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The Effects of Age & Practice on the Speed of Processing in the Functional Field of View

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THE EFFECTS OF AGE AND PRACTICE ON THE SPEED OF PROCESSING IN THE FUNCTIONAL FIELD OF VIEW

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ON THE SPEED OF PROCESSING

IN THE FUNCTIONAL FIELD OF VIEW

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Previous studies have indicated that the useful or functional field of view is a dynamic visual measure. Specifically, it has been shown to constrict as a function of increasing age, decreasing target duration, decreased conspicuity, and to expand as a function of practice. Two possible explanations for the age-related decline were examined: (1) older observers have a deficit in selective attention which prevents them from ignoring irrelevant information, thereby making a target less conspicuous, and (2) the time required to process a given visual area increases with age. The purpose of this study was to determine which of these explanations would most likely account for the age-related constriction of the useful field of view.

Four young, five middle-aged, and five older observers were each tested at five brief target durations on two versions of a peripheral localization task: one with distractors and a similar task without distractors. Both tasks employed a concurrent focal task. All observers were then trained for five consecutive sessions on the same peripheral localization task with distractors, followed by post-training testing on both tasks. As expected, errors in radial localization performance increased with age and also at greater eccentricities for both tasks. Only the middle-aged observers demonstrated significant improvement on both tasks as a result of practice. Young observers, however, performed so well initially that little room was left for improvement. Conversely, older observers performed poorly before and after training reflecting the age-related difficulty of the tasks. Overall, the results were consistent with the hypothesis that the time required to process a given visual area increases with age.

Chapter I

Introduction

Although usually taken for granted, performance in everyday activities is heavily dependent upon vision. In particular, the ability to detect, localize, or identify an object in the periphery allows a person to perform successfully in sports and job-related activities. But most importantly, these abilities allow us to navigate or avoid potential hazards in the environment. For example, certain occupations such as airline piloting and air traffic control obviously rely on sharp peripheral vision. Because of the tremendous reponsibility for public safety associated with these positions, good peripheral vision is very important. However, common activities such as operating an automobile or crossing a busy street are equally dependent upon an adequate field of view (FOV).

Perimetric tests, both static and kinetic, are used clinically to assess the extent of the visual field. This assessment is accomplished by using a spot of light varying in size and intensity to map the borders of peripheral vision. Several studies using these tests have indicated that the visual field constricts with age (Burg, 1968; Drance, Berry, & Hughes, 1967; Harrington, 1964; Wolf, 1967; Williams, 1983). Perimetric tests, however, have not been found to be predictive of visual problems that visually normal, elderly people encounter in ordinary situations. In fact, older individuals have a greater tendency to report problems in situations involving many distracting elements or visual clutter (Kosnik, Winslow, Kline, Rasinski, & Sekuler, 1988). Since perimetric tests incorporate no additional elements, it is not surprising that they fail to confirm the visual difficulties older people experience.

Sekuler and Ball (1986) developed a task which attempted to provide a more "realistic" assessment of the useful FOV (UFOV). By incorporating a secondary focal task and additional distractors in a radial localization task, it was found that older observers do experience a constriction in the FOV, especially in the presence of distractors (Ball, Beard, Roenker, Miller, & Griggs, 1988; Sekuler and Ball, 1986). It was also reported that some of this loss in the UFOV with age could be recovered with practice on the task (Ball et al., 1988; Sekuler and Ball, 1986). In addition, techniques which include both a secondary focal task and distractor stimuli have been found to better predict the frequency and severity of peripheral field problems in everyday contexts than perimetric measures of the visual field (Ball, Owsley, &

Beard, 1989).

There are at least two hypotheses for the observed age decrement in the size of the UFOV. The first hypothesis is based on the results of cognitive studies which demonstrated an age-related deficit in selective attention. Specifically, older observers have been found to have more difficulty ignoring irrelevant stimuli or distractors than their younger counterparts (Layton, 1975; Mackworth, 1965; Rabbitt, 1965). Thus, given the presence of distractor elements, fewer attentional resources can be allocated to the relevant target. The second hypothesis is based on the results of visual masking studies which demonstrated that stimuli persist longer in the nervous system of older adults (Walsh, 1976; Walsh, Till, & Williams, 1978; Walsh, Williams, & Hertzog, 1978). These results, which indicate an age-related slowing in visual processing, could also account for an age-related constriction in the UFOV given that the size of the UFOV varies with stimulus duration.

Since the radial localization task (Ball et al., 1988; Sekuler and Ball, 1986) requires divided attention (i.e., observers are forced to locate the relevant target among simultaneously presented distractors) and age differences are maximized in the presence of distractors, it is possible that a deficit in selective attention could account for previous research findings of an age-related constriction of the UFOV. To test this hypothesis, D. Ball (1985) tested observers in three age groups: younger, middle-aged, and older on their ability to localize a target in a particular set of distractors after training them on another such combination. Prior to training, observers were tested on localizing an oval-shaped face among box distractors and a box-shaped face among oval distractors at two stimulus durations (90 and 120 msec). Half of the observers were then trained on one of the conditions at 120 msec, and half were trained on the other condition at 120 msec. Each observer was retested on both conditions after training. All observers demonstrated improved performance on the trained condition at both stimulus durations. However, only the youngest age group showed a transfer of training to the untrained condition (at 120 msec). No transfer of training occurred at the faster duration for the untrained condition.

D. Ball (1985) argued that if speed of processing was the sole factor influencing the age difference, then the effects of training should have transferred to the untrained condition where the target and distractor were reversed. He concluded, based on these results, that the age-related deficit in radial localization was most consistent with a selective attention deficit theory. He also stated, however, that it was much easier for all observers to localize an oval face in box distractors than a box face in oval distractors. Since there may be a difference between training on an easier target and on a more difficult one, this difference obfuscates any conclusions about the basis behind the effects of training on the stimulus reversal. In addition, since there was a transfer of training to the faster target duration for all observers on the trained condition, the speed of processing explanation can not be ruled out.

The present study sought to systematically examine the effect of stimulus duration on the size of the UFOV using this same radial localization task. Specifically, this experiment attempted to determine if age-related slowing of visual processing could be ruled out as an explanation for the age decrement in the extent of the UFOV.

Chapter II

Literature Review

The Functional Field of View

When the complexity of the modern world is considered, it becomes obvious that peripheral vision is an important and necessary visual function for survival. Specialized occupations such as air traffic control and airline piloting, as well as common activities like driving an automobile or crossing the street, are heavily dependent on an adequate field of view (FOV). Despite the seeming importance of peripheral vision, there has been relatively little research emphasis placed on measures of functional peripheral vision in everyday situations.

Perimetric Measures

Perimetric tests are used clinically to assess the extent of the visual field. Kinetic perimetry tests map the borders or "isopters" which delineate the eccentricities at which the stimulus, moving inward toward fixation, is first detected. Specifically, a spot of light varying in size and intensity is projected onto the inside wall of a dark hemispherical shell. The spot is moved along predetermined meridians from the periphery to the central fixation point, and the point at which the observer sees the spot is recorded. Numerous studies using kinetic perimetry techniques have shown constriction in the visual field of older adults (Burg, 1968; Drance, Berry, & Hughes 1967; Harrington, 1964; Wolf, 1967; Williams, 1983).

Any loss in peripheral vision should have important implications for performance on daily activities such as operating an automobile. For example, Johnson and Keltner (1986) reported that automobile drivers with severe binocular visual field loss had accident and conviction rates twice as high as those with normal visual fields. Other studies, however, have not been able to demonstrate a relationship between driving performance and perimetrically determined visual field loss (Cole, 1979; Council and Allen, 1974).

The failure to find a relationship between everyday activities and normal visual field loss could be due to the way in which visual fields are measured. Perimetric tests measure sensitivity to luminance under highly unnatural conditions; the target is a simple spot of light presented in isolation and observers are aware of where it will appear. On the other hand, common visual activities, such as driving a car, are much more complex than this clinical situation. These activities involve a multitude of visual processes which are not assessed with perimetry tests. For example, clinical tests do not measure performance in the peripheral field while observers perform a secondary task or when the field contains additional stimuli. Measures of the extent of the visual field which incorporate these factors, defined as measures of the "functional" or "useful" field of view (UFOV), provide an index of the total area of the visual field in which useful information can be acquired without eye and head movements (Sanders, 1970). Recently, laboratory tasks designed to more closely approximate situations encountered in everyday life (i.e., to measure the UFOV) have been found to better predict older observers' difficulties with peripheral vision (Sekuler and Ball, 1986). These tasks will now be discussed in relation to age-related declines in the visual field.

Tests which Mimic Realistic Situations

Several studies have examined performance on a peripheral task while observers perform a secondary focal task. For example, the addition of a foveal discrimination task has been shown to result in greater peripheral localization errors for all observers (Sekuler and Ball, 1986; Leibowitz and Appelle, 1969). When the difficulty of the foveal task is increased, localization, detection, and identification performance declines even further (Ball, Beard, Roenker, Miller, and Griggs, 1988; Ikeda and Takeuchi, 1975; Williams, 1982; Williams and Lefton, 1981). Sekuler and Ball (1986), however, reported no age difference in peripheral localization as a result of the addition of the center task. But, in subsequent studies when the difficulty of the foveal task was increased and the visual display expanded (from 15 to 30 degrees), age differences were present with the older observers being at a particular disadvantage (Ball et al., 1988).

Additional stimuli within the visual field is another factor known to influence the size of the UFOV. Several researchers have examined age differences in the UFOV by employing both distractors and a foveal task (Ball et al., 1988; Scialfa, Kline & Lyman, 1987; Sekuler and Ball, 1986). In general, with the addition of distractors, age differences are maximized at greater eccentricities. For example, Sekuler and Ball (1986) reported that localization of a cartoon face was greatly impaired by the presence of 47 outline boxes in the visual field, especially at increasing eccentricities (out to 15 degrees) for older observers. In addition, the presence of those distractors resulted in a greater decline in localization performance than did the concurrent foveal task. In fact, a more recent study which extended the boundaries of the visual display, revealed that while the young and middle aged groups have shown a progressive increase in errors through 30 degrees, the older group reached a ceiling at 20 degrees reflecting shrinkage in the UFOV (Ball et al., 1988). The validity of these results has been strengthened by the findings of a recent survey collected on 113 adults ages 18 to 95. Five times more older than younger adults reported difficulty with everyday visual distractors such as locating a friend in a crowd, or reading a street sign in the presence of other signs (Kosnik, Sekuler, and Kline, 1986). Thus, techniques which include distractor stimuli along with a concurrent focal task are much more predictive measures of the extent of the UFOV than are simple perimetric tests (Ball, Owsley, and Beard, 1989).

There is also evidence that each element in the visual display of a peripheral localization task is processed simultaneously in a parallel fashion. For example, the age-related decline in localization performance reported by Ball et al. (1988) was found to be a function of distractors in the visual field. Furthermore, performance was unaffected by variations in the number of distractors present (Ball et al., 1988). In other words, the presence of distractors rather than the number of distractors was responsible for the age decrement. This result indicates that the visual field is being processed in parallel. Thus, there is an age-related decline in the size of the UFOV that can be processed in a parallel, preattentive manner. This conclusion conflicts with the results reported by Plude and Doussard-Roosevelt (in press). They indicated that age differences are associated with complex visual tasks requiring serial processing, such as feature-integration tasks. No age decrement was evident on tasks which were processed in parallel (i.e., when the target could be discriminated from the distractors based on a single stimulus feature, and display size and eccentricity had no effect on performance). However, when the task required target detection based on a conjunction of stimulus features, processing was serial and age deficits were maximized at the greater eccentricities. The absence of an age-related decrement on the task processed in parallel in this study can be explained by the use of a smaller visual display (10 degrees maximum) and the fact that the stimuli used possessed greater texton differences than the stimuli utilized by Ball, et al. (1988). The age differences reported by Ball et al. (1988) and Sekuler and Ball (1986) using a task processed in parallel, could also be associated with the masking display which follows the stimulus display. As shall be discussed in a later section, older observers are more adversely affected by marking stimuli.

Other studies using a peripheral identification task, however, have demonstrated that the number of distractors does have an impact on identification performance in the periphery. (Drury and Clement, 1978; Mackworth, 1965; Scialfa, Kline, and Lyman, 1987). The discrepancy between these studies and the results reported by Ball et al. (1988) may be due to the nature of the task. It appears that peripheral localization is accomplished in a preattentive mode. The field is searched in parallel and the addition of extra distractors causes no difference in performance. A peripheral identification task, however, seems to require a serial search where additional stimuli must be compared item by item in memory causing a decline in performance speed.

The similarity between the target and the background distractors has also been shown to be a factor in visual search and the size of the FOV (Bergen and Julesz, 1983; Bloomfield, 1972; Engel, 1971; 1974; 1977; Julesz, 1981, Julesz and Bergen, 1983; and Treisman and Gelade, 1980). In fact, it has been demonstrated that the diameter of the visual field that can be searched in parallel varies as a function of the similarity, or texton differences, between the target and the background features (Bergen and Julesz, 1983). Targets very similar in appearance to the irrelevant stimuli would force an item by item search of the visual field. Ball et al. (1988) employed a target (cartoon face) with features very dissimilar to the distractors (outline boxes), so it is not surprising that the number of distractors was not a factor. The other studies, however, have used letters as targets and distractors which create much more difficult discriminations requiring serial search (Mackworth, 1965; Scialfa et al., 1987).

Expanding the FOV through Training

The results of experiments which measure the UFOV as as a function of age, distractor stimuli, and secondery task characteristics illustrate that the size of the UFOV is not static. This conclusion in turn suggests that expansion of the UFOV should be possible under certain circumstances. Several investigators have demonstrated that sufficient practice on a peripheral task can expand the UFOV (Sailor, 1973; Sekuler and Ball, 1986) and that this improved performance endures over several months (Ball et al., 1988).

Ball et al. (1988) measured the UFOV in young, middled-aged, and older observers. A 10 degree shrinkage in the useful FOV was reported with each successive age group. Specifically, performance of the younger observers at 30 degrees was equivalent to the middle-aged observers at 20 degrees and the older observers at 10 degrees. Training was found to partially reverse this loss. After five days of practice on a radial localization task, all three age groups showed expansion of the UFOV by 10 degrees. In effect, the middle-aged observers were able to recover all of the loss in the UFOV due to age, while the older observers were able to recover only half of this loss.

Summary

Kinetic perimetry, radial localization, and radial identification tasks have all demonstrated that the extent of the UFOV declines with age. Citing the absence of a correlation between the size of the UFOV and driving performance, perimetric tests have been criticized for being too artificial. Visual field tests which incorporate both a foveal task and distractors better predict the reported difficulties of older observers (Ball, Owsley, and Beard, 1989). Additionally, these tests capture the dramatic shrinkage of the UFOV with age and demonstrate that this visual loss can be partially reversed with training on a radial localization task.

Two theoretical explanations which address age differences in the extent of the UFOV will now be explored.

Bases for Age Differences in the Functional FOV

There are at least two hypotheses which could possibly account for the age differences indicated by the

Sekuler and Ball (1986) radial localization task. It has been suggested that the reported restriction of the UFOV could be explained by a deficit in selective attention which prevents older observers from ignoring visual noise or irrelevant stimuli (Layton, 1975; Mackworth, 1965; Rabbitt, 1965). A second hypothesis indicates that the age difference in performance may be due to the increased persistence of the stimulus trace in the nervous system of older adults indicating an age-related slowing in visual processing (Walsh, 1976; Walsh, Till and Williams, 1978; Walsh, Williams and Hertzog, 1978). Evidence which supports each hypothesis will be reviewed.

Deficit in Selective Attention

Because the capacity of the visual system is limited, certain inputs must be selected for further processing while other information is filtered out (Norman and Bobrow, 1975). It has been hypothesized that older individuals show a decrement in their ability to filter out the irrelevant information. Layton (1975) has referred to this theory as the perceptual noise hypothesis or the attentional deficit theory. This perceptual distinction is often characterized by a decline in ability to identify or locate a target embedded in a visual field of irrelevant or distracting elements with increases in age. For example, this age difference has been demonstrated using a card-sorting technique (Rabbitt, 1965). Young (mean age 19) and older subjects (mean age 63) were required to sort cards into two separate piles containing either the letter A or the letter B. As the number of distracting letters on each card increased, so did the difference in sorting times between the older and younger subjects. It was concluded that older persons had more trouble sorting cards because of their inability to ignore irrelevant information.

Wright and Elias (1979) argued that the perceptual noise hypothesis is overly simplified. They suggested that the age differences reported by Rabbitt (1965) may have been due to the older subjects' inability to discriminate relevant from irrelevant information rather than to "ignore" irrelevant stimuli.

Methods requiring a selective visual search or divided attention, such as the card-sorting technique cannot determine whether older subjects have trouble discriminating or ignoring distractors. To abrogate this problem, Wright and Elias (1979) used a selective focusing task in which subjects know beforehand the position of the relevant target. This method eliminates the need to discriminate targets from distractors. In their task, the target was presented in the center of a horizontal display. On some trials irrelevant information was presented next to the target. The presence of irrelevant neutral stimuli increased response times for both young and older subjects. There was, however, no age difference. These results suggest that there is no age difference in a selective focusing task, and that the age-related disadvantage reported by Rabbitt (1965) may reflect an older person's inability to discriminate relevant from irrelevant information.

Farkas and Hoyer (1980) conducted two experiments which provided evidence supporting the results of the Wright and Elias (1979) study. Young (18-30 years), middle-aged (37-58) and older (60-81) adults were presented a card-sorting task where the letter target was flanked by letter distractors that were either of the same orientation as the target (parallel) or were perpendicular to the target. Subjects were required to report the orientation of the target. In the divided attention experiment, the position of the target varied from card to card. All the subjects were reportedly slowed by the presence of distractors parallel to the target. However, only the elderly subjects were slowed by distractors perpendicular to the target. In the second experiment, no search was required; the target remained in the same position on each card (focused attention). While no age group was slowed by the perpendicular distractors, only the elderly subjects were slowed by distractors parallel to the target. These results indicate that age differences in selective attention vary as a result of the processing demands on the observer. Age differences are maximized when a visual search is required and when salient physical clues are minimized.

The above findings (Farkas and Hoyer, 1980) illustrate an important distinction. Namely, that the magnitude of age differences is greatest when the cognitive demand of the visual task is also great. These situations are characterized by serial search which is slow and limited in capacity (Shiffrin and Schneider, 1977). Some visual tasks, however, seem to be processed automatically and do not require mental effort or attention. In these cases, the visual field is processed rapidly, in parallel and without capacity limitations. Automaticity is usually developed through extensive training, and once learned, is difficult to alter or suppress (Shiffrin and Schneider, 1977).

Once a visual task has become "automatic" it is believed to be mediated by preattentive mechanisms (Neisser, 1967). If the attentional deficit theory is correct, then age differences should be at a minimum when automatic processes are activated. Based on this assumption, it appears that a deficit in selective attention is inadequate to explain the age differences obtained using a radial localization task, which is processed preattentively (Ball et al., 1988; Sekuler and

Ball, 1986). It must be remembered, however, that this radial localization task differs in several respects from the tasks used to generate this theory. Ball et al. (1988) and Sekuler and Ball (1986) used a localization task incorporating both a secondary focal task and distractors. In addition, they used a high level of uncertainty (24 possible target positions) and a greatly expanded range of eccentricity (out to 30 degrees). In contrast, most experiments have used identification tasks with limited uncertainty and range of eccentricity, and no secondary tasks. So, even though peripheral localization is accomplished in parallel the combination of additional elements which have been presented seems to increase the demand on the visual processing resources. With modification to account for these factors, the attentional deficit theory can account for the results associated with radial localization.

Shiffrin and Schneider (1977) developed a task combining memory search with visual search to explore the characteristics of serial and automatic processing. In each trial, subjects were initially presented a set of letters or digits to be memorized, followed by a rapid sequence of frames, one of which contained the target. Subjects responded to the presence or absence of the target. Automaticity was reportedly developed when the memory set always contained the same elements from one category (e.g., digits) and the distractors from another (e.g., letters) over many trials. Subjects who had developed an automatic detection response were unaffected by changes in memory set size or display size. When the eleMeNts of the memory set and distractors changed from trial to trial, subjects were forced to rely on serial scanning or controlled search processes which were affected by changes in the size of the memory set or display.

Plude and Hoyer (1981) adopted the Shiffrin and Schneider (1977) method to assess adult age differences in serial processing. Young (mean age 23.6) and old (mean age 75.0) subjects were presented displays containing a target from either a constant memory set or a changing memory set. The displays also contained varying numbers of distractors. When the elements of the display changed from trial to trial, older subjects performed poorer than the younger subjects. When the displays were consistent, however, there was no age difference. These results suggest that age differences are associated with greater information processing demands and that these differences can be reduced or eliminated under conditions employing consistent training.

The results from the radial localization task reported by Sekuler and Ball (1986) and Ball et al. (1988) seem consistent with a modified form of the selective attention deficit theory (i.e., accounts for shrinkage in the UFOV with age and the increased processing demand associated with multiple elements and high uncertainty in a parallel task). The task requires divided attention where subjects are forced to locate the relevant target among simultaneously presented distractors. The magnitude of age difference was greatest with the presence of distractors. In addition, performance improved dramatically with practice. One question remaining unanswered from that task, however, regards the underlying basis for improvement. Were subjects learning to allocate a greater percentage of processing resources to the target by discriminating relevant from irrelevant stimuli? If the target was becoming more salient, then switching the trained, relevant target with the distractors should create an immediate reduction in localization performance as well as a substantial increase in age differences.

To test this hypothesis, D. Ball (1985) tested younger, middle-aged, and older subjects' ability to localize both an oval-shaped face amidst box (or square-shaped) distractors, and a box-shaped face amidst oval-shaped distractors at two stimulus durations (90 and 120 msec). Half the observers were trained on the oval face target and box distractors at 120 msec, while the other half was trained on the box face target and oval distractors at 120 msec. Each of the observers was retested after training on all the conditions. Each age group demonstrated improved performance on the trained condition at both stimulus durations. Only the youngest group, however, demonstrated a transfer of training to the untrained condition. No transfer of training occurred at the faster duration. Based on these results, D. Ball (1985) concluded that the performance decrement in radial localization associated with aging is consistent with selective attention deficit theory.

In summary, there is consistent evidence for an age-related deficit in selective attention, especially under conditions where processing demands are great. Age differences are maximized under conditions with changing target sets requiring visual search and on tasks which require divided attention and the ability to discriminate distractors from the target. In contrast, age differences are minimized when processing demands are reduced, when automatic processes are activated and on tasks utilizing selective focusing. The next section reviews evidence for a slowing of visual processes in the elderly.

Deficit in Speed of Processing

The second hypothesis which may explain the age-related restriction in the UFOV states that as people age, the speed of visual processing decreases. As a result, more time is needed to detect, identify, or localize visual stimuli. If a task employs very brief durations followed by a high energy mask, older persons should naturally be at a disadvantage. The following section will review the theoretical basis behind this reduction in processing speed as well as studies that illustrate this concept.

Studies of Visual Persistence

The human visual system is typically conceptualized as a complex information processing machine in psychophysical studies. Haber (1969) and Sperling (1963) described the processing of information as a temporal hierarchy of visual events involving transformation of information and different levels of storage. Visual percepts are created in a stepwise (serial) fashion through interdependent levels of analysis, and this process involves an exchange of energy and time.

Much research has focused on sensory memory, the earliest stage of storage in the visual system. Tachistoscopic studies have demonstrated that figures exposed for very brief durations (as brief as one msec) are perceptible largely because an image remains within the visual system even after the physical exposure is terminated (Sperling, 1960; 1963).

Sensory memory stores all visual information in its literal form for about one second before it decays. This store enables the stimuli to persist perceptually after physical offset during which time visual processing continues. It is also apparent that the perceptual image only lasts long enough to allow four or five elements of a display to be transformed from visual memory to a more permanent, short term verbal memory. Neisser (1967) refers to this sensory store as iconic memory.

Information held in iconic memory is regarded as precategorical. Sperling (1960), using his partial report technique, reported that subjects could not separate elements in a display according to category, digits or letters. In other words, the information is not coded or interpreted while in this storage system. Of course at some point in visual processing, data does become translated into some meaningful form, where patterns are recognized and stimuli are labelled. This process most likely involves recoding and transformation to short term storage.

It is clear from tachistoscopic studies (Sperling, 1960, 1963) and from information processing theory that the duration of the iconic store is a critical variable for visual perception. It is not precisely clear, however, how long the iconic store endures. Sperling (1960, 1963) suggested that it lasts for about one second. But, this estimate is subject to change depending on such variables as stimulus intensity and duration

(Mackworth, 1963). Mackworth (1963) demonstrated that the number of digits correctly reported from a 2x5 array increased dramatically with increases in exposure time (and also intensity which is a function of duration) up to 50 msec. At that point accuracy leveled off, suggesting that the icon had become completely established.

Visual Masking Studies

In addition to factors such as target duration and intensity, a stimulus presented in close temporal proximity to the target stimulus also has an influence on the duration of the icon. Rarely in life is a single stimulus viewed in isolation of other stimuli. Rather, visual events are constantly occurring in succession. Since the duration of each event is extended in iconic memory, there will be in most situations considerable image overlap.

Visual masking studies are based on this kind of interaction; the perception of a test stimulus (TS) is masked or obscured by the close temporal presentation of a masking stimulus (MS). This effect is quantitatively defined as the amount the TS threshold is raised by the presentation of the MS (Weisstein, 1968). The magnitude of this effect is mediated by the figural, spatial, temporal, and intensive characteristics of the interacting stimuli (Felston and Wasserman, 1980). Visual masking is a useful paradigm in that it can control the duration a stimulus is available in the visual system for processing by destroying or interfering with the iconic image (Spoehr and Lehmkuhle, 1982).

Many methods have been used to investigate various aspects of visual masking. One type of study seeks to determine the nature of the MS and its relation to the TS. This kind of experiment varies the stimuli used as a MS. Typical MSs include a homogenous flash of light, a field of random noise, or a patterned stimulus which shares figural characteristics, such as spatial frequency and contour information, with the TS. Another type of study examines the relationship of a mask placed adjacent to the original position of the TS. This arrangement has been shown to result in "erasure" of the contiguous TS, and is referred to as metacontrast masking (Averbach and Coriell, 1961).

A major factor in masking involves the temporal relationship between the MS and the TS. In most masking studies there is a brief interval between the stimuli. The time elapsed between the offset of the first stimulus and onset of the second stimulus is referred to as the interstimulus interval (ISI). The amount of time between the stimuli needed to escape the effects of masking is called the critical interstimulus interval (ISIc). If the ISI is set equal to zero, then the amount of time needed to escape masking would be the critical target duration. However, in some studies, the second stimulus is presented before the offset of the first stimulus or immediately after presentation of the first stimulus. In these cases, the time between the onset of the first and the second stimulus, called stimulus onset asynchrony (SOA), is the relevant variable. When the MS precedes the TS, the effect is called forward masking, and the SOA will have a positive value. If the MS follows the TS, backward masking results and the SOA value is negative.

Age Differences in Stimulus Persistence

There is an overwhelming consensus in the literature that temporal resolving power declines as humans age (Botwinick, 1984; Sekuler, Kline, & Dismukes, 1983). These studies have typically used Haber and Standing's (1969; 1970) measure of stimulus persistence duration. In this method, two stimuli are presented in close temporal succession. At brief intervals the stimuli appear as a single fused, smeared, or conjoined stimulus. The ISIc is the length of time between the stimuli needed to recognize the stimuli as two separate elements. Older adults have been found to require longer delays between stimuli before both are seen as separate percepts.

Kline and Baffa (1976) utilized a clever technique developed by Eriksen and Collins (1967) for assessing age differences in stimulus persistence. They presented two patterned dot stimuli which formed a word when presented simultaneously. Presented alone, each stimulus formed a corresponding word half constructed of assymetrical half letters. It was hypothesized that older subjects would recognize more words at increasing ISI's than young subjects due to increased stimulus persistence in the visual system. Contrary to thought, however, younger subjects identified more words at each level of ISI. The authors suggested that these results may have been due to the older subjects' difficulty in achieving closure with the pattern dot stimuli (Basowitz and Korchin, 1957), as well as luminance summation problems with black stimuli against a white background.

Kline and Orme-Rogers (1978) controlled these problems in a later study by presenting white line segments against a black background. In this attempt, older subjects identified significantly more words at both stimulus durations (20 and 30 msec) than younger subjects. In addition, this advantage increased for the older subjects with longer ISI's. The results of this study provide strong support for the theory that there is a loss in temporal resolution with age. This loss has also been confirmed in studies of critical flicker fusion (Brozek and Keys, 1945; Coppinger, 1955; Misiak, 1947), complementary afterimages (Kline and Nestor, 1977) and masking (Kline and Birren, 1975; Kline and Szafran, 1975).

One explanation for this decline in temporal resolution with age is the stimulus persistence hypothesis (Axelrod, 1963; Botwinick, 1984). It suggests that the older visual nervous system recovers from the effects of stimulation more slowly than younger systems, and that this decline causes stimuli to overlap or combine during processing when presented close in time. Thus, in older subjects, the image of the first stimulus persists longer in the visual system and is more susceptible to interference from a second stimulus.

In summary, the majority of studies utilizing Haber and Standing's (1969) method provide support for the hypothesis that the senescent nervous system slows as it ages, and as a result of this change, older people experience an increase in the visual persistence of stimuli. This finding has an interesting implication for visual masking studies. With age-related increases in stimulus persistence, there should be corresponding changes in masking. The next section explores age differences in studies using a visual masking paradigm.

Age Differences in Masking Studies

Investigations of age differences using masking paradigms have been generally supportive of a major conclusion from stimulus persistence studies; there is greater perceptual interaction between temporally contiguous stimuli for older adults. In other words, older adults have an increased vulnerability to the effects of masking for longer periods of time.

In a study illustrating how the speed of processing slows with age, Kline and Szafran (1975) presented two-digit target stimuli at several durations to young (ages 21 to 36) and older subjects (ages 61-76) in a backward, monoptic masking design. The TS was followed by a 100 msec visual noise MS. They reported that as TS duration increased, the ISI's needed for 50% correct identification of the TS were much greater for the older group. They interpreted these results to mean that older people require more time to process a stimulus completely.

By manipulating the intensity, figural characteristics, and temporal properties of the mask relative to the target, it has been demonstrated that the effects of masking can be systematically imposed at different points of processing in the visual system (Turvey, 1973). For example, a mask comprised of spatially random noise, greater energy than the target, and presented monoptically (same eye as the target) has been shown to create masking interference at a point peripheral to the visual cortex, such as the retina, lateral geniculate nucleus, or the striate cortex (Turvey, 1973). In contrast, a mask with figural characteristics similar to the target, less energy than the target, and presented dichoptically, has been reported to exert masking at a common central or cortical location (Turvey, 1973). The distinction between masking arising peripherally and centrally has provided an impetus for examining developmental changes at different stages of visual processing.

Walsh, Till, and Williams (1978) examined age differences at the peripheral level of processing by using a random noise MS comprised of a pattern of line segments and letter TSs presented at three energy levels (9.6, 19.2, 38.4 cd/m^2 x msec units) in a backward, monoptic task. Changes in target energy resulted in proportional changes in processing speed for both young and older adults. The older adults, however, required longer ISIs at all TS energy levels to escape the effects of masking. This age difference increased as the energy level of the TS decreased. When subjects were tested for identification accuracy at various energy levels without a MS, the results for both age groups were equivalent. Walsh et al. (1978) argued that these results emphasize a slowing in peripheral processing with age as opposed to physical changes in the eye.

Till (1978) replicated the findings reported by Walsh et al. (1978) in a study which greatly extended the range of target energies presented to young (mean age 20.3 years) and old (mean age 55.4 years) subjects. He utilized three similar target energy levels from Walsh et al. (1978) and added four levels considerably greater in energy (15.4, 19.2, 38.4 cd/m^2 x msec units plus 49.2, 76.8, 123.2, 154.0 cd/m^2 x msec units). Older subjects required more time to process targets at all energy levels. However, in this study, the age difference was constant at all levels of TS energy. It is not clear why this difference exists between these studies. The AGE x TE interaction may possibly be limited to TE levels below the lowest value used in the present study, 15.4 cd/m^2 x msec units. Despite the difference, these studies provide strong support for a slowing in peripheral processing with age using Turvey's criteria (see Turvey, 1973).

Age differences in speed of processing are also evident in studies of central visual processing. Walsh (1976) tested young and older adults (mean ages 19.5 and 64.2 respectively) in a backward, monoptic identification task. He used letter stimuli as the TS and patterned line segments as the MS. Two measures were taken: critical target duration with ISI = 0 (TDc=SOA) and ISIc at three levels of target duration. Walsh reported that older subjects required 24% longer SOA to escape masking than younger subjects, and that this difference was constant at all target durations. He argued that these findings represent a slowing in central processes with age as defined by Turvey (1973).

Using the same identification task, Hertzog, Williams, and Walsh (1976) replicated the results of Walsh's study. The absolute difference in processing speed between the age groups was reported to be very similar to the difference found in the Walsh (1976) study (30 msec vs 22 msec respectively). In addition, they indicated that five days of practice resulted in a substantial and equal reduction in the ISIc needed to escape masking for both young and old subjects. These results suggest that age differences in central processing speed are stable even after training.

One problem with the Walsh (1976) and Hertzog et al. (1976) studies involved criterion differences between age groups. Those studies utilized an ascending limits procedure without forced choice responding. Walsh, Williams, and Hertzog (1979) suggested that part of the large age difference in speed of central processing may have been due to a higher response criteria adopted by the older subjects. They examined this possibility by using the same task from the above studies with the addition of forced choice responding and lower target durations. The elderly group was reported to require 36 msec longer SOAs to escape masking than the young group. This result suggests that the age difference is greater over a wider range of TS durations than previously thought. The smaller SOA difference in the earlier studies may actually have been due to more liberal response criteria in the older group.

In summary, studies of masking as well as stimulus persistence have demonstrated a consistent decline in the speed of processing with age. Furthermore, it has been shown that this perceptual slowing is evident in both peripheral and central processing locations. Results from the radial localization task (D. Ball, 1985; Ball et al., 1988; Sekuler and Ball, 1986) could also be explained by a deficit in speed of processing. This task uses a mask comprised of spatially random noise. In addition, very brief durations were utilized. D. Ball (1985) argued that if speed of processing was the sole basis for the age difference, then the effects of training should have transferred to the post-training test where the target and distractors were reversed. Since this did not occur, he argued that a deficit in selective attention may be the more appropriate explanation. However, as he indicated, this conclusion is not definite. For example, the finding that all groups demonstrated improved performance on the trained condition at the faster duration actually supports both theories. On one hand, speed of processing appears to be increasing, but on the other hand, the observers may be learning to distinguish relevant from irrelevant stimuli in less time. However, since the stimuli were not equated in difficulty, and since speed of processing was not systematically studied (i.e., only two duration levels were measured) a slowing of the speed of processing with age cannot be ruled out as a possible explanation for the age decrement in peripheral localization performance.

Hypotheses

The present study is concerned with the plasticity of the UFOV in relationship to age, target duration, and practice. If the deficit in selective attention theory (i.e., the UFOV constricts as a result of older observers' inability to ignore irrelevant stimuli) is correct, then the age x eccentricity effect should be more pronounced on a peripheral localization task with distractors than a task without distractors. This hypothesis would also be supported by a task x prepost interaction whereby improvement from training on the task with distractors is significantly greater than the task without distractors. If training does transfer, then the observers may be improving in ways unrelated or in addition to the selective attention hypothesis.

If the deficit in speed of processing theory (i.e., the UFOV constricts as a result of a generalized decline in the speed of processing visual stimuli as a function of age) is correct, then training on a peripheral task with distractors should transfer to a task without distractors. In other words, there should be a significant difference between the pre and post tests for a task without distractors as a function of training on a task with distractors. However, that finding alone is not enough to make conclusive statements regarding the the deficit in speed of processing theory. In addition, there should be significant improvement from training at all durations for both tasks. In this study, it is hypothesized that training will transfer to the untrained task without distractors and that there will be significant improvement at all durations for both tasks as a result of a generalized increase in the speed of processing.

Since it has been demonstrated that the size of the UFOV that can be processed in parallel varies as a function of target duration (Bergen and Julesz, 1983), it is also hypothesized that shorter target durations will result in a constriction of the FOV, especially for the older observers. This point would be supported by a significant increase in the number of errors at the farther eccentricities at faster durations for the older observers, or a significant age x duration x eccentricity interaction.

Chapter III

Method

Participants

Five adult participants were recruited from each of three age groups. The young adult group ranged in age from 18 to 38 years; middle age adults were in the 43 to 57 year age range; and older adults were 60 to 78 years of age. All the participants were screened for ocular pathology prior to their participation in the experiment. This procedure was necessary to ensure that any age differences would be due to normal developmental changes in the visual system rather than disease.

The following procedure was applied to each person who expressed an interest in participating: First, a screening interview was conducted in which the potential observer reported whether an eyecare specialist had ever diagnosed the presence of any type of eye disease, including macular disease, glaucoma, cataracts, optic neuritis, and diabetic retinopathy. In addition, the participants were asked if they had suffered from any major illnesses, neurological problems, or diabetes. If any participants indicated that they had a history of any of the aforementioned diseases, they would have been informed that their participation was not possible due to the nature of this study. A copy of the Subject Information Form used to record the participants' responses is included in Appendix A.

Next, all observers who had no reported history of eye disease signed an Informed Consent Sheet. A copy of this form is included in Appendix B. They were then informed that they would be paid $6.00 for each experimental session.

Near acuity for each participant was then measured at the experimental viewing distance (23.5 cm) using the Baily-Lovie Near Chart. Each age group had an average near acuity equal to 0.75 MAR (minimum angle resolvable).

Stimuli

The stimuli and apparatus in the proposed experiment were the same as that used in Sekuler and Ball (1986). Since optical changes in the older eye have been shown to cause reduced retinal illuminance, all stimuli were presented at a contrast well above threshold (2 cd/m2) to minimize any differences due to this factor (Weale, 1963). Since differences in retinal illumination, have been shown not to be a factor for different age groups in a radial localization task (Leibowitz and Appelle, 1969), it was not equated. Each trial consisted of four successive displays controlled by an Apple IIe computer and was presented on a large Conrac monitor (60 x 60 degrees). The first display was an outline box, subtending 8 x 9 degrees, which served to direct the observer's fixation to the center of the screen. It had a duration of one second. The second display contained the test stimulus and distractors. It immediately followed the offset of the fixation box and was presented for one of several brief durations. These durations were brief enough to prevent the observer from initiating and completing a shift in fixation. The third display consisted of a high energy, spatially random noise mask presented for a duration of 750 msec. It was presented to obliterate any residual afterimage produced by the stimulus display. There was no time lapse (interstimulus interval or ISI=0) between the stimulus display and the mask display. Thus, target duration was equal to the SOA. The final display consisted of eight equally spaced spokes arranged in a radial pattern. Each spoke was labelled at its peripheral end with a digit from one to eight. This pattern served as a signal to the observer to make a choice regarding the foveal stimulus and the peripheral target. This display pattern remained until the participant responded.

The foveal target was an oval-shaped cartoon likeness of a human face subtending 3.0 x 6.0 degrees of visual angle. It had a luminance of approximately 1.17 cd/m^2 against a background of approximately 0.175 cd/m^2. The foveal target appeared in the center of the screen during the stimulus frame of each trial. Each observer was required to identify whether the face was smiling or frowning. There were two types of peripheral targets. One was a smiling cartoon face with the same size and luminance as the foveal target. The other peripheral target was a probe, or spot of light, subtending 0.37 degrees of visual angle. It had a luminance of 2.86 cd/m^2. The cartoon face or the probe appeared concurrently with the foveal target in each of 24 different radial locations. These locations were along eight radial axes at three different eccentricities (10, 20, 30 degrees) from the center of the display. The target appeared unpredictably, yet equally often, in each of the peripheral locations. When both the foveal and peripheral target were cartoon faces, the stimulus display appeared for one of five durations: 52 msec, 61 msec, 69 msec, 78 msec or 87 msec. When the probe was paired with the foveal target, the stimulus display had a duration of 26 msec, 35 msec, 43 msec, 52 msec, or 61 msec. The faster set of durations was assigned to the probe task in order to minimize any differences in difficulty associated with the tasks (i.e., the probe task without distractors being easier than the face task with distractors).

Forty-seven outline boxes of the same size and luminance as the face stimulus served as distractors in the display whenever the foveal and peripheral targets were both faces. There were no distractors when the probe was presented. These distractors were located at every possible target position along the eight axes (except the position filled by the target) as well as positions in between. The stimulus display thus had a filled appearance on every trial for the face localization task.

Procedure

Each participant was seated with his/her head positioned in a chin rest. The eyes were level with the center of the screen and viewing was binocular. A forced choice procedure was used to control for any criterion differences that might exist across the age groups. A keypad, with two keys corresponding to the foveal task and eight keys representing the eight radial locations of the peripheral target, were located on the table between the participant and the screen. This keypad was equally accessible to the left or right hand. There were two tasks required for each trial. The observer first discriminated whether the foveal target was smiling or frowning by pressing the appropriate center task key. The participant then chose the radial location of the peripheral target by selecting one of the eight radially positioned keys on the same keypad. If the participant responded incorrectly to the presence of the foveal target, the trial was terminated and no response to the peripheral target was accepted. The trial was then re-presented later in the block. The computer provided feedback to the responses by emitting an ascending series of tones for a correct response and a descending series of tones for an incorrect one.

Prior to the experimental conditions, each observer was given a dark adaptation period for approximately five minutes. During this time, a practice block of trials was presented at a longer duration than those used in the experimental conditions. The practice duration was adjusted for each observer so that the task could be easily comprehended and mastered. This practice session allowed each observer to become familiar with the task and the correct responses. Once the observer demonstrated proficiency with the practice task, the experimental conditions were presented.

There were two peripheral target stimulus conditions. The peripheral target was either the face paired with distractors or the probe without distractors. Trials were blocked into groups of 24, corresponding to the 24 peripheral target locations. Each observer received five blocks of trials on the first day with either the face or the probe as the peripheral target (one block of 24 trials for each appropriate target duration). On the second day of testing, each observer received the other peripheral target condition at each of the five corresponding target durations. The order of presentation was randomized using a latin square for each observer. This arrangement provided pre-training measures on ten experimental conditions per observer.

All participants received additional practice on the condition employing the face as both the foveal and peripheral target with box distractors in the background. The presentation speed was set equal to 69 msec. There were five training days consisting of five blocks per day for this single condition. After five training days, each observer was retested on the same ten conditions as in the pre-training sessions. This procedure allowed an assessment of the effects of training. It also provided an opportunity to determine whether or not the training on one condition transferred to the others.

Chapter IV

Results and Discussion

The data will be discussed in two sections: center task performance and peripheral localization. Within the latter section, the results will be examined in four subsections; previous studies (evidence supporting results from previous studies), two sections describing evidence which provide support for the deficit in selective attention and speed of processing hypotheses, and a section examining parallel processing in the UFOV as a function of duration as well as age.

The data of one observer from the youngest age group was deleted from the analysis. After data collection it was learned that this subject had experienced epileptic seizures as a result of a head injury suffered in an automobile accident. This information was not disclosed during the screening interview.

Center Task Performance

It may be recalled that observers were first required to respond as to whether a foveally presented face stimulus was smiling or frowning (to ensure fixation on the center of the display) before responding to the location of the peripheral target. Center task errors were analyzed with a repeated measures ANOVA separately for the face task with distractors (Appendix C) and the probe task without distractors (Appendix D). They were also analyzed for the face and probe targets together at the two common durations, 52 and 61 msec (Appendix E). Age was the only between groups variable (younger, middle-aged and older). Pre-post (pre-training test versus post-training test), and duration (52, 61, 69, 78, and 87 msec for the peripheral face target; and 26, 35, 43, 52, and 61 msec for the peripheral probe target), were the repeated measures for each of the age groups.

In terms of the overall number of center task errors, there was a significant effect of age for both the face localization task ($F(2,11)=9.62$, $p<.01$) and the probe localization task ($F(2,11)=7.72$, $p<.01$). Significantly more center task errors were made by older observers than by the young or middle-aged observers for both tasks (Tukeys, $p<.05$). The young and middle-aged observers did not differ on these tasks. The difficulty of the center task was equivalent for both peripheral tasks. When comparing the center task errors for both tasks at the two common durations (52 and 61 msec), there was no significant difference between the two tasks ($F(1,11)=0.05$, $p>.05$).

There was a main effect of duration on center task performance for both the face task ($F(4,44)=3.87$, $p<.01$) and the probe task ($F(4,44)=12.34$, $p<.0001$). On the face task, the two briefer durations, 52 and 61 msec, were found to differ significantly from the two longest durations, 78 and 87 msec (Tukeys, $p<.05$). Performance at none of the durations differed significantly from the middle duration, 69 msec. Similarly, on the probe task, the two shortest durations, 26 and 34 msec, differed significantly from the remaining durations; 43, 52, and 61 msec. In other words, the point at which the observers made significantly more center task errors occurred at 34 msec or less on the probe task (Tukeys, $p<.05$).

A pre-post analysis indicated that training led to a significant reduction in center task errors for both the face task ($F(1,11)=22.56$, $p<.001$) and the probe task ($F(1,11)=7.40$, $p<.05$). In addition, there was also a significant training by duration interaction for the probe center task indicating that improvement was greater at the shorter durations ($F(4,44)=3.36$, $p<.05$). Specifically, improvement was found to be significant only at the three shortest durations; 26, 34, and 43 msec (Tukeys, $p<.05$). This finding is due to the fact that the older observers center task performance declined after training at 52 msec (see Table 1). In contrast, improvement on the center task for the face target was evident at all durations for all age groups. This finding more than likely represents a a "bad day" of testing at 52 msec for one or more older observers.

As mentioned above, there was a significant main effect of age for both tasks. However, there were no interactions involving age in terms of center task performance. The absence of a significant training x duration x age interaction for either the face or the probe task suggests that improvement on center task performance was equivalent among the age groups. These findings are presented in Table 1.

Table 1. Center task errors for two localization tasks.

Task	Duration	Pretraining			Posttraining		
		Young	Middle	Old	Young	Middle	Old
Face	52	9.25	5.40	14.00	1.25	1.60	6.00
	61	7.50	5.00	16.20	0.75	0.80	8.00
	69	4.50	3.00	13.60	0.50	1.60	5.40
	78	2.50	1.60	10.80	0.00	0.20	4.20
	87	5.00	1.00	7.00	0.25	0.00	3.40
Probe	26	11.50	12.80	22.80	3.50	2.80	16.40
	34	13.00	9.60	22.60	4.75	4.60	20.20
	43	4.50	8.60	15.00	1.50	1.20	12.40
	52	5.25	4.60	11.80	4.75	0.80	15.40
	61	7.75	2.20	13.00	2.00	0.60	11.20

Peripheral Localization

This study was concerned with the distribution of errors in radial localization. Since performance was equivalent on each radial axis, localization errors were summed across the eight radial axes and converted to percentages for each of the three eccentricities (10, 20, and 30 degrees). These proportions were normalized for statistical purposes by taking the inverse sine of the square root of the percent errors. On this scale, a transformed score of 1.2 is equivalent to chance performance or 87.5% errors. Transformed scores of 0.79 and 0.0 correspond to 50% and 0% errors respectively.

Separate 3(age) x 2(pre-post) x 5(duration) x 3(eccentricity) repeated measures ANOVAs were performed on the face localization task data and the probe localization data (Appendices F and G respectively). An additional 3(age) x 2(task type) x 2(pre-post) x 2(common durations) x 3(eccentricity) repeated measures ANOVA was performed to compare the relative effects of each task (face target with distractors and probe target without distractors) at the two common durations, 52 and 61 msec (Appendix H).

Previous Studies

Previous studies have shown that localization performance declines at greater eccentricities, and that this decline in performance increases with increasing age (Ball, et al., 1988; D. Ball, 1985; and Sekuler and Ball, 1986). The results of this study were partially consistent with those findings. There were significantly greater errors at increasing eccentricities on both the face task ($\underline{F}(2,22)=43.97$, $\underline{p}<.001$) and the probe task ($\underline{F}(2,22)=47.90$, $\underline{p}<.001$). Furthermore, the increase in localization errors for both tasks was significant at each 10 degree expansion (Tukeys, $\underline{p}<.05$). There was also a main effect of age for the face task ($\underline{F}(2,11)=4.24$, $\underline{p}<.05$) and the probe task ($\underline{F}(2,11)=7.32$, $\underline{p}<.01$). There were significant differences for both these tasks between the younger and the older observers (Tukeys, $\underline{p}<.05$), where older observers made significantly more errors. The middle-aged observers fell in-between the younger and older observers on both tasks.

It was assumed that age-related declines in localization performance as a function of the eccentricity of presentation would reflect a restriction of the UFOV. Unlike previous studies (Ball, et al., 1988; D. Ball, 1985; Sekuler and Ball, 1986), the age x eccentricity interaction failed to reach significance for either the face task ($\underline{F}(4,22)=0.60$, $\underline{p}>.05$) or the probe task ($\underline{F}(4,22)=0.83$, $\underline{p}>.05$). As can be seen in Figure 1, the differences among the three age groups at each of the eccentricities reflects a function that is more parallel as opposed to an interaction. This finding is unusual considering the reported strength of the phenomenon. The difference in these results from previous studies reflects the fact that older observers performed worse than usual at 10 degrees. This decline in performance at 10 degrees

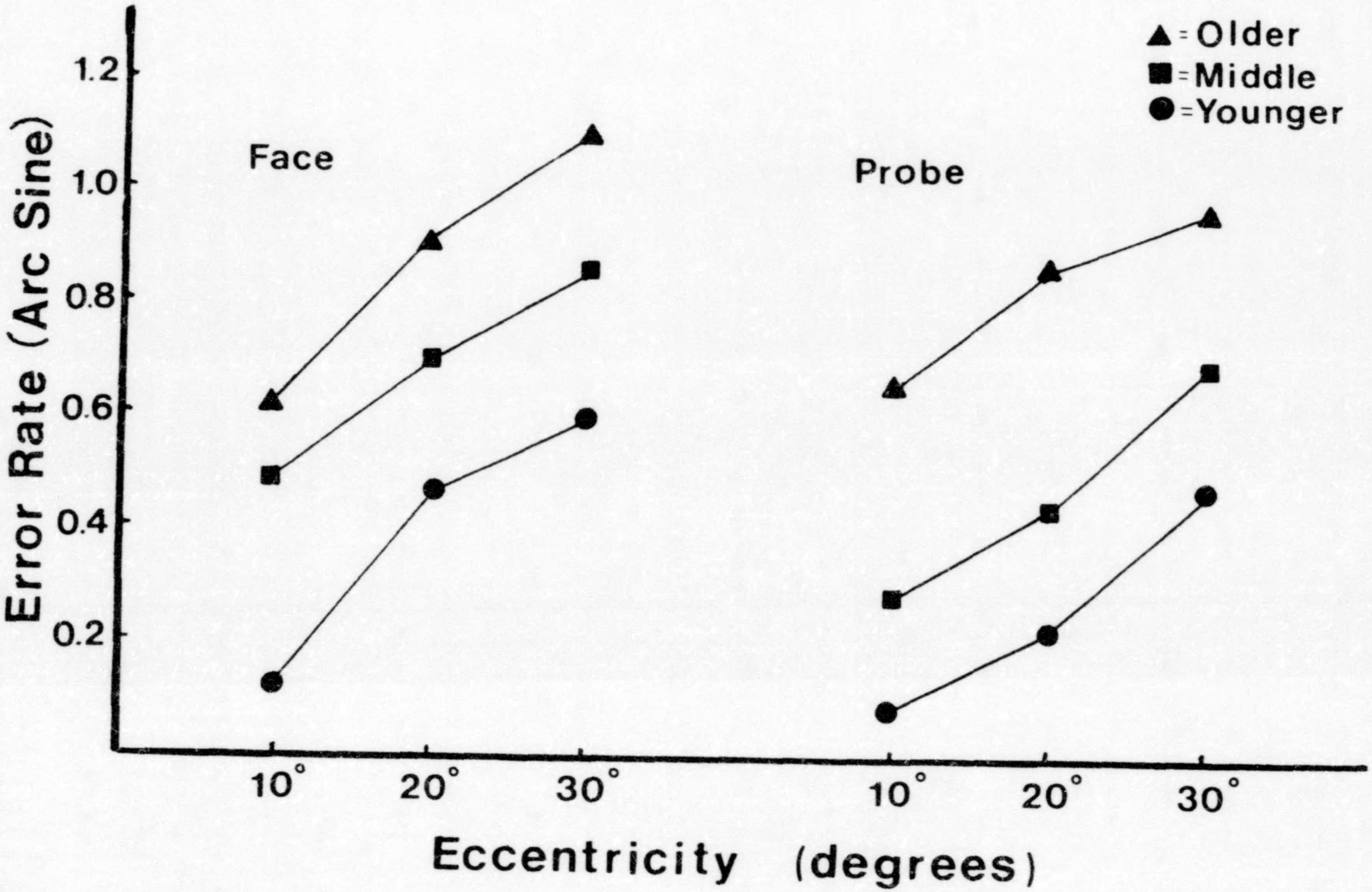

Figure 1. Error rates (arc sine transformed) for two radial localization tasks as a function of eccentricity and age.

may be due to the much briefer durations used in this study. Despite the lack of an age x eccentricity interaction, the main effect of age for both tasks supports an age-related restriction in the UFOV. In addition, the older observers were performaning at level near chance at 30 degrees eccentricity on the pretests for both tasks.

Previously reported results have also demonstrated that there should be a 10 degree eccentricity difference between each of the age groups (Ball et al.,1988). In other words, the performance of the elderly observers at 10 degrees, should be equivalent to the middle-aged observers at 20 degrees and the young observers at 30 degrees. The data from this study support the finding that accuracy of localization performance operates at a 10 degree deficit between each age group for both the face and probe task (Figure 1). As can be seen in the figure, performance of the younger observers at 20 and 30 degrees is equivalent to the middle-aged and older observers performance at 10 and 20 degrees respectively.

It has also been shown that practice can expand the UFOV by about 10 degrees (Ball et al., 1988). For example, observers in each age group at 30 degrees eccentricity were performing at a level equivalent to their performance at 20 degrees prior to training. This same result was expected for the peripheral localization tasks in this study. This same effect was found in the present study. There was a main effect of training (pre-post) for both the face task ($\underline{F}(1,11)=45.73$, $\underline{p}<.001$) and the probe task ($\underline{F}(1,11)=25.60$, $\underline{p}<.001$). The similarity of the training effect in this study to the one described above is demonstrated in Tables 2 and 3.

Table 2. Localization Errors for the Face Task

	Younger			Middle			Older		
Pre-test	10	20	30	10	20	30	10	20	30
52 msec	0.18	0.48	0.84	0.85	0.95	1.00	0.79	0.96	1.16
61 msec	0.13	0.61	0.88	0.66	0.84	1.01	0.69	1.05	1.20
69 msec	0.00	0.75	0.85	0.76	0.89	0.92	0.76	1.04	1.14
78 msec	0.18	0.46	0.71	0.69	0.96	1.01	0.67	1.15	1.00
87 msec	0.22	0.55	0.62	0.78	0.90	0.98	0.87	1.12	1.24
Post-test									
52 msec	0.18	0.31	0.49	0.39	0.44	0.71	0.64	0.83	0.95
61 msec	0.09	0.49	0.60	0.25	0.41	0.68	0.52	0.71	1.13
69 msec	0.00	0.26	0.45	0.22	0.46	0.81	0.52	0.81	0.89
78 msec	0.09	0.22	0.47	0.13	0.43	0.84	0.32	0.68	0.94
87 msec	0.09	0.31	0.54	0.16	0.41	0.57	0.46	0.62	1.09

Table 3. Localization Errors for the Probe Task

	Younger			Middle			Older		
Pre-test	10	20	30	10	20	30	10	20	30
26 msec	0.13	0.55	0.88	0.72	1.00	1.14	0.61	1.09	1.06
34 msec	0.00	0.30	0.64	0.64	0.90	1.22	0.71	0.94	0.93
43 msec	0.18	0.18	0.75	0.52	0.73	0.82	0.70	0.91	1.15
52 msec	0.09	0.09	0.30	0.22	0.30	0.49	0.92	0.95	1.11
61 msec	0.00	0.00	0.30	0.25	0.25	0.45	0.66	0.90	0.84
Post-test									
26 msec	0.09	0.48	0.69	0.18	0.60	0.97	0.58	0.90	1.24
34 msec	0.18	0.18	0.35	0.00	0.37	0.68	0.53	0.76	1.13
43 msec	0.00	0.09	0.19	0.07	0.18	0.62	0.42	0.86	0.87
52 msec	0.09	0.09	0.35	0.10	0.07	0.28	0.45	0.69	0.81
61 msec	0.09	0.09	0.18	0.07	0.07	0.25	0.50	0.66	0.70

Tables 2 (face task data) and 3 (probe task data) present transformed errors for younger, middle-aged, and older observers at 10, 20, and 30 degrees for each duration. In Table 2, it can be seen that the younger observers were able to expand their UFOV by 10 degrees. Performance at 20 degrees on the pre-training face task was equivalent to their performance at 30 degrees after training. Like the younger observers, older persons demonstrated a 10 degree increase in localization performance as a result of training.

Middle-aged observers demonstrated a 20 degree increase in localization performance as a result of practice. Their level of performance at 30 degrees post-training for the face task was equivalent to their 10 degrees pre-training level. This dramatic increase in localization performance following training is greater than previously reported (Ball et al., 1988). This difference may reflect a poor initial testing session for the middle-aged observers, which was comparable to the performance of the older subjects on the initial measure. Training helped elicit their true processing capacity. The data from Table 3 for the probe task indicated similar effects for each age group on the probe task as a result of training on the face task with distractors.

Evidence for A Deficit in Selective Attention

Several studies have demonstrated that older individuals have a deficit in selective attention where they have more difficulty ignoring irrelevant visual detail (Farkas & Hoyer, 1980; Layton, 1975; Mackworth, 1965; Rabbitt, 1965; 1979; Scialfa et al., 1987). In addition, age differences have been found to be maximized at greater eccentricities on a peripheral localization task in the presence of distractors (Ball et al., 1988; D. Ball, 1985; Sekuler and Ball, 1986). Based on these findings, an age-related deficit in selective attention appears to be a plausible explanation for the decline in the UFOV. This section will explore evidence from this study supporting that theory.

Since age differences seem to be maximized in the presence of irrelevant stimuli, it was hypothesized that the age x eccentricity effect should be maximally greater on the face task with distractors than on the probe task with no distracting elements. A significant age x eccentricity x task interaction would support the "deficit in selective attention" theory. This hypothesis, however, failed to be confirmed. The age x eccentricity x task interaction was found to be insignificant ($\underline{F}(4,22)=0.69$, $\underline{p}>.05$). The failure to find this effect may have been a result of the older observers' inability to localize as accurately as expected at 10 degrees and the fact that the range of common durations tested was limited to two rates (52 and 61 msec). If, perhaps, a greater range of common durations were utilized, the age x eccentricity x task interaction might become salient. Figure 2 illustrates how both tasks seemed to be equally difficult for the older age group; there is considerable overlap for the face and probe tasks in terms of error rates. In contrast, younger and middle-aged observers found the probe task to be much easier than the face task at each level of eccentricity. In particular, the younger and middle-aged observers had relatively little trouble localizing the probe at 10 and 20 degrees in contrast to the performance of the elderly.

Despite the failure to confirm the age x eccentricity x task interaction, there was some evidence that the presence of irrelevant stimuli cause a decline in the UFOV. There was a significant task x eccentricity interaction ($F(2,22)=4.63$, $p<.05$). The significant differences between these two tasks occur at 20 and 30 degrees eccentricity (Tukey, $p<.05$), but not at 10 degrees. These results indicate that the effect of eccentricity is more salient for the face localization task, which employs distractors, than for the probe localization task without distractors.

Evidence For A Deficit in Speed of Processing

It has been shown that older observers are more susceptible to the interfering effects of masking stimuli

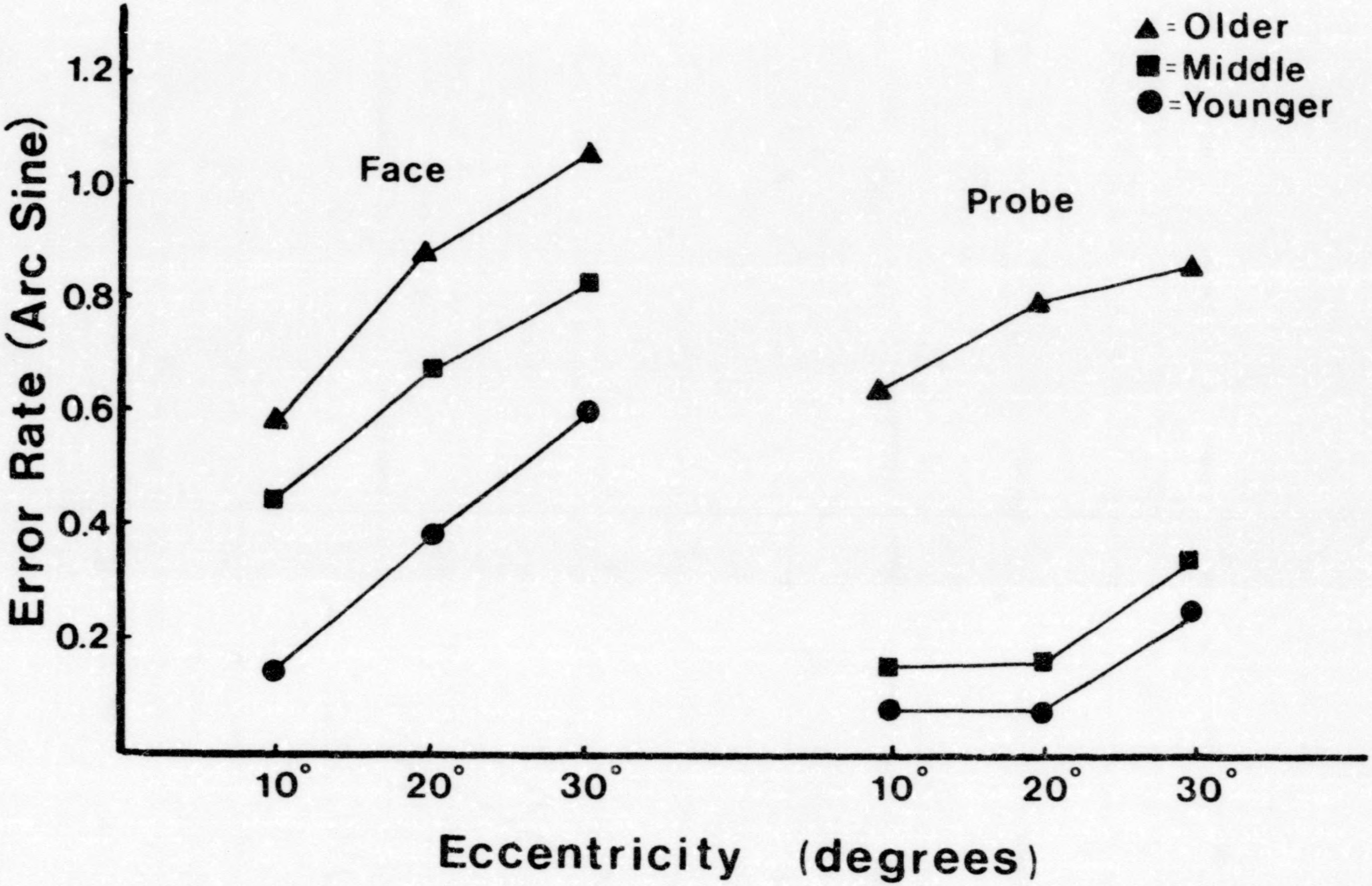

Figure 2. Error rates (arc sine transformed) for two radial localization tasks at two common durations (52 and 61 msec) as a function of eccentricity and age.

(Till, 1978; Turvey, 1973; and Walsh, Till, & Williams, 1978). It was argued that those findings were based on the theory that stimuli persist longer in the visual system of older observers. Thus, in order to efficiently localize a peripheral target, longer target durations would be required for the older observers to escape the effects of the mask.

In the present investigation a noise masking stimulus was presented immediately after target presentation. It was expected that the presence of the mask would create greater performance problems for the older observers, and that a significant age x duration interaction would support the deficit in speed of processing hypothesis. This hypothesis was supported by a significant age x duration interaction on the probe task ($F(8,44)=2.98$, $p<.01$). The older observers experienced the most difficulty with this task; they made the most errors at each of the durations. When post hoc comparisons are compared, the young showed significantly better performance than the older observers at every duration (Tukeys, $p<.05$). The middle-aged observers demonstrated greater variation in their performance. At the two fastest durations (26 and 34 msec), they performed more like the older observers where their localization errors were significantly greater than the younger observers (Tukeys, $p<.05$). However, at the three slower durations

(43, 52, and 61 msec), the middle-aged observers performed more similar to the younger observers. At those rates, younger and middle-aged observers made significantly fewer errors than the older observers (Tukeys, $p<.05$). These findings may be an indication of the gradual slowing in the visual nervous system associated with aging. Figure 3 illustrates these findings.

In contrast to the above results, the age x duration interaction did not reach significance for the face task ($F(8,44)=.76$, $p>.05$). Considering this finding in relation to the same interaction for the probe task, it seems that the age-related decline in ability to localize stimuli is not simply reflective of a deficit in speed of processing. It does suggest that declining speed of processing is one probable factor. But it also indicates that the addition of distracting elements and a peripheral target of greater visual complexity (i.e., in terms of texton differences) increases the difficulty of localizing. The face task, despite having slightly longer durations, was found to be more difficult than the probe task ($F(1,11)=15.14$, $p<.005$). The increased difficulty of the task may require a broader range of durations than the range utilized on this task (i.e., 52, 61, 69, 78, and 87 msec). In other words, these results may reflect a ceiling and/or floor effect for the observers. This problem is reflected by the relatively flat, parallel

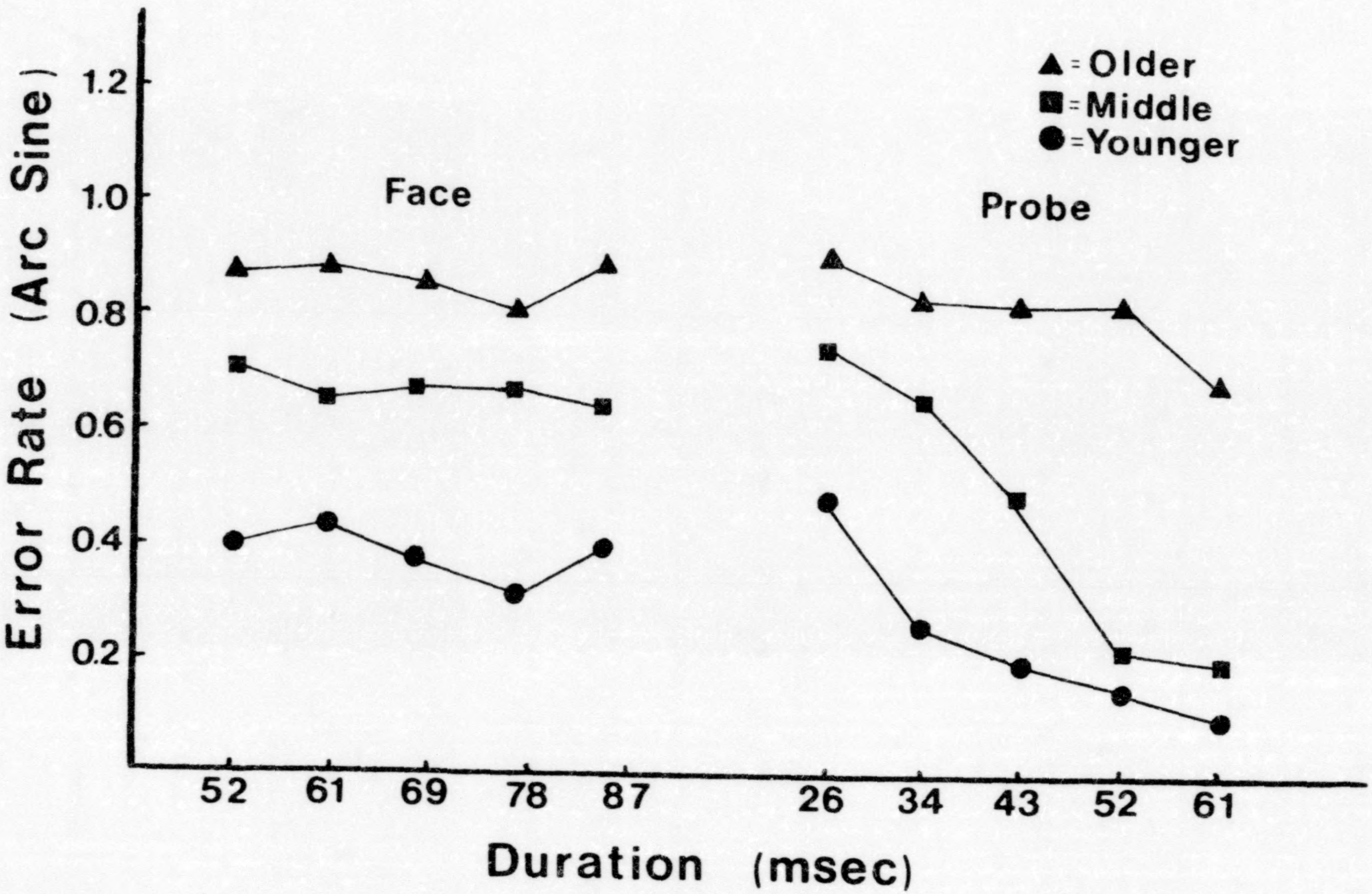

Figure 3. Error rates (arc sine transformed) for two radial localization tasks as a function of duration and age.

functions for each of the age groups for the face task and for the younger and older observers on the probe task in Figure 3. The limited range of durations utilized in this study may have obscured any potential age differences. By extending the range of durations, it might elicit better performance from the older observers, and provide greater opportunities for younger observers to make more errors.

It was also hypothesized that if the age-related constriction in the UFOV is based on a decline in the speed of processing, then any improvement from training should generalize to all durations tested for both tasks. Since no interaction between training (pre-post) and duration was found on either the face task ($F(4,44)=0.53$, $p>.05$) or the probe task ($F(4,44)=1.53$, $p>.05$), this hypothesis was supported. Improved performance from practice did generalize to all durations for both tasks.

The Effect of Duration on the UFOV

It has been demonstrated that the size of a visual field that may be processed in parallel varies with duration (Bergen and Julesz, 1983). At longer durations, the extent or diameter of the UFOV expands. Based on this finding, there should be a variable effect of duration at different eccentricities on the radial localization tasks. It was hypothesized that the decline in localization performance at farther eccentricities would be maximized at the briefer durations. A significant duration x eccentricity interaction for the probe task supports this hypothesis ($F(8,88)=6.14$, $p<.001$). At the three briefest durations (i.e., 26, 34, and 43 msec), localization performance declines significantly at each 10 degrees expansion (Tukey, $p<.05$). At 52 msec, localization performance is significantly worse at 30 degrees than at 20 degree (Tukey, $p<.05$). At the longest duration, 61 msec, there are no significant differences among the three eccentricities. As can be seen in Figure 4, the slope of the eccentricity function gets steeper for the greater eccentricities as duration decreases, reflecting a decline in the area which can be searched in parallel. This effect was not, however, significant for the face task. Figure 4 shows the eccentricity function as being relatively flat and parallel across the durations. As discussed earlier, the absence of this effect may be due to the limited range of durations combined with a difficult visual task (i.e., localizing a face amidst distractors).

It was also hypothesized that this duration x eccentricity effect would be different for the different age groups. Specifically, the difference between younger and older observers should be greater at briefer durations. In addition, training should expand the UFOV equally across all age groups. Although an age x duration

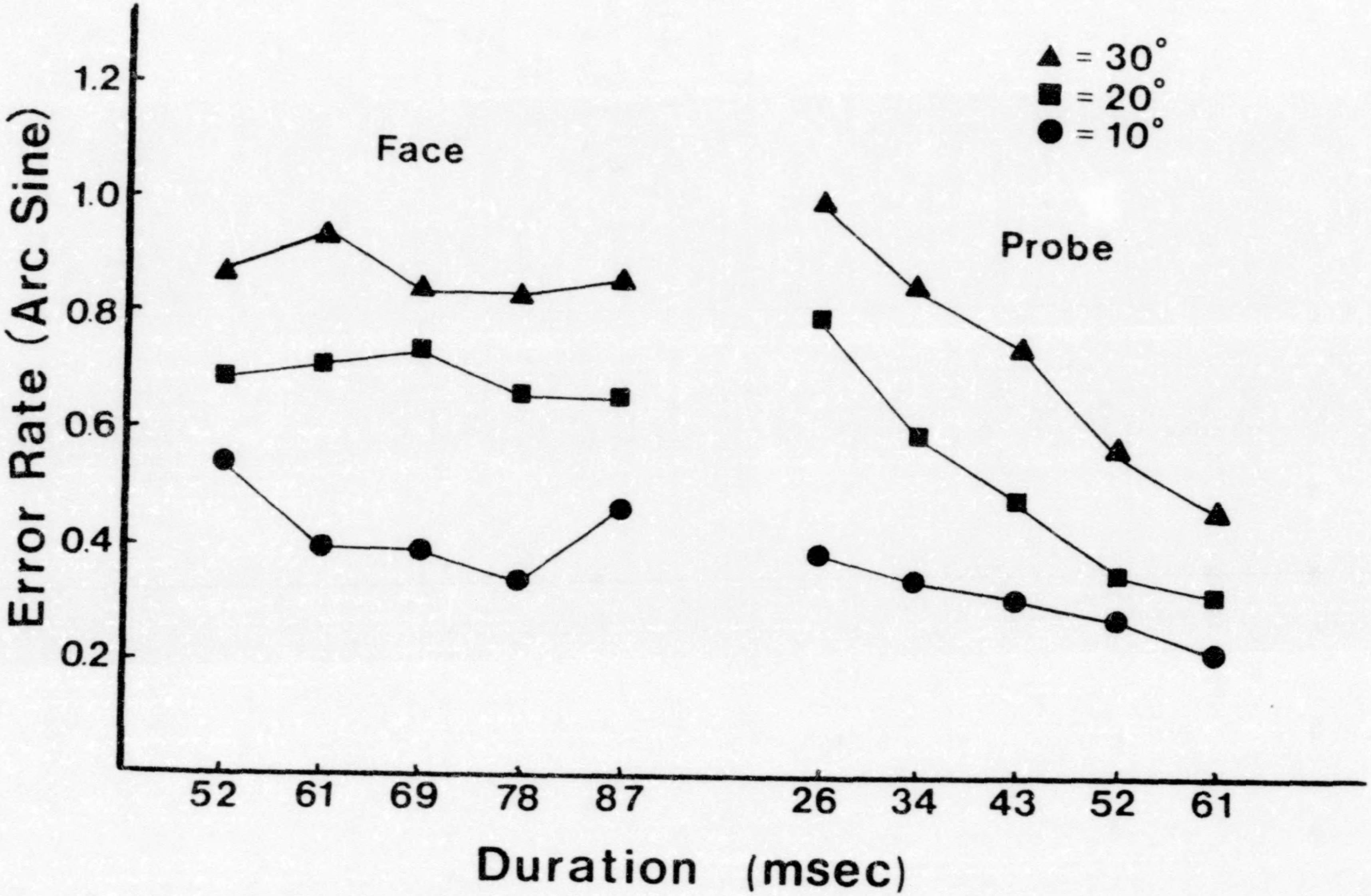

Figure 4. Error rates (arc sine transformed) for two radial localization tasks as a function of duration and eccentricity.

x eccentricity interaction failed to reach significance for either the face task ($F(16,88)=1.10$, $p>.05$) or the probe task ($F(16,88)=0.47$, $p>.05$), the data seem consistent with the hypothesis. Tables 2 (face task data) and Table 3 (probe task data) list the transformed errors for younger, middle-aged and older observers at 10, 20, and 30 degrees for each duration. For example, in Table 2, it can be seen that after training, middle-aged and older observers can localize a face target more accurately at the two longer durations (78 and 87 msec) at 10 and 20 degrees, but still perform poorly at 30 degrees (Tukey, $p<.05$). Before training, these observers in both age groups could not localize accurately at any duration or eccentricity. This result suggests that with training, the field which can be processed in parallel expands in relation to longer durations. This relationship can also be seen in Table 3 for the probe data. Examining the young data, it can be seen that there is no duration effect at 10 degrees because of their excellent performance. However, at 20 degrees they have more difficulty localizing the target at durations below 35 msec. At 30 degrees, even more errors are made. The effect of duration is more evident at 20 and 30 degrees for the young (Tukeys, $p<.05$). The middle-aged observers show a similar trend on the probe task. Localization accuracy improves at 43 msec for 20 degrees eccentricity and at 52 msec for 30 degrees eccentricity. The old did not show any clear trend on the probe indicating their inability to do the task. Despite the nonsignificant interaction, the trend in the data suggests that the area which can be processed in parallel does expand at longer durations relative to the ability of the observer.

Conclusion

In general, the results from this study provide support for the deficit in speed of processing hypothesis as an explanation for the age-related decline in the UFOV. The use of the random noise mask was expected to create greater visual difficulties for the older observers (based on stimulus persistence), and it did: Older observers made greater errors at each of the presentation speeds than middle-aged or younger observers on both tasks (the difference, however, did not reach significance on the face task); there was a lack of a training x duration effect for either task indicating that improvement from practice generalizes to all durations; and the effects of training transferred to both tasks. These results indicate that speed of processing is a factor influencing the decline in the UFOV. The data for the probe task in Figure 3 best illustrates the gradual nature of the decline in speed of processing with age. The performance of the middle-aged observers was found to be more similar to the older observers at the briefer target durations, but more similar to the younger observers at the longer target durations. This effect, however, was not found for the face task. It was found that the presence of distractors and/or a more complex target creates a visual task of greater difficulty. The failure to find the age x duration effect on the face task does not necessarily weaken the deficit in speed of processing argument. Rather, the difficulty of the task was more than likely limited by the narrow range of durations utilized in this study. It was argued that a greater range of durations would probably elicit the interaction which was found on the probe task. Future studies should address this issue.

The effects of target duration on the UFOV was also examined in some detail. Consistent with Bergen & Julesz (1983), the extent of the UFOV was found to decline at briefer durations, as evidenced by a significant duration x eccentricity interaction for the probe task. It was hypothesized that age differences regarding the UFOV would also be maximized at briefer durations. Despite the fact that there was no age x duration x eccentricity interaction to support this hypothesis, the data was consistent with it. For example, the middle-aged and older observers had great difficulty localizing the target at every duration and eccentricity, whereas the younger observers did not. After training, the middle-aged and older observers were able to localize the probe and the face target more accurately at the longer durations at 10 and 20 degrees. In contrast, the younger observers demonstrated no problem localizing the target at 10 degrees, but did show a duration effect at 20 and 30 degrees. Based on these data, the results do offer some support for the hypothesis that the extent of the UFOV declines with age at briefer durations and expands with practice. This relationship also needs to be examined with a greater range of durations.

Support for the deficit in selective attention hypothesis was not as extensive. It was hypothesized that age differences in the extent of the UFOV would be greater on the face task which incorporates distractors. This effect failed to be confirmed. However, there was some evidence that distractors made a difference. For example, the face task required a different range of longer durations than the probe task because of its greater difficulty. In addition, the eccentricity effect was found to be more salient for the face task than the probe task, which suggests that the presence of distractors caused the UFOV to constrict to a greater extent.

In conclusion, the results of this study support the hypothesis that the decline in the UFOV is based on a deficit in speed of processing associated with age. The evidence supporting the age-related deficit in selective attention was generally much weaker. However, because of the evidence that was present and the consistency of the phenomenon reported in previous studies, this hypothesis cannot be ruled out. In fact, both hypotheses are more than likely correct; there is an age-related decline in the extent of the UFOV which is maximized at briefer durations and in the presence of distracting stimuli. Future studies need to examine this possibility in greater detail by extending the range of durations employed, which would provide more overlapping durations to be compared. In addition, the stimuli from both tasks need to be equated in difficulty. And finally, if both hypotheses are relevant, then future studies should seek to determine if there is some duration or range of durations where one hypothesis is more relevant than the other.

Appendix A

Subject Information Sheet

SUBJECT INFORMATION

Name ______________________________ Date ______________

Address ______________________________ Age ______________

______________________________ Phone ______________

* *

Medical History

Medications ______________________________

Major illnesses ______________________________

Visual history

cataracts ________ macular degeneration ________

diabetes ________ glaucoma ________

* *

Correction

Current distance   bifocals   Current near

Left ________ Left ________

Right ________ Right ________

Snellen acuity ________ Near acuity ________

Lab distance   Lab near

Left ________ Left ________

Right ________ Right ________

Snellen acuity ________ Near acuity ________

Date of last eye examination ________ Optom ______ Ophthal ______

Name of Ophthalmologist ______________________________

Visual complaints ______________________________

* *

Personal Information

Driving ________

Occupation ______________________________

Other experiments ______________________________ Date ________

______________________________ ________

______________________________ ________

Other comments ______________________________

____

Appendix B

Informed Consent Sheet

RESEARCH PROJECT: IMPROVEMENT OF VISUAL PROCESSING

Participant Consent Form

I, ______________________________, voluntarily consent to participate in a research study on how the aging process affects vision. The study will take place in the Vision Laboratory at Western Kentucky University, Bowling Green, Kentucky and will involve no more than 10 one hour sessions. The nature and purpose of the study have been explained to me. I understand that I will be asked to view a video monitor and indicate when I see certain patterns on the screen. These sessions use standard eye exam and exercise procedures that involve no risk to the participant. In the event of eye or position fatigue, I know that I can take rest periods when I feel the need and can ask questions at any time.

I understand I will receive compensation for my participation. In addition to any improvements to my visual functioning I may also (participants over 60 years of age) receive a free ophthalmological exam.

All results and eye examinations will be treated as confidential information.

Any questions about the research may be directed to Dr. Karlene Ball (phone 745-4438).

I further understand that I may discontinue participation at any time.

______________________________ ______________________________

Date Signature

Funds for this research program are provided by the National Institutes of Health and Western Kentucky University.

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Appendix C

ANOVA Summary Table for Center Task Errors on the Face Task

ANOVA Summary Table

for Center Task Errors

on the Face Task

Source	DF	SS	MS	F	P
Age (A)	2	1319.471	659.736	9.62	.0038
Error	11	754.300	68.573		
Pre-post (P)	1	806.425	806.425	22.56	.0006
P x A	2	132.200	66.100	1.85	.2031
Error	11	393.200	35.745		
Duration (D)	4	307.821	76.955	3.87	.0088
D x A	8	96.450	12.056	.61	.7669
Error	44	873.850	19.860		
P x D	4	71.572	17.893	1.16	.3394
P x D x A	8	29.336	3.667	.24	.9812
Error	44	676.050	15.365		

Appendix D

ANOVA Summary Table for

Center Task Errors on the Probe Task

ANOVA Summary Table

for Center Task Errors

on the Probe Task

Source	DF	SS	MS	F	P
Age (A)	2	3791.576	1895.788	7.72	.0800
Error	11	2701.860	245.624		
Pre-post (P)	1	608.678	608.678	7.40	.0199
P x A	2	96.021	48.011	.58	.5743
Error	11	904.900	82.264		
Duration (D)	4	940.525	235.131	12.34	.0000
D x A	8	169.110	21.139	1.11	.3756
Error	44	838.490	19.056		
P x D	4	232.472	58.118	3.36	.0175
P x D x A	8	84.936	10.617	.61	.7618
Error	44	761.750	17.313		

Appendix E

ANOVA Summary Table for Center Task Errors on the Face and Probe Task at Two Common Durations (52 and 61 msec)

ANOVA Summary Table

for Center Task Errors on

the Face and Probe Task

at two common durations (51 and 61 msec)

Source	DF	SS	MS	F	P
Age (A)	2	4787.486	2393.743	9.87	.0000
Error	11	2667.560	242.505		
Target	1	1236.788	1236.788	17.25	.0016
T x A	2	323.561	161.780	2.26	.1509
Error	11	788.600	71.691		
Pre-post (P)	1	1408.161	1408.161	21.95	.0007
P x A	2	15.811	7.905	0.12	.8853
Error	11	705.750	64.159		
T x P	1	6.942	6.942	0.13	.7264
T x P x A	2	212.411	106.205	1.97	.1854
Error	11	592.350	53.850		

Source	DF	SS	MS	F	P
Duration (D)	4	1125.288	281.322	13.58	.0000
D x A	8	204.781	25.598	1.24	.3015
Error	44	911.440	20.715		
T x D	4	123.058	30.765	1.69	.1693
T x D x A	8	60.779	7.957	0.42	.9044
Error	44	800.900	18.202		
P x D	4	261.043	65.261	3.55	.0135
P x D x A	8	53.864	6.733	0.37	.9327
Error	44	808.700	18.380		
T x P x D	4	43.000	10.75	0.75	.5622
T x P x D x A	8	60.407	7.55	0.53	.8289
Error	44	629.100	14.298		

Appendix F

ANOVA Summary Table for the Face Task

ANOVA Summary Table

for the Face Task

Source	DF	SS	MS	F	P
Age (A)	2	14.264	7.132	4.24	.0431
Error	11	18.491	1.681		
Pre-post (P)	1	8.542	8.542	45.73	.0000
P x A	2	1.000	.500	2.68	.1129
Error	11	2.055	.187		
Duration (D)	4	.211	.053	.98	.4277
D x A	8	.328	.041	.76	.6365
Error	44	2.361	.054		
P x D	4	.122	.031	.53	.7130
P x D x A	8	.206	.026	.45	.8855
Error	44	2.532	.058		
Eccentricity (X)	2	14.051	7.026	43.97	.0000
X x A	4	.382	.095	.60	.6685
Error	22	3.515	.160		

Source	DF	SS	MS	F	P
P x X	2	.282	.141	1.79	.1900
P x X x A	4	.655	.164	2.08	.1181
Error	22	1.733	.079		
D x X	8	.383	.048	1.45	.1878
D x X x A	16	.583	.036	1.10	.3646
Error	88	2.905	.033		
P x D x X	8	.250	.031	.90	.5199
P x D x X x A	16	.401	.025	.72	.7658
Error	88	3.057	.035		

Appendix G

ANOVA Summary Table for

the Probe Task

ANOVA Summary Table

for the Probe Task

Source	DF	SS	MS	F	P
Age (A)	2	22.373	11.186	7.32	.0095
Error	11	16.809	1.528		
Pre-post (P)	1	3.948	3.948	25.60	.0004
P x A	2	1.228	.614	3.98	.0500
Error	11	1.700	.154		
Duration (D)	4	6.993	1.748	19.18	.0000
D x A	8	2.172	.271	2.98	.0094
Error	44	4.010	.091		
P x D	4	.411	.103	1.53	.2098
P x D x A	8	1.269	.159	2.36	.0329
Error	44	2.955	.067		
Eccentricity (X)	2	10.521	5.260	47.90	.0000
X x A	4	.363	.091	.83	.5227
Error	22	2.416	.110		

Source	DF	SS	MS	F	P
P x X	2	.007	.004	.06	.9379
P x X x A	4	.554	.138	2.51	.0711
Error	22	1.213	.055		
D x X	8	1.884	.236	6.14	.0000
D x X x A	16	.291	.018	.47	.9531
Error	88	3.374	.038		
P x D x X	8	.199	.025	.71	.6855
P x D x X x A	16	.758	.047	1.35	.1885
Error	88	3.099	.035		

Appendix H

ANOVA Summary Table for the Face and Probe Task at Two Common Durations (52 and 61 msec)

Anova Summary Table for Probe and Face Tasks

at Two Common Durations (52 and 61 msec)

Source	DF	SS	MS	F	P
Age (A)	2	16.653	8.326	6.40	.0144
Error	11	14.315	1.301		
Task (T)	1	6.907	6.907	15.14	.0025
T x A	2	1.617	.809	1.77	.2151
Error	11	5.017	.456		
Pre-post (P)	1	3.206	3.206	40.30	.0001
P x A	2	.647	.323	4.07	.0476
Error	11	.875	.080		
T x P	1	.254	.254	2.16	.1695
T x P x A	2	.411	.205	1.75	.2189
Error	11	1.291	.117		
Duration (D)	1	.122	.122	3.03	.1098
D x A	2	.036	.018	.44	.6524
Error	11	.442	.040		

Source	DF	SS	MS	F	P
T x D	1	.051	.051	1.08	.3202
T x D x A	2	.127	.064	1.36	.2975
Error	11	.516	.047		
P x D	1	.018	.018	.35	.5648
P x D x A	2	.018	.009	.18	.8408
Error	11	.548	.050		
T x P x D	1	.016	.016	.34	.5713
T x P x D x A	2	.053	.027	.56	.5880
Error	11	.524	.048		
Eccentricity (X)	2	6.063	3.032	48.43	.0000
X x A	4	.261	.065	1.04	.4077
Error	22	1.377	.063		
T x X	2	.750	.375	4.63	.0210
T x X x A	4	.223	.056	.69	.6072
Error	22	1.783	.081		

Source	DF	SS	MS	F	P
P x X	2	.029	.014	.20	.8215
P x X x A	4	.166	.042	.57	.6852
Error	22	1.598	.073		
T x P x X	2	.030	.015	.42	.6597
T x P x X x A	4	.094	.023	.66	.6240
Error	22	.779	.035		
D x X	2	.075	.038	1.04	.3715
D x X x A	4	.014	.004	.10	.9817
Error	22	.797	.036		
T x D x X	2	.184	.092	2.80	.0828
T x D x X x A	4	.048	.012	.36	.8317
Error	22	.725	.033		
P x D x X	2	.009	.005	.17	.8456
P x D x X x A	4	.099	.025	.91	.4775
Error	22	.602	.027		

Source	DF	SS	MS	F	P
P x D x X x T	2	.009	.005	.17	.8456
P x D x X x T x A	4	.099	.025	.91	.4775
Error	22	.602	.027		

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