

Selective attention to color and location: An analysis with event-related brain potentials

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Event-related brain potentials (ERPs) were recorded from subjects as they attended to colored bars that were flashed in random order to the left or right of fixation. The task was to detect slightly smaller target bars having a specified color (red or blue) and location (left or right). The ERP elicited by stimuli at an attended location contained a sequence of phasic components (P122/N168/N264) that was highly distinct from the sequence associated with selection on the basis of color (N150-350/P199/P400-500). These findings suggested that spatially focused attention involves a gating or modulation of evoked neural activity in the visual pathways, whereas color selection is manifested by an endogenous ERP complex. When the stimulus locations were widely separated, the ERP signs of color selection were hierarchically dependent upon the prior selection for spatial location. In contrast, when the stimulus locations were adjacent to one another, the ERP signs of color selection predominated over those of location selection. These results are viewed as supporting "early selection" theories of attention that specify the rejection of irrelevant inputs prior to the completion of perceptual processing. The implications of ERP data for theories of multidimensional stimulus processing are considered.

Mechanisms of selective attention have become increasingly accessible to investigation by means of event-related potentials (ERPs) recorded from the scalp during task performance. Experiments using the ERP approach have examined the timing and organization of stimulus selection processes and have helped to resolve long-standing questions about "early" and "late" levels of selection (for reviews see Donald, 1983; Hillyard & Kutas, 1983; Johnston & Dark, 1982; Näätänen, 1982). To a lesser extent, ERPs have provided information about the neural systems that mediate attentional selections in different modalities.

In the auditory modality, stimuli belonging to an attended input "channel" (e.g., one of the two ears) elicit a broad negative ERP component that has a latency of onset as short as 60-80 msec (Hillyard, Hink, Schwent, & Picton, 1973; Hillyard, Picton, & Regan, 1978). This attention-related negativity, termed the "processing negativity" or "Nd" wave, accompanies auditory selections based on rapidly discriminable cues such as spatial location, pitch, intensity, speaker's voice, or phonetic category (Hansen, Dickstein, Berka, & Hillyard, 1983; Hillyard & Hansen, *in press*; Näätänen, 1982). Because of its short latency of onset and its hierarchical relationship to later ERPs, it was proposed that the Nd wave was a sign of an

early selection process along the lines of Broadbent's (1970) stimulus set (Hillyard et al., 1973). A similar negativity (N140) accompanies interchannel selections in the somatosensory modality (Desmedt & Robertson, 1977).

In the visual modality, a number of different ERP components have been identified as signs of stimulus selection processes. The earliest ERP alterations occur during spatial selective attention when, for example, subjects pay attention to a sequence of flashes in one visual field and ignore a comparable sequence in the opposite field. In such a task, the attended-field flashes elicit a characteristic sequence of enhanced ERP components, including P100 (80-120 msec), N170 (150-190 msec), P220 (200-240 msec), and N270 (250-290 msec) waves over the posterior scalp and a prominent N160 (140-180 msec) anteriorly (Eason, 1981; Eason, Harter, & White, 1969; Hillyard, Simpson, Woods, Van Voorhis, & Münte, 1984; Van Voorhis & Hillyard, 1977).

Paying attention to other types of visual cues is reflected in different ERP components. Selection between brightness levels has been associated with changes in a P200 wave (Wastell & Kleinman, 1980), whereas selections based on cues of color, spatial orientation, spatial frequency, and amount of contour are reflected in a broad negative wave elicited between 150 and 300 msec (Harter & Guido, 1980; Harter & Previc, 1978; Harter & Salmon, 1972; Previc & Harter, 1982). Harter, Aine, and Schroeder (1982) suggested that selections of different cues are initiated with a latency that depends on their complexity, in

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approximately the following order: location, contour, color, spatial frequency, orientation, and, finally, conjunctions of these features.

ERP experiments have also investigated the processing interactions that occur when stimulus selections are based on two sensory attributes rather than one (Hansen & Hillyard, 1983; Previc & Harter, 1982). These experiments bear on long-standing theoretical controversies about how individual sensory attributes are selected and combined into unified perceptual wholes (Treisman, 1982; Treisman & Gelade, 1980). For example, when a person attends to a stimulus that is defined by the conjunction of two sensory attributes ("A" and "B"), a correct perception could be achieved either by selecting the two attributes independently and then combining the results of those analyses or, alternatively, by selecting the whole A-B "object" or "gestalt" from the outset. These alternatives have been neatly expressed by Kahneman (1983): "Do we attend first to 'attributes' or to 'objects'?"

The question of independent attribute selections can be investigated by recording ERPs to sequences of dual-attribute stimuli, with attributes A and B each having two values that vary orthogonally, thereby defining four possible stimuli. In such a paradigm, the subject is required to attend to one of these stimuli at a time—designated the conjunction, or "A+B+", stimulus. The other three stimuli may be labeled according to whether they share attribute A alone (stimulus A+B-), attribute B alone (stimulus A-B+), or neither attribute (stimulus A-B-) with the attended conjunction. The ERPs recorded to each stimulus type may then be subtracted in different combinations to form "difference waves" that reflect the ERP activity associated with the selection of each attribute, as a function of the value of the other attribute. For example, the difference wave ERP (A+B-) - ERP (A-B-) represents the ERP activity associated with the selection for attribute A, for those stimuli that have the unattended level of attribute B.

If attributes A and B are selected and processed with complete independence from one another, the following relationship should hold among the ERPs to the different stimulus classes:

$$\begin{aligned} \text{ERP (A+B+)} - \text{ERP (A-B+)} \\ = \text{ERP (A+B-)} - \text{ERP (A-B-)}. \quad (1) \end{aligned}$$

That is, the ERP difference wave associated with selection of attribute A should be the same whether attribute B does (left side of equation) or doesn't (right side) have the attended value. On the other hand, to the extent that the ERP in question is specifically associated with selection and/or postselection

processing of the conjunction (i.e., the entire "gestalt") rather than with processing of the attributes independently, the left side of the equation will outweigh the right.

Previc and Harter (1982) employed this type of design to study the selection of square-wave grating stimuli on the basis of their spatial frequency (9 or 36 min) and orientation (horizontal or vertical). The ERP elicited by stimuli sharing either of these attributes with the attended conjunction included a broad negativity between 175 and 250 msec. The early phase of this negativity appeared to reflect independent feature selection (i.e., the ERPs obeyed the above equation), whereas the later phase and a subsequent P300 wave showed greater specificity to the attended conjunction. The data were taken to support the view that parallel feature selections precede the identification of feature conjunctions or objects. In an experiment of similar design in the auditory modality, however, Hansen and Hillyard (1983) found little evidence for an initial stage of independent feature selection for pitch and location when these two attributes were equally discriminable. Instead, the Nd wave was elicited primarily by the attended conjunction, even at its earliest phase.

The dual-attribute paradigm can also reveal hierarchical relationships among cue selections. When Hansen and Hillyard (1983) made one of the pitch-location attributes less discriminable than the other, they found that the early phase of Nd (arising at around 70 msec) specifically reflected selection of stimuli for the more discriminable attribute. About 100 msec later, the Nd wave began to reflect selection based on the less discriminable attribute, but only for the stimuli that had "survived" the earlier selection. This ERP pattern was interpreted as evidence for a hierarchy of cue selections, with processing of more subtle or complex attributes dependent upon the outcome of the prior selection. Hansen and Hillyard viewed these data as consistent with the tenets of early-selection theory (Broadbent, 1970; Francolini & Egeth, 1980; Johnston & Dark, 1982): early selection based on an easily discriminable cue allows a rejection from further analysis of half of the stimuli, thereby protecting higher processing resources from overload.

The present experiment used a similar design to investigate whether hierarchical selections are employed in a visual attention task where stimuli vary in spatial location and color (hue). These attributes were chosen because selection by location and color have distinctive ERP signatures and because these cues are postulated to play very different roles in guiding visual attention. In the theory proposed by Treisman and her associates (Treisman, 1982; Treisman & Gelade, 1980), for example, spatially focused attention is required for the integration of other cues (such as color) into a combined percept. We also wished to examine

the conclusion of Humphreys (1981) that location and color cues are processed via independent dimensional analyzers.

The interactions between color and spatial cues in visual attention were studied by recording ERPs to randomized sequences of red and blue bars flashed at right and left locations, with subjects striving to detect infrequent "target" bars (shorter in height) from "standard" bars having a specific color/location. ERPs were recorded to the attended color/location combination (termed the C+/L+ stimulus), as well as to stimuli having the attended color but unattended location (C+/L-), the attended location but the unattended color (C-/L+), and neither attended attribute (C-/L-).

An experiment with a similar structure was recently reported by Harter et al. (1982). Their subjects selected among green disks and white annuli presented in random order at right and left visual field locations and made speeded motor responses to one of these four stimuli. Harter et al. found that the "interlocation" selection, comparing ERPs to stimuli at attended versus unattended locations, was associated with an early negativity that was larger over the contralateral hemisphere, followed by a late negativity that was greater in amplitude over the posterior right hemisphere. In contrast, the negativity associated with "intralocation" selection was larger over the left hemisphere. Harter et al. concluded that the increased negativity between 100 and 300 msec reflected a "functional hierarchy of premotor selection processes," leading ultimately to the engagement of hemispherically specialized analyzers for different stimulus attributes.

The present experiment extends the study of Harter et al. in several directions. First, pure color (hue) cues were used rather than color-shape ensembles, with red and blue stimuli equated for luminance and shape. Second, the detailed interactions between cue-specific selections were revealed by comparing ERPs to all possible stimulus classes (C+/L+, C+/L-, C-/L+, and C-/L-); this also allowed for the testing of hierarchical selection contingencies between the cues. Third, the subjects made motor responses only to the infrequent targets rather than to all the C+/L+ stimuli; this allowed a distinction to be made between ERP components associated with cue selection and those associated with terminal decision and motor processes. Finally, the role of cue discriminability was evaluated by varying the spatial separation between the right and left bars.

METHOD

Subjects

Fourteen normal adults (10 males and 4 females; age range 19-39, mean = 24 years) served as paid volunteers in the "location-easy" experiment. Four were laboratory personnel familiar with the experimental goals, and 10 were inexperienced volunteers.

There were 12 subjects in the "location-hard" experiment (8 males and 4 females; age range 19-35, mean = 23 years), six of whom had also participated in the location-easy experiment. Of this group, 3 were laboratory personnel and 9 were inexperienced volunteers.

Stimuli

Red and blue vertical bars were presented on a color monitor under the control of a microcomputer. Screen brightness was adjusted to produce a luminance of 0.7 log fL for all stimuli against a background screen luminance of -1.9 log fL, as measured by an exposure photometer. The standard (taller) bars were 2.4 deg in height and 0.3 deg in width at a viewing distance of 90 cm. They were flashed on the screen for 32-msec-long exposures, and stimulus triggers used for ERP averaging were synchronized with the frame onsets.

In the location-easy experiment, the bars were flashed in random order at one of two locations, 5 deg to the left or right of a central fixation point. In the location-hard experiment, the locations were 0.3 deg to the left and right of the midline and 3 deg above the fixation point; the bars were elevated in the second experiment to avoid straddling the fixation point, thereby increasing the task difficulty.

During experimental runs, the four classes of stimuli (red/blue × right/left) were flashed in random order at ISIs that were randomized between 350 and 500 msec (rectangular distribution). Each run contained 250 stimuli, and several randomization patterns were used to prevent the subject's learning any specific event sequences. A random 20% of the stimulus bars of each type were shorter (subtending 2.0 deg in height) than the more frequent, standard bars; the shorter bars of the attended (C+/L+) class were designated as "targets."

Procedure

Each subject was tested in one recording session that lasted 60-75 min. The subject sat in a reclining chair and was given several runs of practice at discriminating the targets from the taller standards. The level of difficulty was such that subjects correctly detected between 67% and 88% of the targets in the location-easy experiment and between 45% and 79% in the location-hard experiment.

Before each experimental run, the subject was asked to fixate the central dot, and accurate fixation was verified throughout the 1.8-min run by recording the horizontal electro-oculogram (EOG). On each run they were told to attend to one of the four color/location stimulus classes (e.g., "the blue bars on the right") and to press a button held in the right hand every time they detected a shorter target of that class. The experiment proper consisted of 24 runs, 6 under each of the attention conditions, administered in counterbalanced order. Subjects were informed of the number of "hits" and "false alarms" they made on each run and were encouraged to maximize the former while minimizing the latter.

The location-easy and location-hard experiments were identical in all respects except the spatial layout of the stimuli and the different subject populations.

ERP Recording

Monopolar recordings were made using Ag-AgCl electrodes placed at mirror-image scalp locations over frontal, central, parietal, and occipital regions of the left and right hemispheres, all referred to linked mastoids. The paired electrode sites were F3-F4 (International 10-20 system), C3'-C4' (1 cm lateral to the C3-C4 sites), P3'-P4' (inferior parietal sites halfway between Pz and the ear canal), and O1-O2 (10-20 system). Vertical eye movements and blinks were monitored with an electrode on the left inferior orbital ridge, also referred to mastoids. The horizontal EOG was recorded bipolarly between the two external canthi.

The two EOG channels were recorded with dc amplifiers and a high-frequency half-amplitude cutoff of 60 Hz. The scalp channels were recorded with a time constant of 8 sec and high-frequency

cutoff of 60 Hz (frontal sites) or 100 Hz (central, parietal and occipital sites). The EEG/ERP activity was recorded on FM tape along with stimulus trigger codes and response markers and was analyzed off-line on a PDP-11/45 computer.

Data Analysis

ERPs were averaged separately for each class of stimulus, attention condition, and electrode site. The averaging program analyzed 1,000-msec epochs beginning 200 msec before each stimulus. Each epoch thus overlapped with the presentation of subsequent stimuli, but the averaged ERPs to the later stimuli were "smeared" out in the averages because of the ISI randomization. Trials contaminated with eye blinks or movements, excessive muscular activity, or amplifier blocking were rejected by the averaging program.

ERP amplitudes were quantified by computer in terms of peak measures (the maximum negative or positive deflection within a specified time window; see Table 1) or mean amplitude measures over a specified time window, both referred to a baseline voltage averaged over the 200-msec interval preceding stimulus onset. These measures were taken on the averaged waveforms from each subject and on the "difference waves" formed by subtracting, point by point, the ERPs recorded under different attention conditions.

Behavioral measures of reaction time (RT) and target detection accuracy were scored by computer. A buttonpress within the interval 200-1,000 msec after a shorter (target) bar of the attended (C+/L+) class was considered to be a "hit," and all other presses were classed as false alarms. Indices of target detectability (d' and β) were calculated for the standard-target discrimination; hit probability was taken to be the ratio of hits/number of attended (C+/L+) targets, and false-alarm probability was estimated as the ratio of false alarms/number of attended (C+/L+) standards.

Speeded Cue Discrimination Task

A preliminary experiment verified that the spatial cues required a longer analysis time in relation to the color cues in the location-hard experiment. A speeded-response classification task was given to a different group of 16 young adult subjects, with no ERPs recorded. The stimuli were identical to those used in the ERP experiments, except that the ISIs were increased to 1,300-1,450 msec in order to allow time for a response to each stimulus. In separate runs, the subjects were required to make a binary judgment of stimulus location or stimulus color. Eight subjects performed under location-easy parameters and eight under location-hard.

In the spatial discrimination runs, the subjects, while ignoring color, made a go/no-go reaction according to stimulus location; on one run (250 trials) they pressed for left flashes, and on another run for right flashes. All responses were symmetrical presses, with the two index fingers, of a button held in the subject's lap. In the color discrimination runs, the subjects made go/no-go responses to either the blue or the red bars, which were delivered in random order to the right location for two runs (125 trials each) and to the left location for another two runs.

Under the location-easy conditions, the spatial discrimination was made more rapidly than the color discrimination [312 ± 27 msec

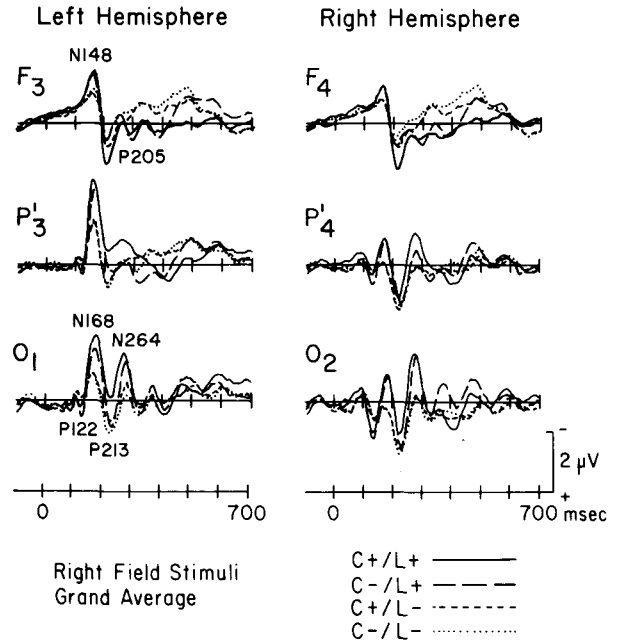


Figure 1. Grand average ERPs over all subjects in response to four types of standard (nontarget) bars flashed in the right visual field. Bars were attended (C+/L+), had the attended color but not location (C+/L-), had the attended location but not color (C-/L+), or had neither attribute (C-/L-). Peaks are labeled according to the polarity (N,P)-latency (msec) convention. ERPs from the central (C3'-C4') scalp sites (not shown) were intermediate in waveshape between the frontal and parietal waveforms.

vs. 350 ± 26 msec; $t(7) = 6.0$, $p < .001$). In contrast, the color discrimination was faster than the spatial judgment under location-hard conditions [360 ± 28 msec vs. 385 ± 34 msec; $t(7) = 2.7$, $p < .02$]. Thus, the spatial discrimination took some 73 msec longer under location-hard than under location-easy conditions [$t(14) = 5.9$, $p < .001$]. The 10-msec difference in color discrimination latencies between conditions was not significant [$t(14) = 1.1$].

RESULTS

Location-Easy Experiment

ERP waveforms. The visual ERPs to standard (nontarget) flashes were characterized by sequences of peaks that varied in morphology according to scalp location. As shown in Figure 1, the ERPs over the posterior scalp contained P122, N168, P213, and N264 peaks (designated by their latencies in the grand

Table 1
Characteristics of Major Peaks in ERP Waveforms and Number of Subjects (out of 14) in Whom Peaks Were Clearly Evident in All Attention Conditions (Location-Easy Experiment)

Component	Peak Latency Range (msec)	Measurement Window (msec)	Laterality*	Clearly Present in N/14 Subjects
Posterior P122	110-130	75-150	symmet.	10
Posterior N168	150-190	150-225	contra. ($p < .001$)	12
Posterior P213	195-230		ipsi. ($p < .01$)	12
Posterior N264	230-280	225-300	symmet.	12
Anterior N148	140-160	100-200	contra. ($p < .001$)	14
Anterior P205	195-215	150-250	symmet.	12

* p values show level of significance for contra/ipsi comparison across all attention conditions at scalp sites of maximum amplitude.

average waveforms), and the anterior recordings showed prominent N148 and P205 peaks. These peaks were quite consistent across subjects (Table 1) and were generally present under all attention conditions.

Preliminary analyses showed that the ERP componentry and the attention effects were equivalent for the red and blue stimuli. Accordingly, the waveforms were collapsed across stimulus color in the figures and statistical analyses. The ERPs were designated according to which attributes of the evoking stimuli were attended, as shown in Table 2.

Left- and right-field stimuli elicited ERPs with highly similar, mirror-image patterns of lateral asymmetry on the scalp (Figure 2), except as noted otherwise. For this reason, ERP component measures (see Table 1) were subjected to analyses of variance with the following factors: stimulus location (attended vs. unattended), stimulus color (attended vs. unattended), electrode site (contra/ipsi re eliciting stimulus), and side of stimulus presentation (left/right). Separate analyses were performed on each component and each left-right pair of electrodes.

Spatial attention effects. Inspection of the grand average waveforms (Figures 1 and 2) shows that all bars flashed to the attended location (both the C+/L+ and the C-/L+ stimuli) elicited enlarged P122, N168, and N264 components posteriorly and an N148 wave anteriorly, in relation to bars at the unattended location (the C+/L- and C-/L- stimuli). The wave-shape of these spatial attention effects can be seen more clearly in the difference waves (Figure 3) formed by subtracting the ERP to bars in the unattended field from the ERP to bars of the same color in the attended field. This subtraction shows that the posterior sequence of peaks enhanced by spatial attention (P122, N168, N264) was almost identical in amplitude and morphology for bars of the attended color (C+/L+ - C+/L- waveforms, left column) and bars of the unattended color (C-/L+ - C-/L- waveforms, right column). In other words, amplitude modulations of this sequence of components largely reflected spatial selection irrespective of stimulus color.

The difference waveform representing spatial-selective processing for stimuli of the attended color also contained a broad, contralaterally distributed negativity between 150 and 350 msec, which was superimposed upon the N168 and N268 peaks (Figures 2 and 3). As discussed below, this negativity (N150-

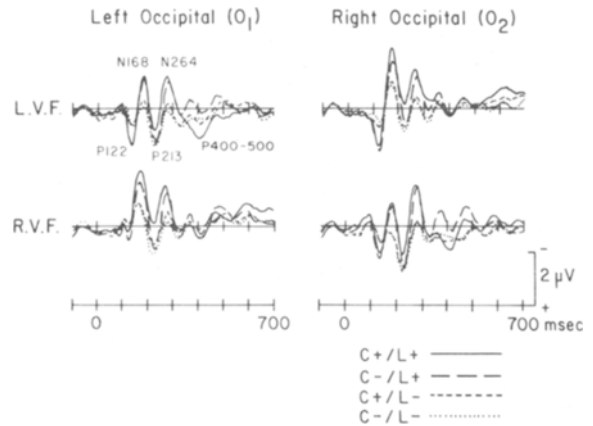


Figure 2. Grand average ERPs from left and right occipital sites (O1 and O2) in response to standard stimuli in the left (L.V.F.) and right (R.V.F.) visual field. Note contralateral distribution of the N168 peak.

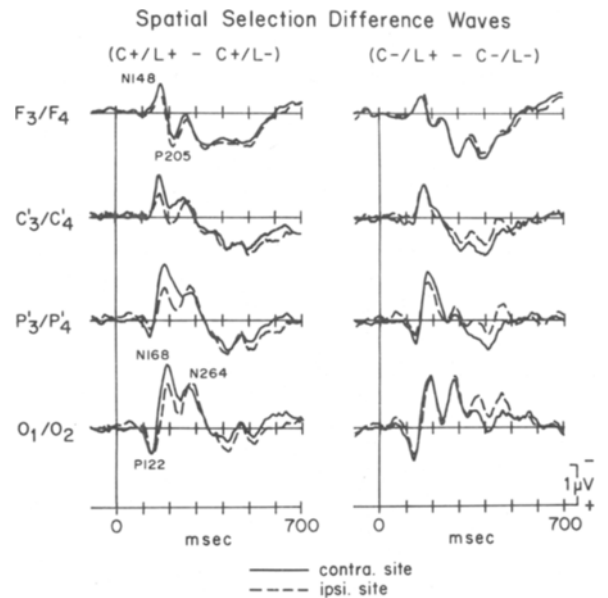


Figure 3. Difference ERPs associated with attended versus unattended spatial locations. Left column shows difference waves formed by subtracting the ERP to the C+/L- stimuli from the ERP to the C+/L+ stimuli. The right column shows similar difference waves for flashes of the unattended color.

350) was elicited primarily by the attended (C+/L+) bars.

The earliest component that was enhanced by spatial attention was the occipital P122 peak onsetting at about 90-100 msec ($p < .01$ for location factor). This P122 enhancement was independent of stimulus color and was bilaterally symmetrical.

The posterior N168 peak measure also showed a highly significant main effect for attended location ($p < .001$ at both parietal and occipital sites). The spatial attention effect on N168 was largest over contralateral scalp sites for stimuli of the attended color, as can be seen in the C+/L+ - C+/L- difference

Table 2
Key for Designating the Stimuli According to Which of Their Attributes Were Being Attended

Stimulus	Attended Color	Attended Location
C+/L+	Yes	Yes
C-/L+	No	Yes
C+/L-	Yes	No
C-/L-	No	No

waves. This asymmetry was largely attributable to the overlapping N150-350 elicited by the C+/L+ stimulus and was reflected in a location \times color \times contra/ipsi interaction (occipital, $p < .002$; parietal, $p < .001$).

The posterior N264 peak measure also showed strong modulation by spatial attention (location main effect: $p < .001$ occipitally; $p < .05$ parietally). This enhancement of N264 was symmetrical on the scalp and did not interact with stimulus color.

Over the anterior scalp, spatial attention augmented the amplitude of the N148 peak, beginning at about 100 msec (location main effect: $p < .001$ centrally; $p < .002$ frontally). This attentional modulation of N148 was largest over the contralateral scalp for stimuli of the attended color (location \times color \times contra/ipsi interaction: $p < .001$ frontally, $p < .02$ central).

A series of positive deflections followed the N148 in the anterior spatial difference waves. The P205 peak did not show a main effect for location but rather a specific enhancement to the C+/L+ stimulus (discussed below). A broad, multilobed positivity extending over 250-500 msec showed strong spatial attention effects (location main effect on mean frontal amplitude over 250-450 msec: $p < .005$), which did not interact with color.

Color selection effects. At the posterior electrode sites, color selection was reflected in a broad negative component beginning at about 150 msec contralaterally and 200 msec ipsilaterally (N150-350), followed by a later positivity peaking at 400-500 msec (Figure 4, left). This negative-positive ensemble was elicited primarily by the C+/L+ stimulus and accordingly was much more prominent in the C+/L+ - C-/L+ difference waves (color selection at the attended location) than the C+/L- - C-/L- difference waves (color selection at the unattended location).

The initial portion of the N150-350 was quantified as the mean amplitude over 150-200 msec. This measure was markedly enlarged to flashes of the attended color (color main effect: $p < .001$ occipitally), particularly over the contralateral scalp (color \times contra/ipsi interaction: $p < .002$ occipitally, $p < .005$ parietally). This lateralized color selection effect was considerably larger for flashes at the attended location (color \times location \times contra/ipsi interaction: $p < .001$ occipitally and parietally).

The later portion of the N150-350 component was quantified as the mean amplitude over 200-300 msec. This negativity showed a strong main effect of attended color at occipital ($p < .001$) and parietal ($p < .002$) sites that was larger for flashes at the attended location (color \times location interaction: $p < .025$ parietally). The contralateral preponderance of this negativity to the attended (C+/L+) stimulus was again reflected in the color \times location \times contra/ipsi interaction ($p < .005$ parietally).

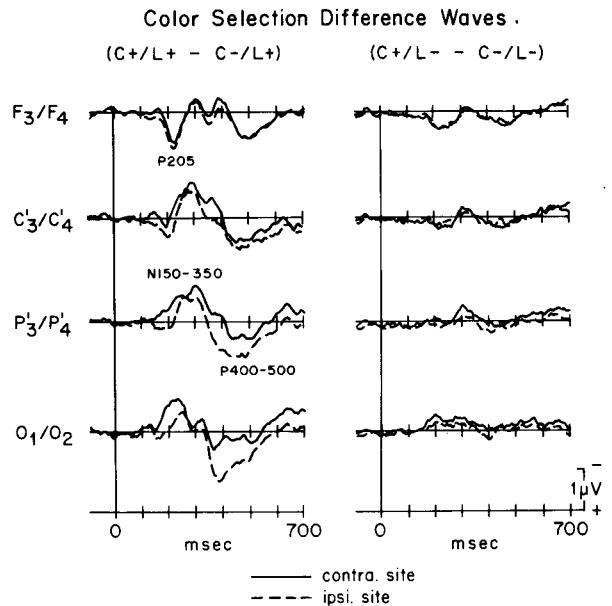


Figure 4. Difference ERPs associated with stimuli of attended versus unattended color. Left column shows difference waves reflecting selection for color at the attended location, and right column shows difference waves associated with color selection at the unattended location.

At the frontal scalp sites, the P205 peak showed maximal enhancement to the C+/L+ stimulus (Figure 1). The positive peak measure (window 150-250 msec) showed a strong attention effect for color ($p < .001$) and a significant color \times location interaction ($p < .02$), but no lateral asymmetries.

The P400-500 component in the color selection difference waves was largest over parietal and occipital sites and was elicited primarily by the attended (C+/L+) flashes (see Figure 2). This was reflected in significant main effects at the parietal sites for attended location ($p < .02$) and color ($p < .001$), and a significant color \times location interaction ($p < .001$) for the mean amplitude over 350-550 msec. As shown in Figure 4 and Table 3, the P400-500 was largest over the ipsilateral scalp ($p < .01$ for the ipsi/contra main effect and $p < .001$ for the location \times color \times contra/ipsi interaction, parietally).

ERPs to targets. The effects of attended location and color upon the ERPs to the target flashes (the shorter bars) were virtually identical to those seen for the standard flashes over the first 300 msec of the waveform. Figures 5 and 6 show that the targets at the attended location also elicited enhanced occipital P122/N168/N264 peaks, and the C+/L+ targets elicited additional negativity between 150-350 msec over the contralateral scalp.

In addition, the C+/L+ targets elicited a substantial late positivity that peaked between 400 and 500 msec and lasted until at least 700 msec. This P400-500 (quantified as the mean amplitude over 350-550 msec) was largest over the posterior scalp and showed strong main effects for attended color

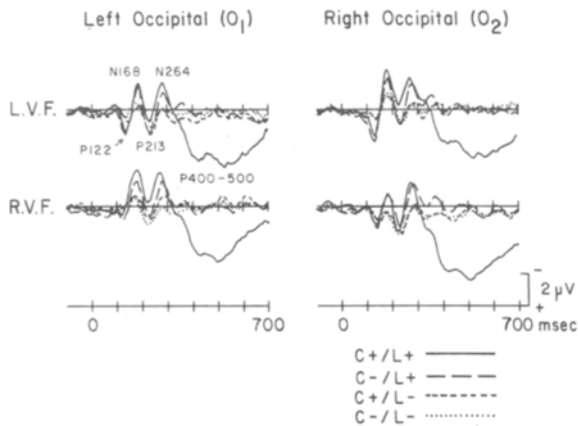


Figure 5. Grand average ERPs at left and right occipital sites (O1 and O2) in response to target stimuli presented to the left (LVF) and right (RVF) visual fields.

and location and a color \times location interaction (all $p < .001$). As with the standard flashes, the late positivity to the C+/L+ targets was larger over the ipsilateral side of the scalp (contra/ipsi comparison: $p < .001$ occipitally; $p < .005$ parietally) (Table 3). This ipsilateral preponderance was seen in 13 of the 14 individual subjects.

Comparisons were made between the C+/L+ standards and targets for all peaks prior to P400-500, to see if the target/standard discrimination was reflected in these earlier components. Only the N264 peak measure was found to be larger to the targets ($p < .02$ occipitally, Figure 6), but this effect can probably be attributed to the inflation of the base-peak amplitudes in the target ERPs by virtue of their being averaged over fewer stimuli. Indeed, the target-standard comparison for the mean negative amplitude over 225-300 msec was not significant.

Location-Hard Experiment

ERP waveforms. The components elicited by the colored bars adjacent to the midline were comparable to those seen in the first experiment, but the latencies were somewhat earlier (posterior P110, N164, N256;

anterior N138, P199) and the amplitudes considerably modified (Figure 7). The P110, in particular, was greatly enlarged in the location-hard waveforms.

In marked contrast to the location-hard waveforms, however, there were no effects of selective attention on any component prior to about 160 msec. Since the attention effects on the ERPs were generally bilaterally symmetrical, Figure 7 shows waveforms collapsed over left and right stimuli. The statistical analyses paralleled those of the first experiment, with waveforms collapsed over stimulus color.

Spatial attention effects. The difference waves for spatial selection (Figure 8) showed little evidence of

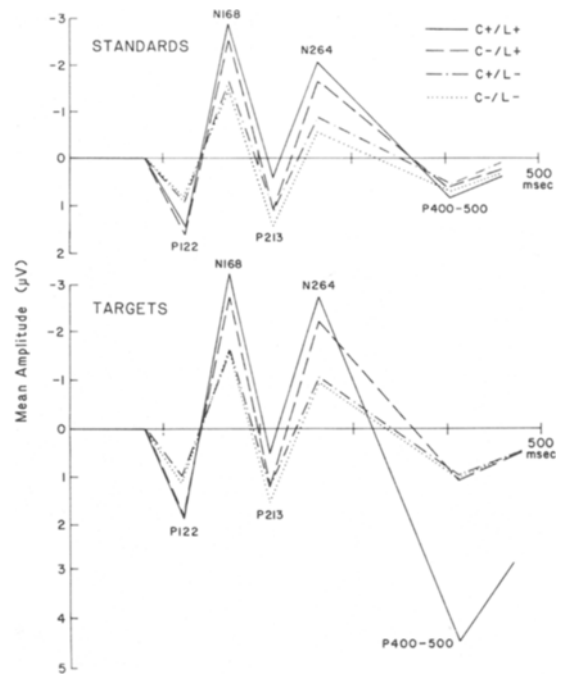


Figure 6. Diagram comparing attention effects on occipital ERP components between standard and target flashes. Amplitude values are mean values of base-peak measures taken on individual subjects in time windows appropriate to each peak (Table 1).

Table 3
Mean Amplitude of P400-500 Component (in $\mu V \pm SE$) to the C+/L+ Flashes Over Ipsilateral and Contralateral Scalp Sites

Scalp Sites	Standards				Targets			
	Ipsilateral		Contralateral		Ipsilateral		Contralateral	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Location Easy								
Central	0.15	.23	0.05	.24	1.40	.49	1.02	.46
Parietal	0.39	.21	0.01	.20	2.72	.46	1.98	.41
Occipital	0.40	.20	-0.11	.18	3.09	.61	2.24	.56
Location Hard								
Central	-0.05	.26	0.03	.23	0.72	.78	0.54	.66
Parietal	0.41	.18	0.34	.19	2.36	.63	2.06	.58
Occipital	0.79	.12	0.58	.19	3.91	.48	2.81	.56

Note—Tabled values are mean amplitude measures in the interval 350-550 msec.

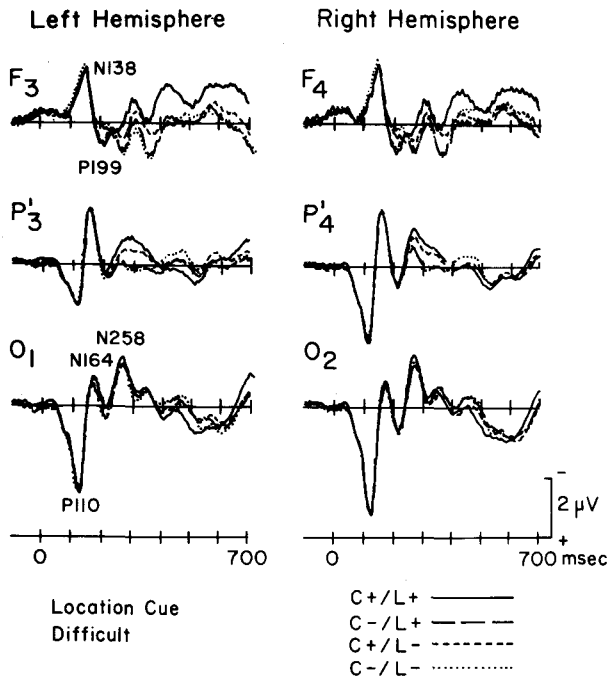


Figure 7. Grand average ERPs to the different classes of stimuli in the location-hard experiment. Waveforms are collapsed over right- and left-field stimuli.

the enhanced posterior sequence of components seen in the location-easy experiment. None of the measures (peak or area) showed any significant location effects for the posterior P110, N164, or N258 components. The only significant effect of location selection was a larger frontal negative wave peaking at around 280 msec for stimuli at the attended location ($p < .05$ for frontal peak between 225 and 400 msec). The broad, negative shift over 300-800 msec seen frontally in the $C+/L+ - C+/L-$ difference wave

was highly variable among subjects and was not statistically significant.

Color selection effects. The components associated with color selection were similar to those observed in the location-easy experiment and included an anterior P199 (equivalent to the P205) and a broad N150-350 deflection at all but the occipital sites (Figure 9). The P199 component showed a highly significant effect of attended color ($p < .001$ frontally), which did not depend on stimulus location. The N150-350 showed significant effects for color selection at both central ($p < .05$) and parietal ($p < .05$) sites, but this component was not asymmetrically distributed on the scalp as in the first experiment. Figure 9 shows the N150-350 for color selections to be slightly larger at the attended location ($C+/L+ - C-/L+$ difference waves) than at the unattended location ($C+/L- - C-/L-$), but the color \times location interaction did not reach significance at central or parietal sites.

The late positive component (P400-500) to the standard stimuli shows no main effects for color, location, or contra/ipsi electrode site, but was largest to the $C+/L+$ stimulus (color \times location interaction, $p < .05$). The sustained late negativity seen frontally to the $C+/L+$ stimulus showed no significant effects for color selection or for the color \times location interaction.

Target ERPs. The targets elicited waveforms similar to those of the standard flashes, but with a greatly enlarged late positivity (P400-500) to the $C+/L+$ stimuli over the parietal and occipital scalp. The P400-500 (quantified as the mean amplitude over 350-550 msec) showed significant effects of color and location, and a color \times location interaction (all $p < .001$). As in the location-easy experiment, the P400-500 was largest over the scalp ipsilaterally to the stim-

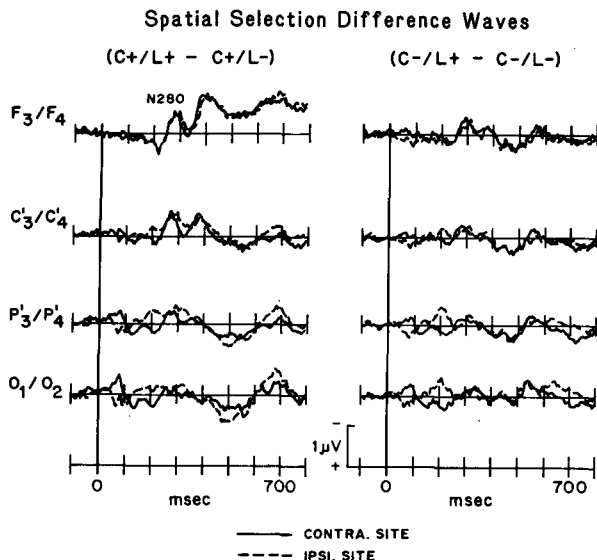


Figure 8. Difference ERPs associated with stimuli at attended versus unattended spatial locations in the location-hard experiment.

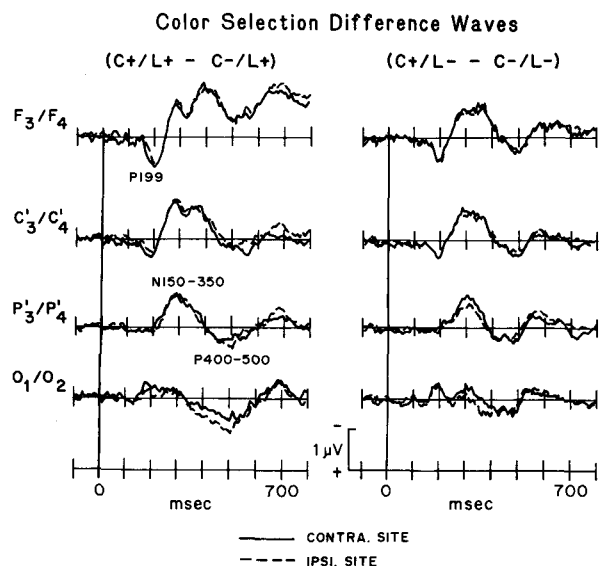


Figure 9. Difference ERPs associated with stimuli of attended versus unattended color in the location-hard experiment.

ulus ($p < .01$ parietally; $p < .001$ occipitally) (Table 2).

In comparison with the C+/L+ standards, the C+/L+ targets had larger N256 components both parietally ($p < .02$) and occipitally ($p < .01$) for the mean amplitude 225-300-msec measure and, of course, greatly enlarged P400-500 waves ($p < .001$).

Interhemispheric Differences

In light of Harter et al.'s (1982) report that selections "between locations" (the C-/L+ - C-/L- comparison) and "within locations" (the C+/L+ - C-/L+ comparison) were associated with late negative components lateralized to the right and left sides of the scalp, respectively, a search was made for such effects in the present data. Table 4 shows the waveform amplitudes at left and right electrodes for occipital peak negativity in a 225-300-msec window, comparable to the N272 peak measure used by Harter et al. To test for possible asymmetries in these attention effects, separate ANOVAs were performed on the inter- and intralocation ERPs, with factors of attended/unattended stimulus, left/right location, and left/right hemisphere.

In the location-easy experiment, the between-location attention effect on the N225-300 was largest occipitally but showed no significant tendencies to be larger on the right or left side of the head. In the location-hard waveforms, these values were near noise levels and similarly showed no significant trends toward lateral asymmetry.

The late negativity associated with the within-location selection was largest over central and parietal scalp sites. There were no significant tendencies toward lateral scalp asymmetries for the standard stimuli, but the targets had consistently larger N225-300 amplitudes in the difference waves over the left side of the head in both experiments (Table 4).

ERP Latency Comparisons Between Experiments

Color selection. To determine whether the ERP signs of color selection occurred with different latencies in the two experiments, a between-groups ANOVA was performed on latency measures of the N150-350 deflection in the C+/L+ - C-/L+ difference waves. Measures of peak latency and "quarter-peak" latency (the time at which the leading edge of the negativity attained an amplitude one-fourth that of the peak amplitude) were compared between the location-easy and location-hard experiments. Although this negativity began 10-20 msec earlier in the location-easy waveforms, the between-experiment comparisons did not reach significance for either measure at central or parietal sites. However, the peak of the frontal positivity (P199, P205) in the C+/L+ - C-/L+ difference waves was significantly earlier in the location-hard than in the location-easy experiment ($p < .01$).

P400-500 to targets. The latency of the late positivity associated with target detection was analyzed in the target minus standard difference waves for the C+/L+ stimuli in the two experiments. Although there was a clear tendency for the P400-500 to onset earlier in the location-easy experiment (398 vs. 443 msec parietally for the quarter-peak measure), this difference did not reach significance in the between-groups analysis ($p > .10$).

Behavioral Measures

Target detection performance. The d' score for discriminating the C+/L+ targets from standards was higher in the location-easy (2.41) than in the location-hard (1.89) experiment [$t(24) = 2.28, p < .02$]. The corresponding percent correct detection scores were 81% and 62%, respectively [$t(24) = 6.12, p < .001$]. The beta scores did not differ between experiments (5.57 and 4.46).

Table 4
Comparison of Amplitudes Over Left and Right Hemispheres of the N225-300 Peak Negativity Associated with Selections "Within Locations" (C+/L+ - C-/L+ Difference Wave) and "Between Locations" (C-/L+ - C-/L- Difference Wave)

	O ₁	O ₂	P ₃ '	P ₄ '	C ₃ '	C ₄ '
Location Easy						
Standard						
(C+/L+)-(C-/L+)	-0.28	-0.18	-0.80	-0.80	-0.64	-0.58
(C-/L+)-(C-/L-)	-1.18	-1.22	-0.16	-0.39	+0.19	+0.33
Target						
(C+/L+)-(C-/L+)	-0.48	-0.27	-0.88*	-0.31	-0.78*	-0.13
(C-/L+)-(C-/L-)	-1.40	-1.48	-0.50	-0.55	+0.05	+0.29
Location Hard						
Standard						
(C+/L+)-(C-/L+)	-0.23	-0.29	-0.66	-0.68	-0.99	-0.80
(C-/L+)-(C-/L-)	-0.15	-0.04	-0.01	+0.07	+0.13	+0.13
Target						
(C+/L+)-(C-/L+)	-0.90*	-0.44	-1.57**	-0.74	-1.57***	-0.62
(C-/L+)-(C-/L-)	-0.25	-0.10	-0.09	-0.01	-0.22	-0.02

* $p < .05$, ** $p < .01$, *** $p < .001$, for left-right hemispheric comparison on attention effect.

Table 5
Distribution of Erroneous Responses (in percent)
Among the Different Stimulus Classes

	Random Responding	Actual Percentages	
		Exp. 1	Exp. 2
C+/L+ std	21	35	46
C+/L- std	21	19	13
C-/L+ std	21	14	10
C-/L- std	21	21	19
C+/L- tar	5.3	3	6
C-/L+ tar	5.3	5	3
C-/L- tar	5.3	2	3
	99.9	99	100

Error analysis. Since the calculation of false-alarm probabilities for the d' scores was based on the assumption that false alarms occurred primarily to the C+/L+ standards, an analysis of the subjects' errors was made to see if this was the case. The distribution of the subjects' errors among the seven different stimulus types (i.e., errors occurring in a 200-1,000-msec window after each type of stimulus) is shown in Table 5. It should be noted that the tabled values are percentages of the *erroneous* responses only, not of the total responses; thus, for example, in Experiment 1 (location-easy), in which 19% of the total responses were erroneous, 35% of these (or 6.7% of the total responses) were made to the C+/L+ standards. It is clear that the C+/L+ standards received a disproportionate share of the false-alarm responses, well above what would be expected on the basis of random responding (left column).

Reaction times. The mean reaction times to the C+/L+ targets were faster in the location-easy (509 msec) than in the location-hard (553 msec) experiment [$t(24) = 2.93, p < .005$].

DISCUSSION

The ERP configurations associated with spatial selective attention were markedly different from those associated with selection by color. When the left and right bars were widely separated (location-easy condition), stimuli at the attended location elicited an enlarged sequence of components that included P122, N168, and N264 waves posteriorly and an N148 and slow positivity anteriorly. This entire wave sequence, which began at 80-90 msec and extended to at least 300 msec, was enhanced in response to all stimuli at the attended location, regardless of color. In contrast, the ERP difference wave associated with color selection consisted of a broad negative component (N150-350) that was larger over the contralateral scalp posteriorly, followed by a late positivity (P400-500). This negative-positive ensemble, together with a frontal P205 wave, was substantially larger for color selection at the attended location than at the unattended location and was elicited primarily by the C+/L+ or "conjunction" stimuli.

When the right and left locations were in close proximity (location-hard condition), however, the ERP signs of color selection preceded those of location selection, and the latter were considerably attenuated. Moreover, the ERP components that differentiated stimuli of the attended from the unattended color (a central-parietal N150-350/frontal P199) were elicited at similar amplitudes and latencies for flashes at both attended and unattended locations. Thus, the timing and pattern of the attention-sensitive ERPs were entirely dependent upon the discriminability of the task-relevant cues.

In both experiments, the attended "target" stimuli (the shorter C+/L+ bars) elicited a large, posterior P400-500 component in addition to all of the earlier ERP signs of selection for location and color attributes. This late positivity was clearly a P3 or P300 component that was contingent upon the terminal decision that a stimulus possessed all of the target attributes (color, location, and height). An enlarged negativity in the 225-300-msec range preceded the P300 to the C+/L+ targets, more prominently in the location-hard experiment. This component was probably equivalent to the "N2" or "N200" wave that is elicited in this latency range by deviant and/or task-relevant stimuli under a variety of conditions (Näätänen & Gaillard 1983; Ritter, Vaughan, & Simson, 1983). A smaller P400-500 was elicited by the C+/L+ nontargets in both experiments, perhaps reflecting erroneous false-alarm responses that occurred to the C+/L+ standards because of their resemblance to the C+/L+ targets (Table 5).

The distinctive ERP components associated with location and color selections are similar to those observed by Harter et al. (1982). In both studies, it was found that the ERP associated with the intralocation (color/shape) selection was a broad negativity over 150-300 msec, followed by a late positivity. Harter et al. also reported that stimuli at attended spatial locations elicited ERPs with an increased positive peak at about 125 msec, "followed by a large progressive increase in negativity from 125 to 222 msec." The present findings, however, emphasize that the spatial attention effect is more a modulation of discrete negative peaks that differ in latency and morphology over the anterior and posterior scalp, rather than a progressive increase in negativity.

The attention-related ERP changes prior to about 300 msec were essentially identical for the target stimuli that required a motor response and for the standard stimuli that did not. Since the attentional tasks used in the studies of Harter and his associates (Harter et al., 1982; Harter & Guido, 1980; Harter & Previc, 1978; Previc & Harter, 1982) required the subjects to make a prompt motor response to all stimuli with the attended cue configuration, there was some uncertainty as to whether the ERP changes they observed were only signs of terminal decision and response processes. The present results argue

strongly against this possibility and support the alternative hypothesis that the ERP changes in the 100-300-msec range observed in the present study and in those of Harter's group were primarily signs of cue-selective processing.

Hierarchical Selection

The present results are in accord with the finding of Harter et al. (1982) that selection for location precedes selection for color/shape when the locations are easily discriminable. The earliest ERP sign of location selection (P122 onset) preceded the earliest sign of color selection (N150-350 onset) by some 40-50 msec. This latency difference is comparable to the 38-msec difference in RT for discriminating the easy-location and color cues in the speeded discrimination task. The difference wave analysis demonstrates further that the selective processing of stimulus color was hierarchically dependent upon the prior selection for the more easily discriminable location cue. That is, only those stimuli that were selected and preferentially processed on the basis of their location, as indexed by the enhanced P122/N168/N264 sequence, were fully analyzed for their color attributes, the latter reflected in the N150-350/P205/P400-500 sequence. Thus, it appears that stimuli belonging to the rejected spatial "channel" were not processed as fully for their other attributes as were attended-channel stimuli, in accordance with "early selection" concepts of attention (e.g., Broadbent, 1970; Johnston & Dark, 1982).

The waveforms presented by Previc and Harter (1982) also revealed a hierarchical pattern of stimulus selection. In that study, the negative ERP indicative of selection for stimulus orientation (onsetting at 225 msec) was dependent upon the earlier selection for spatial frequency (indexed by negativity onsetting at 175-200 msec). Hansen and Hillyard (1983) observed similar contingencies among the ERPs elicited during auditory attention for selections based on pitch and location attributes. In both visual and auditory modalities, then, the ERP data are in accordance with the claim of early selection theories that "attentional selection of stimuli occurs before perceptual processing is complete" (Francolini & Egeth, 1980). If stimuli belonging to a rejected channel are fully processed, as specified by "late selection" models of attention (see Johnston & Dark, 1982, for review), this must be a form of processing that occurs with little or no ERP signature.

In the location-hard experiment, the selection for color was not hierarchically dependent upon location selection. Instead, the N150-350/P199 complex was of comparable amplitude in the color selection difference waves at both attended and unattended locations, indicating that color selection had taken place before the more difficult spatial cue could be resolved. A rapid spatial discrimination was precluded in this experiment, probably because the right and

left locations were both contained within the width of the "attentional spotlight," which is reportedly about 1 deg in diameter (Hoffman & Nelson, 1981). When the relevant locations were in such close proximity, they may have been discriminable only by a relatively slow "location check" operation (Humphreys, 1981), which did not produce a robust ERP correlate. This delay in resolving the locational cue was probably responsible for the fact that the RTs to the targets and the latency of the P400-500 waves to the C+/L+ stimuli were longer than in the location-easy experiment.

The large P400-500 component elicited by the C+/L+ target stimuli reflected the final stage in the hierarchy of stimulus selections. In the location-easy experiment, stimuli were first selected for location, then the L+ stimuli were selected for their color, and finally, the C+/L+ stimuli were selected for their height. Each of these three levels of selection had a discrete time course and a distinctive ERP signature. At each stage of selection, half of the stimuli that had "passed" through the previous stage were rejected, so that the eight original stimulus alternatives were reduced to 4, 2, and 1, in a hierarchical fashion. It was difficult to determine whether the selection hierarchy was comparable under location-hard conditions, however, since the ERP signs of location selection were so diminished.

Nature of Attention-Related ERPs

The principal effect of focusing attention upon flashes at one location was to enhance a sequence of components (P122/N168/N264) that was evident in the ERPs to stimuli at both attended and unattended locations (see also Eason, 1981; Hillyard et al., 1984). This suggests that spatial selective attention acts by modulating exogenous components of the visual evoked potential rather than by triggering an entirely new, endogenous ERP in the manner of the auditory Nd wave. Eason (1981) has proposed that such a modulation or gating could take place pre-cortically, and, indeed, the lateral geniculate is well supplied with reticular afferents capable of altering sensory transmission through this relay (Singer, 1977; Skinner & Yingling, 1977). Harter et al. (1982) point out that the contralateral distribution of the posterior ERP sequence, which is more accentuated for spatial separations of greater than 10 deg, is also consistent with a modulation of activity in the geniculostriate system. This interpretation would imply that a sustained selective set for a discrete spatial location produces a gating of input at a fairly low level of the visual system and provides a basic mechanism for controlling access of stimulus input to higher "analyzers."

In contrast, the broad N150-350 wave associated with selection for color appears to be largely endogenous, being superimposed on evoked compo-

nents with a very different morphology. Moreover, there were clear differences observed in the scalp distribution of the N150-350 between the location-easy and hard experiments (compare Figures 4 and 9). The N150-350 had a more posterior and contralateral distribution at the wider spatial separation than in the location-hard experiment. Since this component was largest to the C+/L+ stimuli, it appeared to reflect processing subsequent to the resolution of both color and location information and to be contingent upon identification of the correct stimulus conjunction. The lateral asymmetry of this ERP suggests that it represents activity in a topographically ordered cortical area where spatially selected input is combined with color-selective information, the latter perhaps originating from cortical zones specialized for the processing of hue (Zeki, 1978).

The N150-350 was more anterior and symmetrically distributed in the location-hard experiment. Since this component, together with the frontal P199 wave, was elicited by attended-color stimuli at both locations, it seemed to reflect specifically the selection for the color attribute. It seems reasonable to assume further that the anterior N150-350/P205 pattern produced in the location-easy experiment also reflected the selection for color, which happened to be contingent on the prior selection for location under those conditions. In line with interpretations proposed for the auditory processing negativity (Nääätänen, 1982; Okita, 1981), the visual N150-350/P199 complex might be a sign of the further processing accorded to stimuli that have met an initial selection criterion of attended color. The N150-350 may well be related to the late negative waves in the N2 or N200 family (Ritter et al., 1983).

The late positivity (P400-500) elicited by the C+/L+ targets and to a lesser extent by the C+/L+ standards showed the posterior scalp distribution and functional properties characteristic of the P300 component (Donchin, Ritter, & McCallum, 1978). The finding that P400-500 was larger over the scalp ipsilateral to the eliciting stimulus, however, contrasts with the general finding that the P300 is bilaterally symmetrical and independent of physical stimulus characteristics (e.g., Desmedt & Robertson, 1977; Simson, Vaughan, & Ritter, 1977; Snyder, Hillyard, & Galambos, 1980). There have been other reports of P300 being larger over the hemisphere ipsilateral to the side of stimulation for both visual (Skrandies, in press) and somatosensory (Josiassen, Shagass, Roemer, Ercegovac, & Straumanis, 1982) decision tasks, as well as a finding of generally larger P300 amplitudes over the left side of the head (Morstyn, Duffy, & McCarley, in press). Some of these asymmetries may have arisen from task-specific, asymmetrical components superimposed on the P300, (e.g., Ragot, Renault, & Remond, 1980). In particular, the posterior N150-350 may have summated its contralateral

negativity with the P400-500, making the latter more positive ipsilaterally. Another possibility, however, is that the P300 generators themselves may be activated asymmetrically in situations in which there is differential hemispheric engagement.

Multidimensional Stimulus Processing

According to the feature integration theory of attention (Treisman, 1982; Treisman & Gelade, 1980), separable features such as color are registered "early, automatically, and in parallel across the visual field," thereby forming "preattentive feature maps." Spatially focused attention is required to conjoin the different features to produce unified perceptions of objects. The ERP evidence suggesting that inputs from an unattended location are gated at an early stage of processing, however, seems incompatible with the idea that early feature registration is completely automatic, inasmuch as this registration would presumably be gated as well. It may be the case that features such as color are registered and identified in parallel across the visual fields only when attention is in a diffused or "distributed" state (Hoffman & Nelson, 1981), and not when attention is focused on a specific location. In terms of the feature integration theory, the P122/N168/N272 sequence appears to index a sustained focal attention towards events at a particular location. Under this assumption, the theory would suggest that this ERP sequence is associated with the integration and/or utilization of feature information contained in those stimuli. This utilization might involve analyzing and judging the relevance of the individual features or conjoining the features into an integrated percept. This would be in accordance with the proposal that color and locational attributes may be conjoined at a fairly early stage of processing (Treisman, 1982).

These ERP data give clear support to the view of Treisman and Gelade (1980) that "features come first in perception," as opposed to the gestalt hypothesis that object perception is primary. In both the location-easy and location-hard experiments, the ERP signs of individual attribute or feature selection precede the signs of "object" or conjunction selection. Moreover, this initial processing of the most discriminable feature was relatively independent of the level of the other feature, as specified by Equation 1. Harter and his associates (Harter et al., 1982; Harter & Guido, 1980; Previc & Harter, 1982) have similarly observed ERP evidence of feature selection preceding the ERPs associated with conjunction selection. The present results are also in agreement with Harter et al.'s (1982) conclusion that selections for different features emerge in a distinct sequence. However, it should be emphasized that these feature selections show specific patterns of contingencies, with selections of some attributes dependent on prior selections for others. Furthermore, it is clear that cue discriminability is of

paramount importance in determining both the timing and ordering of selections for different features.

These results also support the conclusion of Humphreys (1981) that color and location attributes are processed and selected by means of "independent dimensional analyzers." First, the obvious differences in waveform configuration and distribution between the ERPs associated with color and location selections and the dissociability of their respective onset latencies are strongly suggestive of qualitatively different modes of analysis. Second, as noted above, the difference wave analysis showed that the selective processing based on the more discriminable attribute was largely independent of the less discriminable attribute in accordance with Equation 1. Thirdly, the anterior N150-350/P199 complex associated with color selection was little altered as a function of whether the color selection preceded (location-easy) or followed (location-hard) the spatial selection. These observations seem more compatible with concepts of separable feature analyzers for color and location than with holistic models of perception in which multi-attribute stimuli are represented as "blobs" in a perceptual "similarity space" (e.g., Lockhead & King, 1977). Indeed, if selective attention were directed towards holistic blobs or objects rather than towards individual attributes, one would expect the C+/L+ stimulus (i.e., the attended blob) to elicit an ERP signature distinctive from that of the other three stimuli from the outset. Instead, the ERP attention effects elicited by the different classes of stimuli were attribute-specific and were not graded in any obvious fashion according to overall stimulus dissimilarity.

If color and locational cues are indeed processed and selected in separate dimensional analyzers, it is clear from the hierarchical processing contingencies manifested in the ERPs that such analyzers must interact strongly with one another at specific levels of processing. In an auditory attention task using dual-attribute stimuli, the processing contingencies could be accounted for in terms of parallel, self-terminating models of processing (Hansen & Hillyard, 1983; Hawkins, 1969; Snodgrass & Townsend, 1980). These models specify that each nonattended stimulus is processed until enough information accumulates in one of the dimensional analyzers to indicate that it lacks one or more critical attributes, at which time processing of that stimulus terminates. Since less discriminable attributes require a longer time to resolve, the ERP signs of their selection would be contingent upon the analysis of the more rapidly discriminable cue. In the present experiment, however, the processing interactions between the two attributes were not symmetrical. In the location-easy experiment, stimuli at the nonattended location were processed minimally for color, whereas stimuli of the nonattended color continued to show preferential processing for

the attended location. This suggests that spatial selection may have primacy in aborting color processing when the attended and unattended locations are widely separated.

Hemispheric Specialization

Harter et al. (1982) reported that the late negativity (N272) associated with between-location selection was larger over the right hemisphere, an effect they attributed to the role of the right parietal association areas in processing spatial information. Such an asymmetry was not evident, however, in the present interlocation (C-/L+ - C-/L-) difference waveforms. This lack of asymmetry might be attributed to the smaller spatial separation used in this experiment (10 deg, as opposed to 20 deg for Harter et al.), but it does raise questions about the generality of the effect. The present results did confirm Harter et al.'s finding of a greater left-hemispheric amplitude for the late negativity associated with the intralocation (C+/L+ - C-/L+) selection. However, this asymmetry was seen only in response to the targets that called for a motor response. Since Harter et al.'s subjects responded to all the C+/L+ stimuli, it would appear that this asymmetry is specifically associated with stimuli that required an overt motor response. This suggests that the left hemispheric negativity may reflect motor preparatory processes (right-hand responses were used in both experiments) or, less likely, the terminal decision that the stimulus belongs to the relevant class. This lateralized component does not appear to be a general sign of the processing of feature conjunctions or stimulus type.

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