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Chapter 25

Developmental Changes in Attention and Visual Search throughout Adulthood

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The focus of this chapter is to review current work on age-related limitations in visual search within the framework of a two process model of attention. Three hypotheses are presented to account for discrepancies in research findings and interpretations for age-related decrements in visual search. The underlying bases for these decrements are discussed, as well as the impact of these limitations on the performance of routine daily activities. We report that there is clear evidence for age differences at both the attentive and preattentive levels of processing in visual search. However, the bases for diminished performance, when they occur, vary between individuals. Therefore, future investigations should not ignore the high degree of individual differences found in performance among older individuals, but should consider analyzing results in terms of the functional deficit or deficits unique to the individual.

One of the major challenges in aging research today is to identify performance limitations accompanying advancing age and to determine both the bases and loci of these age-related changes. This work is made particularly difficult by the ever increasing variability in performance between older individuals, and the possibility that there may be different reasons for age-related performance limitations in different individuals (Baltes, Willis, Bleiszner, Lachman & Cornelius, 1979; Hoyer, 1974; Schaie, 1980). The focus of this chapter is to review current thinking with respect to age-related limitations in attention, as reflected in a two-process model of visual information processing, and to explore how these limitations might affect the performance of everyday visual tasks.

It is intuitively obvious to most individuals that we can attend to only a very small percentage of the many stimuli around us at any given time. It is also obvious that some objects are easily noticed (i.e., are conspicuous), while other inconspicuous objects may require considerable time and effort to locate. These common experiences capture the basic distinction between the two processes proposed in many models of visual information processing. While they go by different names in different models (ambient vs. focal, automatic vs. effortful, parallel vs. serial) we shall adopt the terms used by Neisser (1967, 1976), Julesz (1981), and others and refer to them as the preattentive and attentive systems of processing.

In most previous descriptions, the preattentive system functions as a guide for the attentive system. It makes use of rapid parallel processing over large spatial areas to alert or orient the attentive system to locations in space where there is relevant or changing information. Once the preattentive system has alerted the attentive system about where to attend, the attentive system can then be used to discern detail, identify, and/or recognize stimuli. The attentive system thus represents a concentration of attentional resources within a small visual area, while the preattentive system represents a diffuse allocation of resources to a much larger spatial extent (considered by some to have no capacity limitations other than sensory).

One research technique that has been used extensively to investigate attention and these two systems of information processing is visual search. In this technique observers must search for one item, or target, amid varying numbers of other items, or distractors, presented simultaneously (Julesz, 1981; Treisman & Gelade, 1980). Under some conditions the entire stimulus array is processed simultaneously (i.e., preattentively) and the relevant target is conspicuous, or "pops out," regardless of the number of elements in the display. In other conditions, however, it appears that items must be processed sequentially (i.e. attentively) such that the number of other items in the display becomes a critical factor in the time required to locate or identify the target.

While a great deal of effort has gone into investigating the characteristics of these two systems, and the stimulus configurations which give rise to either preattentive or attentive processing, the emphasis in the present context is on the impact of age on these processes. In the remainder of this paper we will review the available data on age-related changes in visual search, and discuss three hypotheses proposed to account for the discrepancies in research findings and interpretation of age-related limitations. Secondly, we will discuss potential candidates for the bases of the age-related decrements in visual search, and finally we will examine the impact of these limitations on the performance of routine daily activities.

Aging and visual search

Before discussing the three hypotheses concerning the bases for age-related decline in visual search, an overview of past research results is presented. A number of authors have proposed that the magnitude of age differences is much greater when attentional or effortful processing is required, and that age limitations are minimal or nonexistent when automatic processing is involved (Hasher & Zachs, 1979; Hoyer & Plude, 1980). While the second part of this assumption may prove inadequate to account for all the available data, age-related deficits have been found at the attentive level in a number of different types of experiments (Plude & Hoyer,1985). With respect to visual search specifically, it has generally been found that older individuals have more difficulty attending to relevant targets in the presence of irrelevant information, or distractors (Rabbitt, 1965a, 1965b; Wright & Elias, 1979). This has been attributed by some to an inability to ignore irrelevant information (a focussed attention deficit), and by others to an inability to simultaneously divide or allocate attention to multiple positions in a visual display (a divided attention deficit).

The interpretation of the age effect is complicated by such variables as the similarity between target and distractors, and uncertainty about target location. For example, Plude (1980, 1981) compared the performance of young and older adults in their ability to detect a target letter both with and without distractors, and with either certainty or uncertainty of target position (creating both nonsearch and search conditions). He reported that an age-related deficit occurred only in the search conditions, and suggested that spatial localization of relevant information is an age-sensitive process in selective attention. Madden (1983) found similar results in that older adults received more benefit from cuing, and hence reduced positional uncertainty, than did younger adults.

In contrast to these results, Salthouse and Somberg (1982b) and Somberg and Salthouse (1982) found no age-related differences in selective attention using a dual task methodology. In these experiments subjects were asked to detect the presence of a bar marker in two four-item displays that were presented either simultaneously for 400 msec or successively for 400 msec apiece. Results indicated that even though performance on the simultaneous condition was poorer, as expected, the magnitude of the age differences was constant across both conditions.

The discrepant results between these studies may be due to any number of explanations. For example, even though uncertainty was reduced in the successive presentation condition from eight locations to four, it was not totally eliminated as in the studies which provided a cue. In addition, different durations were used for each subject in the Salthouse and Somberg (1982b) and Somberg and Salthouse (1982) studies, such that presentations were on the average much longer for the older observers and possibly equalized any capacity limitations across age groups.

Alternatively, the stimuli employed in the simultaneous/successive manipulations (detecting a discrepant line segment in a homogeneous field) were probably processed preattentively as shown by Julesz (1981) and therefore the results would not necessarily be expected to resemble those obtained at the attentive level in Plude's (1980, 1981) and Madden's (1983) work.

Spatial localization hypothesis

The first hypothesis which has been proposed to account for the results in aging and visual search experiments is the spatial localization hypothesis (Plude & Hoyer, 1985). It has long been assumed that targets in visual search tasks are selected for identification by location (von Wright, 1970). This implies that clusters of visual features, detected preattentively, are localized before directing focal identification and recognition processes to them in order to determine their task-relevant status (Snyder, 1972). The spatial localization hypothesis asserts that age decrements in selective attention are due to a decline in the ability to locate task-relevant information in the visual field (Plude & Hoyer, 1985). These authors assume that locating information in the visual field is a limited capacity process in character recognition. Furthermore, it is assumed that spatially locating and identifying stimuli are independent processes which may interact depending on the processing demands.

Several different experimental techniques have provided support for this hypothesis. For example, in a study to evaluate age differences in the capacity of preattentive visual storage, Walsh and Prasse (1980) used a modified Sperling (1960) partial-report paradigm and found that older observers had great difficulty with the partial-report procedure if a cue was at all delayed from the stimulus display. This led to a further study which compared: (1) the time needed to identify a letter when location was known, (2) the time required to localize a visual marker, and (3) the time needed to both locate and identify a letter in a visual display. Results indicated that the time needed to both locate and identify a letter was the same as that required for either task alone for the younger observers. However, the time taken to complete both tasks was closer to the sum of the times to complete either task alone for the older observers. Thus older adults are at a disadvantage on tasks requiring the operation of both localization and identification processes.

Another source of evidence for the hypothesis comes from the work of Butler (1980a, 1981) who used tachistoscopic presentations of character arrays followed by different kinds of patterned masks. In these studies subjects were asked to report either the location of a cued target, the identity of the target, or both. Butler found that errors of localization were quite frequent, whereas errors of intrusion (reporting a letter than had not been presented) were far less common. In addition, it was reported that reduced location uncertainty decreased the localization errors, as expected, but did not reduce intrusion errors. Thus, many of the discrepancies in selective attention results may be due to the type of response that was required: localization, identification, or both. Furthermore, any manipulation which reduces the demand required in locating task-relevant preattentive information (advance cuing, more salient targets, more time to locate) would be expected to be of particular benefit for the visual search performance of the older individual.

Perceptual window hypothesis

Given that deficits in spatial localization may be one basis for the age-related declines in visual search, we will now turn to studies which have examined the size of the visual area within which identification and localization information is available. In one such study, young and older individuals had to name a single letter appearing in one of seven horizontally arrayed display positions centered at fixation (Cerella & Poon, 1981). The retinal displacement of the letter, the letter's size, and the context in which the letter appeared (alone versus embedded in a string of distractors) were manipulated to map parafoveal discriminability for each age group. Age decrements in letter identification latency were found to become larger with increasing eccentricity and with decreasing letter size. Also, the visual field within which letters could be identified accurately was reduced by about one-third with age. These results led the authors to conclude that compared to young adults, elderly adults can see fewer elements at once when fixating a display, thus necessitating multiple eye fixations to locate a target. These findings were interpreted by Cerella and Poon (1981) as an age-related shrinkage of a "perceptual window." However, others have argued that these same findings may reflect more of a data limitation problem (poorer peripheral sensitivity or acuity) than an attention or resource limitation on performance (Plude & Hoyer, 1985).

Consistent with the results of Cerella and Poon (1981), Scialfa, Kline and Lyman (1987) also found evidence for the perceptual window hypothesis. In their study target letters were presented from 0 to 10.5 degrees from fixation. The targets were either flanked on each side by one distractor or embedded in a horizontal row of 19 noise elements. Their latency data revealed that age differences were largest for the peripheral targets presented in noise, suggesting that age differences in visual search can be described by a model in which older adults take smaller perceptual samples from the visual scene and scan these samples more slowly.

Plude and Doussard-Roosevelt (in press) set out to determine whether the commonly reported age decrements in visual search could be accounted for by a constriction of the visual perceptual window (i.e., a data limitation) rather than diminished attentional capacity. Their study sought to determine if age decrements in visual search occur at the preattentive level, the attentive level, or both. They reasoned that if age-reductions in extrafoveal discriminability account for age decrements in visual search, then target eccentricity should more strongly affect the speed of target detection among elderly compared to young adults. Thus age differences should increase with increasing eccentricity. On the other hand, if age decrements in selective attention account for the age decrements in visual search, they argued that eccentricity should have comparable effects across age.

The results of their study indicated that for both age groups, when targets were detected without interference from nontargets, the eccentricity of the target did not affect detection time. On the other hand, when attentive processing was required they did find an eccentricity effect, and this effect was greater for the older individuals. They thus concluded that the perceptual window hypothesis only receives support at the attentive processing level and that there are minimal age-related deficits in visual search at the preattentive level. The authors point out, however, that further eccentricities (beyond the six degrees investigated in their study) and stimuli should be explored to confirm this conclusion.

The literature as reviewed to this point thus reveals an apparently conflicting pattern of results. At times stimulus uncertainty, stimulus eccentricity, stimulus duration, and distractors appear to place older individuals at a particular disadvantage, yet at other times they do not. The spatial localization and perceptual window hypotheses both receive some experimental support, and yet in some aspects these two points of view conflict. We will now turn to a different visual search task which has been used to study age-related attentional deficits and which may help to resolve some of these discrepancies.

Useful field of view hypothesis

The final hypothesis we will present to account for age-related deficits in visual search is based on our own work with the *useful field of view* (UFOV). Vision scientists have long been referring to the "functional" or "useful" field of view, and it has been defined as the spatial area or visual field extent that is needed for a specific visual task (Sanders, 1970). Measures of the UFOV are very different from measures of visual field size, and can be very much smaller than the area of visual sensitivity *per se*. The UFOV is usually measured binocularly, and involves detection, localization, and/or identification of suprathreshold targets in complex displays. The limits of this field have been found to vary substantially across individuals and situations (Verriest et al., 1983, 1985). For example, the size of the UFOV is reduced when a secondary central task is added (Leibowitz and Appelle, 1969; Ikeda and Takeuchi, 1975; Williams, 1982; Ball, Beard, Roenker, Miller & Griggs, 1988), when the target is embedded in background distractor stimuli (Drury and Clement, 1978; Sekuler and Ball, 1986; Scialfa et al., 1987; Ball et al., 1988), and as the similarity between the target and distractor stimuli is increased (Bloomfield, 1972; Engel, 1977; Treisman & Gelade, 1980; Julesz, 1981; Bergen & Julesz, 1983).

Furthermore, it has been shown that the diameter of the area that can be searched either serially (Scialfa et al, 1987) or in parallel (Bergen & Julesz, 1983) is related directly to target/distractor similarity as well as stimulus duration. That is, more conspicuous targets can be attended at further eccentricities than less conspicuous targets, given a constant duration, and targets presented for a longer duration can be attended at further eccentricities given a constant level of conspicuity. Most importantly, for the purposes of assessing the UFOV as a function of age, the impact of these variables, in general, has been reported to be much greater for older individuals (Ball et al., 1988). These studies have indicated that aging is associated with a deficit in both serial and parallel visual search, as well as a restricted field of view, and that the degree of restriction can be much greater for visually-healthy older adults than for young adults (Ball et al., 1988). Thus either a divided attention deficit, an inability to ignore irrelevant information, or both could account for the age-related reduction in UFOV.

Since the size of the UFOV varies with stimulus duration, an additional possibility for the basis of reduced UFOV is age-related slowing of visual information processing. In support of this hypothesis, older adults have been found to be slower at preattentive or iconic processing (Abel, 1972; Hoyer & Plude, 1982; Walsh & Prasse, 1980). For example, Walsh and Prasse (1980) performed an experiment in which a backward masking procedure was used to assess age differences in the rate of recognizing letters in a visual display consisting of one, two or three letters. They found that young adults required 60 msec to read a single letter, with a 20 msec increment for each additional letter in the display, while older adults required 85 msec to read a single letter with an increment of 35 msec for each additional letter. The authors concluded that older adults have slower rates of readout from visual displays. Consistent with this, Cerella et al (1982) reported that iconic readout rates slow by an aging factor of 1.3, while processes responsible for storing and transforming iconic information slow by a factor of about 1.8.

In summary, there is an abundance of evidence that the UFOV shrinks with age for either detection, localization, or identification, and that the size of the UFOV can be influenced by manipulating stimulus duration, conspicuity of the target, and difficulty of a secondary task. There is also substantial evidence that the effects of dual tasks, distractors, and brief durations interact with both age and eccentricity, reflecting a shrinkage of the UFOV with age.

In an attempt to incorporate all of these variables into the visual search technique, Sekuler & Ball (1986) designed a UFOV radial localization task that measured how well a single, randomly positioned target could be localized in the presence of distractors, both with and without a secondary center task. As mentioned earlier, it was found that age differences were greatest at increased retinal eccentricities, indicating a restricted UFOV for the older adults relative to the young. Performance on this task was found subsequently to be predictive of the frequency with which older individuals report difficulty with everyday activities involving their peripheral vision (Ball, Owsley, & Beard, in press). In the next section the methodology for this task will be described, followed by more recent work aimed at determining the basis for this age-related decline.

UFOV task methodology. In various versions of the UFOV task observers had to locate an odd target in a rather large visual area (60 degree diameter presented on a large CONRAC video monitor at a distance of 28.5 cm) while performing a central vision task. We maintained the ecological validity of the task by employing highly visible targets, unknown target locations, concurrent use of foveal and peripheral vision, and by presenting targets within some background context. Several variables known to influence performance on this task were manipulated: (1) the conspicuity or salience of the target (relative to its background), (2) the duration of presentation, (3) the complexity of a central visual task, and (4) the level of training on the task.

Every trial consisted of four successive computer-controlled displays. The first display, a bright outline box (8 *x* 9 degrees) directed the observer's fixation. One second after the onset of the fixation box the test stimulus appeared for some short duration (between 12.5 and 150 msec). This presentation was too brief for observers to initiate and complete a shift in fixation during the test interval. Spatially random masking noise (consisting of vertical and horizontal lines of varying intensity) followed the test stimulus and obliterated any residual afterimage on the screen. Finally, a radial pattern appeared with eight equally spaced spokes, each labeled with a digit from one to eight. The spoke pattern remained visible until the observer selected one of eight numbers on a keypad located in front of him/her indicating the radial position of the test stimulus.

A schematic diagram of one type of test stimulus is shown in Figure 1. The test stimulus always contained two components: (1) a central task presented in the fixation box, and (2) a peripheral task presented outside of the fixation box. In our most common test condition the peripheral target stimulus consisted of a cartoon likeness of a smiling face subtending 3 x 6 degrees. The luminance of the face was 2 cd/m^2. The background luminance of the display was low (0.03 cd/m^2). Although such levels are below many encountered in everyday conditions, the stimuli were highly visible, and it has been shown previously that radial localization is, within these limits, not affected by luminance level (Leibowitz et al, 1955). The target face appeared unpredictably, but equally often, in each of 24 different peripheral locations along one of the eight radial spokes (four cardinal as well as four oblique) and at one of three eccentricities: 10, 20, or 30 degrees.

Two responses were required at the end of each trial. The first response was made to the center stimulus, thus ensuring fixation, and the second response consisted of selecting the radial location of the peripheral face. If the first response was incorrect the trial was terminated and presented sometime later within a block of 24 trials.

Age-Related Attentional Deficits. The UFOV has, as previously stated, been defined as the visual area in which useful information can be acquired without eye and head movements. In our paradigm this corresponds to the area within which targets can be localized in a preattentive visual search task. In order to obtain a numerical value for this area we take advantage of the finding that the relationship between errors of localization and target eccentricity is, in almost all cases, linear. In the cases where this relationship is not linear, it is usually due to either floor or ceiling effects. In the case of a floor effect, when there is poor localization at all eccentricities, observers are assigned a UFOV size of 5 degrees for that particular condition which corresponds to the radius required to perform the central task alone. In the case of a ceiling effect, when there is very good or perfect localization at all eccentricities, observers are assigned a UFOV size of 35 degrees which corresponds to the radius of the entire display. In all remaining conditions the best fitting line reflecting the relationship between eccentricity and errors of localization is used to compute a UFOV size corresponding to the point at which observers can localize the peripheral target correctly 50% of the time.

Before analyzing our results based on various attentional explanations, it is important to rule out the data limitation argument raised by others relative to the perceptual window hypothesis. All observers in these experiments were carefully screened for ocular pathology and had acuity in the range of 20/20 or better. We have found that the UFOV results are uncorrelated with acuity, standard visual field measures, contrast sensitivity measures, and pupil size. As noted in Ball et al. (1988), acuity is not related to radial localization errors for the range of acuities reported in these studies. With respect to pupil size, Sloane, Owsley & Alvarez (1988) have reported that age-related miosis, which reduces retinal illuminance in the older eye, is not related to observed sensitivity losses in spatial vision under the light levels tested in these studies. They found, rather, that the miotic pupil had a positive effect on the spatial vision of older adults, possibly due to its minimizing optical aberration and increasing depth-of-focus.

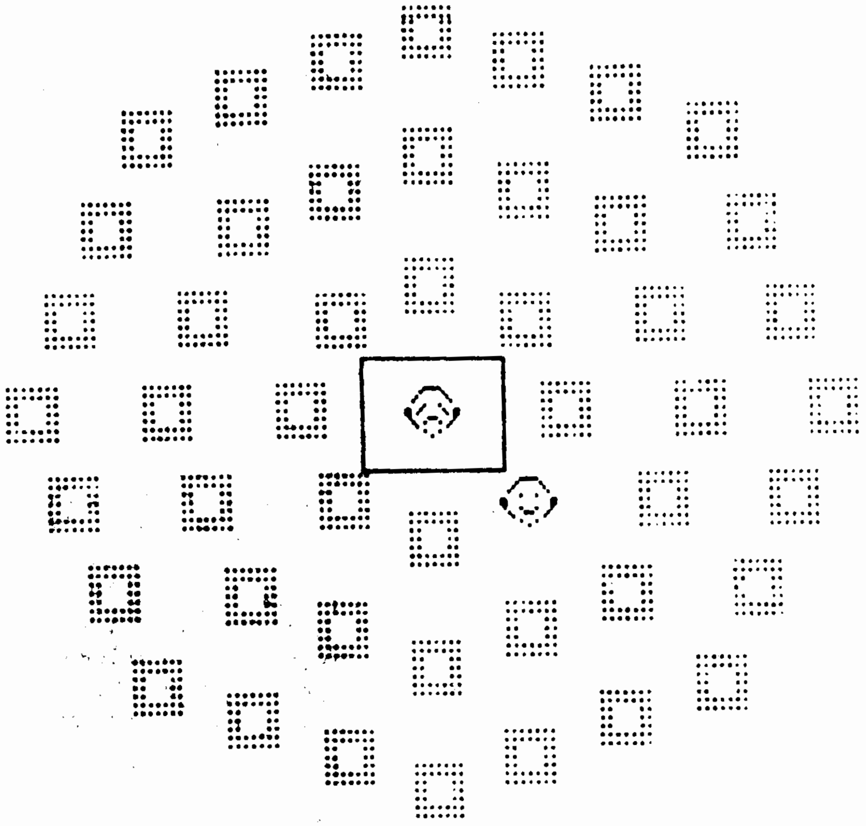

Figure 1. Schematic diagram of the UFOV test stimulus consisting of both a central face identification task and a peripheral localization task for a face target at 10° eccentricity embedded in box distractors.

We will now examine the possible roles of three attentional deficits as bases for age-related reduction in the UFOV: (1) reduced speed of visual processing (as reflected by a greater impact of reducing stimulus duration on the older individuals), (2) reduced ability to divide attention (as reflected by a greater impact of increasing center task complexity on the older individuals), and (3) reduced salience of the target against its background (as reflected by a greater impact of distractors on the older individuals).

In order to sort out which of these well established aging effects was causing the shrinkage of the UFOV, we examined the data on 86 individuals for whom we had measures of each effect. We first assessed the prevalence of each age group in both high and low impact groups for each of the three potential bases. To obtain the effect of decreasing duration we compared UFOV areas for stimulus durations of 125 and 75 msec. If the size of the UFOV was relatively unchanged (0-5 degrees) the effect of duration was designated as having a low impact for that particular individual. If, however, the UFOV was reduced by greater than 6 degrees with decreased duration, the effect of duration was designated as having a high impact for that individual. Similarly, to obtain a measure of the impact of dividing attention we compared the change in UFOV size as the difficulty of the center task was increased and made the same division into high and low impact groups. Finally, for the measure of distractors, we compared the change in UFOV size for localization conditions both with and without distractors.

Figure 2 illustrates the prevalence of each age group in either a high or low impact group for each of the three effects. All but one of the young adults (<40 years) were in the low impact group for all three measures. Middle-aged observers (41-59 years) were in the high impact group 27% of the time for both divided attention and distractors effects, and 45% of the time for duration effects. For the oldest age group, 47% fell in the high impact group for the divided attention problem, 58% for the distractor problem, and 69% for the slowing problem. Additionally, for those observers in the high impact groups, the magnitude of the impact was significantly greater for the older individuals than for the middle aged observers in the same group.

Even though more older individuals were affected by decreasing duration, increasing cognitive demand, and distractors, it is important to note that many of the older individuals were in the low impact groups as well. To study the individual differences for these effects we sorted our participants into eight groups: (1) low impact of all three variables, (2) high impact of duration only, (3) high impact of dividing attention only, (4) high impact of distractors only, (5) high impact of duration and divided attention, (6) high impact of duration and distractors, (7) high impact of divided attention and distractors, and (8) high impact of all three variables. Figure 3 illustrates the size of the UFOV for these eight groups of individuals. Data are shown for a condition incorporating distractors, a 125 msec stimulus duration, and a difficult center task. The outer circles represent the average UFOV size for the individuals with none of the problems. Losses in field size due to each of the separate problems are illustrated as both a loss in the radius of the field and in percentages. Of the three single basis groups, a slowing in visual processing had the greatest effect on field size (reducing it by an average of 54.41% in the high impact group). Also note that the effects of multiple bases, when they occur, are additive such that an individuals with all three effects, on the average, have a loss of 84.28% of the field relative to the group experiencing none of the problems.

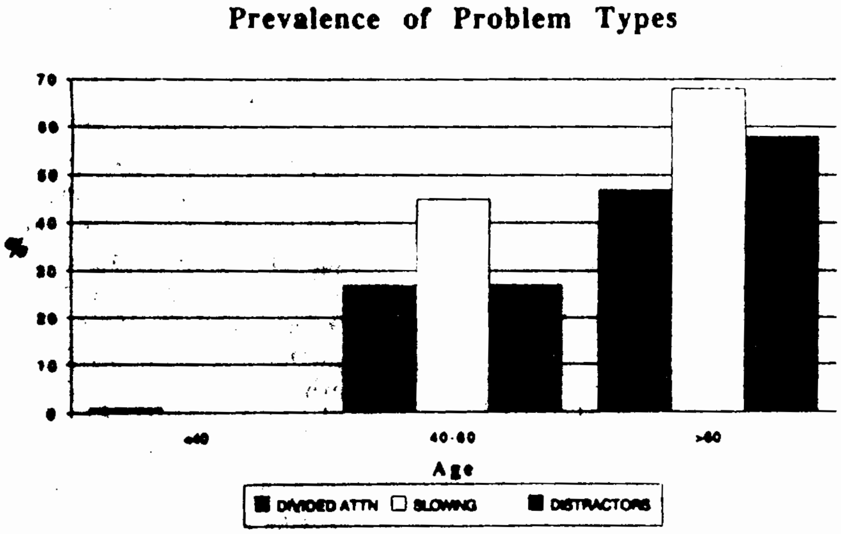

Figure 2. **Prevalence of divided attention, slowing, and susceptibility to distractor problems in three age groups as assessed by UFOV task performance.**

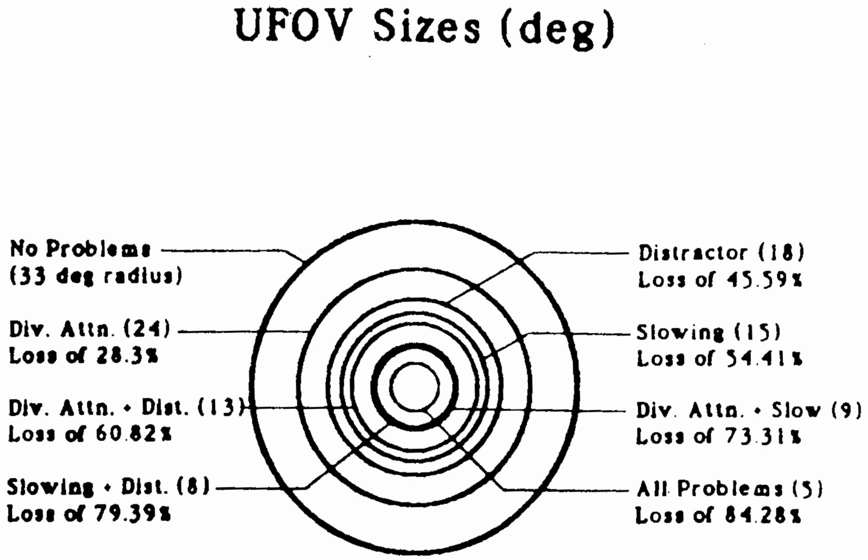

Figure 3. Size of the UFOV (in degrees) for eight groups of individuals exhibiting high impact of distractor, divided attention, and slowing problems relative to a group of individuals exhibiting none of these effects. Data shown illustrate performance on a UFOV condition incorporating distractors, a 125 ms stimulus duration, and a difficult center task.

We further analyzed the basis for reduction in the UFOV by examining the amount of variance in the UFOV accounted for by age, the three attentional bases (slower processing, susceptibility to distractors, and divided attention difficulty), and the combination of all these variables. Table 1 illustrates the results of these analyses. Age alone accounts for approximately 50% of the variance in UFOV. The degree of shrinkage due to each of the three attentional components, however, accounts for 91% of the variance in UFOV. Once the three bases are entered into a regression analysis, adding age accounts for only an additional 1.6% of the variance, indicating that the age-related shrinkage of the UFOV can be accounted for without knowledge of age. Thus the general age trends observed in this task are due to a higher prevalence of the three specific problems in an older age group rather than a general age-related decline in one or more of the three areas.

Table 1. **A comparison of predictors of the UFOV.**

Variables	R^2
Age	.488*
Three Attentional Deficits	.910*
Age + Three Attentional Deficits	.926*

* $p < .001$

UFOV and Everyday Vision. In agreement with these laboratory studies, survey results have indicated that the frequency of difficulty that older adults report on everyday tasks associated with visual search, peripheral vision, and cluttered visual scenes is about five times greater than that reported by younger adults (Kosnik, Winslow, Kline, Rasinski, & Sekuler, 1988). We have previously suggested that a constricted UFOV may be responsible for these reports (Sekuler & Ball, 1986; Ball et al., 1988). Even though individuals have unlimited viewing time in many daily situations, a constricted UFOV could affect performance by forcing the observer to perform more fixations in order to scan the same visual area. Given the age-related increase in the latency of ocular movements (Carter, Obler, Woodward, & Albert, 1983) this would place older individuals at a disadvantage in everyday situations involving visual search.

Although there is good evidence for an age-associated decline in visual field extent and sensitivity in studies in which both standard (Goldmann) perimetry and automated periphery are used (Wolf, 1967; Brenton & Phelps, 1986; Johnson, Adams, & Lewis, 1988), these clinical measures are not predictive of the degree of difficulty that these older adults report with everyday activities such as driving, mobility, visual search, and the slowing of visual processing (Ball, Owsley & Beard, in press). This is probably due to the fact that clinical perimetry measures the detection of a luminance target presented in isolation, whereas everyday activities, such as driving, require responses such as localization or identification of surprathreshold targets in cluttered visual scenes as well as the simultaneous use of both foveal and peripheral vision.

Statistics of driving accidents were compared with both visual field measurements and age in several studies. Older drivers, in general, have been found to have disproportionately more accidents and cited traffic violations (Planek, 1973; Senior Facts, 1982), and their accident profiles (i.e. failures to heed signs, to yield the right of way, to turn safely, and more frequent junction accidents) indicate that they are having difficulty processing information from the periphery (Campbell, 1966; Moore, Sedgely & Sabey, 1982; Kline, 1986). Even so, in most studies no link has been found between age-related visual field loss, as measured by standard techniques, and driving performance (Allen, 1970; Henderson & Burg, 1974; Council & Allen, 1974; Shinar, 1977). Although in a recent large sample study (N = 10,000) a relationship was found between accident rates and severe binocular visual field loss (Johnson & Keltner, 1986), in this study a relationship was not found between age-related visual declines in otherwise visually healthy older adults and driving performance. In another study, however, a relationship was found between driving accident rates and performance in visual tasks incorporating visual clutter (Avolio, Kroeck, & Panek, 1986). These results suggest that assessment of peripheral vision under more realistic conditions may better predict the driving performance of older individuals.

Given that the size of the UFOV shrinks with age, how would this be expected to affect everyday performance? Morgan (1988) provided an anecdotal report of how vision changes affected his own everyday vision where he states:

> *I have the impression that my working visual fields, in contrast to my clinically measured fields (which are normal), are somewhat reduced.... Objects coming from my right that I missed on casual observation sometimes suddenly appear in my field. I think I have to make a greater effort than before to perceive objects in the periphery of my field. If I give my full attention to detecting peripheral objects, as in visual field testing, my performance is*

> *excellent. But when my attention is divided, as in driving, I think that there has been a decrease in the size of my visual fields.*

Conclusions

There is an abundance of evidence for age-related performance limitations at both the attentive and preattentive levels of processing in visual search. However, the high degree of individual differences in performance suggest that comparing the average performance of young and older individuals may mask the fact that many older individuals do not experience any of these "age-related declines." Furthermore, comparing average values both within and between age groups may obscure findings of multiple and/or different reasons for performance limitations in different individuals. With respect to the UFOV task, it appears that there is not one basis for the age-related changes in performance, and that within a given individual there may be more than one change contributing in an additive fashion to their performance decline. Thus disagreements concerning whether age-related differences occur due to selective focussing, an inability to ignore irrelevant information, or slower processing may all be true within different individuals.

Within the visual search literature there appear to be many discrepancies, with some studies indicating age-related deficits in performance and some finding no age effects. These discrepancies may be due to the parameters of the tasks themselves, the level of processing involved, or to the particular populations on individuals being evaluated. For example, we do not find age-related differences in some of the UFOV conditions, but do in others, and therefore the results of Plude & Doussard-Roosevelt (in press) which indicated no attentional limitations in preattentive processing were probably due to their range of eccentricities and the high conspicuity of their target.

The spatial localization hypothesis, perceptual window hypothesis, and UFOV hypothesis all contribute to our understanding of the age-related difficulties in visual search. Future studies should examine the variability between older individuals systematically rather than reporting age-related trends in performance. Analyzing data in terms of the prevalence of various age-related changes may provide a better description of individual performances.

Since UFOV task performance is a much better predictor of many of the reported mobility and driving problems or older adults than tests of sensory performance, visual search techniques may prove useful in the future for assessment of functional abilities. The ability of stimuli to attract our attention and orient us in space is critical in adapting to new surroundings and navigating through complex environments. The UFOV task thus appears to provide an ecologically valid measure of attention that can be used not only to gain a better understanding of attention in general, but to predict real world performance.

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