.

ERPs from one representative subject are displayed in Figure 1. S1 was always a colored diffuse flash; therefore, any consistent changes in the S1 ERP waveform across the two columns of Figure 1 were due to the type of processing required by the task (i.e., processing of sensory colors or word meaning). Effects associated with S1s will be discussed in a later section. S2 ERPs were responses to either colored patterns (left column of Figure 1) or color names (right column of Figure 1). Changes in the S2 waveforms within each column (i.e., solid and dashed lines) were a function of varying the attentional set of the subject (i.e., by varying the attended feature and dimension of the S2 stimuli). For example, the S2 ERPs within the left column were responses to colored patterns when 1) the S2 colored pattern did or did not share the same dimension (i.e., color or word) as the task instruction (Interdimension effects), and when 2) the specific feature of the S2 colored pattern (i.e., color red or blue) of the attended dimension (i.e. colors) did or did not match the preceding S1 (Intradimension effects).

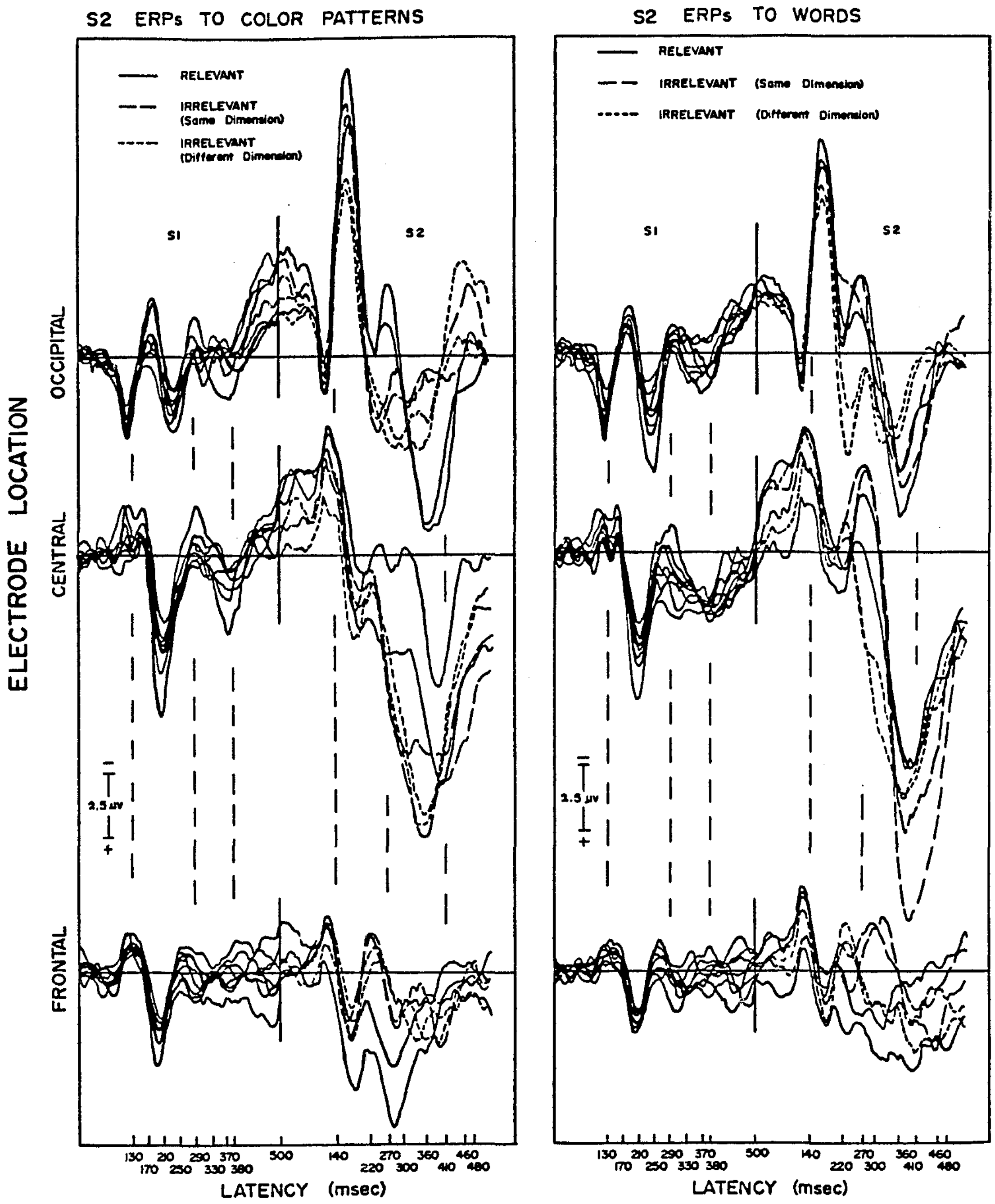
TABLE 3

Derivation of Interdimension, Intradimension, and Indirect Effects of Attention from ERPs to S2 Stimuli

TYPE OF ATTENTION		TASK	S2 ERP	TASK DIMENSION	SIMILARITY BETWEEN S2 AND TASK RELEVANCE / RELEVANT STIMULUS
INTERDIMENSION					
Direct:					
		Match Color-Color	Color blue	Color	IRR (Same Dimension)
	Color =	(red-red)	minus	vs.	vs.
		Match Color-Word	Color blue	Word	IRR (Different Dimension)
		(red-"red")	Δ ERP		
		Match Color-Word	Word "blue"	Word	IRR (Same Dimension)
	Word =	(red-"red")	minus	vs.	vs.
		Match Color-Color	Word "blue"	Color	IRR (Different Dimension)
		(red-red)	Δ ERP		
INTRADIMENSION					
Direct:					
		Match Color-Color	Color red	Color	RELEVANT
	Color =	(red-red)	minus	vs.	vs.
		Match Color-Color	Color red	Color	IRR (Same Dimension)
		(blue-blue)	Δ ERP		
		Match Color-Word	Word "red"	Word	RELEVANT
	Word =	(red-"red")	minus	vs.	vs.
		Match Color-Word	Word "red"	Word	IRR (Same Dimension)
		(blue-"blue")	Δ ERP		
Indirect:					
		Match Color-Color	Word "red"	Color	IRR (Semantic - Different Dimension)
	Color =	(red-red)	minus	vs.	vs.
		Match Color-Color	Word "red"	Color	IRR (Unrelated - Different Dimension)
		(blue-blue)	Δ ERP		
		Match Color-Word	Color red	Word	IRR (Semantic - Different Dimension)
	Word =	(red-"red")	minus	vs.	vs.
		Match Color-Word	Color red	Word	IRR (Unrelated - Different Dimension)
		(blue-"blue")	Δ ERP		

Note: *Interdimension effects* are changes in ERP waveform associated with changing the relevant dimension and following irrelevant S2s (e.g., ERPs to task irrelevant stimuli not sharing the same dimension as the task relevant stimulus was subtracted from ERPs to task irrelevant stimuli sharing the same dimension as the task relevant stimulus). *Intradimension Direct effects* are changes in the ERP waveform associated with changing the relevant stimulus within a dimension and following relevant versus irrelevant S2s (e.g., ERPs to task irrelevant stimuli sharing the the same dimension as the task relevant stimulus were subtracted from ERPs to the task relevant stimuli). *Intradimension Indirect effects* are changes in ERP waveform when both the relevant dimension and stimulus was held constant but the semantic similarity was varied (e.g., ERPs to the task irrelevant and semantically unrelated stimuli of a different dimension from the task relevant stimulus were subtracted from ERPs to task irrelevant but semantically related stimuli of a different dimension from the task relevant stimulus).

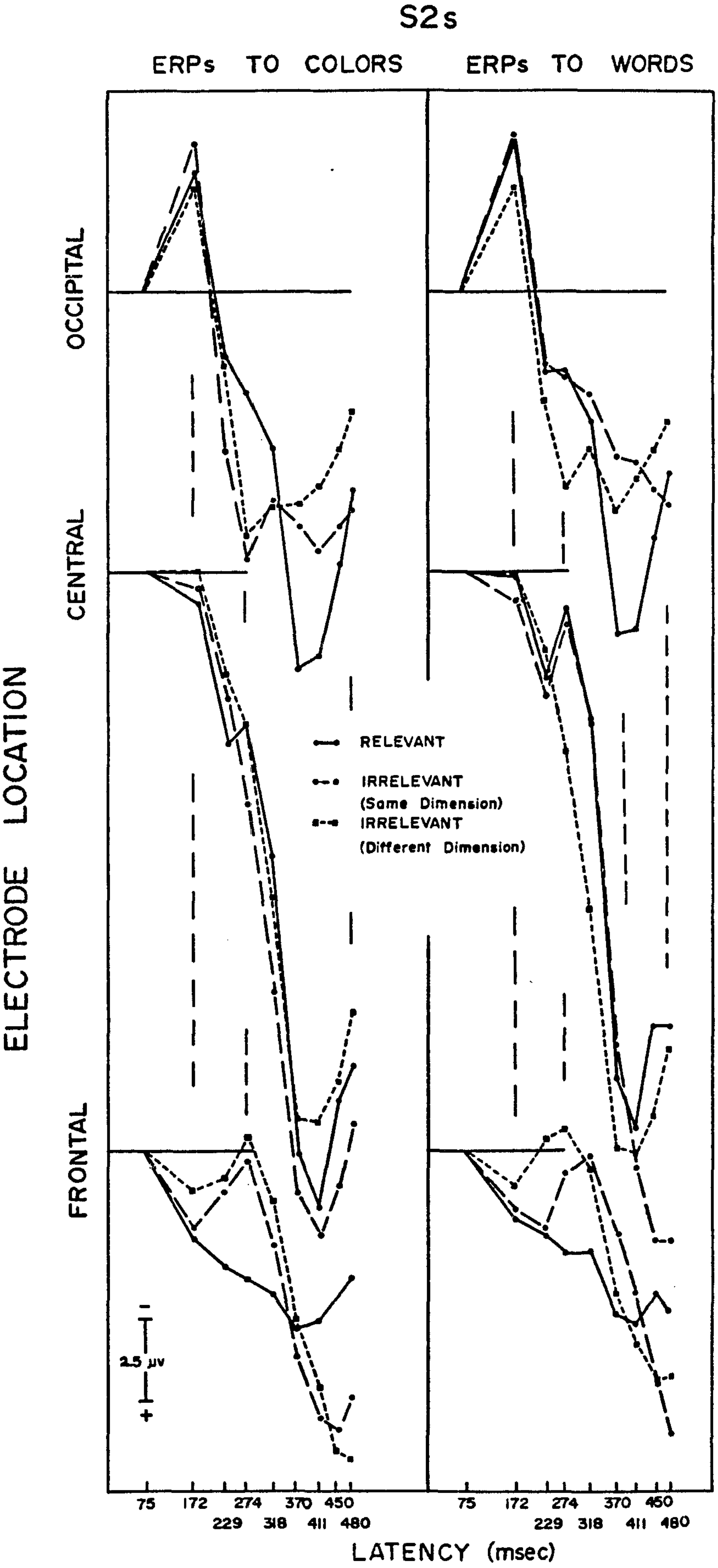
Figure 1. Changes in S1 and S2 ERP waveforms as a function of varying the attended feature and/or dimension of the S1 and S2 flashes. "Raw" ERPs for one subject (CA) recorded from over the left hemisphere of occipital, central, and frontal cortical regions. Left column: ERPs were averaged to color diffuse flashes (S1) during a color-color matching task and to colored patterns (S2) when: 1) the color of the pattern was task relevant (solid lines) during a color-color matching task (a behavioral response was required); 2) the color was task irrelevant (large dashed lines) during a color-color matching task (the S2 shared the same dimension as the task relevant S2); and 3) the color was totally irrelevant (small dashed lines) during a color-word matching task (the S2 did not share the same dimension as the task relevant S2). Right column: ERPs were averaged to color diffuse flashes (S1) during a color-word matching task and to color names (S2) when: 1) the word was task relevant (solid lines) during a color-word matching task (a behavioral response was required); 2) the word was task irrelevant (large dashed lines) during a color-word matching task (the S2 shared the same dimension as the task relevant S2); and 3) the word was totally irrelevant during a color-color matching task (the S2 did not share the same dimension as the task relevant S2). Each S1 and S2 tracing is an average of 50 brain responses. There were a total of eight replications to S1 and two replications to S2 for a single attention condition. The latency measures represent latencies at which all amplitude measures were taken for this particular subject.


ELECTRODE LOCATION
OCCIPITAL
CENTRAL
FRONTAL
S2 ERPs TO COLOR PATTERNS
RELEVANT
IRRELEVANT (Same Dimension)
IRRELEVANT (Different Dimension)
S1
S2
2.5 µV
−
+
130 210 290 370 500 140 270 360 460
170 250 330 380 220 300 410 480
LATENCY (msec)
S2 ERPs TO WORDS
RELEVANT
IRRELEVANT (Same Dimension)
IRRELEVANT (Different Dimension)
S1
S2
2.5 µV
−
+
130 210 290 370 500 140 270 360 460
170 250 330 380 220 300 410 480
LATENCY (msec)

Visual inspection of the occipital data in Figure 1 reveals an enhanced negativity (220-300 msec) of the ERP following Relevant S2s (i.e., the evoking stimuli contained the attended or task relevant feature; Solid lines) when compared with ERPs following Irrelevant S2s (i.e., stimuli not containing the task relevant feature; Dashed lines). This enhanced negativity following Relevant stimuli, referred to as selection negativity, was followed by an enhanced positivity occurring at (300-460 msec), referred to as P300. The enhancement of the ERP following Relevant S2s over frontal regions was reflected as an increase in positivity, rather than a negativity, when compared with ERPs following Irrelevant S2s.

Differences in ERPs following Irrelevant S2s (differences between the two dashed lines in Figure 1) are a function of whether or not the Irrelevant S2 shared the same dimension as the task instruction (Interdimension effects). For example, the ERPs labeled as "Irrelevant-Same Dimension" were responses to either a color when the opposite color was relevant to the behavioral task (left column) or were responses to a word when the opposite word was task relevant (right column). In contrast, the ERPs labeled as "Irrelevant-Different Dimension" were responses to either a color when a nonrelated word was task relevant (left column) or a word when a nonrelated color was task relevant (right column). The quantified data averaged across subjects for these S2 conditions are shown in Figure 2. The latency measures represent the mean latency of each amplitude measure across eight subjects.

Figure 2. Quantified group data demonstrating changes in S2 ERP waveforms as a function of varying the attended feature and/or dimension of S2 flashes. Same as Figure 1 except that each tracing represents the ERP amplitude measures for S2s averaged across two replications, two hemispheres and eight subjects. Latencies depicted at the bottom of this figure and all remaining figures of S2 ERPs represent the mean latency for each of the eight amplitude measures.

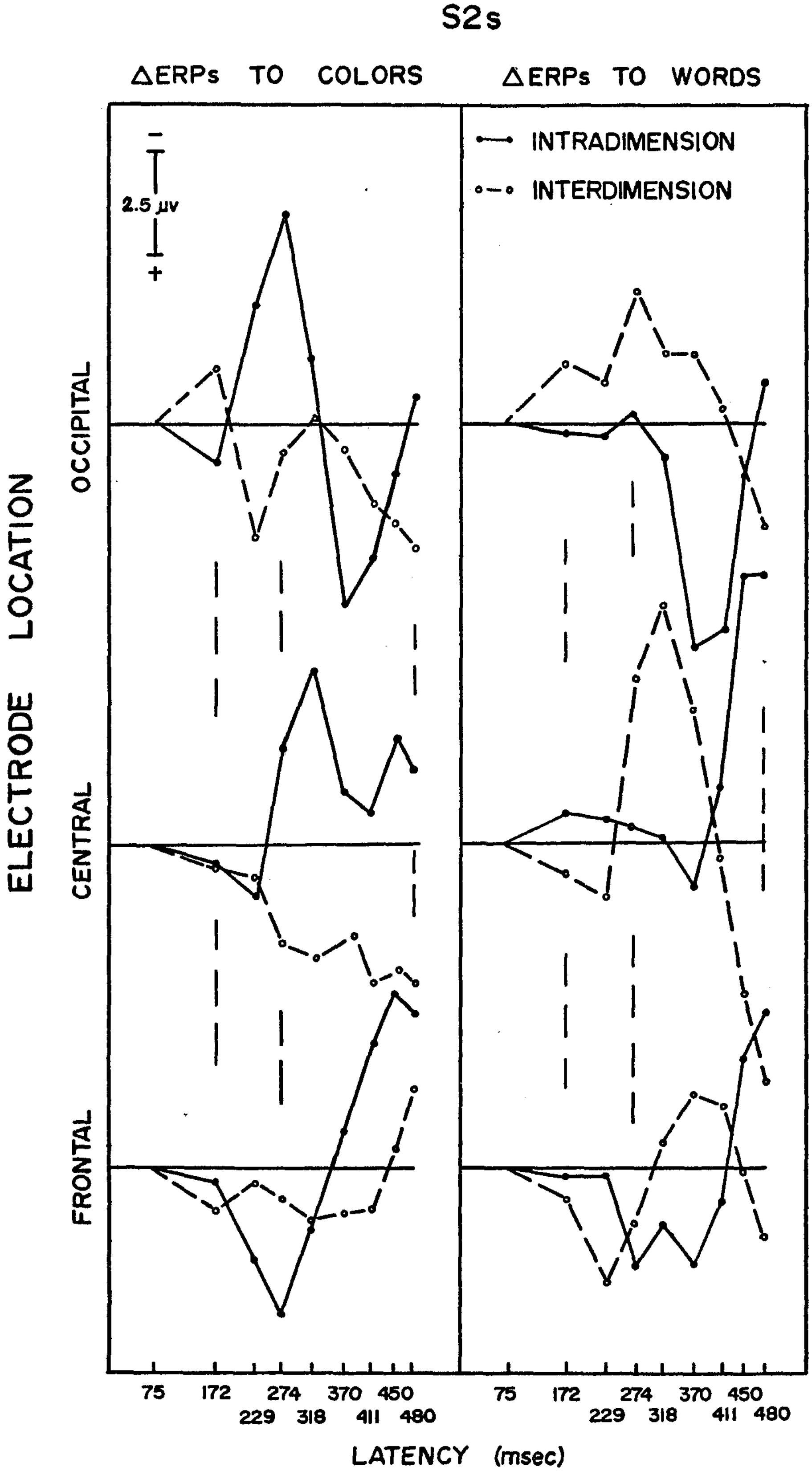

S2s
ERPs TO COLORS
ERPs TO WORDS
ELECTRODE LOCATION
OCCIPITAL
CENTRAL
FRONTAL
RELEVANT
IRRELEVANT (Same Dimension)
IRRELEVANT (Different Dimension)
−
2.5 µv
+
75
172
229
274
318
370
411
450
480
LATENCY (msec)

Inter- and Intradimension: Direct Effects

Changes in S2 ERP amplitude in the quantified group data (Figure 2) as a function of similarity between the evoking flash (colored pattern versus word) and the attended feature and/or dimension of S2 stimuli (i.e., task relevant stimuli) were statistically significant over occipital regions at the following latencies: 172 msec ($F=5.91$; $df=1,6$; $p=.051$), 229 msec ($F=10.65$; $df=1,6$; $p<.025$), 274 msec ($F=15.53$; $df=1,6$; $p<.01$), 370 msec ($F=51.48$; $df=1,6$; $p<.001$), and 411 msec ($F=32.0$; $df=1,6$; $p<.01$). This same interaction was statistically significant over central regions at 274 msec ($F=12.19$; $df=1,6$; $p<.025$) and at the following latencies over frontal regions: 274 msec ($F=20.5$; $df=1,6$; $p<.01$), 450 msec ($F=7.8$; $df=1,6$; $p<.05$) and 480 msec ($F=10.11$; $df=1,6$; $p<.025$).

Difference potentials (ΔERPs) were used to illustrate the effects of two types of attention on the ERPs (Interdimension and Intradimension effects; Figure 3). Difference potentials showing Interdimension effects were derived by subtracting S2 ERPs which were not task relevant and did not share the same dimension as the task relevant stimulus (Irrelevant-Different Dimension; Figure 2) from S2 ERPs which were not task relevant but shared the same dimension as the task relevant stimulus (Irrelevant-Same Dimension; Figure 2). Difference potentials showing Intradimension effects of attention were derived by subtracting the S2 ERPs which were not task relevant but shared the same dimension as the task relevant stimulus (Irrelevant-Same Dimension; Figure 2) from the S2 ERPs which were task relevant (Relevant; Figure 2).

Figure 3. Inter- and Intradimension effects of attention. Same as Figure 2 except difference potentials (△ERPs) were utilized for demonstrating changes in the S2 ERP as a function of task instruction. Left column: Interdimension color effects (dashed lines) - ERPs to the task irrelevant color during a color-word matching task were subtracted from the ERPs to the task irrelevant color during a color-color matching task (i.e., the difference between the two dashed lines in Figure 2). Intradimension color effects (solid lines) - ERPs to the task irrelevant color during a color-color matching task were subtracted from the ERPs to the task relevant color during a color-color matching task (i.e., the difference between the large dashed lines and solid lines in Figure 2). Right column: Interdimension word effects (dashed lines) - ERPs to the task irrelevant word during a color-color matching task were subtracted from the ERPs to the task irrelevant word during a color-word matching task (i.e., the difference between the two dashed lines in Figure 2). Intradimension word effects (solid lines) - ERPs to the task irrelevant word during a color-word matching task were subtracted from the ERPs to the task relevant word during a color-word matching task (i.e., the difference between the large dashed lines and solid lines in Figure 2).


S2s
ΔERPs TO COLORS
ΔERPs TO WORDS
INTRADIMENSION
INTERDIMENSION
−
2.5 μv
+
ELECTRODE LOCATION
OCCIPITAL
CENTRAL
FRONTAL
75
172
229
274
318
370
411
450
480
LATENCY (msec)

Interdimension Effects. For the occipital ERPs, the Interdimension effect following S2 words (Interdimension word effect) was reflected in the ERP as an increase in negativity at 172-411 msec (right portion of Figure 3-dashed lines). An Interdimension effect following S2 colors (Interdimension color effect) was also reflected in the ERPs at 172 msec as an increase in negativity and was immediately followed by an increase in positivity at 229 msec (left portion of Figure 3-dashed lines).

For the central ERPs, the Interdimension effects following S2 colors and words were statistically significant at 274 msec. Interdimension color and word effects occurred at the same point in time over this cortical region, as was the case for the occipital regions, but occurred later in time when compared to occipital regions (172 msec over occipital areas versus 274 msec over central areas). The Interdimension effects were not statistically significant over frontal regions.

Intradimension Effects. For the occipital ERPs, the Intradimension effect following a specific word was evident as an increase in positivity at 370-450 msec (right portion of Figure 3-solid lines). The Intradimension color effect was reflected by the change in ERPs following a specific S2 color as an increase in negativity at 229-318 msec followed by an increase in positivity at 370-411 msec (left portion of Figure 3-solid line). This Intradimension color effect began earlier in time when compared with the Intradimension word effect (229 versus 370 msec, respectively).

The central electrodes did not reflect an Intradimension word effect. This is consistent with previous findings from this laboratory and will be discussed more fully later. The Intradimension color effect, in contrast, was evident as an enhanced negativity at 274 msec which occurred later in time when compared with the Intradimension color effect recorded from over occipital regions (229 msec).

The Intradimension word effect recorded over frontal regions was reflected as an enhanced positivity at 274 msec (Figure 3 - solid line) which occurred earlier in time than the Intradimension word effect recorded over occipital regions (370-450 msec). The Intradimension color effect recorded over frontal regions was inverted in polarity when compared with the Intradimension color effect recorded from over occipital regions. The time-course of this Intradimension color effect was the same for these two cortical regions; however, this effect did not reach statistical significance over frontal regions until 274 msec (left bottom portion of Figure 3). In general, the onset of the Intradimension color effect over frontal regions began before the onset of the Intradimension word effect (229 msec versus 274 msec, respectively) but both peaked at the same point in time (274 msec).

<u>Intra- Versus Interdimension Effects</u>. The ERPs over occipital regions to colors and words (Figure 3) clearly reveal the progressive nature of the selection process (i.e., the sequence in which various types of information is processed temporally). First, an increase in negativity was evident at 172 msec following both S2 colors and words when the evoking flash shared the same dimension as the task relevant

stimulus (Interdimension effect). This increase in negativity following words continued up to 411 msec but terminated at 229 msec following colors. Later in time, the relevant versus irrelevant color and word was selected within the color and word dimension, respectively (229-450 msec for colors and 370-450 msec for words--Intradimension effects). In general, the processing of colored patterns and word patterns per se (Interdimension effects) began at the same time (172 msec) and was followed by the subsequent selection of a specific color (229 msec) and a specific word (370 msec). Separate analyses performed on the Interdimension and Intradimension data indicate that Interdimension effects were statistically significant very early in time (172 msec: F=271.12; df=1,6; p<.0001) while Intradimension effects, in contrast, were not statistically significant at this point in time.

The tendency for Interdimension effects to precede Intradimension effects did not hold true for central cortical regions. The Interdimension color effect began at the same time as the Intradimension color effect (274 msec), both of which occurred later in time when compared with Interdimension and Intradimension color effects in the occipital ERPs. There was no Intradimension word effect in the central data so a comparison cannot be made between the onset of Interdimension and Intradimension effects following S2 words.

Intradimension: Indirect Effects of Attention

Separate ANOVAs were performed on the ERPs to task irrelevant S2s to determine whether they were influenced by their semantic relatedness to the relevant S2 (semantically related versus unrelated). An enhancement of the ERPs was found over occipital regions and is reflected by the difference potentials for the color-word matching task (Figure 4c). This Indirect effect was statistically significant at the following latencies: 229 msec (F=13.06; df=1,6; p<.025), 274 msec (F=7.85; df=1,6; p<.05), and 318 msec (F=10.09; df=1,6; p<.025). The time-course of this effect was consistent with the Intradimension color effect over occipital regions reported above (compare Figure 4a with 4c). These results suggest that when subjects were instructed to match word meaning they were differentially attending to the related color even though it was irrelevant to the behavioral task.

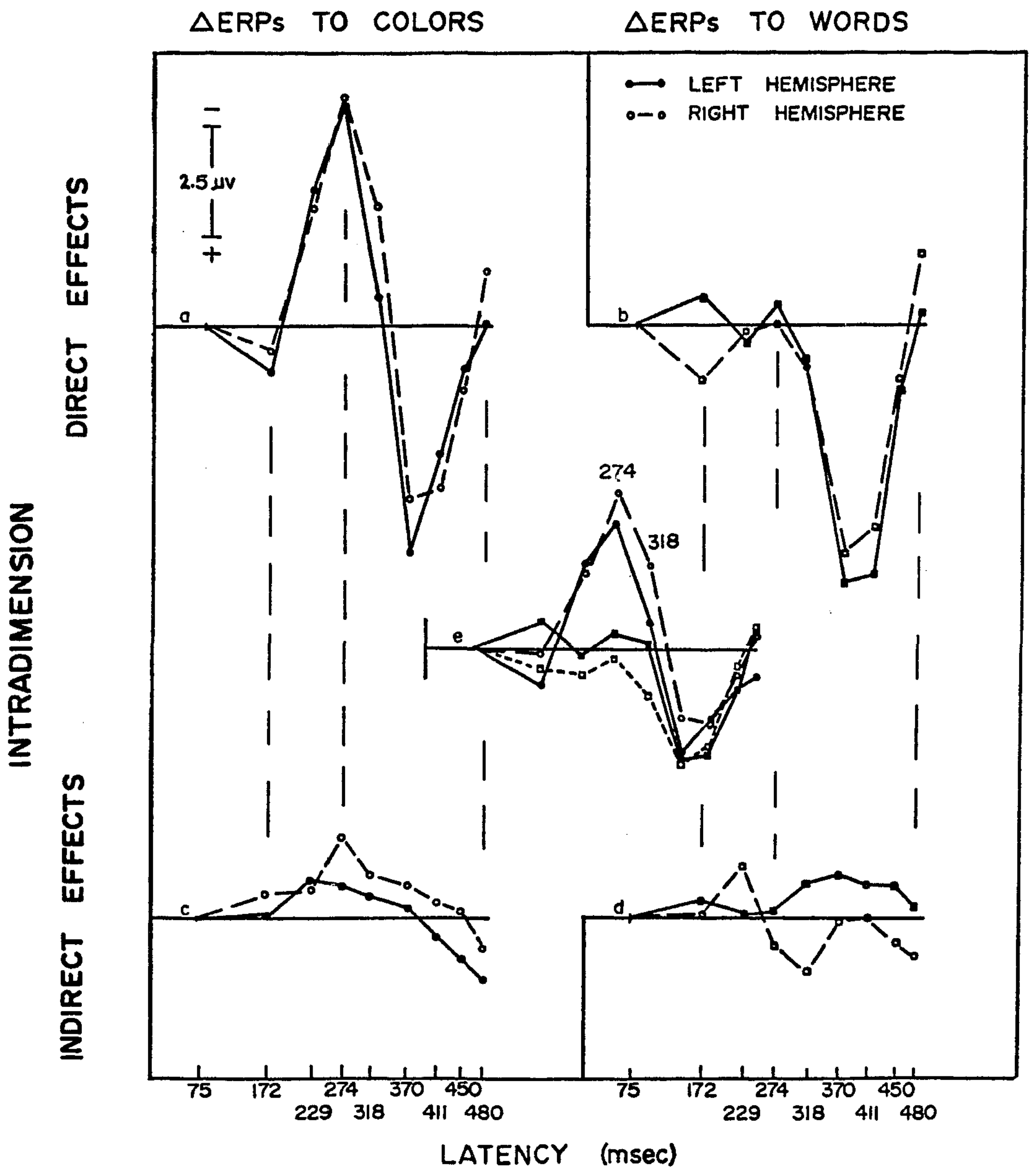
The Indirect effects of attention following S2 colors and words were not statistically significant over central and frontal regions. However, the Indirect effects following S2 words recorded over central regions were statistically significant when gender of the subject was taken into consideration (see below). The main Indirect effects of attention following S2 colors did not approach statistical significance.

Hemispheric Differences

Hemispheric differences were reflected in occipital ERPs for the Intradimension Direct effects following colors and words (Figure 4a and 4b, respectively) and Indirect effects following S2 colors and words (Figure 4c and 4d, respectively). Intradimension effects of attention (Direct and Indirect--Figure 4e) were statistically significant at 274

Figure 4. Hemispheric differences in Intradimension Direct (top row) and Indirect (bottom row) effects of attention recorded from over occipital regions. S2 difference potentials (ΔERPs) in 4a and 4b show differences in the magnitude of the response for Direct color and word effects (left and right columns, respectively) over left and right hemispheres (solid versus dashed lines, respectively). Difference potentials in Figure 4c and 4d show differences in the magnitude of the response for Indirect effects of attention (i.e., enhancement of the ERPs to task irrelevant but semantically related colors--4c or words--4d when compared with the ERPs to task irrelevant and semantically unrelated colors or words) over the two hemispheres. Difference potentials in 4e show differences in the magnitude of response over left and right hemispheres (dashed and solid lines, respectively) when the difference potentials were collasped across the Direct and Indirect effects of attention for colors (circles) and for words (squares).

OCCIPITAL S2s



msec (F=7.94; df=1,6; p<.05) and 318 msec (F=9.25; df=1,6; p<.02). The negativity to color patterns was of greater magnitude over the right hemisphere while the negativity to words was of greater magnitude over the left hemisphere. It should be noted that these particular interactions were marginally significant in the occipital data and were not statistically significant in the central or frontal data. Subsequent analyses indicated that the Intradimension Direct effects were statistically significant at 318 msec (F=13.59; df=1,6; p<.025); whereas, hemispheric differences were not statistically significant for the Indirect effects of attention.

Hemispheric differences due to attention per se, as recorded over frontal regions, were not dependent on task dimension nor type of flash. When subjects were instructed to attend there was a greater positivity over the right hemisphere at 274 msec (F=23.95; df=1,6; p<.01) and 318 msec (F=9.72; df=1,6; p<.025) regardless of the particular feature or dimension attended. Attention effects over frontal regions are of opposite polarity from attention effects recorded over occipital regions; therefore, greater positivity over this region most likely indicates increased processing.

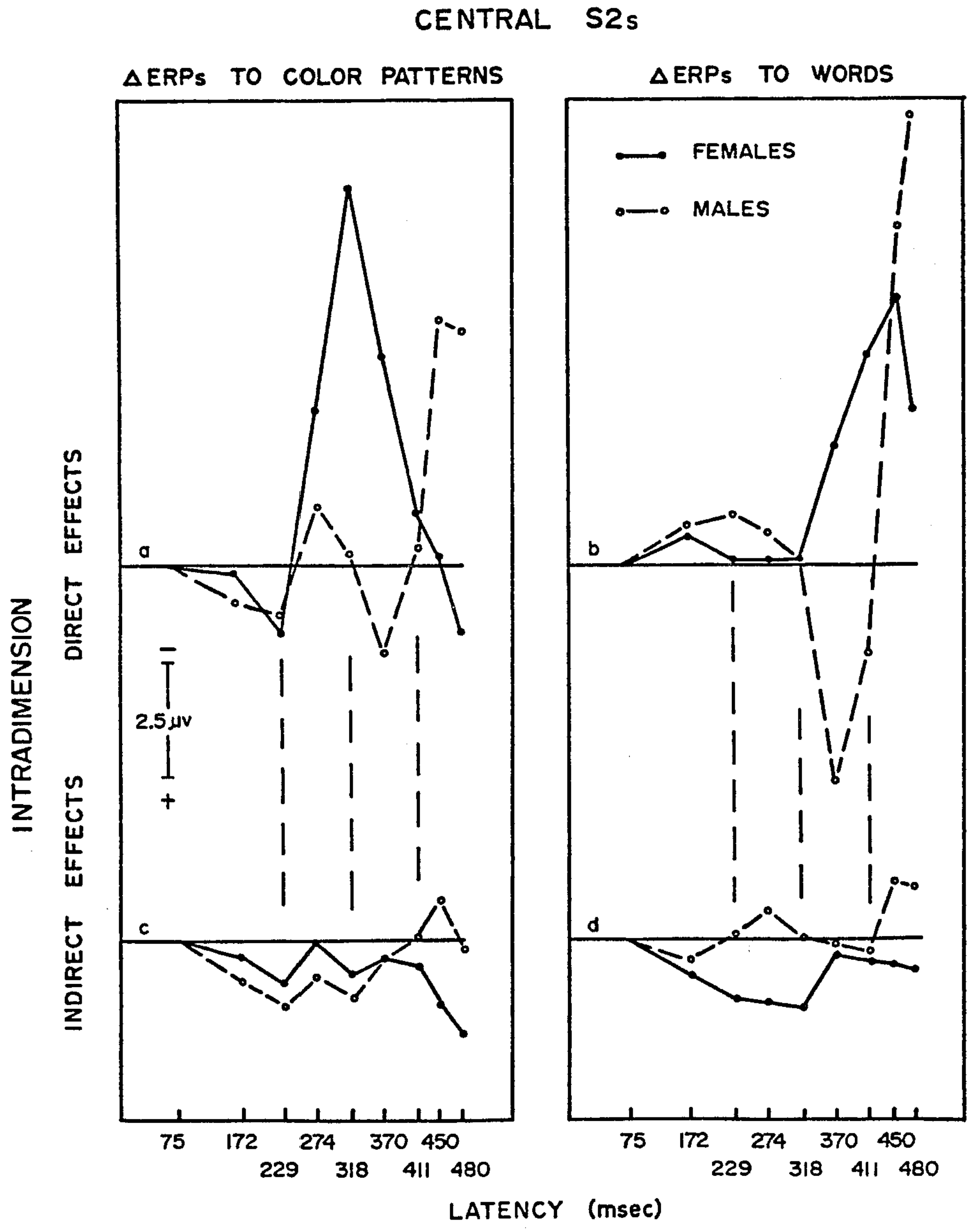
Sex Differences

Although it was not the purpose of the present study to assess sex differences, a number of such effects obtained marginal statistical significance. Intradimension Direct and Indirect effects interacted with sex in data obtained over central regions only.

The difference potentials in Figure 5a and 5b show differences in the Intradimension color and word effects of attention between males and females. Separate analyses on the Intradimension effects revealed a difference in the S2 ERPs between sexes when matching colors at 318 msec (F=7.69, df=1,6; p<.05). Females had an enhanced negativity at this point in time as compared with males. The ERPs following S2 words did not reveal any significant differences, although the waveforms of females appear to be inverted in polarity from that of the males at 370-411 msec (Figure 5b). Visual inspection of the "raw" ERP data shows that one of the four females did not show this inversion of polarity over the central cortical region.

The analyses performed on the Indirect attention effects were statistically significant at 229 and 274 msec (F=17.8; df=1,6; p<.01 and F=7.59; df=1,6; p<.05). The difference potentials in Figure 5d represent changes in S2 ERPs to task irrelevant words, during a color matching task, when words were semantically related to the color of S1 as compared to words which were semantically unrelated to the color or S1. Females (solid lines) show an enhanced positivity of the difference potential at 229 and 274 msec. This result indicates that females were attending to semantically related words during a color matching task even though these words were irrelevant to the behavioral task. It is of special interest that the Indirect effect of word processing, evident in the female data only, occurred <u>before</u> the Intradimension word effect recorded over both occipital (229 msec over central regions versus 370 msec over occipital regions) and frontal regions (229 msec over central

Figure 5. Sex differences for Intradimension Direct and Indirect color and word effects recorded over central cortical regions. Similar to Figure 4 except sex differences are shown rather than hemispheric differences and S2s were recorded over central cortical regions. Female and male difference potentials (solid versus dashed lines) were averaged across hemispheres, replications, and four subjects.


CENTRAL S2s
ΔERPs TO COLOR PATTERNS
ΔERPs TO WORDS
FEMALES
MALES
INTRADIMENSION
DIRECT EFFECTS
INDIRECT EFFECTS
a
b
c
d
−
2.5µv
+
75
172
274
370
450
229
318
411
480
LATENCY (msec)

regions versus 274 msec over frontal regions). Furthermore, the results suggest that Indirect word processing (Figure 5d) can occur at the same point in time as Intradimension color effects (Figure 3).

The Indirect color effect (Figure 5c) was not statistically significant. These difference potentials reflect changes in the S2 ERPs to task irrelevant colors, during a color-word matching task, when colors were or were not semantically related to the color name of S1.

ERPs To S1s

Figure 6 shows a sample of ERPs to S1s (four replications of left hemisphere responses when matching word meaning) for each individual subject across electrode locations. Visual inspection of these data reveal two apparent differences between male and female ERPs: 1) ERPs recorded from male subjects appear to be much more variable than ERPs recorded from female subjects, and 2) the central and frontal electrode locations reveal a pronounced positivity at 221 msec in the ERPs of female as compared to males. This positivity was not evident in the male data. This difference was statistically significant over frontal regions at 221 msec (F=12.95, df=1,6; $p<.025$).

Figure 7 shows the quantified S1 ERP data averaged across sex. Occipital electrode locations showed a main effect of hemisphere at 301 msec (F=9.94; df=1,6; $p<.025$) and at 341 msec (F=7.86; df=1,6; $p<.05$). ERPs were greater in magnitude over the right hemisphere regardless of task instruction.

Figure 6. Sample of "raw" ERPs to S1 stimuli for each subject over the left hemisphere of occipital, central, and frontal cortical regions. Male and female ERPs were recorded during one trial-block of the color-word matching task. ERP amplitude measures were taken at 40 msec intervals. Latency values depicted at the bottom of this figure and all remaining figures represent the mean latency for each of the nine amplitude measures.

ERPs TO SI

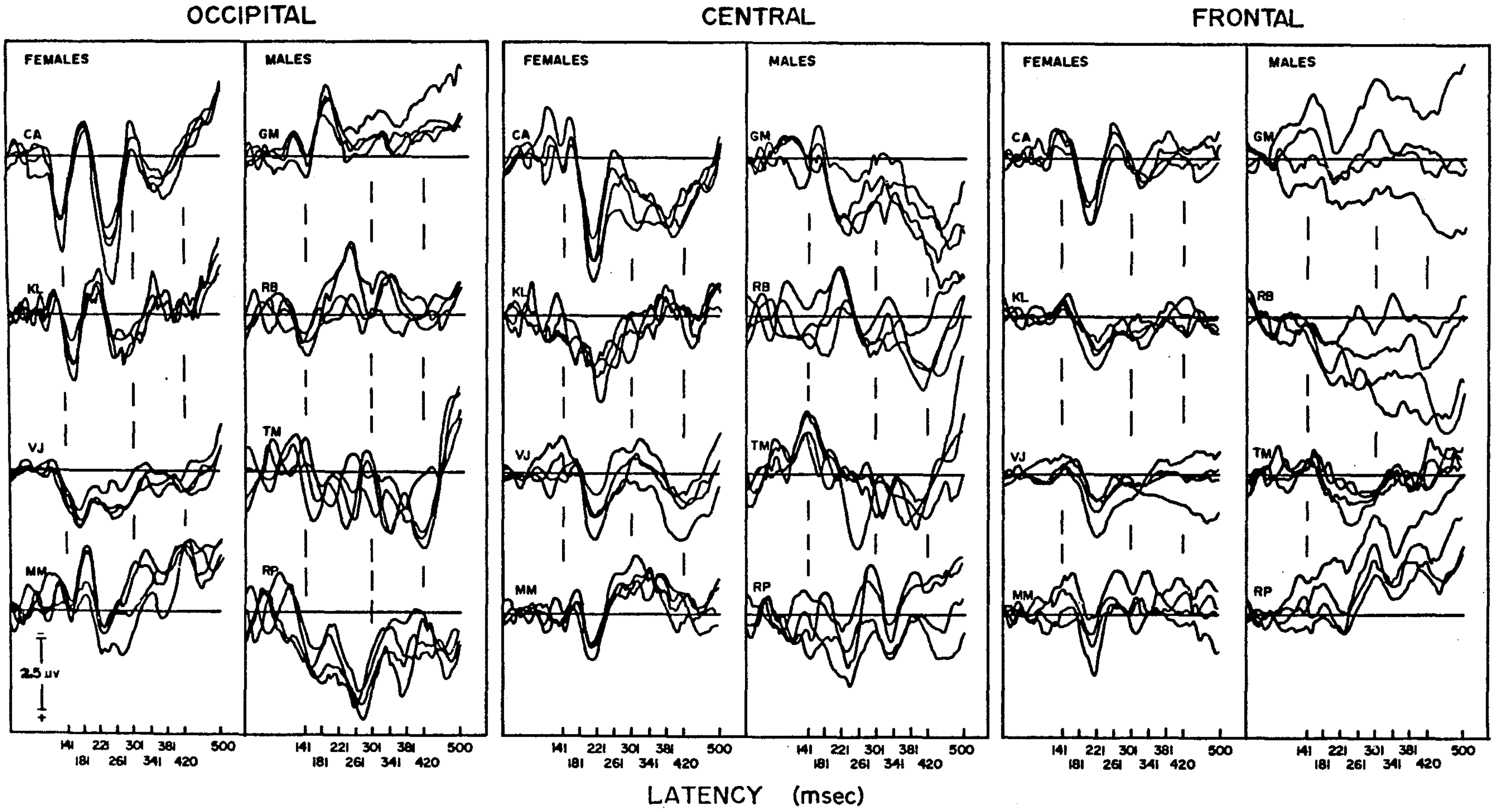
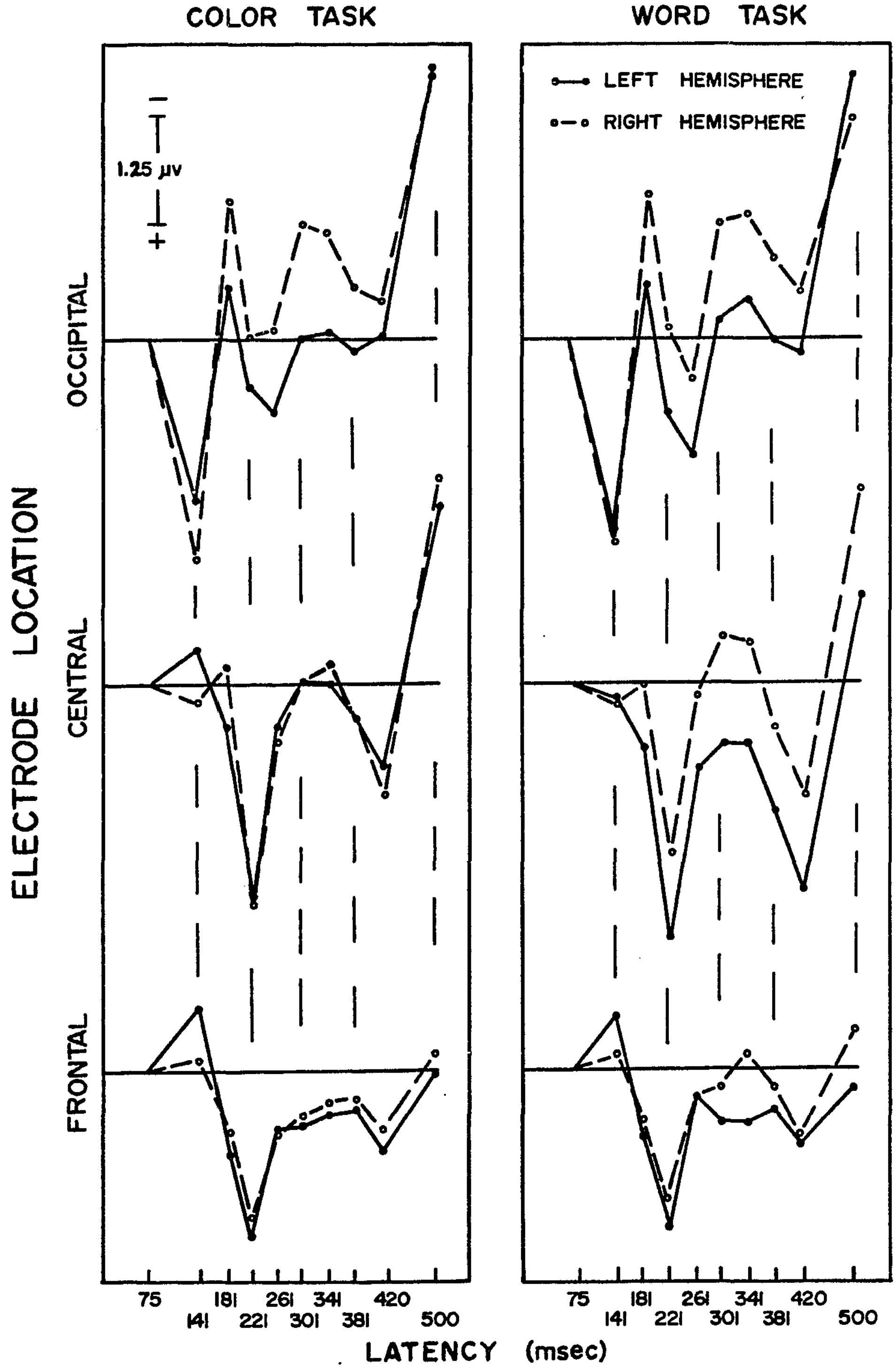

OCCIPITAL
CENTRAL
FRONTAL
FEMALES
MALES
CA
KL
VJ
MM
GM
RB
TM
RP
2.5 µV
−
+
141 221 301 381 500
181 261 341 420
LATENCY (msec)

Figure 7. Hemispheric differences in ERPs to S1 as a function of task instruction. ERPs are to the same physical stimulus (diffuse colored flashes) when subjects processed S1 as a sensory color (left column) or as a color name (right column). Quantified ERP amplitude measures are shown for occipital, central, and frontal cortical regions. S1 ERPs were averaged across hemispheres, eight replications, and eight subjects.

ERPs TO SI


COLOR TASK
WORD TASK
LEFT HEMISPHERE
RIGHT HEMISPHERE
−
1.25 µv
+
ELECTRODE LOCATION
OCCIPITAL
CENTRAL
FRONTAL
75
141
181
221
261
301
341
381
420
500
LATENCY (msec)

The central region, in contrast, showed a hemisphere by task interaction at the following latencies: 141 msec (F=8.5; df=1,6; p<.05), 221 msec (F=6.65; df=1,6; p<.05), 261 msec (F=7.08; df=1,6; p<.05), 381 msec (F=23.65; df=1,6; p<.01), and 420 msec (F=33.3; df=1,6; p<.01). Hemispheric differences were evident during the color match task only at 141 msec (Figure 7). Later in time, hemispheric differences were evident for the match word meaning task (221, 261, 381, and 420 msec). The frontal electrodes did not reveal any hemispheric differences in ERPs to S1.

Since the variability of the S1 responses were not equal for the sexes over central regions (as indicated by tests for unequal variances) and given the sensitivity of this region to differences in sex, separate analyses were performed on the male and female data. Figure 8 shows that both males and females showed an enhanced late positivity when the S1 colors were processed for word meaning in comparison with S1 colors being processed as sensory colors. However, this main effect of task instruction was statistically significant for females only at 381 (F=10.19; df=1,3; p<.05) and 420 msec (F=17.93; df=1,3; p<.025). The time-course of these effects did not differ in the S1 data.

Behavioral Data

There was a significant main effect for Task on the reaction-time data (F=52.03; df=1,6; p<.001). Figure 9a indicates that subjects could respond more quickly during the color matching task in comparison with the color-word matching task (334 msec versus 348 msec,

Figure 8. Sex differences in quantified ERPs to S1 over central cortex as a function of task instruction. Amplitude measures for females and males (left and right columns, respectively) when processing S1 as a color (color-color matching task - solid lines) and when processing S1 as a color name (color-word matching task - dashed lines). Data were averaged across hemispheres, four subjects, and eight replications.

CENTRAL ERPs TO SI

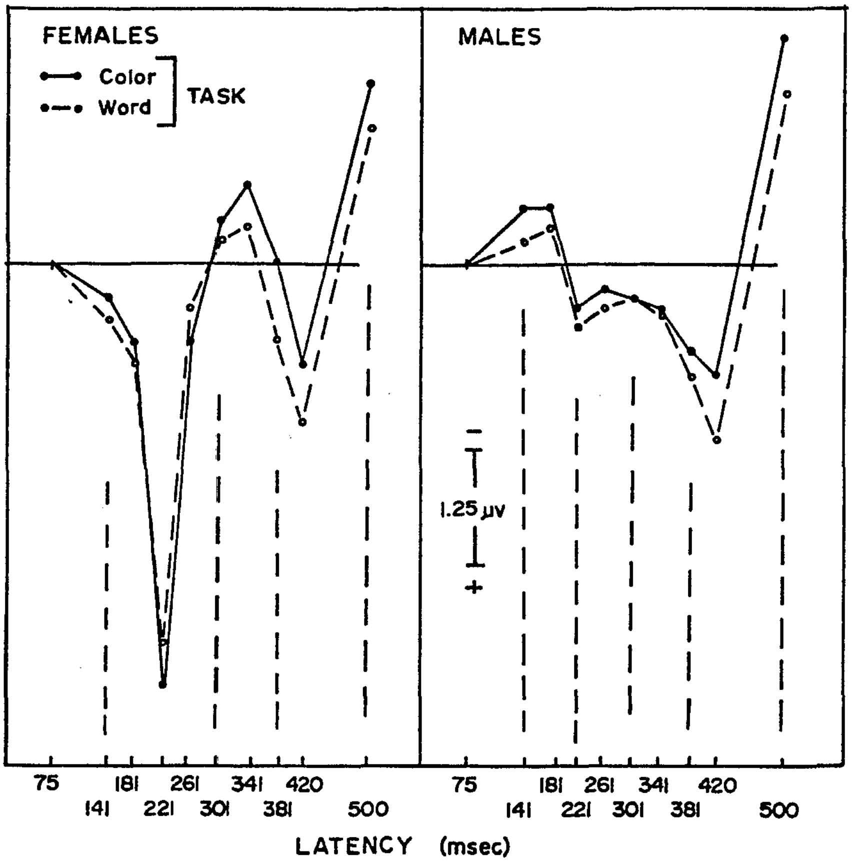
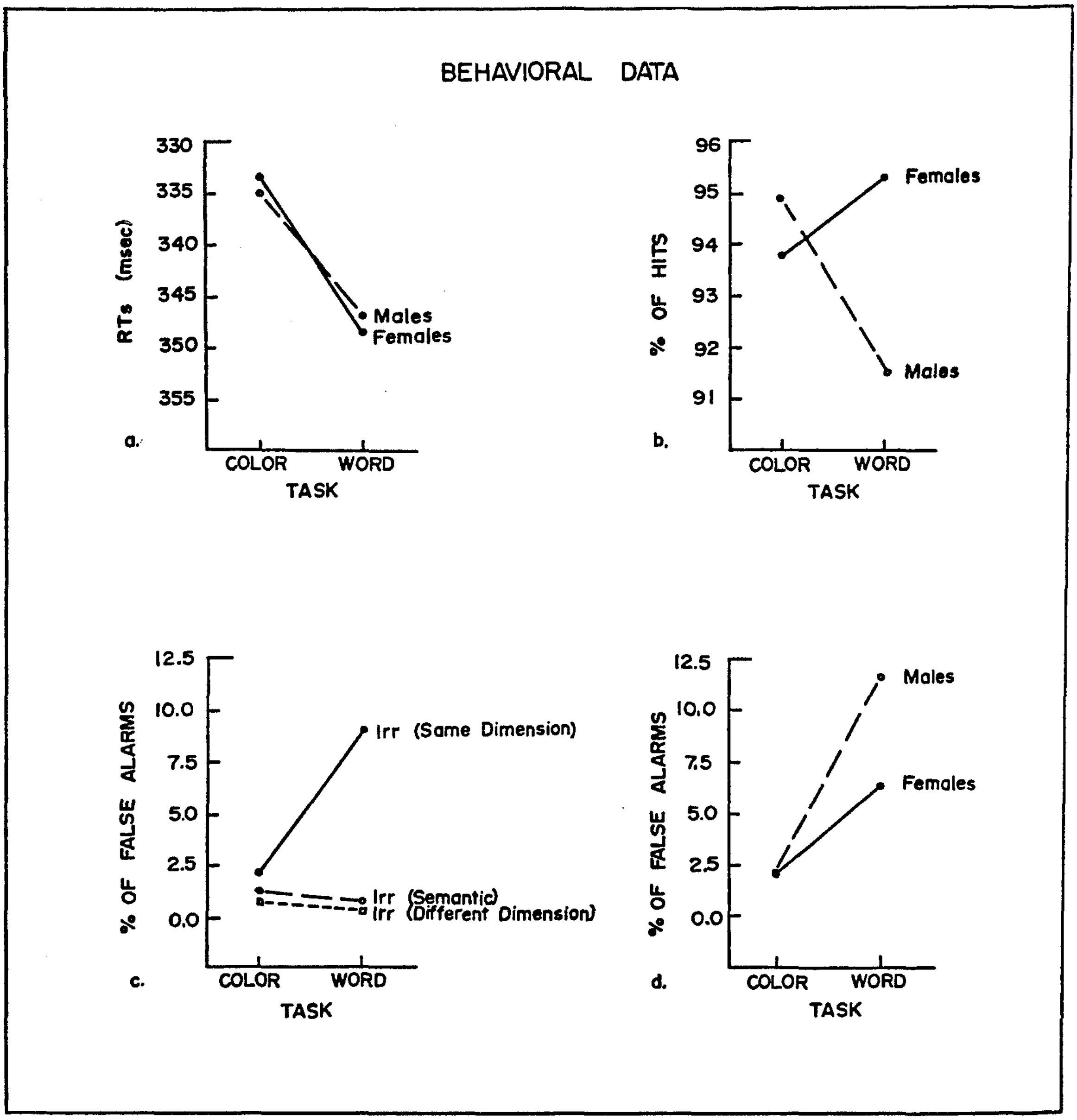


Figure 9. Behavioral data showing reaction-times, percentage of "Hits", and percentage of "False Alarms" for the color and word matching tasks. 9a: Shows the mean reaction-time for both sexes during the color and word matching tasks. Each reaction-time was an average of approximately 50 responses. The mean reaction-time was calculated for twelve replications across four subjects. 9b: Indicates the percentage of "Hits" made by the two sexes when matching colors versus word meaning. 9c: Percentage of "False Alarms" to the task irrelevant S2 when it: 1) shared the same dimension (i.e., color or word) as the task relevant S2 (Irr-Same Dimension); 2) did not share the same dimension as the task relevant S2 (Irr-Different Dimension); and 3) shared the same meaning as the task relevant S2 (Irr-Semantic). 9d: Percentage of "False Alarms" made by each sex during the color and word matching tasks.



BEHAVIORAL DATA

respectively). An analysis of the percentage of correct responses indicates that females had more "Hits" (95.3%) than males (91.5%) when responding during the word matching task (F=31.84; df=1,6; p<.01). In contrast, males had more "Hits" (94.9%) than females (93.8%) during the color task (Figure 9b).

The "False Alarm" data (Figure 9d) indicate that males made more "False Alarms" (11.6%) than females (6.3%) during the match word meaning condition (F=11.23, df=1,6; p<.025). The percentage of "False Alarms" made during the color match condition were virtually identical for males and females (2.1% versus 2.0%, respectively). Together the "Hit" and "False Alarm" data indicate that females were more accurate than males in the word task. There was a tendency for males to be more accurate in the color task.

The "False Alarm" data also indicates that there were no differences between the percentage of "False Alarms" made to irrelevant but semantically related stimuli and irrelevant and semantically unrelated stimuli (Figure 9c). The majority of the "False Alarms" were made to irrelevant stimuli of the same dimension as the task relevant stimuli (F=37.31; df=2,12; p<.001). Most of the "False Alarms" were made to the irrelevant word during the color-word matching task (8.9%) as compared to the percentage of "False Alarms" made to the irrelevant color (2.0%) during the color matching task.

CHAPTER IV

DISCUSSION

The following discussion is based on a number of assumptions which were discussed in the Introduction section of this paper: First, the increase in amplitude of particular ERP components (e.g., selection negativity and P300), associated with an increase in attention to relevant stimuli, reflects the selective increase in neural processing of relevant as compared to irrelevant information (Eason, Harter, and White, 1969; Harter and Guido, 1980; Harter and Salmon, 1972; Naatanen, 1975, 1982; Naatanen and Michie, 1979, pp. 251-267). Neural processing refers to the increased activation of selective neuronal aggregates responsive to a particular feature or features of the stimulus. Second, the ERP reflects the relative sequence and time-course of the processing of various types of stimuli or features of stimuli. And third, the scalp distribution of the ERP (i.e., changes in polarity and amplitude of the ERP at different electrode positions) reflects the general cortical areas involved in the various types of neural processing (e.g., color versus word).

It is the belief of this author that there is value in correlating neural and behavioral measures. Previous studies from this laboratory have demonstrated several types of processing where the neural and behavioral measures correlated; e.g., the time-course between the onset of color and word processing and the difference in reaction-times to colors and words, and a correlation between the behavioral Stroop effect and an interference effect reflected in the ERPs. Therefore, an attempt will be made in the following discussion to relate the present results to the existing psychological literature whenever it seems appropriate.

Hypothesis I: Early Effects

The first hypothesis was that aggregates of neurons first selectively responsive to linguistic stimuli are in a different region in the visual system than those neuronal aggregates first selectively responsive to sensory colors. This hypothesis was based on : 1) neurophysiological data on animals which indicates that receptive-fields along the visual pathway are responsive to different aspects of stimulus configurations, 2) Geschwind's neuropsychological model of the representation of language, and 3) on neurophysiological data on humans which suggest that selective attention modulates the activity of neuronal aggregates responsive to particular features or conjunctions of features of the stimulus configuration. It was predicted that the time-course and scalp distribution of the onset of color and word processing, as reflected by the onset of selection negativity, would indicate that first colors would be processed in the occipital regions and then words would be processed in the central-parietal regions.

Interdimension effects: S2s. The time-course and scalp distribution of the selection negativities associated with color versus word processing did not differ. This result may appear to be contrary to the first hypothesis, but the Interdimension effects do not necessarily reflect differences between color processing and word processing per se. The Interdimension effects may simply reflect an early discrimination between colored and word patterns.

Consistent with Hypothesis I, the occipital regions reflected these early Interdimension effects of processing. The onset of the Interdimension effects were evident first in the occipital ERPs (172 msec) and were noted later in time (274 msec) in the central ERPs. The Interdimension effects were not statistically significant in the frontal data. The time-course and scalp distribution of the Interdimension effects (i.e., the effects were first evident and were of greatest magnitude in the occipital data) suggest, therefore, that the source of these early effects may be localized in the occipital regions. Furthermore, it may be concluded that the onset of Interdimension effects does not reflect color or word processing but rather resembles a stage of early processing known in the psychological literature as pattern recognition. The discrimination between colored and word patterns may have been based on the curved versus linear nature of the patterns, for example.

Intradimension effects: S2s. The relative time-course and scalp distribution of the Intradimension effects following S2 colors and words in the occipital data support the first hypothesis. Intradimension effects following S2 colors began earlier in time than Intradimension effects following S2 words (229 versus 318 msec, respectively). This difference in time-course, in conjunction with differences in scalp distribution (below), suggests that different neural generators mediated the color and word processing effects.

The scalp distribution of the onset of the Intradimension color effect indicated that the amplitude of this effect was greatest in the occipital data. Furthermore, this color-processing effect was opposite in polarity when comparing the selection negativity from occipital regions with the selection positivity from frontal regions. This inversion, along with the magnitude of the color effect over occipital regions, suggests that the source of the color-processing effect is located in posterior temporal cortical regions. This interpretation is consistent with the neurophysiological and neuroanatomical data on monkeys which indicate that inferotemporal cortex is responsive when attending to colored stimuli.

The onset of selection negativity associated with the word processing effect in the occipital data at 318 msec was of greater amplitude when compared with the word processing effect at the same point in time in central and frontal data. However, when examining the scalp distribution of the earliest word-processing effect, the results indicate that the frontal data show a word-processing effect sooner in time (274 msec) than the occipital data. The present findings suggest, therefore, that there may be two neural generators for the onset of word processing: one early in time and localized in frontal regions, and the other later effect localized in occipital regions.

Differences in the onset of word processing effects across cortical regions is a particularly interesting finding since it offers a possible explanation of how word meaning can interfere with color processing during the Stroop interference effect. Subjects could differentiate between specific words sooner in time than the ERPs from occipital regions indicate. Early frontal word processing could act to modify processing in posterior regions.

This early word effect in the frontal data also makes one question why word information is processed so late in time in the occipital region (274 versus 370 msec)? Do these two regions analyze word information simultaneously but in slightly different ways? Perhaps the function of word processing in occipital regions is a continuation of the previously reported pattern discrimination effects (Interdimension effects) but more refined (i.e., pattern discrimination between specific words). Frontal regions, in contrast, may be more concerned with the meaning of words.

The possibility that linguistic stimuli may be processed in terms of their physical characteristics in occipital regions gains support from two additional findings. First, in the present study, the occipital regions tend to reveal a progressive nature of the selection process when attending to linguistic stimuli. The Interdimension word effect was evident very early in time (172 msec) over occipital regions and appeared as a more global discrimination process (i.e., the discrimination between color patterns versus word patterns). This Interdimension word effect was followed by the Intradimension word effect (370 msec) which reflected the discrimination between specific words. This progression of the selection process parallels the findings of Harter and Guido (1980) where the contour of attended gratings was evident in the occipital ERPs before the specific orientation of the gratings (i.e., horizontal versus vertical). The global selection process reflected the discrimination between diffuse and grating flashes, regardless of the particular orientation of the grating. Later in time, the specific orientation of the grating was selected (i.e., vertical versus horizontal). These contour and orientation-specific effects were interpreted as being generated from occipital regions.

Second, Johnston and Chesney (1974) and Kutas and Hillyard (1980) suggested that the occipital regions were sensitive to the physical characteristics of the stimuli rather than the meaning of the stimuli. For example, Kutas and Hillyard found that the occipital regions were sensitive to physically aberrant stimuli (e.g., the seventh word presented in sequence was larger in size than the other six words which preceded it), whereas the central-frontal regions were more sensitive to the meaning of the seventh word when it was semantically incongruent with the rest of the sentence.

Together these findings suggest that the onset of the Intradimenion color and word effects in occipital regions are mediated by different neural generators and the Intradimension effects, in general, represent a more refined discrimination process than the Interdimension effects. The discrimination is between particular features within a dimension rather than the discrimination between dimensions.

ERPs to S1. Part of Hypothesis I was to determine whether the early portion of S1 ERP waveforms over occipital regions would differ between the color-color match and color-word match conditions. More specifically, it was predicted that there would be an earlier enhancement of the S1 ERP negativity (200-300 msec) during the color match conditions than during the color-word match conditions (300-400 msec). However, as Figure 7 demonstrates, Hypothesis I was not supported in this regard. The ERPs recorded during the different tasks were very similar in waveshape.

Since the color of S1 was always attended, one cannot examine "attention effects" per se in the ERPs to S1 since there were no ERPs to S1 when it was not attended. However, another way of demonstrating differences in the ERPs as a function of task instruction is to examine the hemispheric asymmetries associated with these different types of processing. But, the central region was the only region to show hemispheric differences as a function of task instruction. The S1 ERPs over occipital regions did not reflect differences between the processing of color as sensory colors versus the processing of colors as color names.

This negative result for the S1 ERPs recorded from occipital regions (i.e., the task instruction did not influence the S1 ERPs) may be accounted for, in part, by the fact that the type of processing required to S1 stimuli differs from the type of processing required to S2 stimuli. Information pertaining to S1 must be retained (in memory?) until an S2 is presented. Since the processing of S1 reflects higher-order processes one might expect differences due to processing features versus semantic meaning to be evident in the central or frontal data as suggested by Johnston and Chesney and Kutas and Hillyard. Similarly, the present results have already shown that the earliest effects of word meaning were evident in the frontal regions not in the occipital regions.

Hypothesis I: Late Effects

It was predicted that the late portion of the ERP negativity to both S1 and S2 over central regions may reflect activity associated with the synthesis of a feature and its related linguistic representation or the "meaning" of the stimulus per se. Colors may become neurally associated with the representation of their linguistic label at higher levels of the nervous system even though the linguistic labels may not be physically contained in the stimulus. If the time-course of the late portion of S1 and S2 ERP negativities (i.e., peak activation) is not the same then it can be assumed to indicate that color and word processing occurred at different points in time. This result would suggest that the representation of colors and words do not become synthesized into a unitary representation.

ERPs to S2. The difference in time-course when processing colors versus words of the late portion of the S2 ERP negativity (i.e., peak activation) in the central data support Hypothesis I. This result argues against the view that colors and color names become synthesized into a unitary representation at higher levels of the visual system. Figure 3 indicates that the Intradimension word effect remained as a late positivity from 370-411 msec over all electrode locations while Intradimension color effects showed peak activation at 274 msec over occipital regions and at 318 msec over central regions. Furthermore, the magnitude of the effect of processing colors was greater than the magnitude of the Intradimension word effect. These results are contrary to the predictions; colors and words are not represented later in time as a conjunction of features since the time-course and scalp distribution of these late effects differ.

The peak activation of the Intradimension word effect in the central data suggested an unexpected finding when sex of the subject was taken into account (Figure 5b). The late positivity noted in the occipital data for both sexes was reflected as a late negativity in the central data when females were engaged in word matching tasks and as a positivity for males. This finding, if reliable, suggests that the neural generator of the late word-processing effect may be localized in different cortical regions for males versus females or that the orientation of the dipole differs between the sexes. If the difference between the sexes is attributable to different cortical regions, then the female data suggest that the late word-processing effect was generated in parietal regions. The generator for the late word effect in the male data may be localized inferior to this parietal region. Ojemann (in press) has also found sex differences in brain organization for language which suggests differences in intracortical organization between sexes.

ERPs to S1. Effects in the ERPs due to task instruction (i.e., process the S1 colors as sensory colors versus color names) were statistically significant over central regions only. These results support Hypothesis I since the time-course of hemispheric asymmetries differed when processing S1 as a color versus a color name. However, these results can be reconciled with the view that central regions are more responsive to the "meaning" of stimuli. Hemispheric differences associated with late effects of S1 processing were noted only when processing the S1 color as a color name. In addition, an enhanced positivity was reflected in the ERP (females only) when processing S1 as a color name in comparison with the ERP associated with processing S1 as a color. The time-course of these two effects, hemispheric asymmetry and change in waveform due to processing S1 as a color name, corresponded with one another. Therefore, it may be concluded that the late central S1 ERP effects did reflect effects of word processing even though the word itself was not contained in the physical stimulus.

Both S1 and S2 ERP results supported Hypothesis I which argues against the view that color features are automatically associated (neurally) with its color name at higher levels of the visual system. However, S1 ERPs suggest that word "meaning" is represented in the central region. This conclusion necessarily follows from the type of processing required of S1 stimuli.

Differences in processing demands to S1 and S2 stimuli yield useful information for determining the relationship between the S1 and S2 ERPs. The processing of "meaning" is required of subjects when attending to S1 as a color name in order to perform the behavioral task. Furthermore, subjects had to retain S1 information until a S2 stimulus was presented. When S2 was presented the task resembled a discrimination or detection task. Was the S2 a particular color or a particular word? The emphasis of the S2 task was actually on the physical characteristics of the S2 stimuli. Therefore, the late word-processing effects to S2s, noted in occipital and central regions, most likely reflected activity generated from occipital or parietal regions. As reported earlier, the scalp distribution of the S2 effects is consistent with this notion. The early word-processing effect reflected in the frontal data more closely resembles the effect of word processing in the S1 ERPs, both of which probably reflects the processing of word "meaning". A question which cannot be answered at this time is whether the color processing effect noted in the S1 ERPs recorded from central regions (e.g., a very early hemispheric asymmetry associated with color processing) reflected the "meaning" of color or the processing of color features.

Conclusions for Hypothesis I

The earliest attention effects (Interdimension effects) did not reflect color and word processing, but rather, an early type of processing localized in occipital regions which was responsive to global physical features of the stimuli. The Interdimension effects reflect the discrimination between colored patterns versus word patterns per se.

The Intradimension effects over occipital regions represent a more refined discrimination process than the Interdimension effects. Rather than discriminating between dimensions of stimuli (colored patterns versus word patterns) the discrimination was between features within the same dimension (e.g., color blue within the color dimension). It is concluded that both Interdimension and Intradimension effects in the occipital ERPs are sensitive primarily to attending the physical characteristics of the stimuli.

The difference in the onset of the Intradimension color and word effects in the occipital data supported the hypothesis that brain areas initially responsive to colors versus linguistic features differ. Regions responsive to sensory colors appear to be localized in posterior temporal regions (inferotemporal cortex), whereas regions responsive to linguistic stimuli appear to be localized in parietal or central regions. The Intradimension color effects were evident sooner in time over occipital regions than Intradimension word effects. The reaction-times supported this trend which suggests that features represented at early levels of the visual system (peripheral) may be processed and responded to behaviorally sooner in time than features represented at higher levels. Therefore, the difference in the time-course between the onset of Intradimension color versus Intradimension word effects correlates with the subjective feeling of "task difficulty". Subjects found the color-word match condition to be more difficult because, in essence, they had less time to make a decision of whether or not to respond to a particular word since it was processed later in time than colors.

ERPs to S2 stimuli recorded from central regions most likely reflected activity from occipital or parietal areas. The early Intradimension word effect recorded from frontal regions, however, indicates that there are parallel pathways which mediate the processing of linguistic stimuli. In contrast to the occipital and central areas, frontal areas may be primarily concerned with word meaning.

The ERPs to S1 stimuli recorded from central regions supported the view that central regions are responsive to the "meaning" of stimuli. However, "meaning" is not a result of some automatic neural association between the representation of a feature and its label in one brain region (i.e., as a conjunction of features). The occipital regions, in contrast, did not show changes in waveform or hemispheric asymmetries due to task instructions.

In conclusion, the data indicate there are several parallel pathways in the visual system some of which process the same information but in slightly different ways. Features of a stimulus, such as patterns and colors, are processed before or during the processing of the "meaning" of the stimulus per se. The discrimination between physical features of linguistic stimuli, however, takes longer than the discrimination between color features since the brain region responsive to these features are located more centrally than color or pattern features. Therefore, the "meaning" of linguistic stimuli may be obtained before the physical features per se have been processed.

Hypothesis II

It was predicted that color processing would be of greater amplitude over the right hemisphere as reflected by occipital ERPs. Figure 4 indicates that Hypothesis II was supported; the right hemisphere effect was greater for both the Intradimension and Indirect color processing effects. Conversely, the left hemisphere effect was greater when subjects were processing words.

One purpose of the present study is to provide an adequate interpretation of the left hemisphere effect reported by Harter, Aine and Schroeder (1982) and Aine and Harter (A). The elimination of alternative interpretations of this left hemisphere effect was approached in the present study by utilizing stimuli consisting of color embedded within a simple nonlinguistic pattern (i.e., a horizontal bar with notches cut out of both upper and lower regions). If the left hemisphere effect in the previous studies was associated with attention to a conjunction of features then there should have been a left hemisphere effect when matching colors in the present study. The present results do not support this interpretation. An alternative interpretation, that the left hemisphere effect was associated with attention to one of several features presented sequentially to one point in space, was not supported either. The dissociation between the left and right hemisphere effects when attending to words versus colors, respectively, argues against this interpretation. Therefore, it is concluded that asymmetries noted over occipital regions are dependent on the particular type of processing involved in the task (e.g., processing location information, linguistic information, etc.).

It is possible, however, that subjects did not perceive the colored nonlinguistic pattern as a conjunction of features but rather as a color and that effects due to attending colors are greater over the right hemisphere. If this interpretation is correct, it suggests that the subjects in Aine and Harter (A) may not have ignored the word dimension of color/word stimuli. This interpretation is consistent with the suggestion in the psychological literature that words are processed "automatically" in some way. However, it is not clear as to what this interpretation implies for the Harter, Aine, and Schroeder (1982) finding where the conjunction of features consisted of a diffuse color or white ring associated with a specific location in space. Is the location of stimuli also difficult to ignore?

The frontal data indicate that attention effects were greater over the right hemisphere at 274-318 msec (the same time period for hemispheric asymmetries over occipital regions) regardless of the particular task instruction (i.e., match colors versus match word meaning) and type of stimulus flashed. The frontal regions may determine the relevance of stimuli and then provide efferent feedback to occipital regions which results in a more detailed analysis of the physical features. The notion that more anterior regions may be involved in the direction of attention is not new (Kolb and Whishaw, 1980, pp 264-266). Furthermore, the notion that anterior regions may direct attention to posterior regions is consistent with the conclusion reached for Hypothesis I, that is, posterior regions may be more sensitive to the actual processing the physical characteristics of the stimuli.

Hypothesis III

ERP indicants of "meaning" can be assessed by examining the relative time-course and scalp distribution of the Indirect effects of attention and the relationship of these effects to the Intradimension color and word effects. "Meaning" was operationally defined as an enhancement of the ERP to task irrelevant but semantically related stimuli (an enhancement of the selection negativity to semantically related S2s)--that is, the Indirect effects of attention. Differences in behavioral responding cannot account for the Indirect effects of attention since all of the S2 stimuli were task irrelevant and the behavioral data did not show significant differences between the percentage of "False Alarms" made to the semantically related stimuli versus the semantically unrelated stimuli.

If the "meaning" of a stimulus becomes associated neurally with a stimulus configuration after the stimulus features per se have been processed (e.g., consistent with a hierarchical and serial conception of the visual system), then the time-course of Indirect and Intradimension color and word effects should differ (i.e., Intradimension Indirect effects should be reflected later in time in the ERP than the Intradimension Direct effects). The scalp distribution of the Intradimension Indirect and Direct effects should also differ (e.g., Direct color effects would be evident primarily over occipital regions and the Indirect color effect would be pronounced anterior to this region).

When subjects were engaged in matching word meaning, an Indirect color effect was evident over occipital regions for both sexes. The time-course of this effect (229-274 msec) was identical with the Intradimension color effect referred to previously (See Figure 4a and 4c).

This finding is consistent with Rosch's (1975) findings, in the psychological literature, that a color category (e.g., "red") enabled her subjects to respond more quickly when matching color patches. The present results suggest that a similar kind of "priming" could have occurred during the color-word match condition. Subjects would typically sub-vocalize the color name when the S1 color was presented and this could have primed the color response with efferent feedback. An alternative explanation for this effect is that the excitation from the color of S1 could have summated with the excitation from the S2 color which resulted in an enhancement of this response. If this was the case then one would expect the enhancement to be greatest over occipital cortex which it was.

The Indirect word effect was not evident in the group data when subjects were responding to sensory colors. However, when gender of the subject was taken into account, females did reveal an enhancement in the ERP to the task irrelevant but semantically related word. The difference potentials exhibited this effect as an enhanced positivity at 229-274 msec over central cortical regions, where sex differences appear to be most pronounced (Figure 5d). Furthermore, the time-course of this effect is identical to the Indirect color effect over occipital regions. There are three possible explanations for this Indirect word effect demonstrated by females.

First, it is possible that females sub-vocally labeled all S1 colors even though they were instructed not to do so. When examining the S1 ERPs of females, however, there was a significant difference in the ERPs due to task instruction alone. In other words, females were processing the S1 stimuli differently during the match color-color and match color-word conditions. Therefore, the females most likely were processing the S1 colors as sensory colors during the color-color match condition rather than as color names.

Secondly, it is possible that the females just happened to attend to the semantically related but irrelevant words even though they were not supposed to do so. But, the time-course and scalp distribution of the Indirect word effect and Intradimension word effects were not the same. The Indirect word effect over central regions began <u>before</u> the Intradimension word effect over frontal regions (229 versus 274 msec). In addition, attention to the semantically related but irrelevant stimuli would hinder their performance in the behavioral task. The behavioral data indicate that the subjects did not make significantly more "False Alarms" to the semantically related but irrelevant words versus semantically unrelated words.

Finally, it is possible that this early Indirect word effect is an involuntary type of processing. There may have been an automatic neural association between the representation of sensory colors and their corresponding color names. Both the Indirect color effect (all subjects) and Indirect word effect (females only) had identical time-courses (229-274 msec) but were evident over different cortical regions (Figure 4c and 5d). Therefore, the neural association between the representations of colors and their names does not appear to be a conjunction of the neural representations of linguistic and physical aspects of the stimulus per se (i.e., as if both aspects are coded as one at a higher level of the nervous system). It is more likely that color processing, whether Intradimension or Indirect, occurs in posterior cortical regions while early portions of word processing occur over more central-frontal regions. The association that exists between the representations of colors and their names (i.e., Meaning?) is most likely a result of the automatic activation of pathways connecting the two brain regions.

This interpretation of the neural association between color representations and the representation of color names is consistent with several studies reported in the psychological literature. Conrad (1975, pp. 103-120) concluded that when a single word is presented, the visual features, name, and semantic representation for that word are activated in memory which produces priming effects when a second stimulus appears. The spoken word facilitates the retrieval of both visually and phonemically similar word representations (spreading activation). The results of the present study suggest that "memories" are not located in one cortical region but are a result of the neural connections between the different processes which are activated in parallel when attending any physical or imaginal stimulus.

The present findings do not support Klatzky and associates′ (Klatzky and Rafnel, 1976; Klatzky and Stoy, 1978, pp. 71-101) suggestion that nonverbal objects are processed with its verbal label in a unitary way (i.e., semantically). The results are partially consistent with Paivio′s Dual-coding model (Pinker and Kosslyn, 1983, pp. 43-71; Yuille and

Marschark, 1983, pp. 131-155) in that the processing of nonlinguistic objects and linguistic labels does appear to be occurring in different brain regions (e.g., color in occipital regions and color names in central-frontal regions). However, in contrast to Paivio's model, although the processing of color preceded the processing of color names (i.e., Intradimension effects), "meaning" was reflected in the ERP at the same time for colors and color names rather than the encoding of linguistic labels following the encoding of objects.

The Indirect effects of attention may also be considered in relation to the psychological construct of "automaticity". Shiffrin, Dumais, and Schneider (1981) defined automaticity (rule 2) as "any process that demands resources in response to external stimulus inputs, regardless of the subject's attempts to ignore the distinction is automatic". This involuntary type of processing suggested by the Indirect effects of attention may be interpreted as automatic processing. However, these results do not imply that words are processed any more automatically than colors. Furthermore, this involuntary type of processing, in the present study, is evident for semantically related stimulus configurations only.

Other Relevant Aspects of the Results

Replication of Intradimension Effects in Aine and Harter (A). The time-course and polarity of the Intradimension color and word effects were virtually identical to that found in Aine and Harter (A) for color and word processing (colors: 152-273 msec and words: 273-326 msec). The major difference between the scalp distribution of the effects in these two studies was that the occipital difference potentials which reflected word processing in the present study showed a late positivity for this effect rather than an early negativity followed by a late positivity. Therefore, it can be concluded that changes in the ERPs (i.e., difference potentials) to color versus word stimuli were not due to pattern differences between the two types of stimuli, but rather were due to the type of processing required by the task.

The waveform of the difference potentials to color patterns over central regions also closely resembled the waveshape of the difference potentials to colored words in Aine and Harter (i.e., positivity followed by a negativity) when matching or attending sensory colors. However, the effects of processing colors over central regions reached statistical significance later in time in the present study (225 msec in Aine and Harter versus 274 msec in present study). Consequently, the Intradimension color effects in the present study occurred later in time over the central regions when compared with the Intradimension color effects over occipital regions (occipital: 229 msec versus central: 274 msec). Intradimension word effects did not reach statistical significance over central regions in both the present and previous studies. The present data suggest that the variability noted over central regions may be accounted for, in part, by sex differences.

Stroop interference effects. Color and word processing now have been investigated in this laboratory in four different paradigms which utilized two different types of color and word stimuli. Intradimension word processing has not been shown to occur earlier in time than

Intradimension color processing in any of these studies. The present study has contributed to the previous findings of this laboratory by demonstrating that Intradimension word effects can occur earlier in time over central and frontal regions than over occipital regions. Secondly, the peak activation of this Intradimension word effect occurred simultaneously with the peak activation of the Intradimension color effect over frontal regions. Thirdly, none of the subjects could ignore the color of a stimulus when responding to the related color name and females could not ignore the color name when responding to the related sensory color. The time-course of these Indirect effects (229-274) were identical and correspond with the point in time when interference effects were evident in the ERPs of previous data (225-250 msec) from this laboratory.

Klein (1964) has shown, in the psychological literature, that by varying the degree of relatedness between color patches and symbols (linguistic and nonlinguistic) one can vary the amount of interference between the two. When the word was highly related to the color there was more interference. "Meaning" or the degree of association between the color and color name seems to a critical factor as suggested by Logan (1980).

Treisman and Fearnley (1969) mentioned that it was difficult to attend to only one dimension of color and word stimuli. By taking Klein's results into account, this difficulty may be due to the relatedness between colors and color names, per se. Aine and Harter (C) manipulated the response time of the subjects in an attempt to minimize the behavioral Stroop interference effect. It was hypothesized that subjects would not have enough time to read the words. However, these words were still processed to some extent for the behavioral data indicated a Stroop effect and a Reverse Stroop effect.

The present study offers a simple explanation for both a neural and behavioral interference effect. Attention to colors of incongruent color/word stimuli may elicit an Indirect word response (i.e., the neural representation of the semantically related color name is activated) which may compete with the word processing associated with the physical aspect of the stimulus. Similarly, attention to words results in competing color responses (Indirect color processing and processing of the color of the physical stimulus). If congruent stimuli were utilized then facilitation would result.

Input filter versus response selection theories of attention. In direct contradiction to both Hansen and Hillyard (1983) and Naatanen (1982), all irrelevant stimuli were not filtered out at an early stage of the attentional process on the basis of physical features. The Indirect effects of attention argue against this notion; irrelevant stimuli which were not physically similar (e.g., a color patch versus a word) but were semantically related did show a differential effect of attention when compared with responses to irrelevant and semantically unrelated stimuli. Somehow "meaning" was extracted before or during the suppression of the responses to irrelevant stimuli. This interpretation is consistent with Johnston and Venables' (1982) finding of an early positivity in the ERP (P85) which was enhanced to specific colors or words (probe stimuli) while subjects were naming the colors or reading the words of target stimuli. They concluded that this result argues against a filter model of attention which suggests that early selection relies on the discrimination of simple physical characteristics.

These results do not, however, support the Response Selection model of attention either. All stimulus attributes were not first fully analyzed by central brain mechanisms with subsequent selection being based on this outcome as, for example, the progressive selection process for words (Figure 2). The suppression of the ERPs to irrelevant information or enhancement of the ERP to relevant stimuli (whichever may be the case) depends on what information is available to the nervous system at that point in time. The Interdimension word effect was most pronounced initially; this effect is analogous to pattern discrimination. The word patterns were not analyzed fully, but were processed enough to determine that they were not colored patterns (Figure 2). The Intradimension word effect occurred later in time which required a finer discrimination; this effect represents the discrimination between the word "blue" and the word "red." Only the relevant word received continued processing at this point in time.

Conclusions

The present study suggests that the hierarchical nature of the selection process holds true predominantly over posterior cortical regions. Interdimension effects were most pronounced over occipital regions which appeared to reflect a more global discrimination process.

Intradimension color and word effects over occipital regions reflected a more refined discrimination process between specific colors or specific words. The fact that word effects were evident very early in time over frontal regions (Intradimension word effect) and central regions (Indirect word effect for females) in comparison with occipital regions, suggests the existence of two parallel pathways mediating slightly different functions.

There was an early hemispheric effect over frontal regions. The right hemisphere revealed greater enhancement of the ERP to relevant stimuli in comparison with irrelevant stimuli, regardless of the type of processing required or type of flash. This suggests that anterior regions may mediate the directing of attention to more posterior regions. Kolb and Whishaw (1980) have suggested that the anterior region of the temporal lobes is primarily involved in the directing of nervous system attention to particular aspects of the sensory input. Such an organization could have an advantage in that the nervous system could respond quickly on the basis of a little information while making finer discriminations later in time. Harter, Aine, and Schroeder (1982) found an enhancement of the selection negativity associated with attention to locations in space which occurred earlier in time over central as compared with occipital regions. It was suggested that central regions may modulate the activity of posterior regions when attending to locations in space. This same rationale could suggest that the early Intradimension word effect over frontal regions may have modulated the later activity in occipital regions associated with the processing of specific words. This implies that "meaning" and "relevance" of the stimulus in part may be determined by anterior regions before the specific features of linguistic stimuli have been processed in the occipital regions.

The "meaning" of stimuli is reflected in the ERPs very early in time and does not require sustained attention. Sustained attention does not accelerate the processing of "meaning", but rather, acts to increase neural activity associated with the processing of "meaning" and to prolong this activity. The time-course of the Indirect words effect for females and Intradimension word effect over frontal regions was very similar. The major difference was that the frontal word effect was statistically significant later in time. One could question why the Indirect word effect was evident in central regions while the Intradimension word effect was evident in frontal regions since both presumably reflect word meaning. In one case, direct attention was involved (frontal effect), whereas attention was not directed to the irrelevant but semantically related stimuli (Indirect effects). According to Ojemann (in press), a semantic matching task was altered by stimulation at frontal, parietal, and posterior temporal regions. Specialized cortex for specific language functions is seen all along frontal and parietal-temporal regions.

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