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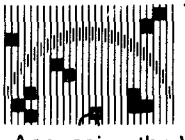

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Aging and selective attention to location and color: Visual event-related potentials

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The University of North Carolina at Greensboro, 1988

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AGING AND SELECTIVE ATTENTION TO LOCATION AND COLOR: VISUAL EVENT-RELATED POTENTIALS

by

Mary Marvin Schroeder

A Dissertation Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
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Approved by

Dissertation Advisor

APPROVAL PAGE

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SCHROEDER, MARY M., Ph.D. Aging and Visual Selective Attention to Color and Space: Event Related Potentials. (1988)
Directed by Dr. M. Russell Harter. 105 pp.

Studies of selective attention in normally aging individuals using event related potential (ERP) and reaction time (RT) measures have suggested slowing and reduced selectivity with age, particularly when the location of the relevant stimulus is uncertain. The purpose of this study was to investigate the effects of age on the time course and scalp distribution of ERP indicants of spatial and feature selective attention. Group differences in spatial relevance effects were expected to be earlier and more frontal; feature relevance effects, later and more posterior.

Healthy normal subjects were recruited for the study. The mean age of the 8 younger and 8 older subjects was 25 yrs. and 70 yrs., respectively. The stimuli consisted of red and green flashes presented in the left or right visual field, one of which was task relevant. ERPs were recorded from occipital, central, and frontal sites. The amplitude and latency of the largest deflection in four time windows of the ERP associated with feature and spatial relevance effects were measured (P144, N188, N325, and P445).

The differences between the groups for spatial relevance were earlier (N325) and at all scalp locations; the differences between the groups for feature relevance were later (P445) and more posterior (occipital and central). The RT and the peak of the P445 component were significantly delayed for the older group.

The results support the hypothesis that age-related changes in early spatial selective attention processes slow later feature selection. The dissociation of the relevance effects in scalp

topography is consistent with current models of cortical visual systems and visual selective attention.

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CHAPTER 1

INTRODUCTION

Normal aging is characterized by a generalized slowing of behavior (Botwinick, 1981; Welford, 1977) and changes in performance on measures of attention, perception, learning, and memory (Birren, Woods, & Williams, 1980; Siegler, 1980). This study was designed to investigate the influence of age and task relevance on the time course and scalp topography of event-related potentials (ERPs). The predictions were based on: a) neurophysiological models of selective attention (Harter & Aine, 1984) and dual cortical visual systems (Ungerleider & Mishkin, 1982) b) results of ERP studies of feature and spatial visual selective attention (Harter, Aine & Schroeder, 1982; and c) data from reaction time studies of age and visual selective attention (Madden, 1983; Plude & Hoyer, 1986).

SELECTIVE ATTENTION

Selective attention has been defined as the differential processing of simultaneous sources of information (Johnston & Dark, 1986). For the purposes of this investigation, selective attention was defined as the selective neural processing of information as a result of the task relevance of the information. This selection results in ERPs that are larger in amplitude to relevant information than to irrelevant information (Donald, 1983; Harter & Aine, 1984).

The operation of attentional mechanisms is inferred when a relatively enhanced behavioral and/or neural response is associated with task relevant stimuli (or stimuli similar to the relevant stimuli) as compared to other stimuli. In this study, selective attention of elderly subjects as compared to young adults will be assessed by behavioral and ERP measures.

NEUROPHYSIOLOGICAL MODELS OF SELECTIVE ATTENTION

The neural specificity model of selective attention (Harter & Aine, 1984) assumes that selective attention at a neural level is the modulation of incoming sensory information by efferent fibers from higher cortical areas. Visual information, for instance, is organized by receptive fields. Receptive fields are areas of the retina that, when stimulated by specific types of information, enhance the activity of specific neural units in the visual system. Several neural units that are activated by the same type of retinal stimulation may be called a neural channel. This study was based on the assumption that selective attention is the result of the differential regulation of neural channels carrying specific codes of sensory information. This regulation (enhancement and/or suppression) of specific afferent information is presumably accomplished by efferent connections at synapses between neurons at various levels of the information processing sequence.

A model of selective attention proposed by Skinner and Yingling (1977) relies heavily on the role of the frontal cortex and the thalamus in the gating of incoming sensory information. In this model, the frontal cortex inhibits neural output from the thalamus to

cortical, subcortical, and limbic structures.

In human lesion studies, the effects of damage to the prefrontal granular cortex have been systematically evaluated by Milner (1964) and Luria and Homskaya (1970). Damage to these areas results in a deficit of the ability to sort relevant from irrelevant stimuli, particularly in novel situations and changing conditions.

NEUROPHYSIOLOGY OF THE NORMALLY AGING CNS

Normal aging is characterized by an overall reduction in brain weight from an average of 1450 grams at age 30 to 1350 grams at age 75 (Kolb & Whishaw, 1980). Loss of neurons with age may account for this weight change (Greenough & Green, 1981). Certain areas of neocortex are affected more by this loss than are other areas of the brain (Brody, 1980). Areas of cortex showing prominent neuronal loss are precentral gyrus, superior temporal gyrus, and superior frontal gyrus (Brody, 1978).

Studies by Scheibel's group have documented dendritic degeneration in precentral cortex (1977), superior temporal and prefrontal cortex (1975), and in the limbic system (1976). The pattern of deterioration starts with loss of dendritic spines, followed by loss of horizontal components, and vertical components of the dendritic tree.

Within many neurons there is an age-related increase in incidence and quantity of lipofuscin, a dusky colored, fatty pigment. The relationship between pigment accumulation and pathology has not been clearly established (Bergi, 1982), but it has been suggested that lipofuscin may damage the neuron by altering its geometry and decreasing its metabolic efficiency (Brizzee, Ordy, Knox, & Jirge,

1980; Chang & Pao, 1982). Other neuronal changes that have been noted are increases in the number of neurofibrillary tangles and localized increases in the number of senile neuritic plaques (Orlavskaya, 1982). Neurofibrillary tangles decrease the efficiency of the neuron while plaques appear to be composed of deteriorated neurons. Neurofibrillary tangles and neuritic plaques are highly correlated with severity of dementia, and are most frequently studied in relation to pathologies of the aging process (Orlavskaya, 1982).

The elderly years have been characterized as being a time of neurotransmission imbalance (Walker, Seagall, & Timiras, 1980). Normal transmitter function is necessary for, and completely dependent upon the normal structure and function of the neuron. As neural structure is lost, neurotransmitter function is disrupted in normal aging. Changes in neurotransmitter levels alter firing patterns and disrupt the transmission of incoming sensory information, as well as the inhibition of interfering information.

Neurotransmitter imbalance has been linked to several pathologies that occur more frequently in old age (Eisdorfer, 1982). The high incidence of depression in senescence has been linked to low levels of norepinephrine, and increased levels of monoamine oxidase. Parkinson's disease appears to be associated with low levels of dopamine in subcortical structures, while the loss of cholinergic neurons has been linked to Alzheimer's disease (Bartus, Dean, Bear, & Lippa, 1982).

Kinsbourne (1980) proposed that the reduced effectiveness of selective attention processes is the primary cause of memory problems

in the normal elderly. He argued that focal damage cannot explain memory loss since memory "traces" cannot be localized to one particular area of the brain. If the cueing of memory is a process of providing some portion of the material "to be remembered", the same pattern of neural activity that occurred during the "to-be-remembered" event must be reinstated. In order for that neural pattern to be primed, attentional mechanisms must inhibit the salience of current events, stimulating alternative neural patterns. He argued that if attentional resources are limited as the result of diffuse neuronal damage, inadequate cueing of memory will result in memory deficits.

The role of the frontal lobes in Kinsbourne's model is to narrow the aperture of attentional focus, and the role of the parietal lobes is to broaden the focus of attention. He proposed that these opponent processes keep each other in check, and more damage in one area would tend to allow for the dominance of the other. In light of the findings on frontal area loss with age, it could be concluded that the older individual will have more difficulty with the narrow focus of attention, and would tend to perceive the world in a more holistic pattern.

In summary, normal aging is characterized by wide-spread changes in the central nervous system, the most dramatic of which are neuroanatomical changes in frontal areas. Given the importance of frontal areas in neurophysiological models of selective attention, these frontal losses might be related to aging subjects' difficulty with selecting and inhibiting incoming sensory information.

COGNITIVE MODELS OF SELECTIVE ATTENTION AND AGING

It has been proposed that aged subjects display deficits in tasks requiring more cognitive capacity: controlled processing (Hoyer & Plude, 1980) and/or divided attention tasks (Craik, 1977). More capacity is needed in controlled processing tasks that vary the response and/or stimulus display so that there is a trial by trial dissociation of one stimulus to one response. Automatic processes are often sufficient to perform tasks that are highly repetitive and that have a reduced amount of variable response requirements.

Age differences are found on tasks requiring attention to be divided a) between two input sources, b) between stimulus input and rehearsal, and c) between rehearsing and retrieving or responding (Craik, 1977). It has been suggested that the aging deficit seen in divided attention tasks is a disruption of short term memory by shifts of attention between perception and recall (Welford, 1980).

ERP STUDIES OF AGING AND SELECTIVE ATTENTION

The differential enhancement of event-related potentials due to task relevance has been demonstrated in the visual (Eason, Harter, & White, 1969; Harter & Aine, 1984; Hillyard & Munte, 1984), auditory (Hillyard & Picton, 1979; Naatanen, 1982), and somatosensory (Desmedt & Robertson, 1977) modalities. By analyzing the topography and time course of the differential enhancement of ERPs it is possible to infer the level of the visual system at which different types of information are selected, e.g. flash vs. pattern, (Harter & Guido, 1980), or colors vs. words (Aine & Harter, 1984).

ERP studies of information processing and aging have been concerned with speed and capacity (Ford, Duncan-Johnson, Pfefferbaum, & Koppell, 1982a; Ford, Roth, Mohs, Hopkins, & Kopell, 1979b; Marsh, 1975; Pfefferbaum, Ford, Roth, & Koppell, 1980). A primary concern has been the development of norms in order to compare age matched individuals for diagnostic purposes (Goodin, Squires, Star, 1978; Pfefferbaum, Ford, Wenegrat, Roth, & Koppell, 1984a; Picton, Stuss, Champagne, & Nelson, 1984).

The following review of ERP studies of aging is organized around four major components of the visual ERP wave forms (P1, N1, N2, & P3) which are positive or negative deflections from baseline within specific latency windows after the stimulus. Some investigators choose to label the component by the latency window within which the peak was measured, e.g. P315-512 instead of P3. In the proposed study the components will be labeled by the grand average of the peaks within each window, e.g. P445 instead of P3. Since some of these components have been shown to be differentially influenced by task manipulations (e.g. Ritter, Simson, Vaughan, & Macht, 1982), they are considered independent markers of the processing of a sensory event.

The P1 is a positive peak that occurs about 110 msec after stimulus onset (Simson, Vaughan, & Ritter, 1977). This component has not been reported in visual ERP studies of aging, but it has been shown to increase in amplitude to the relevant stimulus in visual spatial attention tasks (Harter et al., 1982; Hillyard & Munte, 1984).

The N1 is a negative peak that occurs at about 160 msec after

stimulus onset and, like P1, is sensitive to manipulations of the physical parameters and the task relevance (spatial manipulation) of the evoking stimulus. The amplitude of N1 is maximal over the primary and secondary visual areas suggesting that it may be generated in these areas (Simson et al, 1977). The visual N1 component has not shown age-related changes in amplitude or latency in ERP studies of aging. Attention effects, however, were reported on the N1 component for both young and elderly groups in an auditory attention task (Ford, Hink, Hopkins, Roth, Pfefferbaum, & Kopell, 1979a).

The N2 is a negative deflection following P2, between 250 and 330 msec. This component increases in latency with age, but is not lower in amplitude in aged subjects (Beck, Swanson, & Dustman, 1980; Brent, Smith, & Michaelewski, 1977; Goodin, Squires, Henderson, & Starr, 1978; Pfefferbaum et al., 1984a; Schroeder & Harter, 1985). N2 amplitude differences have been the primary evidence for task relevance effects (spatial and feature manipulations) (Harter & Aine, 1984; Hillyard & Munte, 1984), and therefore, differences between groups on this measure are likely if in fact elderly selective attention processing is deficient compared to that of the younger population.

The P3 component is a positive deflection occurring between 350 and 600 msec after the stimulus over the parietal area with a broader distribution on the scalp than the earlier components (Simson et al., 1977). In both auditory and visual paradigms, P3 is delayed in older adults. The delay, computed by regression analyses, has been reported as 1.7 msec/year (Pfefferbaum et al., 1984a) or 1.8 msec/year (Goodin

et al., 1978). However, the latency of P3 has been shown not to increase with task difficulty for older subjects (Pfefferbaum et al., 1980; Ford, Pfefferbaum, Tinkleberg, Kopell, 1982b), when the same manipulation is associated with a latency difference in the younger group. In fact in a difficult task situation the regression analysis failed to find a correlation between the latency of P3 and age, but in a simple task situation the correlation of latency with age was significant (Ford et al., 1982b).

Age-related P3 amplitude differences interact with scalp topography. P3 increases in amplitude with age when measured over the frontal areas but decreases in amplitude with age over parietal and occipital areas (Ford et al.,1982b; Mullis, Holcomb, Diner, & Dykman, 1985; Pfefferbaum et al., 1984a; Schroeder & Harter, 1985; Tecce, Cattanach, Yrchik, Meinbresse, & Dessonville, 1982). The distribution of P3 for young subjects is maximal over the posterior areas. Aged subjects show more positivity frontally and less positivity in the posterior areas, resulting in a greater uniformity of P3 across scalp locations with age (Goodin et al., 1978; Pfefferbaum et.al., 1984a; Smith, Brent, Thompson & Michaelewski, 1978; Smith, Michaelewski, Brent, & Thompson, 1980). A controversial issue in the ERP literature is whether there are two P3's - an earlier P3a in frontal areas and a later P3b in posterior areas (Squires, Squires, & Hillyard, 1975). Whether this age-related anterior - posterior difference in the amplitude of P3 supports two different P3s has not been examined experimentally.

SELECTION OF TWO TYPES OF VISUAL INFORMATION

Visual systems are organized to represent WHAT the stimulus is and WHERE the stimulus is located (Ungerleider & Mishkin, 1982). This study was designed to test the hypothesis that age has a significant impact on selective attention processes in these two systems. First the single unit and lesion data supporting this division of the visual system will be reviewed, followed by ERP studies addressing the same question.

Damage to inferotemporal cortex produces deficits in visual object recognition (Milner, 1968). Lesions of posterior parietal lobes result in a variety of visual-spatial problems, including location deficits (Mesulam, 1981). The neural systems subserving this division were thought to be the geniculostriate and tecto-pulvinar systems. Ungerleider and Mishkin (1982) have used data from crossed lesion studies to argue that in primates, the WHAT and WHERE information is carried primarily by the geniculostriate system up to the cortex; then, at higher levels in the system, diverging cortico-cortical connections from striate cortex carry spatial information to the parietal area and feature information to inferotemporal areas.

A number of researchers have investigated attentional control of information processing in one or both of these systems. Nuwer and Pribram (1979) recorded single unit activity in the inferotemporal cortex of monkeys and found areas that were responsive to pattern only if it was task relevant. The receptive fields of cells in inferotemporal cortex are sensitive to stimulus pattern features

(Ungerleider & Mishkin, 1982) and monkeys with lesions in this area lose the ability to select relevant complex stimuli from similar irrelevant stimuli (Kolb & Whishaw, 1980). Thus, it appears that the inferotemporal cortex is a higher order association area involved in directing discrimination of relevant from irrelevant patterns.

The posterior parietal lobes are specialized for directing visual attention to points in space. Recordings from single cells in posterior parietal lobes of monkeys have shown enhancements to visually presented peripheral relevant stimuli (Bushnell, Goldberg, & Robinson, 1981). In order to differentiate the functions of parietal neurons, a series of tasks were used that required a monkey to 1) lift a bar and make an eye movement to a relevant stimulus and 2) lift a bar demonstrating attention to the stimulus without making an eye movement toward it. The neural enhancement recorded from parietal neurons was spatially selective and independent of eye movement.

The phenomenon of contralateral neglect in humans and monkeys with posterior parietal lesions has been considered a deficit in attention to points in space (Friedland & Weinstein, 1977; Heilman, 1979; Mesulam, 1981). Contralateral neglect is observed when, in various stimulus and performance conditions, patients without primary sensory or motor deficits, fail to report, respond to, or orient to stimuli presented to the side contralateral to a parietal lesion. Right parietal damage results in contralateral neglect more often than left parietal damage (Friedland & Weinstein, 1977). It has been proposed that the deficit is more common with right parietal lesions due to the specialization of the right hemisphere for the analysis of

spatial information (Heilman, 1979; Friedland & Weinstein, 1977).

Harter, Aine, and Schroeder (1982) found separate (feature and spatial) task relevance effects on the time course and scalp topography of ERPs to central and peripheral stimuli. Spatial relevance effects (enhancement of ERP to stimuli in the relevant vs. irrelevant location) were, first, greatest to stimuli in the peripheral visual field and in ERPs (N1) measured over the contralateral occipital areas. There was a large bilateral enhancement at central electrodes for spatial relevance effects. This was interpreted as evidence of posterior parietal lobe involvement in these processes. Feature relevance effects (enhancement of ERP to relevant vs irrelevant stimuli in the same location) affected later portions of the ERPs, were greater to central stimuli, and statistically significant over occipital cortex, particularly the left hemisphere. This was interpreted as evidence of involvement of inferior temporal areas specialized for pattern selection.

In a replication and extension of this study, Hillyard and Munte (1984) manipulated the difficulty of spatial discrimination of the stimuli, and showed a decreased predominance of spatial relevance effects on ERPs, compared to feature relevance. Neville (in press) had subjects respond to moving targets in left, central, or right visual fields and found enhancement of ERPs was greatest at the contralateral parietal electrode for peripheral stimuli and bilaterally in the occipital area for the central stimuli. Also, feature relevance effects were greater in the occipital areas for both central and peripheral targets.

In a study of visual selective attention and aging by Schroeder and Harter (1985) the ERPs of both older and younger subjects showed an interaction between task relevance and the location of stimuli. At the mid-occipital electrode the spatial relevance effects (P350-512) to peripheral flashes occurred earlier in time than the effects due to feature relevance. The amplitude of this peak showed an interaction between age and task relevance; the feature relevance effect on P350-512 was greater for the young than the aged group. The spatial relevance effect, however, was similar for both groups.

The issue of aging deficits in spatial vs. feature relevance has been addressed recently in the cognitive literature on selective attention and aging (Madden, 1983; Plude & Hoyer, 1986, Wright & Elias, 1979). In these studies the efficiency of selective attention processes is inferred from increased reaction times occurring when the number of non-target stimuli are increased. Several studies were designed to test whether the aging individual had deficits in "selective search" for relevant information, or deficits in "selective filtering".

Rabbitt (1965, 1980) demonstrated that elderly subjects did not perform as well as the younger subjects when the number of irrelevant stimuli in a display was increased. When the number of relevant stimuli was increased the performance of both groups slowed at an equal rate. The conclusion was that older subjects have more difficulty ignoring irrelevant information than younger subjects (Farkas & Hoyer, 1980; Layton, 1975; Rabbitt, 1965; Rabbitt, 1980). This has been called the "display size effect" (Rabbitt, 1965).

Wright and Elias (1979) took issue with this interpretation arguing that in Rabbitt's task the irrelevant information was not "truly" irrelevant since it had to be processed as the subject searched a card for the relevant stimulus. They tested older and younger subjects with a task that involved selectively attending to a relevant stimulus in one location as the number of irrelevant flanking stimuli varied. Both groups were slowed at the same rate by an increase in the number of flanking irrelevant stimuli. They argued that this was a selective filtering task and labeled the Rabbitt task as a selective search task.

Using three age groups, Farkas and Hoyer (1980) contrasted fixed vs. variable target position and the difficulty of the target vs. non-target discrimination. When the target position was constant and the discrimination was easy, all groups were unaffected by the addition of irrelevant information, but when either the target position varied or the discrimination was difficult, the older group had significantly slower responses. When both the target position varied and the discrimination was difficult, all groups slowed at the same rate. The authors concluded that the aged subjects were not able to use early pre-attentive grouping factors to screen out irrelevant stimuli, causing the efficiency of later selection processes (e.g., focal selection and feature detection) to be reduced.

Madden (1983) demonstrated that spatial cueing could reduce age-related non-target interference effects. By varying the target position, Plude and Hoyer (1986) found that impaired performance of older subjects was not due to decreased parafoveal acuity. They

suggested that the aged subject's difficulty with the search condition was due to a specific deficit in the ability to accurately localize targets in space.

The Harter et al., (1982) study showed that ERP effects of feature and spatial selection were topographically specific: feature selection effects were most prominent at occipital sites whereas spatial effects were maximal at the central electrodes. This dissociation suggests that if anterior electrodes had been included in the Schroeder and Harter (1985) study, spatial selection differences between age groups might have been seen at those sites while remaining absent in occipital recordings.

STATEMENT OF PURPOSE

The purpose of this study was to investigate the changes in ERPs during visual selective attention in young and elderly individuals. Because different brain regions have been implicated in spatial vs. feature selection, as reviewed above, ERPs were recorded from homologous left and right hemisphere sites overlying frontal, central, and occipital cortex. The stimulus presentation and task requirements were designed to 1) replicate the Harter et.al. (1982) effects of the manipulation of task relevance in the young group's data, and 2) to test the following predictions about the influence of age on RT and ERP task relevance effects.

Group differences in ERPs

1) If anterior, compared to posterior, positivity increases with age (Pfefferbaum et al., 1984) , the frontal and central electrodes should show increased late positivities for the aged group compared to the young. This increase in frontal positivity should result in a more uniform distribution of P3 across the scalp for the older subjects.

2) The age variable was expected to increase the latency of the reaction time and the P3 measure (Beck et al., 1980; Pfefferbaum et al., 1984; Schroeder and Harter, 1985). If the latency of the occipital N1 is the same for both groups, then age related slowing in P3 could not be explained simply by age differences in the conduction velocity of central visual afferent pathways.

The influence of age on relevance effects

3) If aged subjects have difficulty with spatial location tasks (Plude & Hoyer, 1986), then young subjects should have greater spatial relevance effects in the ERP recordings (P1, N1, N2).

4) If spatial selection effects are larger at central electrodes, compared to occipital (Harter et al., 1982), and if the analysis of spatial information progresses from primary visual cortex to anterior areas (Ungerleider & Mishkin, 1982), group differences in spatial relevance effects should be seen in occipital, central, and frontal areas (P1, N1, and N2).

5) If the normal elderly have difficulty selecting relevant from irrelevant items (Farkas & Hoyer, 1980), young subjects should show greater feature relevance effects in the ERP recordings (N2, P3).

6) If feature relevance effects are due to activity in the occipital-infero-temporal visual pathways (Harter et. al., 1982; Ungerleider & Mishkin, 1980) group differences in feature relevance effects should be greater in occipital and central, compared to frontal recordings.

ERP effects unrelated to age

7) For both groups, spatial selection, as evidenced by increased amplitude of components, was expected to occur earlier (P1, N1, & N2) than feature selection (N1, N2, & P3) (Harter et al., 1982; Hillyard & Munte, 1984; Schroeder & Harter, 1985). Amplitude enhancements were expected to be greater in the right hemisphere N2 recordings for spatial relevance and in the left hemisphere N2 recordings for feature relevance (Harter et al., 1982).

8) It was expected that both groups would have larger N2 amplitude feature selection effects to flashes in the right visual field than in the left. Although most visual ERP studies of selective attention do not analyze for visual field effects, greater amplitude feature selection effects have been reported to stimuli in the right, compared to the left visual field (Harter et al., 1982).

CHAPTER II

METHOD

SUBJECTS

Two groups of eight right-handed subjects participated in the study. Each group was composed of four males and four females. The young group (20-29 years old) consisted of undergraduate and graduate student volunteers from the University of North Carolina at Greensboro. The older group consisted of volunteers from the community, 65-76 years old. The two groups were roughly equivalent in terms of educational level. All subjects in the study were high school graduates, and of those, six in each group were college graduates. Three subjects in the older group were Ph.D. Professor Emeriti at the University, and three corresponding in the young group were enrolled in the Ph.D program in Psychology.

Subjects were screened by interview to insure that they were in excellent health, that there was no history of significant cardiovascular problems, nor any uncorrected peripheral vision problems. If the subject wore glasses s/he was asked to wear them if that helped in detecting the stimuli. A consent form (see Appendix A) was obtained from each subject after the subject had been fully informed about the study. A debriefing statement (see Appendix B) was given to each subject after the first session in order to facilitate understanding of the purposes of the study. Subjects completed all

the experimental conditions in either two two hour sessions, or three one and 1/2 hour sessions.

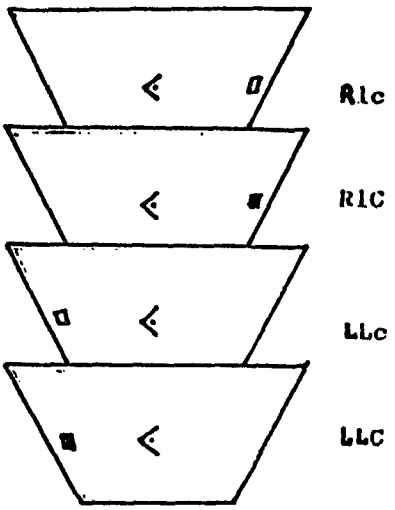
STIMULI

Size and location: The stimuli were ASCII characters generated by an IBM - PC (Model # 5150) and presented on a Princeton color monitor (Model # PGS-HX-12). Red and green flashes of light, (5 x 5 mm) subtending 0.52 degrees of visual angle, were presented 10 degrees left or right of center on a black background (see Fig. 1).
The subjects were seated 55 cm. from the display. Central fixation cues were either "< " or " >" depending on whether the target flash was in the left or right visual field. When the white dot in the center of the fixation cue turned yellow for 37.5 msec., (see sequence explained below) subjects were asked to give a finger lift response to this change to yellow, which forced the subjects to maintain a central fixation. Except for the central cues (< or >), the stimulus display was the same for both relevance conditions.

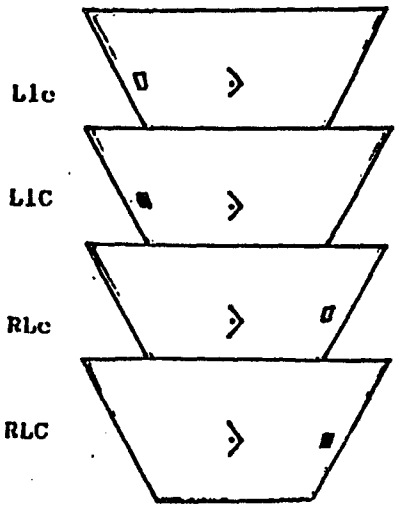
Sequence of stimuli: The fixation point remained on for the entire relevance condition except when error messages were flashed. After the subject pressed the response key down, a series of randomized red and green flashes began flashing in both left and right visual fields. In Figure 1 the four possible flash or relevance conditions are displayed in each response condition. If the flash was the target, it was in the relevant location and was the relevant color and it was labeled LC. The non-target or "wrong color" in the same (relevant) visual field was labeled Lc. The target color flash in the irrelevant visual

Figure 1. **Stimulus Display and Response Conditions.** On the top left the "left relevant" response condition is displayed, on the top right, "right relevant". The four screens show the four flash stimuli to which ERPs are averaged (LC, Lc, lC, lc, preceded by R or L to indicate visual field of flash) (see p.3 for explanation of flash labels). The rectangles below each "subject" show the 6 channels of ERP data that are collected for each of the four types of stimuli in each response condition for each subject. The chart in the lower part of the figure identifies which ERPs are compared for each effect in each visual field.

RESPOND TO LEFT RED FLASH

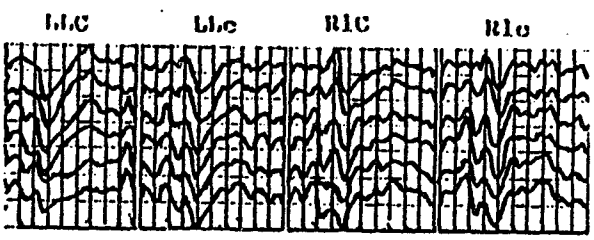


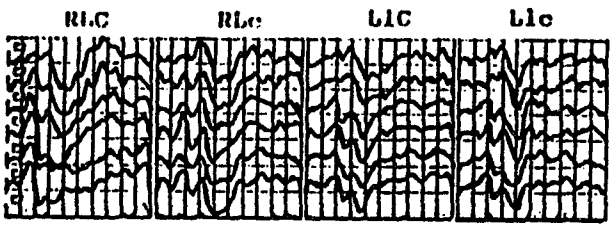
RESPOND TO RIGHT RED FLASH



■ RED

□ GREEN





ATTENTION EFFECT	VISUAL FIELD	
	LEFT	RIGHT
SPATIAL SELECTION	LLc - LLc	RLc - RLc
FEATURE SELECTION	LLC - LLc	RLC - RLc

field was labeled 1C (not used in relevance effects) and the non-target color in the irrelevant visual field was labeled 1c. Each flash was on for 62.5 msec. Only one flash was presented at a time. The inter-stimulus interval was no less than 1.2 sec. The color and location of the flashes was randomized. Each of the four color flashes and the central yellow flash change were presented 20% of the time.

TASK INSTRUCTIONS AND MANIPULATION OF RELEVANCE

Two response conditions were defined by having the subject respond to a specific color flash in the left visual field (LLC), or a specific color flash in the right visual field (RLC). An additional response condition - respond to a specific color flash in both left and right visual fields - was included, but not analyzed for this study. One-half of the subjects in each group responded to red in all conditions, the other half responded to green. The order of these conditions was completely counterbalanced across subjects, within each group and across four replications (the results of the first replication have been analyzed for this study). The subject was asked to fixate on the central cues and respond to the red or green flash by lifting the index finger of the right hand as quickly as possible off a microswitch key.

Initial training instructions:. After the subject was made as comfortable as possible in the experimental room, the experimenter made sure that the subject could detect and distinguish all of the stimuli presented. As soon as it was clear that the subject was accurately labeling the flashes (red and green)(approximately 10

flashes), the experimenter held the subject's finger on the microswitch key and demonstrated how to lift the index finger to the target (LC) (approximately 10 flashes). The subject was instructed to emphasize accuracy first and then speed during the training session. The subject practiced in this manner until 75% of the targets were correctly responded to within 650 msec. after the onset of the flash.

The critical response time (CRT):. During the experiment the critical response time was fixed at 650 msec. If the finger lift response to a relevant flash occurred after the CRT, or did not occur at all, the subject heard a "boop" (500 Hz tone) and the following message appeared on the monitor, "Whoops! You missed one." Either of these events was recorded as a Miss. If the finger lift response occurred to an irrelevant stimulus, the subject heard a "boop" and the message,"Uh - Oh ! That was a non-target," appeared on the monitor and this was recorded as a False Alarm. If the subject's response to the relevant stimulus occurred before the CRT, the subject heard a "beep" (3000 Hz tone), and this was recorded as a Hit. If the subject did not respond to an irrelevant stimulus, no auditory feedback was given and this was recorded as a Correct Rejection. At the end of each response condition a summary of the behavioral data collected was displayed on the monitor for the subject.

Other Instructions:. Subjects were instructed to hold their eyes perfectly still during the presentation of the stimuli. They were be able to stop the presentation of the stimuli and collection of ERP's at any time by releasing the response key. Subjects were encouraged

to do this when they needed to blink their eyes, move around, or talk to the experimenter. Each response condition took approximately 7 minutes to complete. A response condition was terminated when at least 25 ERP's had been collected for each of the four stimulus conditions. After each response condition the experimenter went into the experimental booth to discuss the behavioral data generated on the last run and to attempt to make the subject as comfortable as possible. After approximately 3 to 4 relevance conditions, the subject was brought out of the experimental booth for a break.

COLLECTION OF ERPs

The procedure employed to collect ERPs was safe, standard, and non-harmful. All subjects wore an Electro-cap, a cap that fits snugly on the subject's head. There were electrodes embedded in the hat, corresponding to the International 10-20 System. In order to reduce scalp resistance to less that 10 K ohms, the scalp under these electrodes was rubbed and Electrogel was applied. These electrodes were referenced to linked earlobe electrodes, and one electrode was placed 2 cm to the right and 2 cm below the right corner of the right eye to measure eye movement and eye blink artifacts.

The visual ERP's and the eye movement potentials (EOG's) were amplified by a Grass 7DAC driver amplifier, a Grass 7P5A preamplifier, and six Grass 7P511J amplifiers. One half amplitude high and low frequency filters were set on 35 and .3Hz, respectively. The EEG's and EOG's were sampled every 20 msec. from the onset of the flash for 1 sec. The ERP's were averaged and then stored on a floppy disk by a Plessy Peripheral Systems Computer. ERP's were collected at six scalp

locations: O1, O2 (occipital left and right), C3', C4' (central left and right), F3, and F4 (frontal left and right), according to the International 10-20 System (approximate placements can be seen in Figure 1). The central electrodes, C3' and C4', were located 2 cm posterior to International 10-20 placements C3 and C4. In both of the response conditions, ERP's were collected and averaged following each of the four flashes: left red, left green, right red, and right green. The four ERP waveforms at each scalp location were the average of activity following at least 25 flashes for each subject.

Artifact Rejection: Rejection criteria were established in order to exclude from averaging ERPs occurring in conjunction with eye movements, eye blinks, behavioral errors (false alarms and misses), and electrical artifacts. The electro-oculogram (EOG) and ERP criteria were set individually for each subject during the initial practice trials. The critical window for the ERP was activity less than approximately 70 microvolts and, for the EOG, less than 60 microvolts.

STATISTICAL ANALYSIS OF DATA

Behavioral data: The behavioral data were collected by an IBM-PC computer, printed out at the end of each response condition, and stored on a floppy disk. Two-way analyses of variance were performed on the speed (average reaction time) and accuracy (percent correct hits and percent false alarms) data, with age as the independent between group variable and visual field as the independent within group variable. The results of these ANOVAS are presented in Appendix C, Table 1.

ERP data For the purpose of visual inspection, the data from subjects in each group were averaged together and plotted. For the spatial relevance effect, the ERP to the non-target flash in the relevant location (Lc) was compared to the ERP for the same non-target flash when it was in the irrelevant location (lc)(Figs. 1 & 2). For the feature relevance effect, the ERP to the target flash in the relevant location (LC) was compared to the ERP to the non-target flash in the relevant location (Lc) (Figs. 1 & 3). Difference potentials for each type of relevance effect were obtained by subtracting the irrelevant from the relevant waveform (Fig. 4).

The group means were inspected for enhancements due to relevance at expected latencies in accordance with data from studies reviewed above. The following time windows were chosen for for objective computer measures of the latency and amplitude of peaks within each window for each subject: the peak positivity between 100 and 200 msec (P144); the peak negativity between 160 and 220 msec (N188); the peak negativity between 240 and 400 msec (N325); and the peak positivity between 350 and 600 msec (P445). After the latencies were obtained each component was named for the actual average latency of that peak across all 16 subjects.

In order to test the influence of age, scalp location, relevance, hemisphere, and visual field on the amplitude of these components, mixed ANOVAS were performed on amplitudes of the peak of the ERPs in these four time windows (see Appendix C, Table 2). The analysis of latency differences between groups on ERP measures was limited since the major focus of the study was on amplitude differences.

Figure 2. **Spatial Relevance.** Grand mean ERP waveforms for the young (8 subjects) and aged (8 subjects) groups at left and right occipital (O1,O2), central (C3',C4'), and frontal (F3,F4) sites, averaged over both visual fields to the non-target stimulus in the relevant location (Lc) (thick line) and to the same flash when it is in the irrelevant location (lc) (thin line). Asterisks (*) indicate N325 component showing increased negativity due to relevance. Time scale: 100 msec per division. Stimulus onset at 0 msec.

SPATIAL RELEVANCE EFFECTS

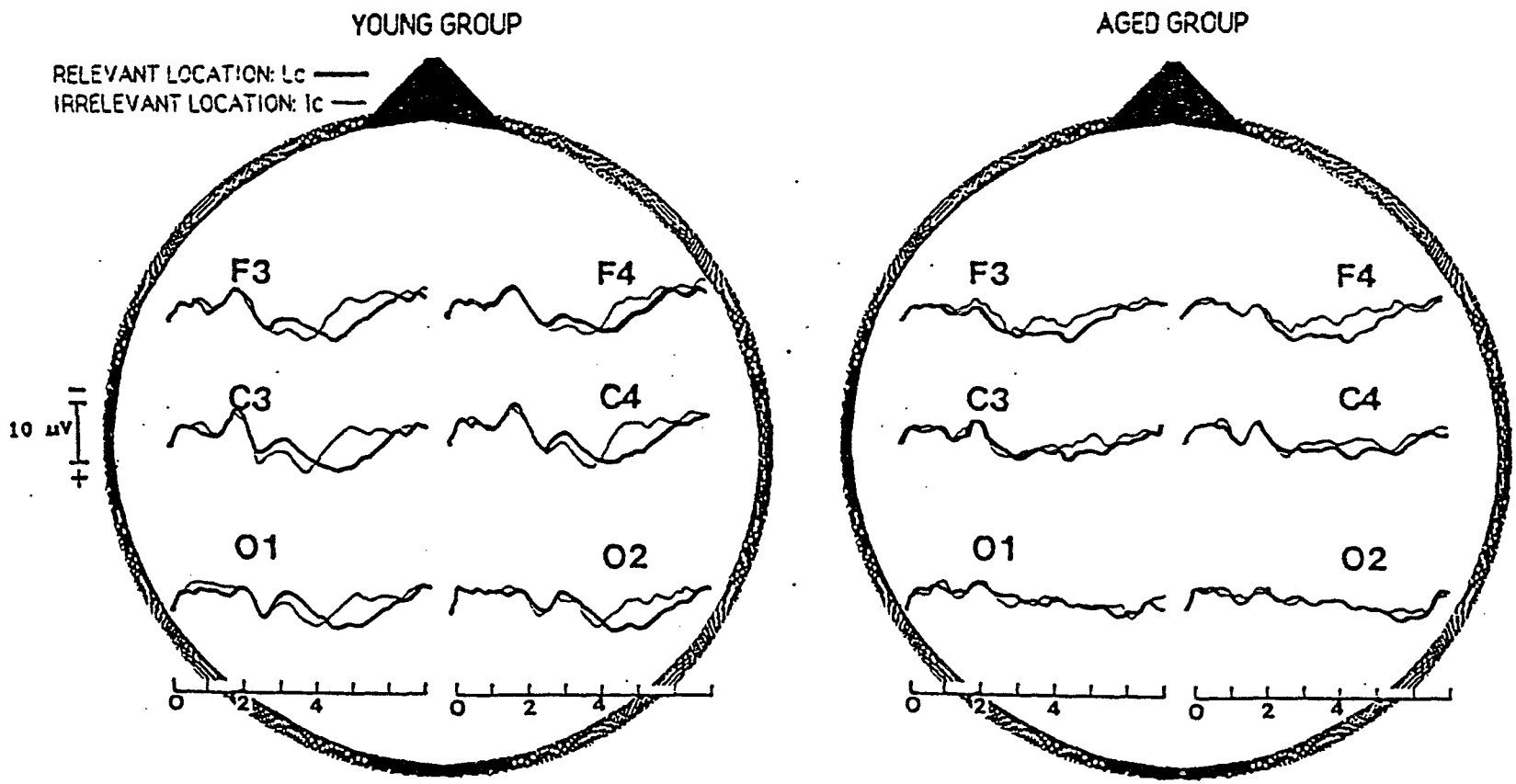


Figure 3. **Feature Relevance.** Grand Mean ERPs as in Fig. 2 to the target in the relevant location (LC) (thick line) and the non-target in the relevant location (Lc) (thin line). The asterisks (*) indicate the P445 component showing increased positivity due to feature relevance.

FEATURE RELEVANCE EFFECTS

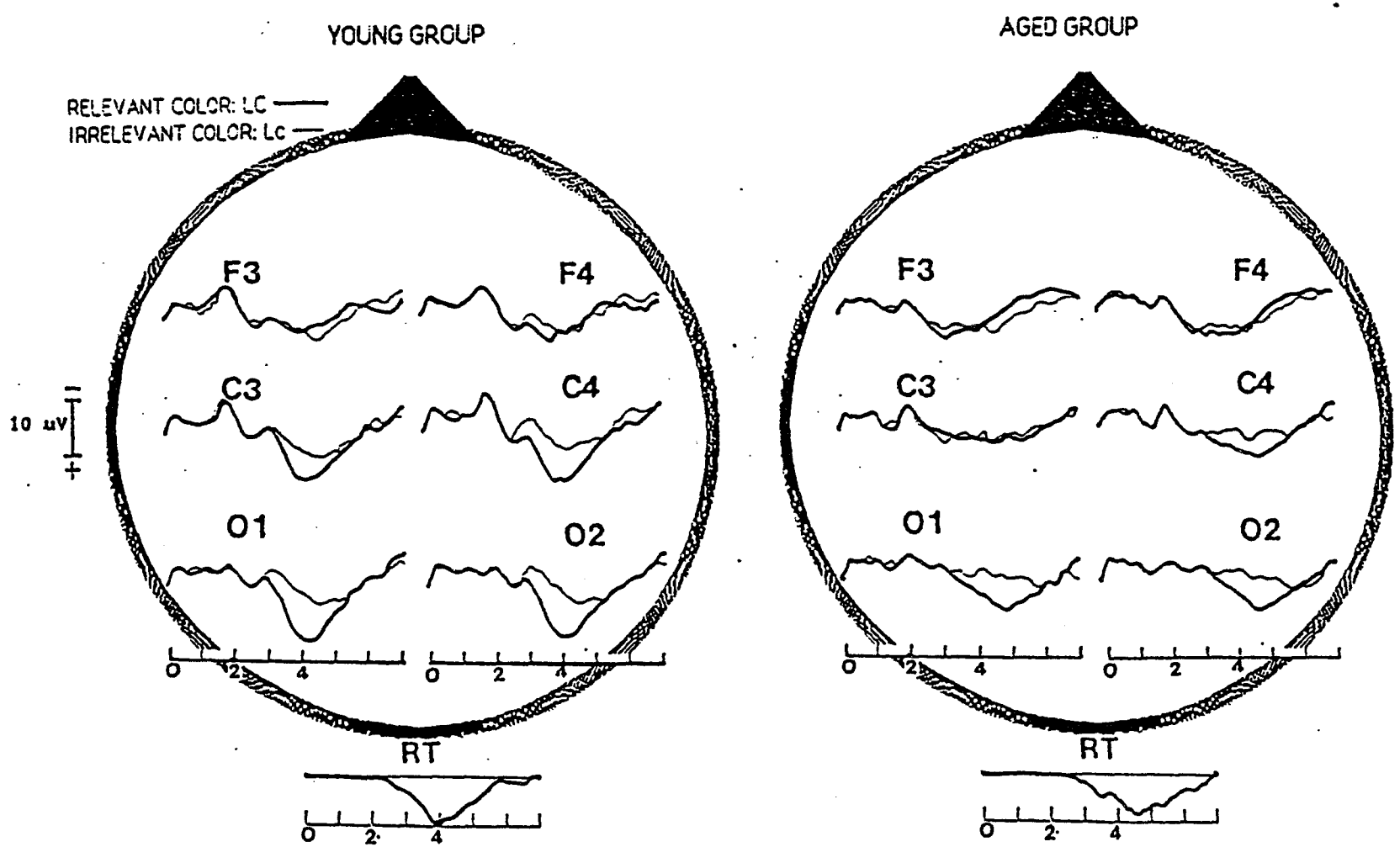
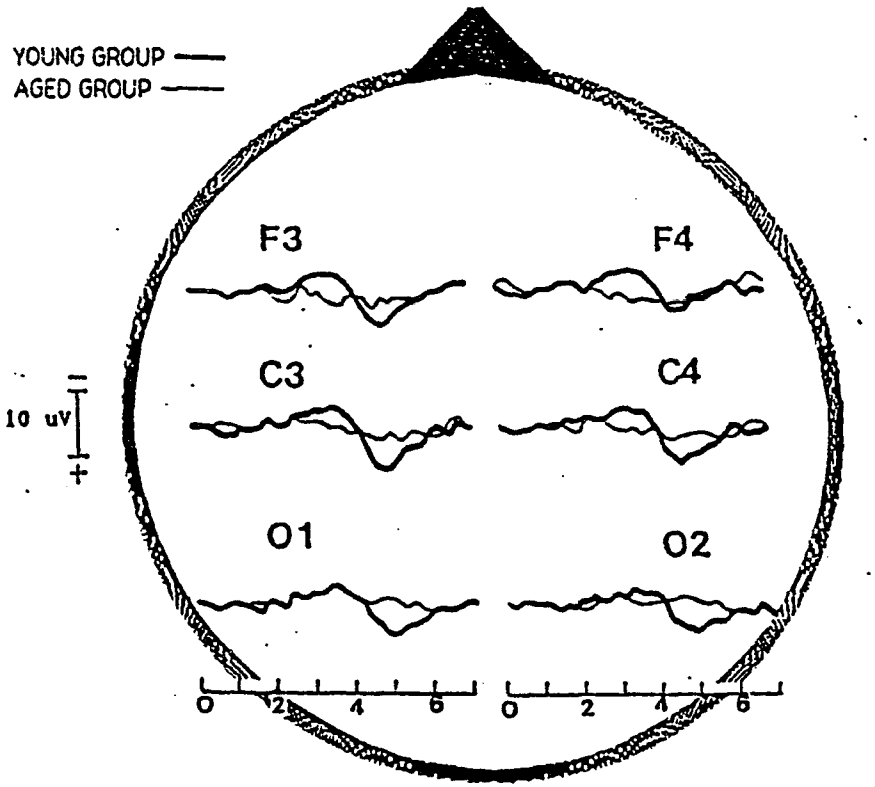


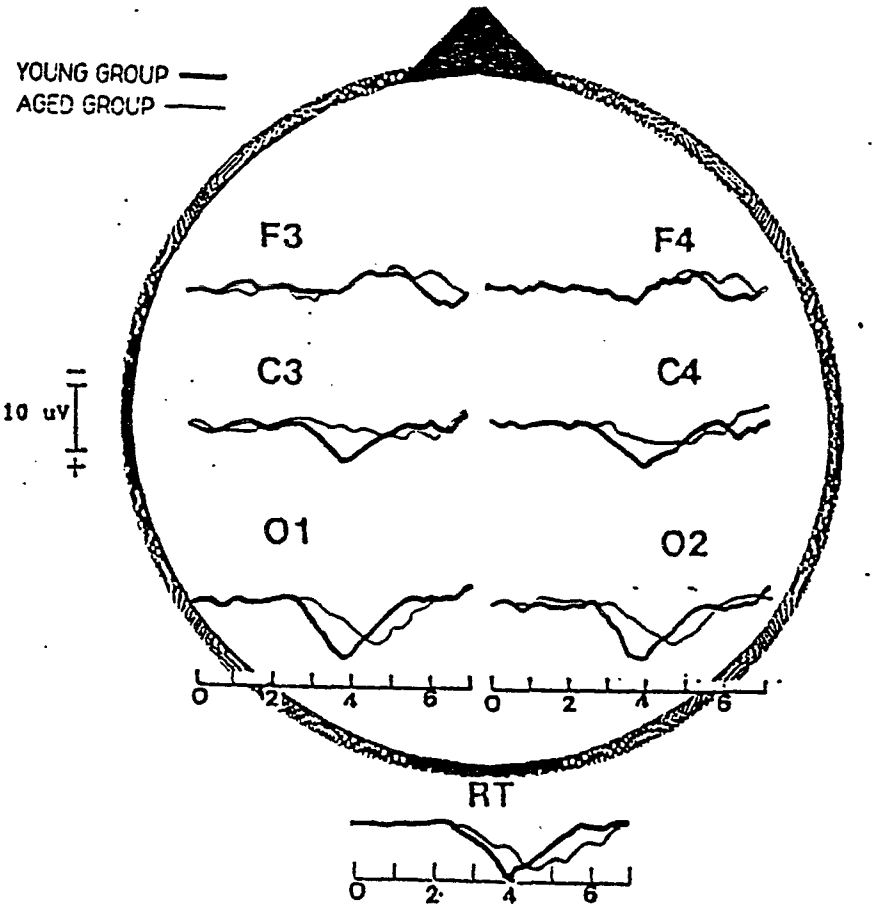
Figure 4. **Grand Mean Difference Potentials** The ERPs in Figs. 1 & 2 obtained by subtracting Lc-lc for spatial relevance effects (left), and LC-Lc for feature relevance effects (right). Young (thick line) and aged (thin line) potentials are superimposed. Asterisks (*) indicate increased negativity in N325 in the young subjects data. Brackets (-)indicate group latency differences in the peak of P445.

DIFFERENCE POTENTIALS

SPATIAL Lc - lc



FEATURE LC - Lc



manipulations. The influence of age on the latency of occipital N188 and P445 was tested by performing ANOVAS on each of these data sets (see Appendix C, Table 3).

The between group independent variable for each analysis was age (A) (young vs. aged). As a control measure, the groups were equally balanced for sex. (Initially sex was a second between group variable, but it was dropped from the analyses since no specific predictions had been made for sex differences and visual inspection of the grand means indicated that there were no consistent sex differences in the ERP waveform.) The within group independent variables for the amplitude analyses were scalp (S) (occipital, central, and frontal), relevance or flash condition (R) (LC, Lc, and lc), visual field (F)(left vs. right), and hemisphere (H) (left vs. right). Tukey post hoc comparisons (Keppel, 1973) were performed on the means of significant ($p.<.05$) main effects and interactions (see Appendix C, Tables 4 - 12).

CHAPTER III

RESULTS

The major purpose of this study was to investigate the influence of age on the latency and amplitude of scalp recorded visual ERP indicants of selective attention. Visual field and hemisphere effects were also included in the design. The main effects of age, relevance, and the interaction of these two variables can be seen in the grand mean ERP waveforms (Figs. 2 & 3) and in the grand mean difference potentials (Fig. 4).

Group differences in the spatial relevance effects were seen in the N325 measure. The young subjects showed a predicted increase in the amplitude of N325 due to spatial relevance (ERPs to the Lc flash compared to the lc flash) at all six scalp locations, which was not seen in the aged subjects' N325 (Figs. 2 & 4). The group difference in feature relevance occurred in the P445 measure (Figs. 3 & 4). The occipital P445 peaked earlier in the young (438 msec) than the aged (483 msec). The modal reaction time was 380 msec for the young subjects, and 460 msec for the aged subjects. The late positivity, P445, was largest at the occipital and central electrodes for the young group but equal in amplitude across the scalp for the aged group.

The ERP effects depicted in Figures 2 and 3 can be seen more clearly in the difference potentials presented in Figure 4. The ERPs for spatial relevance show age differences in N325 amplitude at all scalp recordings. For feature relevance the slower P445 for the aged group is particularly evident in the occipital recording.

AGE DIFFERENCES IN ERPS

Age differences in amplitude:. The mean amplitude of P144 in the aged group was more positive than in the young group ($F(1,14)=7.05$, $p<.0188$). The upper graph in Figure 5 illustrates this main effect of age. Later, however, at P445 there was an interaction of scalp x age $F(2,28)=4.67$, $p<.0178$). The young P445 is larger than the aged at occipital and central (critical range (C.R.) = 1.18, $p<.01$), but not frontal locations (see Appendix D, Table 4) (Fig. 5, lower graph).

The predicted posterior focus of the P445 amplitude for the young group, and a more uniform topography for the aged group can also be seen in the lower graph of Figure 5. The amplitudes of the occipital and central P445s were greater than the frontal P445 in the young subjects' data (see Appendix D, Table 4, comparing scalp at each age: C.R.=1.36, $p<.01$). The aged subjects' P445, however, did not vary significantly in amplitude across the scalp.

Age differences in contralateral projection effects (FxHxA):. There was a predicted interaction of field x hemisphere x age in the P445 component across all scalp locations and relevance conditions ($F(1,14)=6.24$, $p<.025$)(Fig. 6). For the young group, the amplitude of P445 to the flash in the field contralateral to the hemisphere from which recordings were obtained was larger than P445 to the flash in

the ipsilateral field (see Appendix D, Table 5, comparing the means of field of flash at each level of hemisphere and age: Left Hem., C.R.=.496, $p<.01$; Right Hem., C.R.=.357,$p<.05$). The means of the older group did not show a significant difference in this contralateral focus.

Increased latency of components with age: The occipital N188 did not show a latency increase with age (young M = 187 msec, aged M = 193 msec). Later, as predicted however, the occipital P445, was slower for the aged group $F(1,14)=15.53$, $p<.0015$ (Fig. 7).

AGE DIFFERENCES IN ERPS AND RT DUE TO RELEVANCE: (RxA)

Spatial Relevance (Lc>lc): The group difference in spatial relevance effects occurred in the N325 measure in all three scalp locations (SxRxA, $F(4,56) = 2.74$, $p<.03$)(Fig.8). The means of the N325 to the Lc flash were greater than the means to the lc flash at all three scalp locations for the young group (see Appendix D, Table 6: occipital and frontal, C.R. = 1.18, $p<.05$; central, C.R. = 1.58, $p<.01$). For the aged group there was no significant difference between the N325 means of the relevance conditions at occipital and central locations, and in the frontal electrodes, the lc flash is greater than the Lc flash (C.R. = 1.58, $p<.01$). In the grand means, (Figs. 2 & 4) the late P445 component showed greater spatial relevance effects for the younger group: the difference between the Lc and lc flash was greater in young subject data, compared to the the aged subjects data. The groups did not differ statistically on this measure. Figure 9 shows the P445 amplitude difference for each relevance effect, for each group at each scalp location.

Feature Relevance (LC>Lc): It was predicted that the N325 measure would show an interaction of scalp, relevance, and age reflecting a significant increase in the amplitude of the N325 to the LC as compared to the Lc flash for the young group. The early onset of the P445 in the young subjects' data however, resulted in the opposite effect - the young N325 to the LC flash was more positive than the young N325 to the Lc flash. In Figure 3, in the young occipital recordings, at about 300 msec as the Lc flash is showing the predicted negativity, the ERP to the LC flash is more positive, due to the early onset of P445 for the young group (C.R. = 1.18, $p<.05$) (SxRxA, see Appendix D, Table 6).

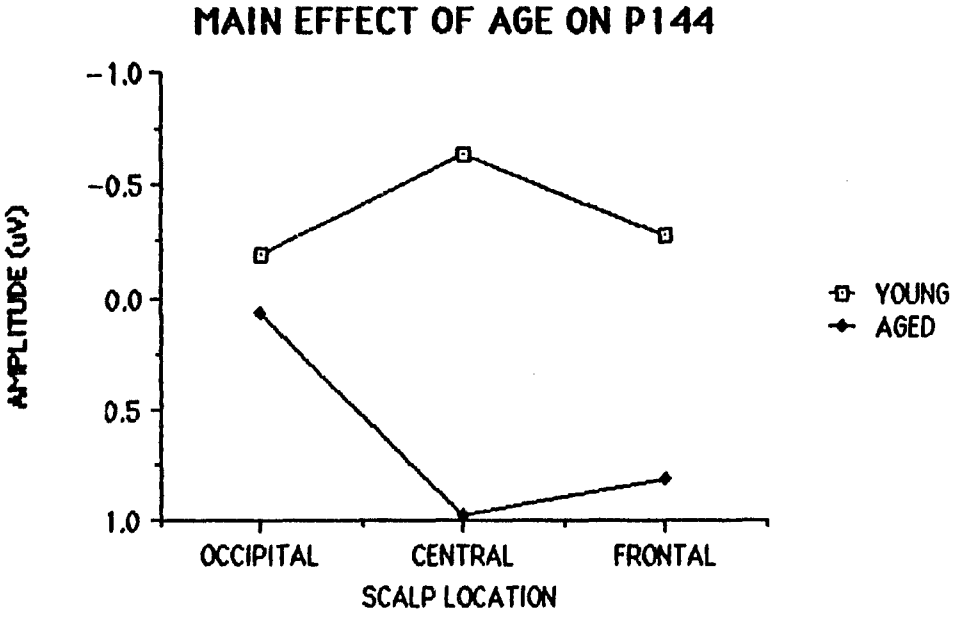
The difference in the mean amplitude of P445 in Figure 9 for each group demonstrates the trend in the predicted direction (greater difference potentials for young compared to aged) for both relevance effects at occipital and central areas. The peak of the P445 was significantly longer for the aged group as discussed above.

The average RT to the LC flash was longer for the aged group ($F(1,14)=6.86, p.<.025$) (Fig. 10). The mean percent hits and false alarms were greater for the younger group, as expected (Fig. 10) but these differences were not statistically significant.

ERP EFFECTS UNRELATED TO AGE

Increase in Amplitude: Spatial Relevance (Lc>lc): The effects of spatial relevance on the amplitude of P144, N188, N325, and P445 at occipital, central and frontal electrodes are graphed in Figure 11. At the first measure, P144, there was a main effect of spatial relevance ($F(2,28)=5.52$, $p<.0095$). The ERP to the Lc flash

Figure 5, **Effects of Age on amplitude of P144 and P445.** The average peak amplitude of P144 and P445 at occipital, central, and frontal sites, for each group, collapsed across relevance conditions (3), visual fields (2), and hemispheres (2). Negative is up.


MAIN EFFECT OF AGE ON P144
AMPLITUDE (uV)
-1.0
-0.5
0.0
0.5
1.0
OCCIPITAL
CENTRAL
FRONTAL
SCALP LOCATION
YOUNG
AGED

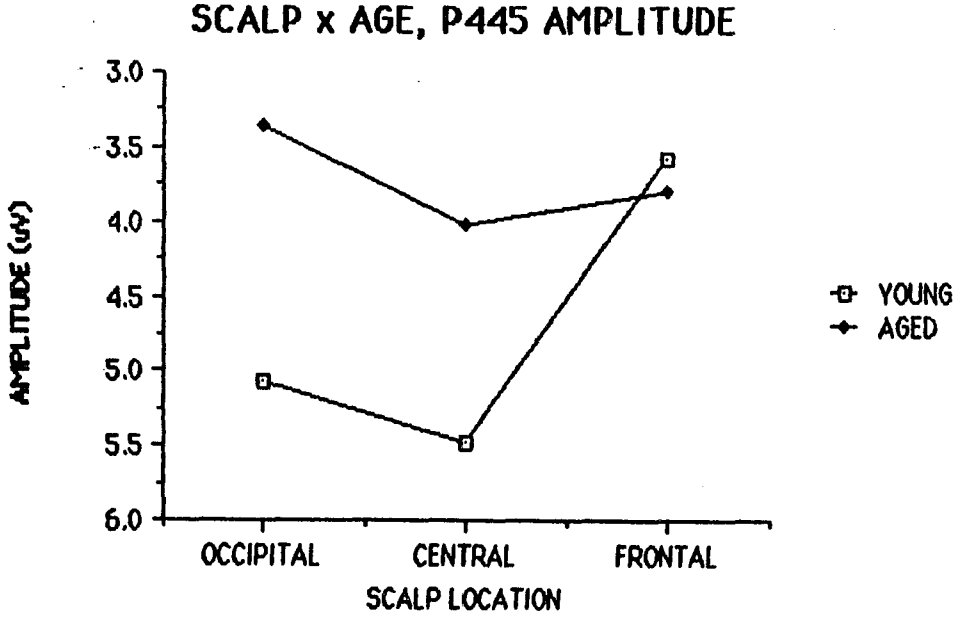

SCALP x AGE, P445 AMPLITUDE
AMPLITUDE (uV)
3.0
3.5
4.0
4.5
5.0
5.5
6.0
OCCIPITAL
CENTRAL
FRONTAL
SCALP LOCATION
YOUNG
AGED

Figure 6. **Field x Hemisphere x Age, P445 amplitude.** Means of visual field differences in amplitude of P445 at each level of age and hemisphere, collapsed across scalp location (3) and relevance condition (3). Positive is up.

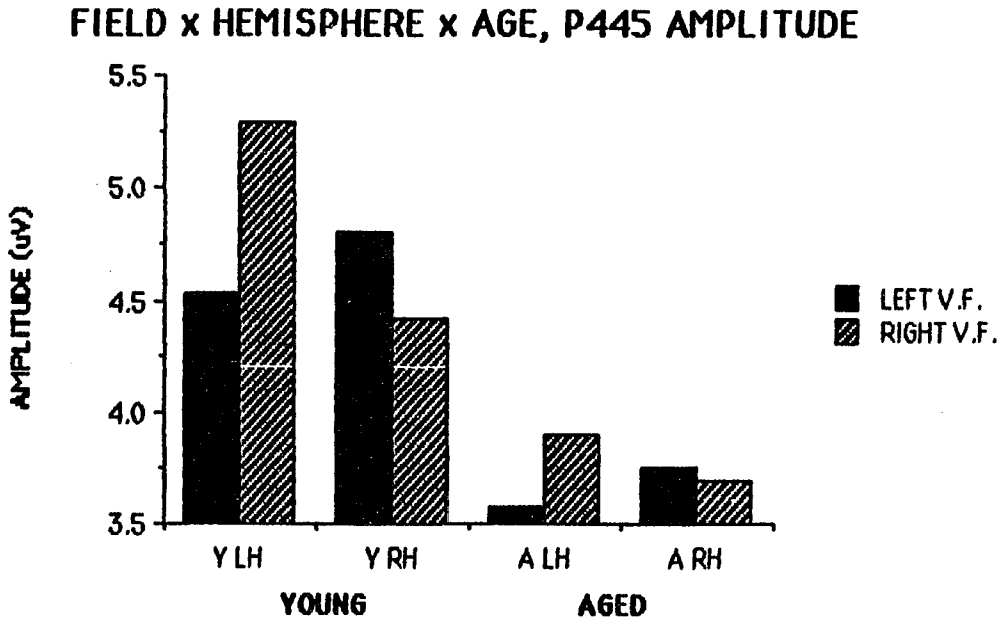

FIELD x HEMISPHERE x AGE, P445 AMPLITUDE
AMPLITUDE (uV)
5.5
5.0
4.5
4.0
3.5
Y LH
Y RH
A LH
A RH
YOUNG
AGED
LEFT V.F.
RIGHT V.F.

Figure 7. **Main effect of age on latency.** The latency of the occipital P445 to LC, Lc, and lc flashes, for both groups collapsed across visual fields (2), and hemispheres (2).

MAIN EFFECT OF AGE ON LATENCY OF OCCIPITAL P445

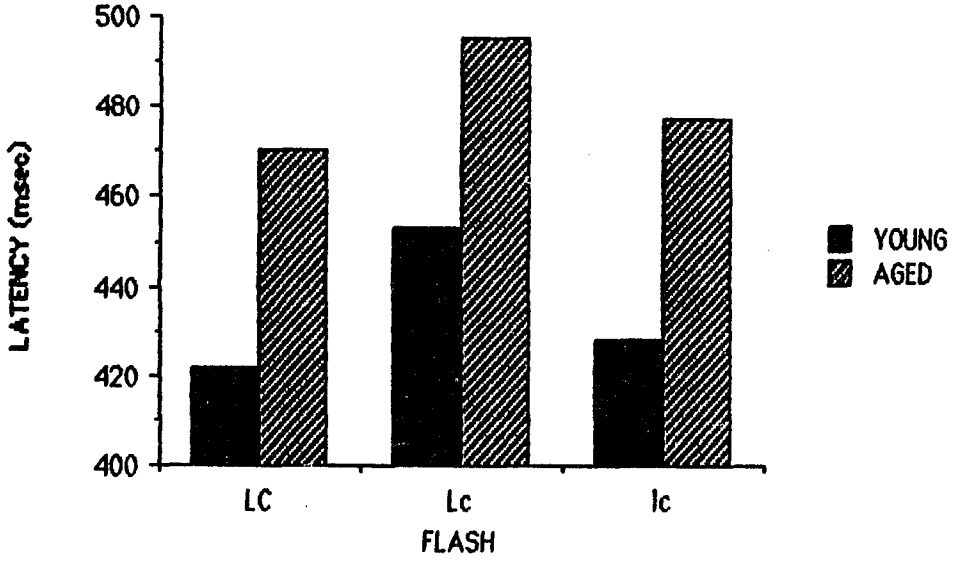


Figure 8. **Scalp x Relevance x Age, N325.** Difference in means of relevance conditions at levels of age and scalp, collapsed across visual fields (2) and hemispheres (2). Negative is up.

SCALP X RELEVANCE X AGE: N325

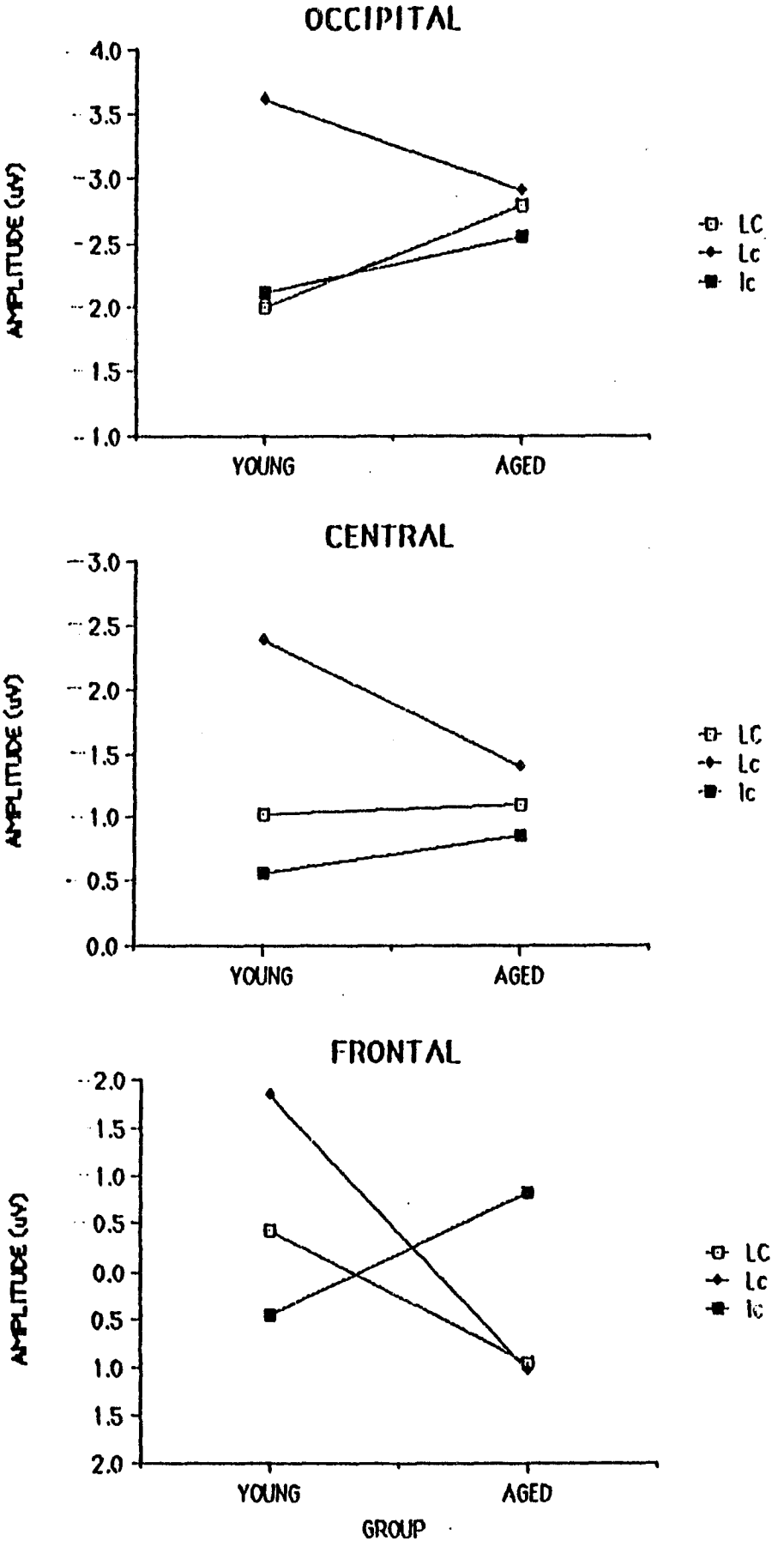


Figure 9. **Amplitude Difference in P445 for Relevance Effects.** The difference in amplitude of P445 for spatial and feature relevance effects, for each group, at each scalp location, collapsed across visual field (2) and hemisphere (2).

RELEVANCE EFFECTS: P445

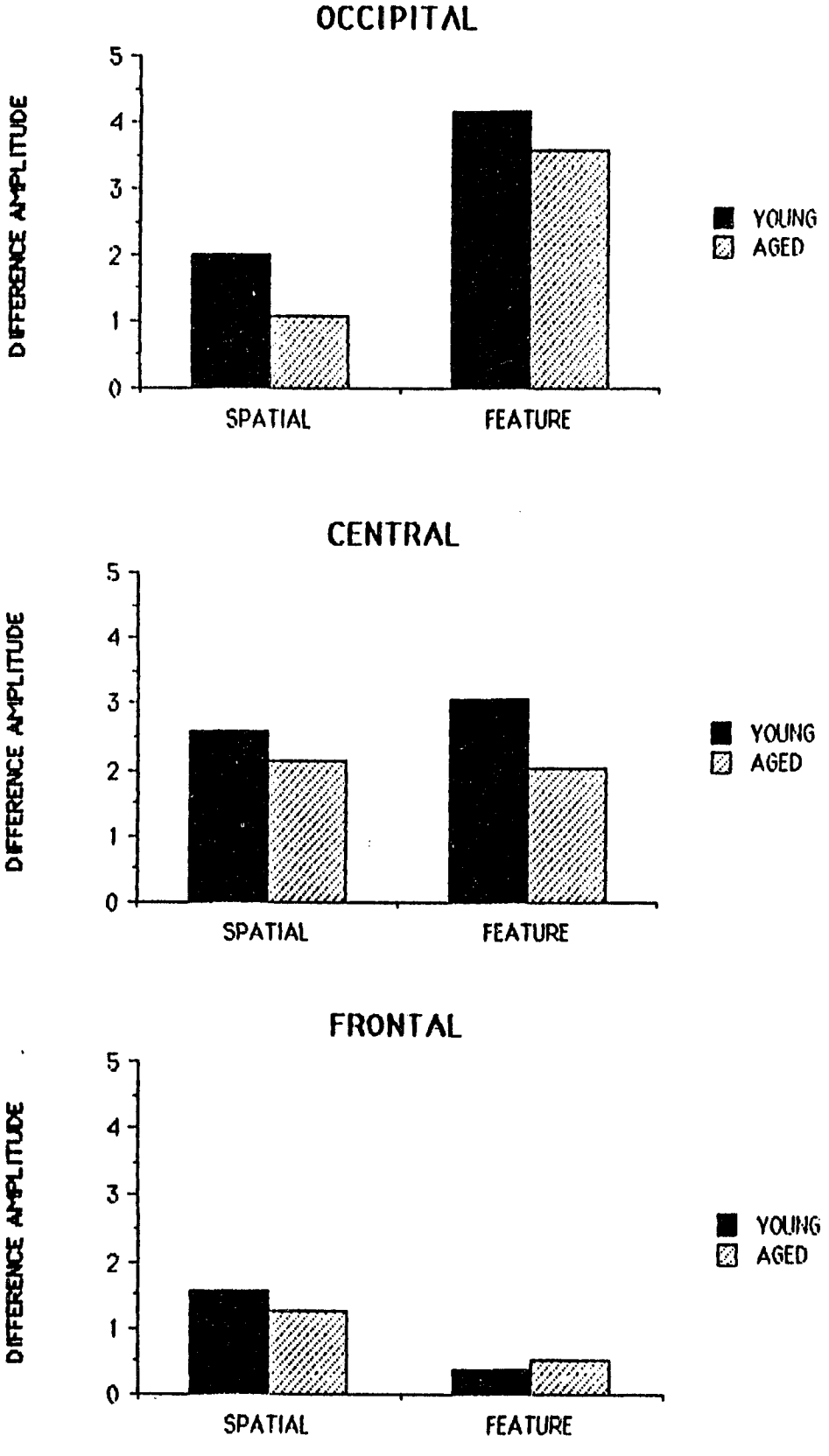
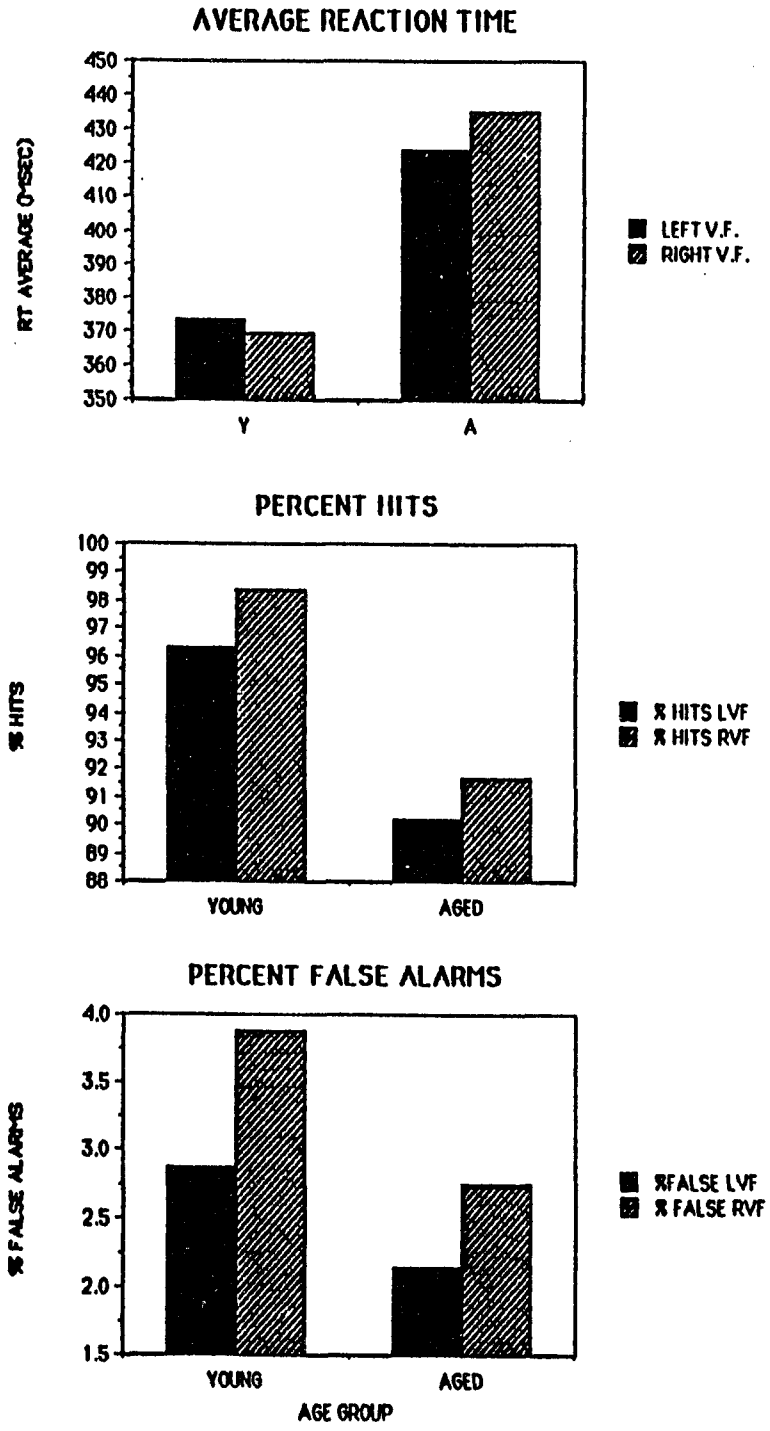


Figure 10. **Behavioral data** Mean RT (top), % hits (middle) and % false alarms (bottom) for young and aged subjects to left and right visual field stimuli.

BEHAVIORAL RESPONSE DATA



was more positive than the ERP to the lc flash for all subjects by .861 uV (see Appendix D, Table 7: C.R.=.762, p<.01). There were no significant effects of relevance in the N188 measure, and in the N325 measure the effects at all scalp locations were only significant for the young group (SxRxA reported above). At each scalp location the P445 component in the ERP to the Lc flash was significantly more positive than the P445 component in the ERP to the lc flash (SxR, F(4,56)=14.74, p<.0001; see Appendix D, Table 8: C.R.= .10, p<.01).

Effects of Feature Relevance (LC>Lc): As predicted, the feature effects (significant differences between the amplitude of components in the LC and Lc flashes) occurred later in time and were more evident in the posterior areas (Fig. 12). Although the onset and peak of the P445 feature relevance effects were earlier for the younger group (discussed above) and the magnitude of the peak amplitude was greater for the younger group, statistically the mean amplitude effects were not significantly different for the two groups. The peak of the P445 LC measure was significantly greater than the Lc measure at occipital and central, but not frontal areas (see Appendix D, Table 8: C.R.=.10 p<.01).

Increased latency of P445 due to visual field of flash: The latency of the occipital P445 was increased if the flash was in the the left (466 msec) compared to the right (448 msec) visual field (F(1,14)=14.6, p.<.01.).

Increase in amplitude due to hemisphere: Statistically significant hemispheric differences were primarily in the central and frontal recordings. The first measure, P144 shows an

Figure 11. **Effects of Spatial Relevance** Amplitude of P144, N188, N325, and P445 to Lc and lc flashes at each scalp location, for each group, collapsed across visual field(2) and hemisphere (2).

SPATIAL RELEVANCE

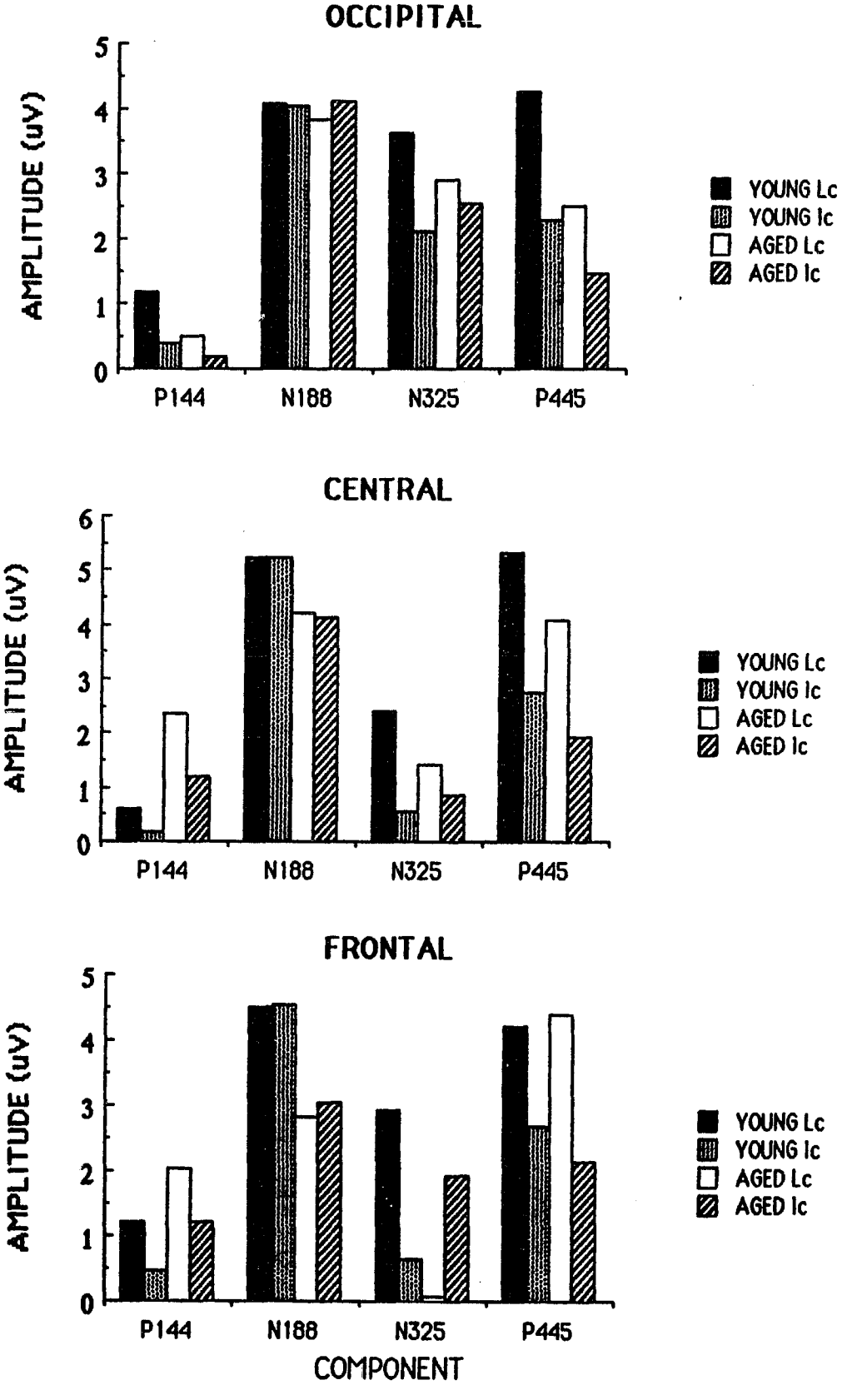
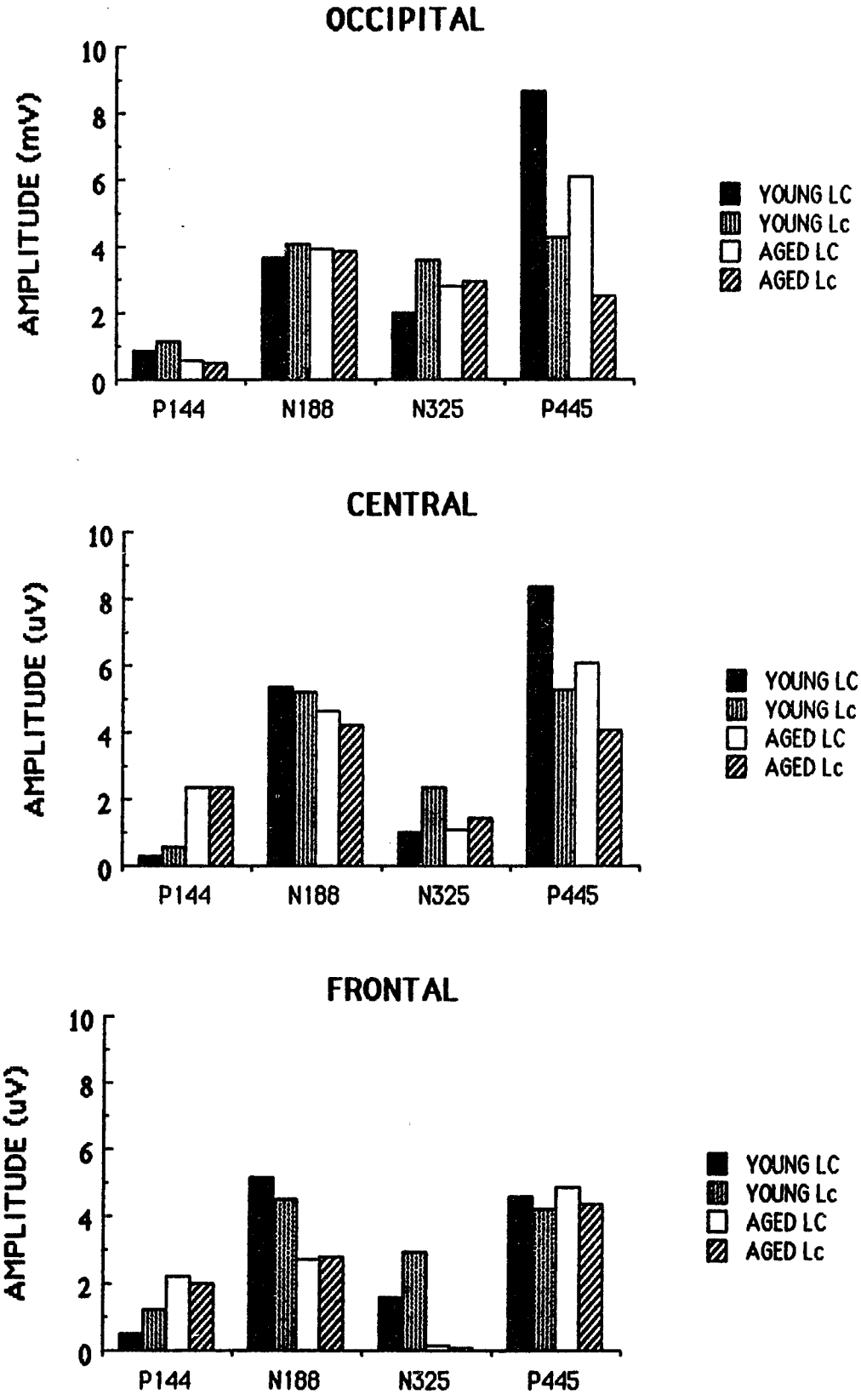


Figure 12. **Feature Relevance Effects.** Amplitude of P144, N188, N325, and P445 of ERPs to LC and Lc flashes at each scalp location for each group collapsed across visual fields (2) and hemispheres (2).

FEATURE RELEVANCE



interaction of scalp x hemisphere ($F(2,28)=3.76$, $p<.0358$). The central left hemisphere P144 was significantly more positive than the central right hemisphere measure by .330 uV. The left and right hemisphere P144 measures were not significantly different (see Appendix D, Table 10: C.R. = .285, $p<.05$). Hemispheric differences in the N188 measure interacted with field. (see below).

Hemispheric differences in N325 depended on both scalp location and relevance (SxRxH, $F(4,56)=3.24$, $p<.0184$) (Fig. 13). As predicted, the central and frontal left hemisphere N325s were more negative than the right for the LC flash (see Appendix D, Table 11: central, 1.21 uV, C.R.=.520, $p<.01$; frontal, .49 uV, C.R.=.389, $p<.05$). However, for the lc flash the right hemisphere is more negative than the left at central and frontal sites (central, .61 uV, C.R.=.520, $p<.01$; frontal, .43 uV, C.R.=.389, $p<.05$). The occipital N325 reflected no significant hemispheric differences.

Field x Hemisphere: As predicted the N188 was greatest in the hemisphere contralateral to the visual field stimulated at all scalp locations (Fig. 14) ($F(1,14)=19.07$, $p<.0006$). The N188 recorded at the left hemisphere was .8 uV greater (C.R.=.644, $p<.01$), to the right visual field flash (contralateral) compared to the N188 to the left visual field flash (ipsilateral). The N188 recorded at the right hemisphere was .53 uV greater (C.R.=.464, $p<.05$), to the left visual field flash (contralateral) than the N188 to the right visual field flash (ipsilateral),(see Appendix D, Table 9).

Figure 13. **Scalp x Relevance x Hemisphere, N325.** Means of left and right hemisphere N325 measures at each level of flash and scalp, across age (2) and visual field (2).

SCALP x RELEVANCE x HEMISPHERE, N325

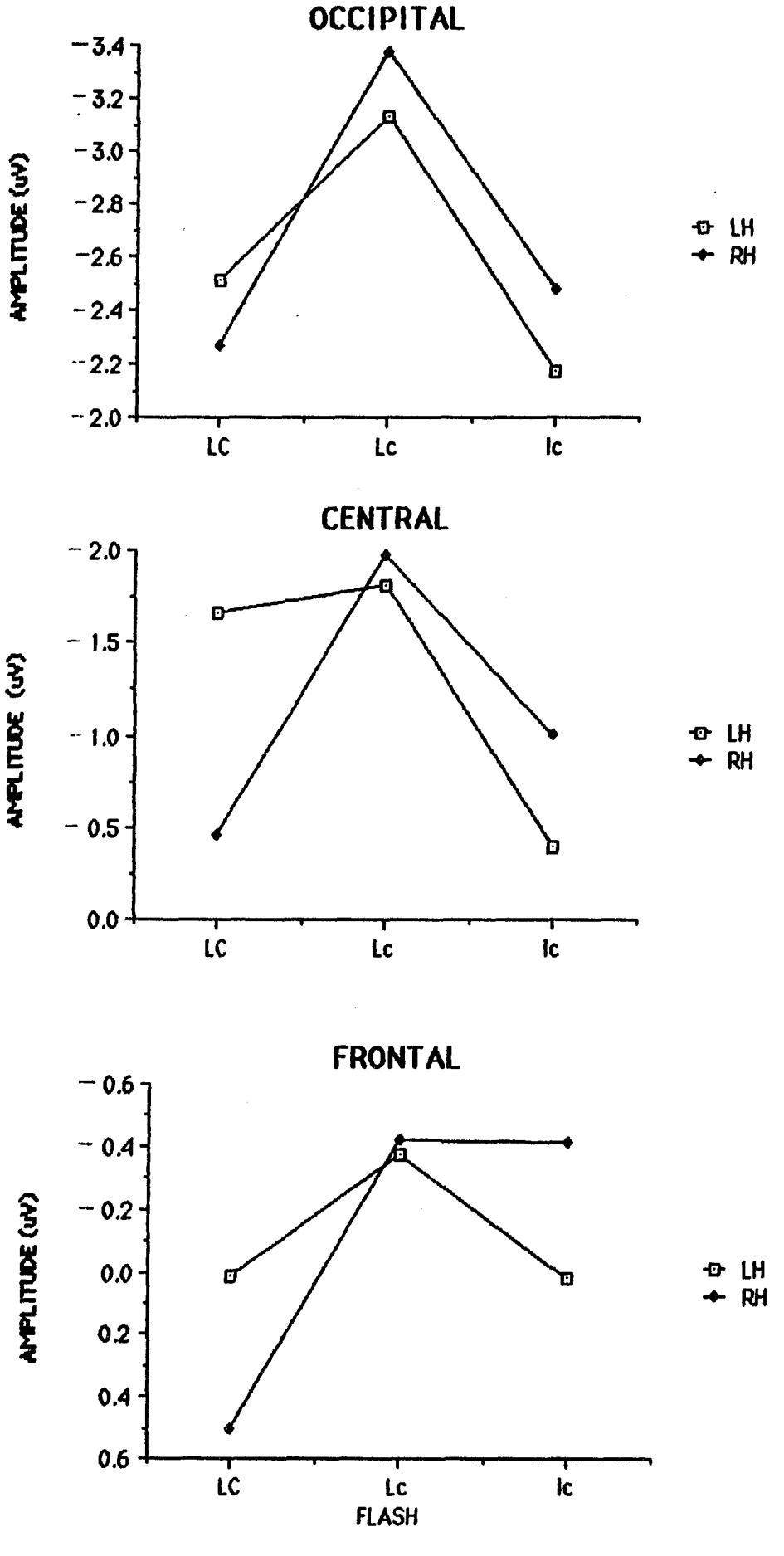
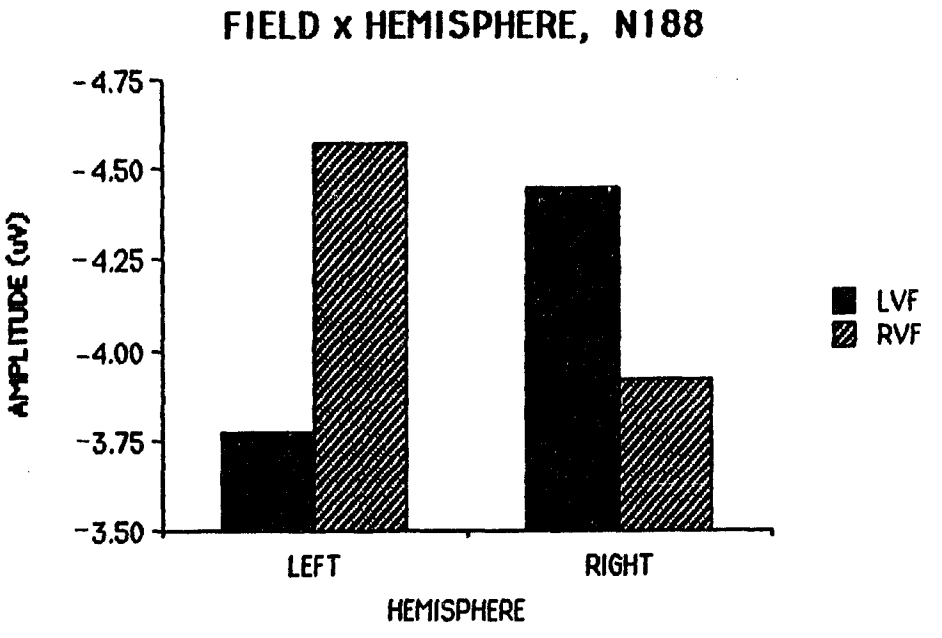


Figure 14. **Field x Hemisphere, N188.** Mean of N188 to left and right visual field flashes at each hemisphere collapsed across scalp (3), relevance (3), and age (2).


FIELD x HEMISPHERE, N188
-4.75
-4.50
-4.25
-4.00
-3.75
-3.50
AMPLITUDE (uV)
LEFT
RIGHT
HEMISPHERE
LVF
RVF

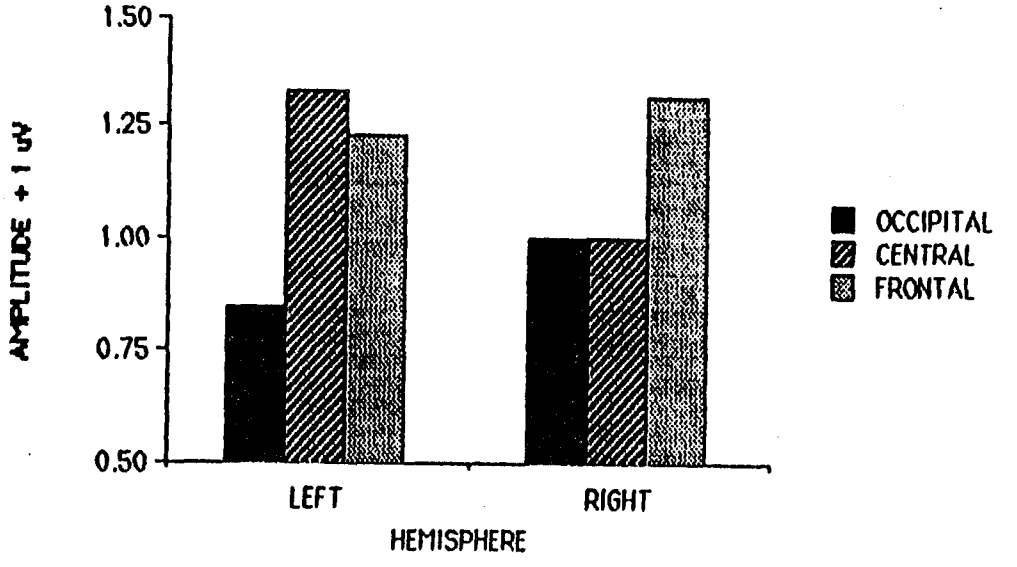
Effect of scalp location on amplitude of components:. There was a shift of focus of amplitude from anterior to posterior areas over the time course of the ERP (see Figure 15). In the left hemisphere P144s, both central and frontal amplitudes were greater than the occipital (SxH: $F(2,28)=3.76$, $p<.0358$; see Appendix D, Table 10: central .485uV, C.R.=.429, $p<.01$; frontal, .387 uV, C.R.=.332, $p<.05$). In the next measure, N188, both central measures are greater than the frontal ($F=3.93$, $p<.0312$; C.R.=.972, $p<.05$: see Appendix D, Table 12). In the N325 measure the occipital amplitude was greater than the central, and both occipital and central were larger than the frontal N325 (SxRxH, $F(4,56)=3.24$, $p<.0184$; see Appendix D, Table 11: C.R. = .595, $p<.01$). The late positive component, P445, also has a posterior focus for the younger group (discussed above).

SUMMARY OF RESULTS

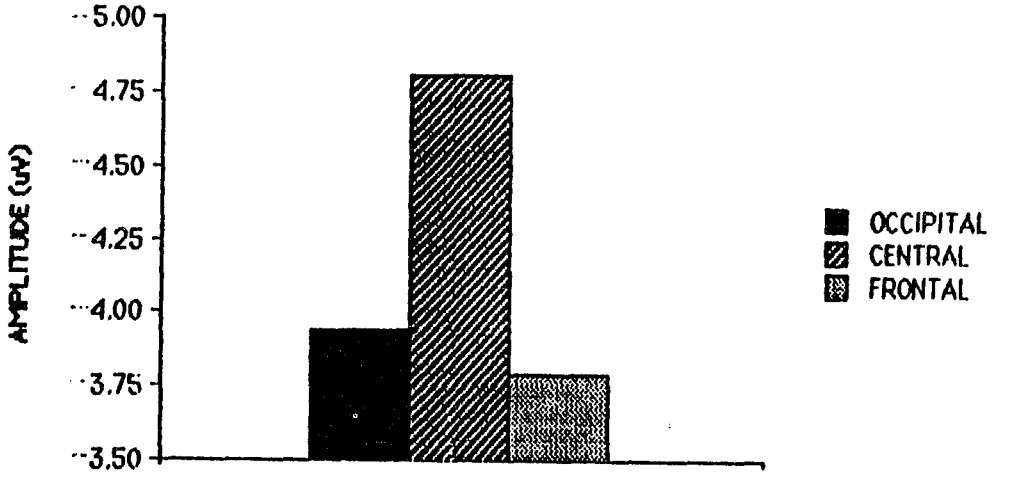
Overall differences due to age were found for P144 and P445 amplitude, P445 latency, and for the scalp topography of the P445. There was an initial increase in overall positivity (P144) for the aged group. Later, however, P445 was more positive for the young compared to aged group at occipital and central locations. Occipital P445 was significantly delayed for the older group. Also, P445 amplitude was greater in posterior areas for the young group, whereas the aged group's P445 was uniform in amplitude across the scalp. An additional group topography difference in P445 was a contralateral projection effect for the young group that did not reach significance for the aged group.

Figure 15. **Influence of scalp location on amplitude of P144, N188, and N325.** The upper graph shows means of P144 at each hemisphere collapsed across visual fields (2), flash (3), and age (2). (One microvolt was added to each mean to bring all means above 0 for graphing). The middle graph shows differences in the mean of N188 between scalp locations, collapsed across relevance (3), visual field (2), hemisphere (2), and age (2). The lower graph compares the scalp location means of the N325 component at each level of hemisphere and relevance condition collapsed across age (2) and visual field (2).

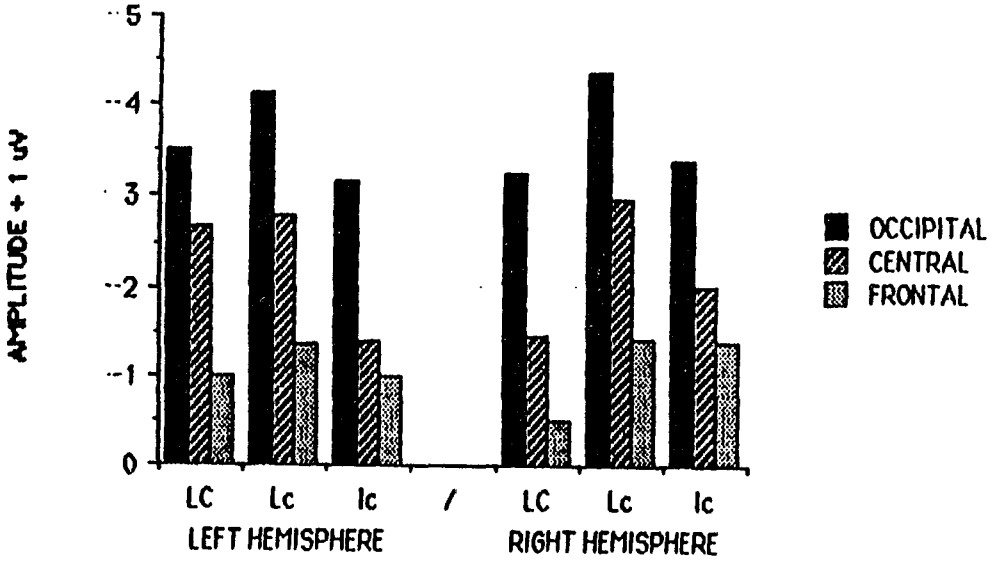
SCALP x HEMISPHERE, P144



MAIN EFFECT OF SCALP, N188



SCALP x RELEVANCE x HEMISPHERE, N325



Group differences in task relevant effects were most evident for N325. The young group showed the predicted spatial relevance effect at all three scalp locations; the aged subjects did not have this effect. Feature relevance effects in the P445 component began and peaked earlier in the young subjects' data. The reaction time of the aged group compared to the young, was significantly slowed.

For both groups, as predicted spatial relevance effects occurred earlier (P144) and were more frontally distributed (occipital, central, and frontal) than feature effects (P445, occipital and central).

There was a significant increase in the latency of the P445 when the flash was in the left visual field, across age, relevance condition, and hemisphere measures. Hemispheric differences were found over central and frontal measures. Hemispheric differences interacted early with scalp location (P144) and field (N188) and later with relevance (N325). The early contralateral projection effect (N188) across groups, relevance conditions, and scalp locations, was only significant in the young subjects' P445 measures.

Differences in mean amplitude across the scalp shifted over the time course of the ERP from an early anterior focus (P144), to central (N188), to a later posterior focus (N325 and P445).

CHAPTER IV

DISCUSSION

The purpose of this study was to measure the effect of age on the ERP indices of selective attention. Two types of relevance effects were investigated: spatial relevance and feature relevance. The predicted topographical separation of the two kinds of relevance effects, at all scalp locations measured for spatial effects (P144, N325, P445) and occipital and central for feature effects (P445) was consistent with the Ungerleider and Mishkin (1982) model of two cortical visual systems, and the Harter and Aine proposal (1984) that selective attention processes operate within these pathways to modulate the flow of information, enhancing the processing of relevant information.

THE INTERACTION OF AGE AND RELEVANCE

As predicted, group differences for each relevance effect occurred in different scalp locations. The most robust effect of age on task relevant effects was seen in the N325 component at all scalp locations for spatial relevance. The major group difference in feature relevance effects was that the onset and peak of the posterior P445 component was delayed for the aged group. Also, for feature relevance, P445 indicants of selection suggested group differences in amplitude over the occipital region.

These data show an early P144 spatial attention effect for both groups. The N325 component however, showed increases in negativity due to relevance only for the young group. These data suggest that

spatial selection processes initially represented by P144 did not change with age. At longer latencies, however, the aged ERPs did not show a negativity associated with increased processing of the stimulus in the relevant location.

Although the generators of negativities associated with cognitive processes have not been identified, it is often suspected that they arise from the excitation of neurons in the superficial layers of cortex (Vaughan & Arezzo, in press). At this point in time these neurons would be receiving cortico-cortical inputs from other association areas. The first positivity (P144), however, is probably arising from inputs more closely associated with incoming information from thalamo-cortical connections. This age-related loss of negativity may be due to diffuse damage to the integrity of neural patterns in association areas responsible for the coding of stimuli occurring in relevant visual space.

Overall age-related reductions in anterior negativity are consistently reported in the ERP literature, and some examples are discussed (below) in the section on the main effects of age. The loss of negativity due to relevance in N325 in this study in the aged group data, however, can not be explained solely by a reduction in frontal negativity since this occurred across the scalp. Also, there was no age - related difference in the negativity for the N188 component which might be expected with an overall reduction in negativity.

The late positive component (P445) for both groups peaked after the reaction time response, suggesting that it is some outcome of the processes leading up to the behavioral response. It has been suggested that the amplitude of the late positive component is sensitive to a variety of experimental parameters including stimulus probability, task relevance, subjective expectancy, and memory updating (Pritchard, 1981). The onset and peak of this latter stage of the feature selection process, as reflected in the occipital and central P445, was delayed for the elderly subjects. If feature selection is accomplished in the geniculostriate and then inferotemporal areas, the P445 data would argue that the outcome of the differential modulation of target vs. non-target information in these pathways is slowed by age.

The amplitude of the relevance effects was smaller for the aged group, but not statistically different from the young. The slower RT of the older subjects, with no significant reduction in hit rate or false alarm rate, suggests that the latter stages of the aged group's feature selection processes were similar to those of the young group, only delayed. However, if more subjects had been run the group differences in feature relevance effects might have been statistically significant. If the color discrimination in the task were made more difficult, there might have been a significant group difference in the amplitude of the feature relevance effects.

Interpreting the age differences within Hillyard and Mangun's (1987) explanation of feature vs. spatial selection, these data would indicate that the attentional mechanisms responsible for feature

selection, were not as affected by age as those responsible for spatial selection. According to this model, these data suggest that for feature selection the activity of the special set of neurons engaged in enhancing the signal associated with an attended target were slowed with age; whereas, mechanisms responsible for enhancing cue specific channels in spatial attention were altered more by age as reflected by the reduced amplitude of N325 to Lc at all three scalp locations. Decreases in the efficiency of spatial selective attention processes might result in the slowing of the feature selection processes as reflected by the delayed P445 and RT for the elderly group. Cognitive models of early and late selection as well as ERP data, suggest that location is selected before color features (Johnston & Dark, 1986). If early selection of the location of the stimulus is less efficient, then the later selection of color feature would be delayed.

If, on the other hand, the spatial selection task is viewed as secondary to the primary task of feature selection, the age-related reduction in N325 spatial relevance effects could be a reflection of reduced processing of the secondary task. If the capacity for the coding of the stimulus events is reduced with age, ERPs to the target should show the greatest relevance effects, and the ERPs associated with additional stimuli in the stimulus display should show smaller relevance effects. A major assumption of the selective attention paradigm used in this study is that the subject must maintain vigilant "attention" to a point in space while waiting for the target. Any stimulus appearing in that relevant area of field should

be processed more than one outside that "spotlight." In the case of the aged subject, the capacity for the neural registration of non-target stimuli in that space may be reduced.

The age-related reduction in the N325 spatial relevance effect is consistent with RT studies that utilized a task associated with spatial selectivity (Farkas & Hoyer, 1980; Plude & Hoyer, 1986) and indicated that aged subjects have difficulty with accurately locating targets in space. In the present study, the subjects knew where the stimulus was going to be. The spatial deficit here reflects an age-related reduction in the neural activity associated with the presentation of information in the attended field, as opposed to the irrelevant field.

The absence of group differences in the latency or amplitude of occipital N188 component indicated that later group differences in ERPs and reaction time were not due to age-related acuity problems and/or higher thresholds for peripheral visual stimuli. Whether varying the size and intensity of the stimuli would change the group differences reported here remains an experimental question. It is possible that there is an intensity level of visual stimulation, below which age-related selective attention deficits appear, without indication of sensation deficits.

A related issue is the possibility that the size of the "attentional spotlight" is getting larger with age. If there is more frontal loss of neurons and neural connectivity with age, then the older subject's attentional spotlight may not be as narrow in focus, accounting for the lack of differential processing of stimuli in

relevant vs. irrelevant fields. Varying the separation of flashes within and between visual fields would provide some information about the size of the the specificity of coding of spatial information and how this changes with age.

Two methodological confounds concerning the stimulus display could have contributed to the differential effect of age on spatial and feature relevance effects. First, if the spatial cue at the fixation point had also been a cue for the target color, the older subjects may have been able to make the target selection as a match with the cue color. This might have reduced the latency of the RT and the P445 component for the older group, since the target selection could have been made by a visual match on the screen.

Secondly, although the subjects responded to only one color, they switched their attention to the opposite viusal field at the beginning of the second run. Since there was a practice time for the second run the difference between groups on the spatial task was probably not due to this switch. Future studies could manipulate a change in instruction for the relevant visual field, as well as the target color, to examine the effect of the instruction change on group differences.

THE MAIN EFFECTS OF AGE

The age variable was expected to increase the latency of the late positive component (P445) (discussed above) and increase the positivity in ERPs collected over anterior areas. The positive shift in the ERPs in this study (P144) was earlier and had a broader extent (all three scalp sites) than reported previously (Beck et al., 1982;

Teece, 1980). If this increase of positivity is actually due to a loss of frontal negativity and a loss of inhibition in anterior areas, as has been suggested (Teece, 1980, Beck et al., 1982), it should have been a) influenced by relevance, resulting in larger group differences in ERPs to irrelevant stimuli; b) followed by group differences in the amplitude of N188; and c) greatest in the anterior areas. If scalp recorded negativities are the result of post-synaptic activity in the superficial laminae of cortex (discussed above), then this increased positivity could be interpreted as a reflection of reduced post-synaptic activity in neurons that are engaged in inhibiting other neurons.

Although the aged P144 was more positive than the young, the young P445 was more positive than the aged. This reversal in the main effect of amplitude between groups suggests that if the earlier increase in positivity with age was due to an overall loss of frontal negativity it was confined to early processes (P144). The group difference in the latter component is probably due to more "psychological" influences - such as task relevance and reduction of uncertainty. This was one of four group differences in amplitude that changed in the ERP recordings from an early to a later measure (in addition to the latency shift in P445 reported above). The other three instances suggested the principle of increase in the uniformity of recordings across the scalp from earlier to later measures.

A second group difference, occurring in a later measure but not present in an earlier measure, was the contralateral projection

effect. At N188, for both groups, there was a significant difference between the amplitude of the contralateral flash compared to the ipsilateral flash recorded over each hemisphere. At P445, however, the contralateral effect was significant only for the young group. This finding is consistent with previous reports of the age - related increase of uniformity of amplitude of the late positive component across the scalp (Pfefferbaum, et al., 1985).

This tendency toward uniformity in the elderly was also demonstrated in the absence of a posterior amplitude effect for the elderly P445. Earlier, at P144 and N188, the amplitude of the components is significantly larger over anterior sites, for both groups (discussed below).

The fourth group difference that emerged in a later component was the group difference in spatial relevance effects. Earlier at P144 both groups showed spatial relevance effects (discussed below).

The emergence of group differences over the time course of the ERP should be considered in light of the assumption that later components reflect activity of "higher" cortical areas, beyond the primary projection areas of cortex. The fact that spatial relevance effects and contralateral projection effects are robust for both groups in early components, and then only present for the young group in later components, may be due to age-related losses of neurons and neural connectivity in higher association areas.

EFFECTS OF RELEVANCE FOR BOTH AGE GROUPS

The main effects of relevance in this study were separable topographically and temporally, as expected. The significant effects

of relevance occurred later in time than in the Harter, et al. (1982) study, but followed the same pattern in time and scalp topography. Specifically, the effects of spatial relevance in the Harter, et al. (1982) study were earlier and more robust in the central measures, as compared to occipital sites. In the present study, the effects of spatial relevance, when significant, were seen at all scalp locations at the following latencies: P144, N325, & P445). The first measure, P144, showed spatial effects for both groups. The next enhancement due to spatial relevance was seen in the N325 for the young group and then in the P445 for both groups. As predicted, the enhancement of components due to spatial relevance (P144) occurred earlier than that due to feature relevance (N325 & P445). Also, the spatial relevance effects were more anterior than feature relevance effects. The significant effects of feature selection were in the amplitude of the P445 component in the occipital and central areas. In the Harter et. al., study the significant effects of feature selection were predominantly occipital, beginning with a negativity peaking at 272 msec, and continuing through the late positive component. In the present study, feature selection effects were predominantly in the occipital areas, but not evident until onset of the late positive measure.

A similar topographic separation can be seen in Neville and Lawson's (in press) study of selective attention to moving targets in which feature relevance effects for targets occurred in the occipital measures; location relevance effects for standard stimuli were most robust in the parietal measures.

There are some important differences in task difficulty between the present study and others reported that may explain some of the differences in results, specifically the relatively delayed effects of relevance in the present study. In the Harter et al. study the stimuli were 20 degrees from a central fixation point in the left and right visual fields, the inter-stimulus interval (ISI) was 520 msec. and the subject had to respond to the relevant stimulus within 350 msec. from stimulus onset. In the Neville study the stimuli were 18 degrees from the central fixation point in the left and right visual fields, and the ISI was 324 msec. In the present study stimuli were 10 degrees in the peripheral fields, the ISI was at least 1.2 sec. and the critical response time was 650 msec. If subjects are required to respond more quickly, it is assumed that the selection of relevant information is occurring earlier in time and these effects will be seen earlier in the ERP. The longer the subject takes to make a response, the more opportunity for variability of the early components in the average, which results in later relevance effects in the final averaged event-related potential. In this study the earliest effects of relevance were observed in a positivity at 144 msec. It should be noted that recent studies of auditory selective attention have reported enhanced positivities at 20 to 50 msec (Woldorff, Hansen, & Hillyard, 1986). Oakley, Eason, and McCandies (1986) reported enhanced negativities in difficult visual tasks at 40 msec.

The fact that spatial relevance in the present study occurred at all electrode sites, and feature relevance only occurred in

posterior areas is consistent with Mishkin's (1982) model of two cortical visual systems. According to this model, all visual information arrives at the level of the cortex in the primary visual area, and then progresses to infero-temporal areas for further analysis of pattern features, and to parietal and frontal areas for further analysis of spatial features. The neural specificity model of visual selective attention (Harter & Aine, 1985) predicted that relevance effects would reflect modulation of incoming information in these separate pathways, and the effects of feature and spatial relevance would differentiate in the event-related potentials in topography and in the time of onset of the effect.

Hillyard and Mangun (1987) have agreed that mechanisms responsible for spatial relevance effects are different from those for feature relevance effects. They also agreed that the mechanisms underlying spatial relevance effects are well described by the neural specificity model - when the "activity in neuronal populations representing inputs from attended spatial locations is facilitated in relation to the inputs arriving over unattended spatial channels" (p.276).

In Hillyard's model feature relevance effects, however, are due to the activity of groups of neurons that are specifically designed to process target stimuli, rather than by facilitating a "cue specific neural input channel" (p. 276). In this study, feature relevance effects were later than spatial effects and had a different topography, which would be consistent with Hillyard's explanation of the different relevance effects.

INFLUENCE OF VISUAL FIELD ON ERPS

It was predicted that feature selection would be more evident in the right visual field. There was an increased latency, bilaterally, for the stimuli in the left as compared to the right visual field, in the occipital P445. The delay of the late positivity may reflect a delay in the processing of stimuli in the left visual field. In this case, the delay is not specific to only relevant stimuli, but is true for the irrelevant stimuli in the left visual field as well. The right visual field could have an advantage because of reading practice. As an individual reads from left to right, the detection and registration of visual stimuli to the right of central fixation may be more quickly processed because of years of practice.

The complex relationship between visual field effects and hemisphere effects could be addressed more adequately by a study in which the difficulty of feature selection and location selection are varied, in a high demand task situation.

INFLUENCE OF HEMISPHERE ON ERPS

It was expected that early spatial relevance effects would be significantly greater in the hemisphere contralateral to the relevant visual field. This relevance x field x hemisphere effect occurred early in the occipital measures of the Harter et al. study, providing further evidence for the validity of the neural specificity model of selective attention. The neural enhancement due to relevance appeared to be following known contralateral projection pathways. In this study there were no early contralateral feature selection effects for either group, which may have been due to a

longer ISI and a more lenient critical response time. As pointed out above, in this study the peripheral flashes were 10 degrees out from central fixation. In the Harter et al. study, the flashes were 20 degrees, projecting on more peripheral areas of the retina, which project back to more lateral areas of the occipital cortex, increasing the chances of recording hemispheric differences. In this study there was a robust field x hemisphere effect in the N188 measure and for the young people in the P445 measure which is consistent with the predicted effect.

The difference in Lc and lc was expected to be greater over the right hemisphere than the left; the difference in LC and Lc was expected to be greater over the left hemisphere than the right. In the present study, at central and frontal sites, the left hemisphere N325 was greater than the right for the LC flash and the right hemisphere N325 was greater than the left for the lc flash (Fig. 13). This interaction is in the direction of the prediction, but there was no significant difference in relevance at levels of hemisphere as predicted. The grand means (Fig. 3) do show a greater left hemisphere enhancement to the relevant stimulus (LC) for the younger group in the occipital recordings but statistically this difference between hemispheres is not significant.

Harter and associates (Harter et al., 1982; Harter, Anllo-Vento, Wood, & Schroeder, in press) have shown a left hemisphere enhancement of negativity for relevance, particularly in the feature relevance effects. The stimuli in the present study, however, were not chosen to maximize hemispheric differences. Pattern, letter, and or word

stimuli might have produced greater hemispheric differences, but would have introduced problems in controlling for acuity differences between the groups. The only other ERP study of aging investigating hemispheric differences across the life span (Picton, 1985) found no hemispheric differences due to age in simple visual, auditory and somatosensory tasks.

THE EFFECTS OF SCALP LOCATION ON ERPS

Over the time course of the ERP, the maximum amplitude of the components measured shifted from anterior to posterior areas: the P144 measure had a central and frontal focus; the N188, central; N325, occipital; and P445, a posterior focus for the young subjects. Topographic mapping of the focus of P1 and N1 (e.g. Simson, et al., 1977) were made from ERPs collected to visual stimuli, projecting to the fovea, the primary projection area of which is in the most posterior area of primary visual cortex. In this study the P144 and N188 may have a more frontal distribution because the stimuli are in the peripheral areas, projecting to more lateral sites. The fact that the N325 shifts to posterior areas indicates that the activity was still concentrated in visual association areas. Topographic mapping of ERPs to missing stimuli (Simson, Vaughan, & Ritter, 1976) has shown that even though the "trigger" event was the lack of a stimulus, the largest amplitude of the N2 was still over the primary and secondary areas for that modality: over occipital for missing visual stimuli, and over central areas for missing auditory stimuli. The posterior focus of the P445 for the younger subjects is most likely the reflection of parietal activity, the typical focus of the

late positive component, in either visual or auditory paradigms. The fact that the older subjects did not show this posterior focus is most likely due to the large frontal P3 frequently reported with age (discussed above).

SUMMARY

The major finding of this study was a difference between the young and aged groups in spatial relevance effects. This difference was evident in the N325 component, particularly in the frontal locations. The finding of greater differences between the age groups in spatial relevance effects than feature relevance effects is consistent with the findings of reaction time studies of age-related changes in visual selective attention (Plude & Hoyer, 1986; Wright & Elias, 1979).

The components showing feature relevance effects (N325 and P445) showed a later onset and peak effect. The amplitude of the feature relevance effect, was reduced and delayed in the older subjects data, but the difference was significant only for the latency shift.

A number of group differences were not evident in the early measures, but were significant in the later measures: the spatial relevance effects were significant for both groups in P144 but only for the young group in N325. The occipital latency difference between groups was not significant at N188 (9 msec) but increased to a significant 50 msec difference at P445. There was a uniformity of amplitude across the scalp for the aged group, whereas the young group showed a posterior focus in the P445 measure. These group differences after the N188 measure suggest age-related changes in

later stages of information processing systems, and/or in cortical association areas responsible for later stage processing.

The topographical separation of spatial (at all scalp locations) and feature (posterior) relevance effects was a systematic replication of the Harter et al. study (1982) and is consistent with current neurophysiological models of two cortical visual systems (Ungerleider & Mishkin, 1982) and visual selective attention (Harter & Aine, 1985).

BIBLIOGRAPHY

Arezzo, J.P., Vaughan, H.G. (in press). The neural basis of event-related potentials. In T.W. Picton (Ed.) EEG Handbook: Human Event-Related Potentials. The Netherlands: Elsevier.

Bartus, R.T., Dean, R.L., Beer, B., Lippa, A.S. (1982). The cholinergic hypothesis of geriatric memory dysfunction. Science, 217, 408-417.

Beck, E.C., Swanson, D., Dustman, R.E. (1980). Long latency components of the visually evoked potential in man: Effects of aging. Experimental Aging Research, 6(6), 523-543.

Bergi, E. (1982). The significance of lipofuscin in the aging process: Especially in the neurons. In R.D. Terry, C.L. Bolis, G. Toffano (Eds.) Neural Aging and Its Implications in Human Neurological Pathology. New York: Raven Press.

Birren, J.E., Woods, A.M., Williams, M.V. (1980). Behavioral slowing with age: Causes, organization, and consequences. In L.W. Poon (Ed.), Aging in the 1980's. Washington, D.C.: American Psychological Association.

Botwinick, J. (1981) Neuropsychology of Aging. In S.B. Filskov & T.J. Boll (Eds.), Handbook of Clinical Neuropsychology. New York: Wiley & Sons.

Brizzee, K.R., Ordy, J. M., Bartus, R.T. (1980). Localization of cellular changes within multimodal sensory regions in aged monkey brain: Possible implications for age-related cognitive loss. Neurobiology of Aging, 1, 45-42.

Brizzee, R.R., Ordy, J.M., Knox, C., Jirge, S.K. (1980). Morphology and Aging in the Brain. In G.J. Maletta & F. J. Pirozzolo (Eds.), The Aging Nervous System. New York: Praeger.

Brody, H. (1976) An examination of cerebral cortex and brainstem aging. In R.D. Terry & S. Gershon (Eds.), Neurobiology of Aging. New York: Raven Press.

Brody,H. (1980) Neuroanatomy and Neuropathology of Aging. In E.W. Busse & D.G. Blazer (Eds.), Handbook of Geriatric Psychiatry. New York: Van Nostrand Reinhold.

Brown, W., Marsh, J., LaRue, A. (1983). Exponential electrophysiological aging: P3 latency. Electroencephalography and Clinical Neurophysiology, 55, 277-285.

Bushnell, M.C., Goldberg, M.E., Robinson, D.L. (1981). Behavioral enhancement of visual responses in monkey cerebral cortex. I. Modulation in parietal cortex related to selective visual attention. Journal of Neurophysiology, 46, 755-772.

Chang, H-T., Pao, X. (1982). Lipofuscin pigment formation in cultured neurons. In R.D. Terry, C.L.Bolis, & G. Toffano (Eds.). Neural Aging and Its implications in Human Neurological Pathology. New York: Raven Press.

Craik, F.I.M. (1977). Age differences in Human Memory. In J.E.Birren & K.W. Schaie (Eds.), Handbook of the Psychology of Aging. New York: Van Nostrand Reinhold.

Craik, F.I.M. (1983) On the transfer of information from temporary to permanent memory. Philosophical Transactions of the Royal Society of London, 302, 341-359.

Desmedt, J.E., Robertson, D. (1977). Differential enhancement of early and late components of the cerebral somatosensory evoked potentials during forced paced cognitive tasks in man. Journal of Physiology, 271,761-782.

Donald,M.W. (1983). Neural selectivity in auditory attention: Sketch of a theory. In A.W.K. Gaillard & W. Ritter (Eds.), Tutorials in Event Related Potential Research: Endogenous Components. New York: North-Holland Publishing Co.

Eason, R.G., Harter, M.R., White, C.T. (1969). Effects of attention and arousal on visually evoked cortical potentials and reaction time in man. Physiology and Behavior, 4, 283-289.

Eisdorfer, C. (1980). Neurotransmitters and aging: Clinical considerations. In R.C. Adelman, J.Roberts, G.T. Baker, S.I. Baskin, & V.J. Cristofalo (Eds.), Neural Regulatory Mechanisms During Aging. New York: Alan R. Liss, Inc.

Farkas, M.S. Hoyer, W.J. (1980). Processing consequences of perceptual grouping in selective attention. Journal of Gerontology, 35(2), 207-216.

Ford, J.M., Duncan-Johnson, C.C., Pfefferbaum, A., Koppell, B.S. (1982a). Expectancy for events in old age: Stimulus sequence effects on P300 and reaction time. Journal of Gerontology, 37(6), 696-704.

Ford, J.M., Hink, R.F., Hopkins, W.F., Roth, W.T., Pfefferbaum, A., Kopell, B.S. (1979a). Age effects and event-related potentials in a selective attention task. Journal of Gerontology, 34, 388-395.

Ford, J.M., Pfefferbaum, A., Tinkleberg, J.R., Kopell, B.S. (1982b). Effects of Perceptual and cognitive difficulty on P3 and reaction time in young and old adults. Electroencephalography and Clinical Neurophysiology, 54, 311-321.

Ford, J.M., Roth, W.T., Mohs, R.C., Hopkins, W.F., Kopell, B.S.(1979b). Event-related potentials recorded from young and old adults during a memory retrieval task. Electroencephalography and Clinical Neurophysiology, 47, 450-459.

Friedland, R. Weinstein, E. (1977). Hemiinattention and hemisphere specialization : Introduction and Historical Review. In R.P. Friedland & E.A. Weinstein (Eds.) Advances in Neurology, Vol.IX.

Goodin, D.S., Squires, K.C., Star, A. (1978). Long latency event-related components of the auditory evoked potential in dementia. Brain, 101, 635-648.

Greenough, W.T., Green E.J. (1981). Experience and the changing brain. In J.L. McGaugh and S.B. Kiesler (Eds), Aging: Biology and behavior. New York: Academic Press.

Harter, M.R., Anllo-Vento, L., Wood,F.B., Schroeder, M.M. (in press).II Separate Brain Potential Characteristics in Children with Reading Disability and Attention Deficit Disorder: color and Letter Relevance Effects. Brain and Language.

Harter, M.R., Aine, C.A. (1984). Brain mechanisms of visual selective attention. In Parasuraman (Ed.), Varieties of Attention. New York: Academic Press.

Harter, M.R., Aine, C. Schroeder, C.E.(1982). Hemispheric differences in the neural processing of stimulus location and type: Effects of selective attention on visual evoked potentials. Neuropsychologia, 20, 421-438.

Harter, M.R., Guido, W. (1980). Attention to pattern orientation: Negative cortical potentials, reaction time, and the selection process. Electroencephalography and Clinical Neurophysiology, 49, 461-475.

Heilman, K.M. (1979).Neglect and related disorders. In K.M. Heilman & E. Valinstein (Eds.), Clinical Neuropsychology. New York: Oxford University Press.

Hillyard, S.A., Mangun, G.R. (1986). The neural basis of visual selective attention: A commentary on Harter and Aine. Biological Psychology. 23, 265-279.

Hillyard, S.A., Munte, T.F. (1984) Selective attention to color and location: An analysis with event-related brain potentials. Perception and Psychophysics. 36(2), 185-198.

Hillyard, S.A., Picton, T.W. (1979). Event-related brain potentials and selective attention. In J.E. Desmedt (Ed.) Progress in Clinical Neurophysiology. Basel: Karger.

Hoyer,W.J., Plude, D.J. (1980). Attentional and perceptual processes in the study of cognitive aging. In L.W. Poon (Ed.) Aging in the 1980's. Washington, D.C.: American Psychological Association.

Hoyer, W.J., Plude, D.J. (1982). Aging and the allocation of attentional resources in visual information processing. In R. Sekuler, D. Kline, and K. Dismukes (Eds.), Aging and Human Visual Function. New York: Alan R. Liss, Inc.

Hoyer, W.J., Rebok, G.W., Sued, S.M. (1979). Effects of varying irrelevant information on adult age differences in problem solving. Journal of Gerontology, 34, 553-560.

Johnston, W.A., Dark, V.J. (1986). Selective Attention. Annual Review of Psychology. vol. 37, 43-75.

Kinsbourne, M. (1980). Attentional dysfunctions and the elderly: Theoretical models and research perspectives. In Poon, Fozard, Cermak, Arenberg, Thompson, (Eds.),New Directions in Memory and Aging. New Jersey: Erlbaum, 113-130.

Kolb, B., Whishaw, I. (1980). Fundamentals of Human Neuropsychology. San Francisco: W.H. Freeman and Co.

Layton, B.(1975). Perceptual noise and aging. Psychological Bulletin, 82(6): 875-883.

Luria, A.R. & Homskaya, E.D. (1970). Frontal lobes and the regulation of arousal processes. In D.I. Motofsky (Ed.), Attention: Contemporary Theory and Analysis. New York: Appleton-Century-Crofts.

Madden, D.J.(1983) differences and similarities in the improvement of controlled search. Experimental Aging Research, 8(2), 22-26.

Marsh, G.R. (1975). Age differences in evoked potential correlates of a memory scanning process. Experimental Aging Research, 1, 3 - 16.

Marsh, G.R., Thompson, L.W. (1977). Psychophysiology of Aging. In J.E. Birren & K. W. Schaie (Eds.), Handbook on Aging, New York: Van Nostrand Reinhold Company.

Mesulam, M.M. (1981). A cortical network for directed attention and unilateral neglect. Annals of Neurology, 10(4), 309-325.

Milner, B. (1964). Some effects of frontal lobectomy in man. In J.M. Warren & K. Akert (Eds.), The Frontal Granular Cortex and Behavior. New York: McGraw Hill.

Milner, B. (1968). Visual recognition and recall after right temporal lobe excision in man. Neuropsychologia, 6, 191-209.

Mullis,R.J., Holcomb P.J., Diner, B.C., Dykman, R.A. (1985). The effects of aging on the P3 component of the visual event related potential.Electroencephalography and Clinical Neurophysiology, 62, 141-149.

Naatanen, R. (1982). Processing negativity: An evoked potential reflection of selective attention. Psychological Bulletin, 92(3), 605-640.

Neville, H. Lawson, D.(in press) Attention to central and peripheral visual space in a movement detection task: An event-related potential and behavioral study. I. Normal hearing adults. Brain Research.

Nuwer, M.R., Pribram, K.H. (1979). Role of the inferotemporal cortex in visual selective attention. Electroencephalography and Clinical Neurophysiology, 46, 389-400.

Oakley, M., Eason, R.G., McCandies, T.(1986). Pre-cortical gating in the human visual system during selective attention: a topographical analysis. Abstracts of the Society for Neuroscience. Vol. 12, p.1447.

Orlovskaya, D. (1982). The process of aging in light of clinical neuropathology. In R.D. Terry, C.L. Bolis, G. Toffano (Eds.) Neural Aging and Its Implications in Human Neurological Pathology. New York: Raven Press.

Pfefferbaum, A., Ford, J.M., Roth, W.T., Kopell, B.S. (1980). Age differences in P3 - reaction time associations. Electroencephalography and Clinical Neurophysiology, 49, 257-265.

Pfefferbaum, A., Ford, J.M., Wenegrat, B.G., Roth, W.T., Kopell, B.S.(1984a). Clinical application of the P3 component of event-related potentials. I Normal Aging. Electroencephalography and Clinical Neurophysiology, 59, 85 - 103.

Pfefferbaum, A. Wenegrat, B.G., Ford, J.M., Roth, W.T., Kopell, B.S. (1984b). Clinical applications of the P3 component of event-related potentials. II Dementia, Depression, and Schizophrenia. Electroencephalography and Clinical Neurophysiology, 59: 104-124.

Picton, T.W., Stuss, D.T., Champagne, S.C., Nelson, R.F. (1984). The effects of age on human event-related potentials. Psychophysiology, 21(3), 312-325.

Plude, D.J., Hoyer, W.J. (1986). Age and the selectivity of visual information processing. Psychology and Aging, 1(1), 4-10.

Podlesny, J.A.,Dustman, R.E., Shearer, D.E. (1984) Aging and respond - withhold tasks: Effects on sustained potentials, P3 responses and late activity. Electroencephalography and Clinical Neurophysiology, 58, 130-139.

Pritchard, W.S., (1981). Psychophysiology of P300. Psychological Bulletin, 89(3), 506-540.

Rabbitt, P.(1965) An age decrement in the ability to ignore irrelevant information. Journal of Gerontology, 20, 233-238.

Rabbitt, P. (1980). A fresh look at changes in reaction times in old age. In G. Stein (Ed.), The Psychobiology of Aging: Problems and Perspectives. Elsevier North Holland, Inc.

Ritter, W., Simson, R., Vaughan, H.G., Macht, M. (1982). Manipulation of event-related potential manifestations of information processing stages. Science, 218, 909-911.

Scheibel, M.E., Lindsay, R.D., Tomiyasu, U., Scheibel, A.B. (1975). Progressive dendritic changes in aging human cortex. Experimental Neurology, 47, 392-403.

Scheibel,M.E., Lindsay,R.D., Tomiyasu, U., Scheibel, A.B. (1976). Changes in the aging human limbic system. Experimental Neurology, 53, 420-430.

Scheibel, M.E., Tomiyasu, U., Scheibel, A.B. (1977). The aging human betz cell. Experimental Neurology, 56, 598-609.

Schroeder, M.M., & Harter, M.R. (1985) Aging and selective attention: visual event-related potentials. Abstracts for the Society for Neuroscience, Vol 11, p.273.

Siegler, I. (1980). The psychology of adult development and aging. In Busse & D. Blazer (Eds.), Handbook of Geriatric Psychiatry. New York: Van Nostrand Reinhold.

Simson, R, Vaughan, H.G., Ritter, W. (1976). The scalp topography of potentials associated with missing visual or auditory stimuli. Electroencephalography and Clinical Neurophysiology, 40, 33-42.

Simson, R, Vaughan, H.G., Ritter, W. (1977). The scalp topography of potentials in auditory and visual discrimination tasks. Electroencephalography and Clinical Neurophysiology, 42, 528-535.

Skinner, J.E., Yingling, C.D. (1977). Central gating mechanisms that regulate event-related potentials and behavior: A neural model for attention. In J.E. Desmedt (Ed.), Attention, Voluntary Contraction, and Event-Related Cerebral Potentials. Basel: S. Karger.

Smith, D.B.D.,Brent, G., Thompson, L., Michalewski, H. (1978). Age related differences in habituation, orientation and attentional state as indicated by the average evoked potential. Abstracts of the XIth International Congress of Gerontology. Tokyo: Scimed Publications.

Smith, D.B.D., Michalewski, H.J., Brent, G.A., Thompson, L.W. (1980). Auditory evoked potentials and aging: Factors of stimulus task and topography. Biological Psychology, 11, 135-151.

Squires, N.K., Squires, K.C., Hillyard, S.A. Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neurophysiology, 1975, 38, 387-401.

Squires, K., Goodin, D., Starr, A. (1979). Event-related potentials in development, aging, and dementia. In D. Lehmann & E. Callaway (Eds.), Human Evoked Potentials. New York: Plenum Press.

Tecce, J.J, Cattanach, L., Yrchik, D.A., Meinbresse, D., Dessonville, C.L. (1982). CNV rebound and aging. Electroencephalography and Clinical Neurophysiology, 54,175-186

Thompson, L.W., & Marsh, G.R. (1973). Psychophysiological studies of aging. In C. Eisdorfer & M.P. Layton (Eds.), The Psychology of Adult Development and Aging. Washington, D.C.: American Psychological Association.

Ungerleider, L.G., Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M. A. Goodale & R.J. Mansfield (Eds.), Analysis of Visual Behavior. Cambridge,Mass: MIT Press.

Walker, R.F., Seagall, P., Timiras, P.S. (1980). Neuroendocrinology of Aging. In G.J. Maletta & F.J. Pirozzolo(Eds.), The Aging Nervous System. New York: Praeger Publishers.

Welford, A.T. (1977). Motor Performance. In J.E. Birren & K.W. Schaie (Eds.), Handbook of the Psychology of Aging. New York: Van Nostrand Reinhold Company.

Woldorff,M., Hansen, J.C., Hillyard, S.A. (1986). Selective attention alters human auditory sensory processing at 20 - 50 msec. Abstracts of the Society for Neuroscience, vol 12, 1448.

Wright, L.L., Elias, J.W.(1979). Age differences in the effects of perceptual noise. Journal of Gerontology, 34, 704-708.

APPENDIX A

WRITTEN CONSENT FORM

WRITTEN CONSENT

I,_____, voluntarily consent to participate in this study of selective attention under the direction of M. Russell Harter, Ph.D.

A. The implications of my participation in the study, its nature, duration and purpose, the methods and means by which it is to be conducted, including the application of the electrodes have been thoroughly explained to me.

B. I have been given an opportunity to ask any questions I wish concerning this study, and all such questions have been answered to my complete satisfaction. I understand that my participation in this study can be terminated at any time upon my request without any penalty.

C. I understand that my name will never be used to identify information obtained by the project.

D. I am aware that further information about the conduct and review of human research at the University of North Carolina at Greensboro can be obtained by calling 379-5013, the Psychology Department.

_____ _____

signature of subject date

_____ _____

signature of witness date

APPENDIX B

WRITTEN STATEMENT OF PURPOSE AND PROCEDURES

VISUAL SELECTIVE ATTENTION IN YOUNG AND OLDER ADULTS

We have been using brain waves to investigate attentional mechanisms for several years in this laboratory at UNC-G. We are interested in finding out how people can attend to some things and ignore other things that are going on around them. We call this SELECTIVE ATTENTION because people select things on which to focus their attention, and at the same time, select things to ignore.

By measuring electrical activity from the scalp, we get a profile of the activity of different areas of the brain. This profile may be related to attending some event in the environment. This is why we call the brain waves EVENT-RELATED POTENTIALS. We are interested in how brain waves may give us information about what areas of the brain might be involved in selective attention.

There are two things that are different about this study: subjects will be all different ages of adults, form 18 to 85 years old, and the task will be brief so it can be completed several times. The major question that is being addressed by this study is whether selective attention changes as adults get older.

The brain waves will be measured with the standard, safe unharmful procedures that have been used in all of our earlier studies. This procedure involves wearing a cap that fits snugly on one's head. There are electrodes embedded in the cap. One electrode is put on each ear, and one is put high over the right cheekbone to measure eye movements. In order to reduce scalp resistance, the scalp under these electrodes will be rubbed and a small among of gel will be applied.

We will be measuring your brain waves while you play a game that involves paying attention to flashes on a computer screen. While you play it will be necessary to hold very still and not move your eyes. You will be able to stop the game at any time, as often as you want, to rest or move around.

It is important for all subjects to realize that we are only using people in this study that are very healthy mentally and physically. We are not studying or looking for people with "attentional problems". We are only interested in the selective attention mechanisms in NORMAL healthy adults of different ages.

We hope that you will find participation in this study interesting and informative. It will take approximately two blocks of two hours to run one subject completely. Your participation is completely voluntary and you are free to drop out at any time.

APPENDIX C

ANOVA TABLES

TABLE 1

ANALYSIS OF VARIANCE SUMMARY - BEHAVIORAL RESPONSE DATA
F RATIOS > / PROBABILITY

	RT AVERAGE	PERCENT HITS	PERCENT FALSE ALARMS
AGE (A)	6.86/.0202	3.58/.0795	1.01/.3313
FIELD (F)	.24/.6330	1.13/.3064	2.24/.1563
FxA	.97/.3417	.03/.8574	.12/.7347

TABLE 2

ANALYSIS OF VARIANCE SUMMARY - ERP AMPLITUDE
F RATIOS > / PROBABILITY

SOURCE	DF	P144	N188	N325	P445
AGE (A)	(1,14)	7.05/.0188	1.59/.2283	.17/.6900	.95/.3455
SCALP(S)	(2,28)	.72/.4936	3.93/.0312	29.55/.0001	4.93/.0147
SA	(2,28)	2.71/.0840	2.96/.0685	1.60/.2205	4.67/.0178
RELEV(R)	(2,28)	5.52/.0095	.08/.9268	2.23/.1261	31.67/.0001
RA	(2,28)	1.50/.2398	.03/.9735	3.38/.0486	.29/.7485
SR	(4,56)	.33/.8592	.85/.4998	.85/.5015	14.74/.0001
SRA	(4,56)	.34/.8511	1.10/.3678	2.74/.0372	1.87/.1287
FIELD(F)	(1,14)	.01/.9912	.30/.5919	.59/.4549	.26/.6211
FA	(1,14)	.04/.8424	.58/.4591	.46/.5100	.19/.6685
SF	(2,28)	2.10/.1413	.64/.5370	1.94/.1625	4.07/.0218
SFA	(2,28)	.23/.7954	.34/.7129	2.56/.0950	.33/.7188
RF	(2,28)	.09/.9115	3.14/.0590	1.15/.3314	.63/.5405
RFA	(2,28)	.39/.6833	.76/.4780	.42/.6625	.55/.5815
SRF	(4,56)	.85/.4992	.88/.4801	.74/.5695	1.12/.3546
SRFA	(4,56)	.54/.7048	.31/.8699	.55/.7022	.81/.5258
HEMI(H)	(1,14)	.05/.8249	.01/.9293	.02/.8944	.57/.4635
HA	(1,14)	1.73/.2097	.80/.3854	.28/.6061	.01/.9614
SH	(2,28)	3.76/.0358	.16/.8510	.50/.6119	2.38/.1110
SHA	(2,28)	2.99/.0663	1.33/.2804	1.27/.2964	1.55/.2307
RH	(2,28)	.68/.5130	.99/.3829	6.98/.0035	1.86/.1750
RHA	(2,28)	.63/.5393	.05/.9469	2.03/.1503	.68/.5145
SRH	(4,56)	.18/.9479	.36/.8331	3.24/.0184	2.80/.0346
SRHA	(4,56)	.84/.5039	.49/.2166	1.34/.2660	1.00/.4178
FH	(1,14)	4.74/.0471	19.07/.0006	.56/.4657	23.11/.0003
FHA	(1,14)	.04/.8364	.31/.5885	4.50/.0522	6.24/.0256
SFH	(2,28)	.33/.7197	.15/.8640	.96/.3941	1.54/.2317
SFHA	(2,28)	.18/.8364	.21/.8133	1.47/.2461	.68/.5151
RFH	(2,28)	.39/.6787	2.47/.1029	1.25/.3030	.30/.7460
RFHA	(2,28)	1.00/.3804	1.59/.2215	.04/.9611	1.13/.3365
SRFH	(4,56)	.48/.7488	.41/.8033	1.12/.3543	1.64/.1781
SRFHA	(4,56)	.32/.8666	.18/.9488	.67/.6122	.89/.4740

TABLE 3

ANALYSIS OF VARIANCE SUMMARY - LATENCY OF ERPS
F RATIOS> / PROBABILITY

SOURCE	DF	N188	P445
AGE (A)	(1,14)	2.72/.1216	15.53/.0015
RELEV(R)	(2,28)	.46/.6382	2.17/.1329
RA	(2,28)	1.08/.3519	.04/.9633
FIELD(F)	(1,14)	.20/.6590	7.71/.0149
FA	(1,14)	.20/.6590	.70/.4154
RF	(2,28)	.26/.7727	1.35/.2760
RFA	(2,28)	.10/.9028	.54/.5894
HEMI(H)	(1,14)	3.66/.0765	1.06/.3205
HA	(1,14)	.01/.9213	.01/.9380
RH	(2,28)	.81/.4566	.95/.3975
RHA	(2,28)	.22/.8027	2.58/.0937
FH	(2,28)	.01/.9152	2.21/.1592
FHA	(2,28)	1.99/.1804	.93/.3523
RFH	(2,28)	.09/.9150	1.69/.2029
RFHA	(2,28)	.17/.8483	.73/.4923

APPENDIX D

TUKEY POSTHOC TABLES

TABLE 4

POST HOC TESTS FOR SCALP x AGE, P445
Comparing scalp at levels of age

Young	OCC	CEN	FRO	Aged	OCC	CEN	FRO
	5.07	5.47	3.57		3.35	4.03	3.80
OCC	-	.4	1.5**		-	.68	.45
CEN	-	-	1.9**		-	-	.23
FRO	-	-	-		-	-	-

Critical Range (tukey)
* 1.06, $p<.05$
** 1.36, $p<.01$

Comparing age at each level of scalp

OCC	Y	A	CEN	Y	A	FRO	Y	A
	5.07	3.35		5.47	4.03		3.57	3.80
Y	-	1.56**	Y	-	1.44**		-	.23
A	-	-		-	-		-	-

Critical Range (tukey)
* .87, $p<.05$
** 1.18, $p<.01$
Age (A): Young (Y), Aged (A)
Scalp (S): Occipital (OCC), Central (CEN), Frontal (FRO)

TABLE 5

POST HOC TESTS FOR FIELD x HEMISPHERE x AGE, P445
Comparing fields at levels of hemisphere and age

Y,LH	LVF	RVF	Y,RH	LVF	RVF
	4.53	5.29		4.81	4.43
LVF	-	.76**	LVF	-	.38*
RVF	-	-	RVF	-	-
A,LH	3.57	3.90	A,RH	3.75	3.69
LVF	-	.33	LVF	-	.06
RVF	-	-	RVF	-	-

Critical Range (tukey)
* $p < .05 = .357$
** $p < .01 = .496$
Age (A): Young (Y), Aged (A)
Field (F): Left visual field (LVF), Right visual field (RVF)
Hemisphere (H): Left hemisphere (LH), Right hemisphere (RH)

TABLE 6

POST HOC TESTS FOR SCALP x RELEVANCE x AGE, N325
Comparing relevance at each level of scalp and age

OCC, Y	LC	Lc	lc
	-2.00	-3.60	-2.11
LC	-	1.60#	-
Lc	-	-	1.49*
lc	-	-	-

OCC, A	LC	Lc	lc
	-2.78	-2.90	-2.54
LC	-	.12	-
Lc	-	-	.36
lc	-	-	-

CEN, Y	LC	Lc	lc
	-1.03	-2.38	-.56
LC	-	1.35#	-
Lc	-	-	1.82**
lc	-	-	-

CEN, A	LC	Lc	lc
	-1.10	-1.40	-.85
LC	-	.30	-
Lc	-	-	.55
lc	-	-	-

FRO, Y	LC	Lc	lc
	-.44	-1.84	.45
LC	-	1.40#	-
Lc	-	-	1.41*
lc	-	-	-

FRO, A	LC	Lc	lc
	.96	1.03	-.84
LC	-	.07	-
Lc	-	-	1.87@
lc	-	-	-

Critical Range (tukey)
1.18, * $p<.05$
# $p<.05$ (in opposite direction of prediction, feature)

1.58, **$p<.01$
@$p<.01$ (in opposite direction of prediction, spatial)
Age (A): Young (Y), Aged (A)
Scalp (S): Occipital (OCC), Central (CEN), Frontal (FRO)
Relevance (R): LC (Relevant location and relevant color),
Lc (Relevant location and irrelevant color)
lc (Irrelevant location and irrelevant color)

TABLE 7

POST HOC TESTS FOR THE MAIN EFFECT OF RELEVANCE, P144

	LC	Lc	lc
	.275	.470	-.391
LC	-	.195	-
Lc	-	-	.861**
lc	-	-	-

Critical Range (Tukey)
* $p<.05$ = .5732
** $p<.01$ = .7617
Relevance (R): LC (Relevant location and relevant color),
Lc (Relevant location and irrelevant color)
lc (Irrelevant location and irrelevant color)

TABLE 8

POST HOC TESTS FOR SCALP x RELEVANCE, P445
Comparing relevance at levels of scalp

OCC	LC	Lc	lc
	7.38	3.39	1.87
LC	-	3.99**	-
Lc	-	-	1.52**
lc	-	-	-

CEN	LC	Lc	lc
	7.22	4.68	2.34
LC	-	2.54**	-
Lc	-	-	2.34**
lc	-	-	-

FRO	LC	Lc	lc
	4.73	4.30	2.41
LC	-	.43	-
Lc	-	-	1.89**
lc	-	-	-

Critical Range (Tukey)
* $p<.05$ = .751
** $p<.01$ = .997
Scalp (S): Occipital (OCC), Central (CEN), Frontal (FRO)
Relevance (R): LC (Relevant location and relevant color),
Lc (Relevant location and irrelevant color)
lc (Irrelevant location and irrelevant color)

TABLE 9

POST HOC TESTS FOR FIELD x HEMISPHERE, N188
Comparing Visual fields at levels of hemisphere

LH	LVF	RVF	RH	LVF	RVF
	-3.77	-4.57		-4.45	-3.92
LVF	-	.8**	LVF	-	.53*
RVF	-	-	RVF	-	-

Critical Range (Tukey)
* $p<.05$ = .464
** $p<.01$ = .644
Field (F): Left visual field (LVF), Right visual field (RVF)
Hemisphere (H): Left hemisphere (LH), Right hemisphere (RH)

TABLE 10

POST HOC TESTS FOR SCALP x HEMISPHERE, P144
Comparing hemisphere at levels of scalp

OCC	LH	RH	CEN	LH	RH	FRO	LH	RH
	-.159	-.002		.326	-.004		.228	.312
LH	-	.157	LH	-	.330*	LH	-	.084
RH	-	-	RH	-	-	RH	-	-

Critical Range (Tukey)
* p<.05 = .285

Comparing scalp at levels of hemisphere

LH	OCC	CEN	FRO	RH	OCC	CEN	FRO
	-.159	.326	.228		-.002	-.004	.312
OCC	-	.485**	.387**	OCC	-	.002	.314
CEN	-	-	.098	CEN	-	-	.316
FRO	-	-	-	FRO	-	-	-

Critical Range (Tukey)
* p<.05 = .332
**p<.01 = .429
Scalp (S): Occipital (OCC), Central (CEN), Frontal (FRO)
Hemisphere (H): Left hemisphere (LH), Right hemisphere (RH)

TABLE 11

POST HOC TESTS FOR SCALP x RELEVANCE x HEMISPHERE, N325
Comparing hemisphere at levels of scalp and relevance

OCC,LC	LH	RH	OCC,Lc	LH	RH	OCC,lc	LH	RH
	-2.57	-2.27		-3.13	-3.37		-2.17	-2.48
LH	-	.24	LH	-	.24	LH	-	.31
RH	-	-	RH	-	-	RH	-	-

CEN,LC	LH	RH	CEN,Lc	LH	RH	CEN,lc	LH	RH
	-1.67	-.46		-1.81	-1.97		-.40	-1.01
LH	-	1.21**	LH	-	.61	LH	-	.61**
RH	-	-	RH	-	-	RH	-	-

FRO,LC	LH	RH	FRO,Lc	LH	RH	FRO,lc	LH	RH
	.01	.5		-.38	-.42		.02	-.41
LH	-	.49*	LH	-	.04	LH	-	.43*
RH	-	-	RH	-	-	RH	-	-

Critical Range (Tukey)
* $p<.05$ = .389
** $p<.01$ = .52

Comparing scalp at levels of relevance and hemisphere

LH,LC	OCC	CEN	FRO
	-2.51	-1.67	.01
OCC	-	.84**	2.52**
CEN	-	-	1.68**
FRO	-	-	-

RH,LC	OCC	CEN	FRO
	-2.27	-.46	.5
OCC	-	1.81**	2.77**
CEN	-	-	.96**
FRO	-	-	-

LH,Lc	OCC	CEN	FRO
	-3.13	-1.81	-.38
OCC	-	1.32**	2.75**
CEN	-	-	1.43**
FRO	-	-	-

RH,Lc	OCC	CEN	FRO
	-3.37	-1.97	-.42
OCC	-	1.4**	2.95**
CEN	-	-	1.55**
FRO	-	-	-

LH,lc	OCC	CEN	FRO
	-2.17	-.40	.02
OCC	-	1.77**	2.19**
CEN	-	-	.42
FRO	-	-	-

LH,lc	OCC	CEN	FRO
	-2.48	-1.01	-.41
OCC	-	1.47**	2.07**
CEN	-	-	.60**
FRO	-	-	-

Critical Range (Tukey)
* $p<.05$ = .468
** $p<.01$ = .595
Scalp (S): Occipital (OCC), Central (CEN), Frontal (FRO)
Relevance (R): LC (Relevant location and relevant color)
Lc (Relevant location and irrelevant color)
lc (Irrelevant location and irrelevant color)
Hemisphere (H): Left hemisphere (LH), Right hemisphere (RH)

POST HOC TABLE 12

POST HOC TESTS FOR MAIN EFFECT OF SCALP, N188

		OCC -3.94	CEN -4.80	FRO -3.79
OCC	-		.86	.15
CEN	-		-	1.01*
FRO	-		-	-

Critical Range (Tukey)
* $p<.05$ = .972
** $p<.01$ = 1.254
Scalp (S): Occipital (OCC), Central (CEN), Frontal (FRO)