Visual selective attention and aging

Citation for published version (APA):
Mccalley, L. T. (1995). *Visual selective attention and aging*. [Phd Thesis 1 (Research TU/e / Graduation TU/e), Industrial Engineering and Innovation Sciences]. Technische Universiteit Eindhoven. https://doi.org/10.6100/IR439112

DOI:
10.6100/IR439112

Document status and date:
Published: 01/01/1995

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

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VISUAL SELECTIVE ATTENTION AND AGING

Proefschrift

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven,
op gezag van de Rector Magnificus, prof.dr. J.H. van Lint,
voor een commissie aangewezen door het College van Dekanen
in het openbaar te verdedigen
op dinsdag 6 juni 1995 om 16.00 uur

door

Lorna Theo McCalley

geboren te Fresno, California, USA

Dit proefschrift is goedgekeurd door de promotoren:

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Cover design by L. T. McCalley

VISUAL SELECTIVE ATTENTION AND AGING

Dissertation

by

Lorna Theo McCalley

For Jan and Ricky

Periculum dulce est
(McCalley clan motto)

Acknowledgements

I wish to acknowledge the moral support and invaluable advice of my promotor prof. Don Bouwhuis. I also owe many thanks to prof. Juola of the University of Kansas for his fine advice and contributions to my work and to prof. Jelle Jolles, my second promotor, for his constructive comments which contributed substantially to the contents of this thesis.

I am also indebted to the following people:

Dr. Frits Engel for his many valuable comments, for reviewing all my manuscripts, and for his never failing encouragement.

Dr. Rudy van Hoe for excellent statistical advice.

Prof. Jim Fozard, prof. Fergus Craik and prof. Patrick Rabbitt, all experts in the field of aging, for stimulating discussions and helpful critiques of my work.

Dr. Tom Harrington and prof. Bob Solso of the University of Nevada-Reno for getting me started in the field.

My IPO colleagues who were always willing to drop what they were doing to help me.

I would also like to add a very special thanks to the subjects who gave so generously of their time and effort to my experiments.

Finally, I wish to thank my family, Jan, Ricky, Roger, Mom, Dad and Liz, for their continuing support and encouragement, without whose help I could never have accomplished this feat.

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Chapter 1

Introduction

The goal of this study was to establish a basis for understanding the source of reading problems that affect the daily functioning of older adults. Elderly people often complain that specific reading tasks which require the acquisition of word information in complex visual environments, where words often appear briefly and away from where the eyes are focused, are particularly difficult. Examples of such tasks include reading television subtitles (d'Ydewalle & Gielen, 1994), computer menus, telephone numbers in a phone book, and street signs while driving (e.g. Ball, Beard, Roenker, Miller & Griggs, 1988; Kosnik, Winslow, Kline, Rasinski, and Sekuler, 1988; Ponds, Brouwer & Wolffelaar, 1988; Sekuler & Ball, 1986). These tasks all require that a primary component of reading, word recognition, be carried out in a complex, distracting, and thus attention demanding, visual environment.

In response to these complaints of the elderly, this study was conducted to explore age effects on the relationship between visual selective attention and word recognition with special regard to briefly presented visual information in "cluttered" arrays. In particular, visual word recognition in the extrafoveal visual field is explored as all of the abovementioned tasks have a common need for scanning and gathering information away from where the eyes are currently focused. It is commonly accepted that letter information from words presented outside of the fovea (point of fixation) speed the processing of those words and aid guiding appropriate eye movements that subsequently place words on the fovea for maximal processing (e.g. Besner & Humphreys, 1991; Blanchard, Pollatsek & Rayner, 1989; Humphreys & Bruce, 1989; Inhoff, 1989; Underwood, Clews & Everatt, 1990). In the case of some parafoveal word recognition tasks such as reading subtitles and looking for a street sign from a moving car, the need for speedy processing is especially important.

In determining why these particular everyday tasks seem so difficult for older people each of the necessary components of gathering visual word information away from fixation must be examined. It is obvious that both vision and attention play major roles. Consider the example of a driver on a busy street searching for a particular street sign. Good general visual acuity is indisputably necessary. In addition, the driver must also be attentive to the traffic. However, the driver must not only be able to attend to other vehicles, but to shift attention to objects along the way so that a street sign may be located and read while still monitoring the actions of the other vehicles as well as the driver's own actions and driving strategies. This task then requires adequate peripheral vision and good selective attention, including the ability to ignore irrelevant information.

If we accept both the empirical data (e.g. Ball, Roenker & Bruni, 1990) and the self-reported difficulties of older persons (Kosnik et al., 1988) with such tasks then we must ask where those difficulties originate. They are obviously age-related as a survey conducted by Sekuler and Ball (1986) found that five times more older people than younger people reported difficulties with tasks containing visual distractors. A review of what is currently known about the aging aspects of vision and attention, follows.

1.1 Age-Related Changes

Vision

Many functions of the visual system gradually decline with age from sometime after the twentieth year onwards (Weale, 1975). In normal healthy older adults visual acuity associated with the optical structure (the eye) is, however, often well preserved. Therefore, much of the loss of acuity associated with age must be due to changes in the neural, and more central, components of the visual system (Weale, 1975). In hierarchical order, this system consists of the retina, the optic nerve, the lateral geniculate body, and the visual cortex. There is strong evidence that much of the age-related change observed in basic perceptual processes underlying, for example, visual search, originate in the highest areas of the central nervous system (Fozard, 1990; Kline & Schieber, 1985). Yet despite evidence of at least some deterioration at all levels, older adults maintain a high degree of visual functionality implying the use of compensatory resources of the brain (Kline & Schieber, 1985).

The driving example illustrates that visual search also depends upon being able to observe objects in the parafoveal and peripheral visual field without eye movements. Objects falling within the central two degrees of visual angle can be said to fall within the foveal area. Those falling outside the foveal area up to five degrees visual angle are referred to as parafoveal, and those falling outside the parafoveal region are referred to as peripheral (Balota & Rayner, 1991). According to Kline and Schieber (1985), "The field of vision of an eye is the total area over which effective sight is maintained relative to a constant, straight-ahead fixation point". It is the gathering of information in this field, outside the point of fixation, which is the focus of this study.

There is ample evidence that the visual field shrinks with age (e.g. Drance, Berry & Hughes, 1967, Haas, Flammer & Schneider, 1986; Jaffe, Alvarado & Juster, 1986; Williams, 1983; Wolf, 1967). The cause for the shrinkage cannot be wholly accounted for by optical factors (Johnson, Adams, Adams & Lewis, 1988) but is more likely due to age-related changes in retinal metabolism (Wolf & Nadroski, 1971). It is therefore likely that older adults are unable to obtain as much information from the visual field as younger adults thus seemingly providing an explanation of the self-reported driving problems of the elderly. However, these declines alone cannot predict the high degree of difficulty that older people report not only driving, but in many other everyday activities (Ball et al., 1990).

For example, reading television subtitles also requires that much information be gathered in the region away from fixation. This task normally takes place within a much smaller field of view. If a person views a television screen from the distance of two and a half meters then the screen represents only 12.5 degrees of visual angle; well within the approximately 20 degree visual angle range of the narrowed visual field (Williams, 1983). In addition, some researchers (e.g. Ball, Beard, Roenker, Miller & Griggs, 1988; Cerella, 1985) have found that peripheral presentation of a single target alone in the field does not engender age-related performance differences. These differences only occur when the target is presented among distractors. According to Hartley (1992), these results indicate that the problems older individuals have in identifying objects in parafoveal and peripheral vision cannot be due to reduced vision alone, nor can they be compensated by simply enlarging targets in the periphery.

Ball, Roenker, and Bruni (1990) have done an in-depth investigation into the causes for age-related limitations in visual search. They propose that the size of the visual field and the useful field of view are different. The Useful Field of View (UFOV) is defined as, "...the visual area in which useful information can be acquired without eye and head movements", for a particular visual task (Ball, et al., 1990). Unlike the visual field the UFOV is measured binocularly, requiring detection, localization, and identification of targets in a complex visual display (Ball et al., 1990). This area shrinks or expands according to attentional demands, number of distractors, and similarity of target to distractors. Ball et al. (1990) conclude that older adults, despite good acuity, experience a shrinkage of the UFOV due to a deficit in one or more of three areas; attention, suppression of distractors, or visual processing speed, and that these effects are additive. The following sections address the above effects and describe the two most prevalent theories of cognitive slowing associated with age that specifically relate to attention. Each of the theories relates to one of the above three possible areas of decline thought to underlie age-related reduction of the UFOV as put forward by Ball et al. (1990).

Attention

Attention is fundamental to cognitive functioning and is therefore a possible source of age-related changes affecting the processing of extrafoveal information. However, to date, research has not provided a definitive answer as to whether attention generally changes with age (e.g. Hartley, 1992). It is more likely that some aspects of attention do change while others are maintained. It is therefore necessary to clearly define attention in order to understand what those aspects of attention are that might cause a shrinkage of the UFOV discussed above.

Attention can be generally defined as, "...the concentration of mental effort on sensory or mental events", (Solso, 1988). In this study only the selective aspects of attention pertinent to the aforementioned everyday problems of the elderly will be examined in depth: in particular the detection or identification of visual targets.

Posner (1988) has provided a clear and useful definition of selective attention which has been adopted for this study.

> Attention involves selection of higher levels of processing, including conscious processing, while preventing access of other signals to those same high levels of processing.

Referring to the above definition, it can be stated that attention consists of a selective component where an object or area is chosen to receive a concentration of resources to optimize processing, and an inhibitory component where all other areas are simultaneously suppressed so as to protect the selective processing from the interference of irrelevant information (see also Posner, Snyder & Davidson, 1980; Posner & Snyder, 1975; Posner, 1980). It is possible that a defecit in either, or both, of these aspects of attention might affect extrafoveal processing of information. In fact, the two most prevalent theories of attentional deficits related to aging which have received the most empirical support are a theory of general slowing which proposes that both aspects of attention simply function more slowly with age, and a theory of reduced inhibition which proposes that age-effects reduce the suppression of irrelevant information. The first of these theories is reviewed in this section as it relates in a general way to attention. The second is directly related to the suppression of distractors and is reviewed in the following section.

A Theory of General Slowing

Many researchers view cognitive and attentional deficits associated with aging as an outcome of a general slowing, whether it be neuronal (e.g. Birren, 1974; Myerson, Hale, Wagstaff, Poon & Smith, 1990), or unspecified (see Hartley, 1992, for a review). In this view, age-related attentional changes are artefacts of general slowing. However, this hypothesis is so wide in scope that it accounts for most of all age variance when results are not analyzed in a detailed manner, perhaps allowing many small, but significant differences to be overlooked (Hartley, 1992). Hartley (1992) also points out that many studies claim that it takes older adults about 1.5 to 2 times longer to process information than younger adults. However, cuing and priming studies, where advance information is given as to where a target is most likely to appear, do not show an equivalent lengthening of processing for older adults in the time course of using the prime or the cue as the general slowing theory predicts.

Suppression of Distractors

As Ball et al. (1990) suggest, an inability to suppress distractors in the visual field might lead to a shrinkage of the UFOV for older adults. This concept is directly related to the second prevalent hypothesis of attentional decline; reduced inhibitory functioning in older adults. Rabbitt (1965) was one of the earliest to suggest that older adults were less able than younger adults to ignore irrelevant information. Rabbitt found that the addition of distractor letters in a card sorting task disproportionately slowed older adults. Hasher and Zacks (1988) later developed a hypothesis of reduced inhibitory functioning to account for declines in both visual and memory search functioning in older adults.

This later, formalized, theory of reduced inhibition of irrelevant information implies the view of attention as encompassing two separate processes: inhibition and selection. Inhibition is thus viewed as a resource that allows selection of one stimulus from competing stimuli. It is thought that perhaps the selection process remains intact in older persons but the inhibitory process does not. In his comprehensive review, Hartley (1992) states that in a visual search task where a cue indicates the area in which an object is likely to appear, older people may benefit from a correct cue but will not suffer costs from an incorrect cue if they are unable to suppress, or inhibit, the uncued area. In the same task younger people would have both benefit for a correct cue and cost for an incorrect cue because they would be selectively attending to the cued area and inhibiting the uncued areas. Prior to the present study, no evidence for the hypothesized reduced inhibition of the elderly had been found using cuing tasks. However, evidence from many other types of studies support an hypothesis for reduced inhibition (Plude et al., 1994) and it only remains for converging evidence from cuing studies to make the hypothesis creditable.

Visual Processing Speed

The speed of visual processing is dependent on the duration of a series of neurophysiological processes which transform sensory input and the speed with which these processes are initiated. A reduction of visual processing with age is the result of an overall slowing of the neuronal processes but cannot account for the fact that, for example, many elderly are able to maintain high reading rates (Aberson & Bouwhuis, 1993; Hartley, 1986, 1993). It is therefore unlikely that either an overall slowing of visual processing, or reduced acuity in the peripheral visual field discussed earlier, can explain all the reported difficulties that older people have in gathering information outside fixation. Therefore further explanation is sought in the area of attention studies and the corresponding underlying theories.

Summary

Some researchers suggest that cognitive changes associated with aging might be due to a general slowing of all cognitive processes. In this view, results of many attentional studies where older adults are found to be slower than younger adults in identifying a parafoveally presented target, are seen as artefacts of an overall age-related slowing. However, because of the questions that cannot be answered by a general slowing hypothesis, many researchers have sought to explain age-related cognitive deficits as either the result of an overall decline of selective attention or of a decline of the inhibition process. Yet, evidence from cuing and priming studies that would give general support to a hypothesis of reduced inhibition has so far been lacking. Still other researchers sought an underlying physiological or structural explanation, such as visual decline, for age-related differences in attention studies, without regard to the cognitive aspects. Nonetheless, neither visual decline due to a general slowing of visual processing, nor shrinkage of the visual field affecting peripheral vision, can account for all reported problems of the elderly for visual tasks carried out in cluttered scenes.

1.2 Modelling Attention

The Experimental paradigm

The effects of attention on visual search are often investigated using a spatial cuing task based on that developed by Posner, Nissen, and Ogden (1978). In such a task, subjects must keep their eyes fixed on a central fixation point while locating and/or identifying a specified target object which might be, for example, a geometric shape, a letter, a number, or a word. Prior to presenting the target stimulus a cue is presented which gives information as to where the target is likely to appear. The cue might be, for example, an arrow, a word (visual or auditory), or a flashing box. Cues presented in the far periphery are thought to be a special case eliciting a quick (<150 ms) automatic orientation of attention (Müller & Rabbitt, 1989). Auditory, or more centrally placed cues are thought to require a controlled orientation of attention which takes more time to achieve (>300 ms) (Müller & Rabbitt, 1989). The current study is concerned with the controlled allocation of attention to various areas of the visual field in order to enhance the visual processing of letter or word information and thus utilizes spatial cues that appear within the peripheral boundary of the stimulus display.

In the case of Posner et. al. (1978, Experiment 1), subjects fixated the center of a visual display and were then presented with either a cross (neutral cue condition) or an arrow pointing either left of right. An "X" would then appear to one side of fixation and the subject responded with a corresponding button press. In 80% of the non-neutral cue trials the arrow correctly indicated the side where the target would appear (valid cue condition). On the remaining 20% of trials the target appeared opposite to the arrow (invalid cue condition). The rationale for the paradigm is that attentional shifts will be reflected by variations in response times (RTs) and error rates which in turn reflect specific types of responses to the cue. A valid spatial cue is expected to lower RTs and errors, and an invalid spatial cue is expected to cause an increase in RTs and errors. These reactions are termed benefit and cost, respectively. Benefit and cost patterns give information as to how effective the cue is and how well the subject is able to respond to the cue (see also Posner, 1980). A comparison of benefit and cost patterns between younger and older adults can show how these groups might differ in both their response to a particular cue and to particular stimuli. When the time between the presentation of the cue and the presentation of the stimulus display is changed it can yield information as to the speed of processing of the cue. These varying times are referred to as stimulus onset asynchronies (SOAs).

Models of Attention

Previous work at the Institute for Perception Research has led to the development of various quantitative models of attentional allocation based on the data of younger subjects (Juola, Bouwhuis, Cooper, & Warner, 1991). These models have been adapted and refined for use in this age comparison study.

In the Juola et al. (1991) study, three metaphors for attentional allocation were compared by means of quantitative modelling. These three metaphors are the spotlight (e.g. Tsal, 1983; Posner, Snyder & Davidson, 1980), the zoom lens (Eriksen & St. James, 1986, LaBerge, 1983), and the ring (Egly & Homa, 1984; Juola, Crouch, & Cocklin, 1987, Juola et al., 1991) which were initially proposed as theoretical models of how attention is distributed in the visual field. Illustrations of how attention is distributed according to these three models can be seen in Figure 1. As an example of how a quantitative model is developed, the example of the zoom lens model will be used. Eriksen and St. James (1986) proposed that attention is distributed out from the point of fixation and expands and contracts from this point much like a zoom lens in response to demands in the visual field. This model then predicts that if information is to be gathered from an object close to the fixation point, attention remains in a concentrated beam around this point, enhancing the processing of the object. If information must be gathered from an object further from fixation, then the beam spreads out, distributing attention in a broader, but less effective manner. At some point attentional resources thin to the point that they no longer are effective and the perception of the to-be-processed object receives no more enhancement than any other object in the same peripheral range from fixation.

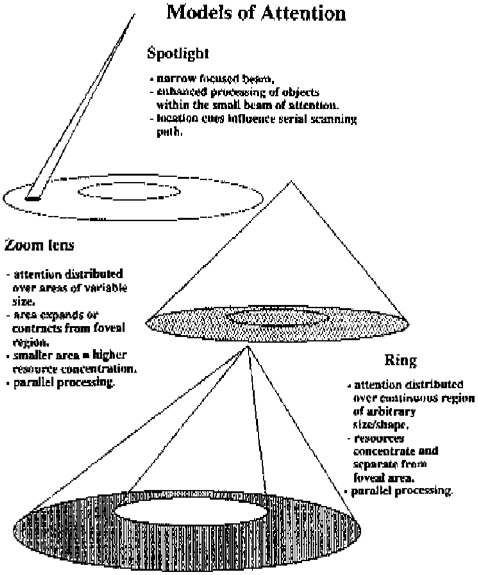

Figure 1. *Models of attention.*

From this theoretical distribution of attentional resource allocation gross benefits and costs for a spatial cue can be predicted as was done by Egly and Homa (1984, Table 4) for costs of invalid cues only. Juola et al. (1991) then used the theoretical distribution of attention to devise a mathematical model using the principle of least squares (see Juola et al., pp.130, 1991). The mathematical model of the theoretical distribution uses actual data to predict how much benefit or cost is engendered by a cue. This study makes use of the three aforementioned models corresponding to the spotlight, zoom lens, and ring metaphors and extends them in order to compare whether or not older and younger adults distribute attention in the same manner, and how changes in stimuli affect attentional distribution within the age groups.

1.3 The Experiments

Goals

Prior related studies of attention concentrated on whether or not attention remained effective with age and on age-related differences in the time course of processing visual stimuli, with little regard to whether the stimuli were shapes, words, numbers, etc. Some previous visual field studies have addressed age changes in the useful field of view with relation to (attentional) demands of a central task (e.g. Ball et al., 1988). However, the influence of age-related changes on the relationship between attention and visual factors still remained to be sorted out. By using varying stimuli, a consistent experimental paradigm, and a sensitive modelling technique, the testing of various theories of attention may be possible.

Overview

The comprehensive study proceeded in a systematic manner beginning with the modelling of attention for simple shapes for a normal, healthy, younger adult group and a normal, healthy, older adult group. In the first experimental chapter (2), two experiments are contrasted. The first experiment was designed as a close approximation to the earlier experiments of Juola et al. (1991) in order to establish whether or not older adults distribute attention in the same manner as younger adults when viewing simple shapes. The second experiment varied only the size of the stimuli with visual eccentricity in order to assess the effects of the visibility of objects in the peripheral visual field on attentional distribution differences between the two age groups. A quantitative model comparison was performed in order to test theoretical differences in the distribution of attention for both age groups, and to compare age effects of the attentional distribution and the time course of cue response. The models were also used to compare the precise impact of visual processing of words in the parafoveal region for both age groups.

Chapter 3 reports the findings of a third experiment designed to extend the analysis of attentional distribution patterns of young and old to more complex stimuli (words). In this chapter, a comparison of attention to shapes and words is made and implications to word identification in complex environments are discussed. Two of the three models developed in the first two experiments were used for age comparison purposes and theoretical evaluation.

Chapter 4 reports the results of a fourth experiment that was designed to further explore age-related differences in the effects of attention on word recognition. In this study an age comparison was made for the localization and identification of words on moving and still pictorial backgrounds. Again, mathematical models, similar to those of the previous experiment, were used to test the significant statistical interactions in order to explain differential behavior between the two age groups. The design of the experiment allowed for a direct generalization of the results to everyday tasks.

Chapter 5 is a discussion of the performance differences between young and old on Experiments 2 (shapes) and 3 (words). The results of these two experiments are analyzed in terms of right and left visual field differences as they relate to the right and left hemispheric brain processes. Consistent use of a single general paradigm throughout the different experiments allowed for a variety of factors to be analyzed. In this case, the systematic collection of data from left and right visual field presentations provided an opportunity to test the contribution of interhemispheric transfer, reflecting the functioning of a single brain structure, the corpus callosum, to age-related slowing of cognitive processes. This chapter provides an example of how results of classic cognitive psychology research can be observed from a neuropsychology perspective thereby offering not only speculative, but concrete evidence of organic bases of behavior. Chapter 5 also includes a comparison of analytical methodologies appropriate to the type of age comparison experiments used in this study.

Finally, Chapter 6 summarizes the results of the experiments and the various analyses discussed in chapters 2 through 5. Furthermore, the implications of these results are discussed both in terms of current theories of cognitive aging and how they might be generalized to everyday activities of elderly people. A discussion regarding the direction for future research is also included.

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Chapter 2

Age Changes in the Distribution of Visual Attention[1]

Abstract

Two experiments examined adult age differences in the controlled allocation of visual selective attention. Both experiments were identical with the exception of the stimulus display where targets and distractors were linearly increased in size with eccentricity in Experiment 2. A spatial cuing task was used with four cue-target presentation intervals (SOAs) of 250, 500, 1000, and 2000 ms (Experiment 1) and 250, 500, 750, and 1000 ms (Experiment 2). Results were fit to three quantitative models based on attentional distribution metaphors (spotlight, zoom lens and ring) in order to determine the best fitting model of attentional distribution. Data from Experiment 1 indicated that older subjects distributed attention in a qualitatively different manner than younger subjects and suggested a different time course of processing. When stimuli visibility was controlled a single flexible resource allocation (ring) model of attention could account for the results of both age groups at all SOAs. Results further suggested that older adults employ compensatory strategies to offset visual processing difficulties.

2.1 Introduction

It has been asserted that age differences in attentional processes might underlie at least some age-related declines in cognitive functioning (e.g., Hartley, 1992; Hasher & Zacks, 1988; Hoyer & Plude, 1982; Madden, 1990; Salthouse, 1988). Differences

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[1] This chapter has been accepted for publication as McCalley, L.T., Bouwhuis, D.G. & Juola, J. (in press). Age changes in the distribution of visual attention. Journals of Gerontology: Psychological Sciences. Experiment 1 has, in part, been published as McCalley, L.T., & Bouwhuis, D.G. (1992). Adult age differences in the allocation of visual selective attention. In H. Bouma & J. Graafmans (Eds.) Gerontechnology (pp. 245-252). Amsterdam, IOS Press.

among age groups could exist in either selective aspects of attention or in attentional capacity. Selectivity refers to the ability to separate relevant and irrelevant information (i.e., speed and/or effectiveness with which attention can be focused onto a relevant stimulus and irrelevant stimuli filtered out), and capacity refers to the amount of processing resources that can be allocated to task performance.

The present research explores the selective aspect of visual attention and seeks to answer the question of whether or not younger and older adults are able to allocate attention over the visual field in similar ways. If age differences in selection patterns can be found to vary when sensory factors, such as visibility, are changed, then attention could serve a role as a compensatory mechanism for sensory decline. In addition, allocation patterns could be affected by varying cue-target presentation intervals (Stimulus Onset Asychronies or SOAs), reflecting age differences in the time course for processing of cues, such as a general slowing. According to Hartley (1992), one of the strongest arguments against the General Slowing Theory of cognitive aging is a failure to find a monotonic relationship between the time course of experimental factors such as cuing and priming effects and the generalized slowing of overall processing for older adults.

Prior research using spatial cuing tasks has dealt mainly with how attention is shifted in response to advance information (e.g., Hartley, Kieley & Slabach, 1990; Hoyer & Familant, 1987; Madden, 1992; Nissen & Corkin, 1985). In cuing studies, attention is measured in terms of total benefits for valid cues and costs for invalid cues in response time or accuracy data when compared with results from a neutral, or no-cue, condition. Information as to the probable location or identity of the target stimulus is provided by a cue which could be a word (Hartley et al., 1990), a digit (Hoyer & Familant, 1987) or an arrow indicating the likely area for the target to appear (Nissen & Corkin, 1985; Posner, 1980). Patterns of attentional allocation which might be due to more subtle strategy differences in attentional distribution patterns across age groups, for example, differences in the relationship of cost to benefit, have rarely been sought.

In all of the studies reviewed here, older adults were able to use location cues to increase speed and/or accuracy of response to a target. In addition, many related studies have varied the SOAs to test for time course differences with mixed results (Hartley, 1992). However, these results do not determine the relationship of attention to cognitive decline associated with increased age. Thus, as yet, no definite age differences in attentional processes have been discovered beyond a generalized slowing and otherwise equivalent costs and benefits for spatial cues (Folk & Hoyer, 1992; Hartley, 1992). Other possibilities exist as to why no age-specific attentional changes have been found beyond the frequently observed, but unexplained, slowing. Disadvantageous choices of cue types, visual discrimination difficulties, and cue-display SOAs can result in procedures that are not sensitive enough to detect subtle age differences in processing abilities. Sensory factors can mask or alter attentional effects by confounding age-related changes in speed of processing and central or peripheral visual acuity with attentional manipulations (see Hartley, 1992). For example, a study by Madden (1992) showed larger cue benefits for older adults than for younger adults, but he admitted that this result could have been due to visual information processing differences between young and old subjects, allowing cues to have a larger effect for elderly subjects.

As Salthouse (1991) states, definitive research is lacking regarding the relationship between age, sensory limitations, and cognitive performance. Therefore, what is needed is a means of analysis whereby attentional effects, thought to underlie age-related cognitive decline, can be separated from sensory effects. This type of analysis requires quantitative models with parameters that meaningfully reflect changes in sensory and attentional processes with age, enabling the generalizability of theoretical models to all age groups. In this manner the identity of, and extent to which, component processes of visual perception change with age can be analyzed. The present study is an attempt to evaluate spatial cue and SOA effects in young and elderly adults while controlling for visual discrimination difficulty. In addition, quantitative models are developed specifically for assessing sensory and attentional contributions to overall performance. Each of these issues will be discussed in turn.

Cues and SOAs

In studies of age-related changes in visual selective attention, location cues are typically visual and can be presented either in the center of the visual field, indicating the direction of a potential target area, or peripherally, near the position of a potential target. Peripheral cues, such as a flash of light, an indicator of some kind, or the abrupt onset of a potential target, are thought to cause an automatic orientation of attention. Peripheral cues produce peak facilitation for processing task-relevant information at the cued location within 150-200 ms after the cue. Central cues are typically symbolic, occur at the fixation point, and are thought to direct a controlled orientation of the attentional mechanism. This controlled response has a longer latency, achieving maximum benefit after 200 ms and remaining effective over a longer period (Müller & Rabbitt, 1989). Both types of cues have been used in studies of age-related changes in attention, and they have been found to produce costs and benefits that are at least as great for elderly subjects as for young subjects (Folk & Hoyer, 1992; Hartley, 1992; Hartley, Kieley, & Slabach, 1990; Juola, Koshino, Warner, McMickell, Fiori & Peterson, 1993).

It has been found that age-related changes in cognitive performance are generally more evident in controlled or effortful processes (such as interpreting and responding to central, symbolic cues), than in automatic responses to peripheral cues (e.g., Craik & Byrd, 1982; Hasher & Zacks, 1979; Hoyer & Plude, 1980, Rabbitt, 1979; but see also Folk & Hoyer, 1992). If so, one would expect that elderly subjects would make relatively less use of central cues than peripheral cues when compared with young adult subjects, but the results have generally not supported such a distinction (see Hartley, 1992). The cue used in the present studies was a light, but distinct, greying of the area most likely to contain the target. The neutral cue was a greying of the entire relevant visual field.

The SOAs used in the present studies were chosen to tap a wide range (250, 500, 750, 1000, and 2000 ms) in which costs and benefits would be most likely to be well-established for both age groups as shown by prior research (e.g. Folk & Hoyer, 1992; Hartley, Kieley & Slabach, 1990; Hoyer & Familant, 1987; Nissen & Corkin, 1985).

Visual perception

It is possible that elderly subjects might show reduced acuity effects and greater visual interference in cluttered displays as compared with younger subjects (e.g., Cerella, 1985), despite matching the groups for overall acuity. Thus, age-related performance differences in detection and search tasks might be due to visual as well as attentional effects. It might be that if care is taken to eliminate potential visual differences, older persons will exhibit the same patterns of attentional allocation as younger adults. From the opposite perspective, it can be assumed that uncontrolled visual difficulties in such a task could lead to adaptations or compensatory attentional strategies for older adult subjects.

In a study not related to aging, Anstis (1974) found that acuity (as measured by letter recognition accuracy) declined linearly with eccentricity up to about 30 degrees of visual angle. Based upon this finding he specified letter sizes that should be equally discriminable and above threshold across a range of eccentricities. In addition, Cerella (1985) found that there is shrinking, by approximately one third, of the effective visual field with age. Therefore, based upon these measures, a target display including letters or letter-like forms should subtend a region no more than about 20 degrees of visual angle if comparisons are to be made between younger and older adults. In addition, conditions which do not correct for reduced acuity in the visual periphery should be compared with those that do, as it might be the case that, for certain tasks, vision interacts with attention and the effective field of view narrows with increased attentional demands. In support of this proposal, it has been found by Ball, Beard, Roenker, Miller, and Griggs (1988) that the effects of distractors in the peripheral visual field increase with attentional demands in the fovea (see also Ball, Roenker & Bruni, 1990).

Quantitative models

Salthouse (1988) has recommended the use of formal modelling techniques to estimate quantifiable parameters that reflect age-related changes in attention. Yet very few prior studies of attention have attempted to use quantitative models to describe attentional differences between younger and older adults. Differences in the amount, efficiency, and speed of attentional resource allocation by younger and older adults were explored by Hartley et al. (1990). They used models to assess only the total amount, and not the spatial distribution, of attentional resources. Results of their study were best fit by models predicting no age-related differences (Hartley et al., 1990). Madden (1992) applied resource allocation models to age differences by comparing relative weightings of focused and distributed attention based on the Eriksen and Yeh model (1985). Again, the modelling analyses revealed no age differences in the allocation of attention.

In a study unrelated to aging, several common models for attentional allocation were contrasted by Juola, Bouwhuis, Cooper, and Warner (1991) in a paradigm which enabled reliable parameter estimation. Their procedures were adopted in the current project in an attempt to identify age-related changes in the nature of attentional responses. The models evaluated included (1) a spotlight metaphor, in which the visual field is examined in a strictly serial, self-terminating search for the target item, (2) a zoom lens metaphor, in which attention can be expanded or contracted around the fixation point, and items within the beam of attention can be searched in parallel, and (3) a resource allocation metaphor in which the beam of attention can be separated from the fixation point yet extend over regions in space of somewhat arbitrary size and location. Again, search within the attended region can be parallel. Details of these models will be considered when they are fit to data from two experiments reported below.

2.2 Experiment 1

The present experiments were developed from a classic paradigm (Jonides, 1981; Posner, Snyder & Davidson, 1980) to assess costs and benefits for the effects of visual cues on performance in a visual search task. Each display included one of two possible target characters among a set of similar distractors distributed in circular rings around the fixation point. Experiment 1 was specifically designed to test differences between two age groups in the pattern of allocation of attention. Visual display characters were of uniform size at all eccentricities. As discussed earlier, cue-target stimulus onset asynchronies (SOAs) were chosen to tap the range (250 to 2000 ms) in which costs and benefits would be most likely to occur for both age groups.

Method

Subjects. A total of 24 subjects participated in Experiment 1. Twelve young adults (mean age = 21.5 years, range = 19-24) were selected from the subject pool at the Institute for Perception Research/IPO. The young subject group consisted of six males and six females, and they either were students of the University of Technology, Eindhoven, or were students of high vocational training institutes in the same area. The 12 old adults (mean age = 69.1 years, range = 62-81) were recruited from both the subject pool at IPO and through other subjects, and all had high vocational or university training. This group consisted of four female and eight male volunteers. All subjects had normal or corrected-to-normal near and far visual acuity as measured by the Landolt test. All acuity measures were converted to the Snellen scale with a near acuity range of 20/20 to 20/25 for the young group and 20/20 to

20/40 for the old group. Near acuity was considered to be the most appropriate measure for the experimental task. All subjects reported good to excellent health.

Apparatus. The stimuli were presented on the video screen of a Macintosh Plus computer. The screen was placed at a distance of 57 cm from the subjects' viewing position, at which distance one centimeter on the display surface corresponds to one degree of visual angle. The Macintosh Plus controlled the timing of stimuli presentation and registered participants' response choices and times. A two-button pad was used for collecting responses.

Materials. Each trial consisted of a sequence of five stimuli (Figure 1).

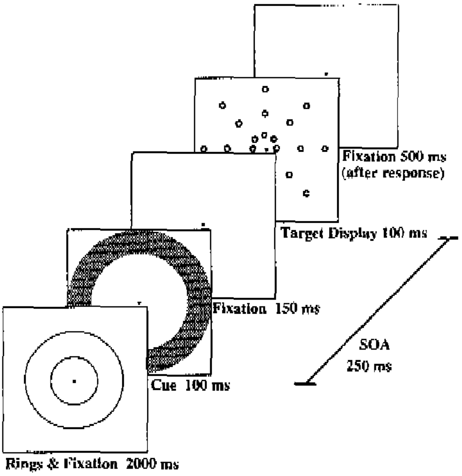

Figure 1. Sequence of stimulus displays used in experiment 1.

The first stimulus contained two concentric rings with a fixation dot in the center and was presented for 2 sec. The rings served to indicate three circular or ringlike areas which could contain the target; one within the center ring, one between the center and outer ring, and one outside the outer ring. The innermost ring had a radius of 2 cm and the outermost ring a radius of 4 cm. The second stimulus display was presented for 100 ms and contained a cue which appeared as a light, but distinct, greying of the white screen corresponding to one (center, middle or outside cue conditions) or all (neutral or uninformative cue condition) of the three areas. The cue thus indicated either a solid circular area in the center with a radius of 2 cm (center cue condition), a ring-like area with a width of 2 cm between the two rings (middle cue condition), or another ring-like area outside the outer ring, again 2 cm in width (outside cue condition). The neutral cue condition consisted of a greying of all three areas at once creating a solid circular area. Thus the total display area had a radius of 6 cm, corresponding to approximately six degrees of visual angle. The cue stimulus also contained a central fixation dot for all cue conditions. The third stimulus contained only a central fixation dot. This display served to define the ISI (Inter Stimulus Interval) and was varied across each of the four experimental sessions for each subject. The 100-ms cue and the ISI thus defined the Stimulus Onset Asychrony (SOA), the time between cue onset and target display onset. The fourth stimulus display consisted of 24 stimulus figures, including 23 circles (distractors) with a diameter of 0.55 cm and one Landolt-like "C" of the same size as the circles, with the opening facing either right or left. This open circle served as the target.

The display always contained one target and was presented for 100 ms. The figures were spaced along invisible axes formed by overlaying an X and a cross centered on the fixation dot. On each of the four axes were six figures, two lying 1 cm on either side of the fixation point, two lying at about 3 cm from fixation, and two lying at about 5 cm from the fixation point. In this way three rings of eight figures each were formed, corresponding to the three possible cue areas, and they were centered within these areas. The open figure serving as the target appeared in only one of the 12 locations on the diagonal axes. The fifth, and final, stimulus display consisted of the fixation dot on a blank field. This display, lasting

500 ms, appeared after the subject's response and served to indicate the end of the trial. Between the target display and the final fixation display the field remained blank. The following trial began after an inter-trial blank screen interval of 1 sec.

Procedure. The experiment consisted of a two-alternative, forced-choice identification task in which subjects were required to identify the target by indicating with a button press with the index finger of either hand as to whether the opening in the "C" faced right or left. Subjects were instructed to fixate on the center dot in the first stimulus display and not to move their eyes. They were then instructed to focus their attention on the ring(s) as indicated by the cue and were told that the cue would aid them to detect and identify the target, as it would most likely appear in the cued area. In fact, the cue was valid on 80% of the non-neutral cue trials. On valid trials, the target appeared randomly in one of the four possible positions in the cued ring; on invalid trials, it appeared randomly in one of the eight possible positions in the non-cued areas. On neutral-cue trials, the target could occur in any of the 12 positions with equal probability. Subjects were told to push the appropriate button as rapidly and accurately as possible and to guess if they were not certain whether they had detected or properly identified the target.

Subjects attended a total of five sessions, each lasting approximately 2 hours. The first session was a training session in which subjects were read a training manual and subsequently given practice blocks of 24 trials each until they had either completed 6 blocks or had reached a performance level of 90% correct responses; whichever came first. The four remaining sessions consisted of the counter-balanced presentation of four different SOA values of 250, 500, 1000, and 2000 ms. Sessions were blocked by SOA. At the beginning of each session subjects were given a practice block of 24 trials. Following the practice block, subjects were given 4 full blocks of 72 trials, each of which included 48 valid, 12 invalid, and 12 neutral cues, all of which were randomized for all cue by target conditions. Subjects were encouraged to rest for approximately 10 minutes between blocks at which time they were also given feedback as to the number of errors they had made in the block.

Results

Introduction. One subject in the older adult group exceeded an arbitrary error criterion of 30% and was excluded from further analyses. The mean age of the remaining older subjects was thus 67.0 years. Two forms of analyses were performed on the RT (Response Time) and error data. The data were subjected to analyses of variance (MANOVA) and model fits.

Before analyzing RT data for correct responses, outliers were removed. Outliers were defined as any RT < 100 ms or exceeding twice the mean of its cell. In all, fewer than 0.7% of the data were thus removed. The mean RTs and error percentages in the various cue and target location conditions for each SOA condition are shown in Table 1. The data collapsed across SOAs are shown in Figure 2a (RTs) and 2b (errors).

Response times. The RT data were analyzed using a 2 (Age Group) x 3 (Target Location - center, middle, or outside ring) x 4 (Cue Type - neutral, center, middle or outside) x 4 (SOA) mixed model design with repeated measures for all variables except Age Group.

The RT analysis supported the trends visible in Figure 2a, showing a large Age Group effect (F (1,21) = 42.27, $p<.001$), and an increase in RT from center to outside Target Locations (F (2,20) = 35.35, $p<.001$). There was also a significant effect of Cue (F (3,19) = 5.96, p = .0048), and a Cue x Target Location interaction (F (6,16) = 6.66, p =.0011), indicating that valid cues generally produced benefits and invalid cues incurred costs at all locations relative to the neutral cue condition.

Table 1. Mean Response Times (ms) and Percent Errors (in parentheses) for all conditions of Experiment 1.

Stimulus Location			
	Center	Middle	Outside
SOA x Cue		Younger Adults	
250 ms			
Neutral	577 (7.8)	543 (2.0)	640 (9.9)
Center	530 (3.7)	650 (4.2)	779 (19.8)
Middle	568 (7.3)	556 (3.0)	704 (16.7)
Outside	641 (9.4)	541 (3.1)	640 (12.2)
500 ms			
Neutral	608 (9.9)	572 (3.7)	666 (13.5)
Center	537 (3.9)	660 (1.0)	788 (12.5)
Middle	614 (8.3)	569 (3.9)	656 (22.9)
Outside	648 (10.4)	597 (5.2)	652 (13.0)
1000 ms			
Neutral	610 (14.1)	569 (6.3)	664 (12.0)
Center	535 (3.7)	659 (4.2)	788 (12,5)
Middle	662 (12.5)	568 (5.5)	663 (17.7)
Outside	645 (14.6)	607 (7.3)	650 (10.4)
2000 ms			
Neutral	600 (12.0)	573 (4.2)	665 (12.5)
Center	551 (4.4)	631 (6.3)	760 (10.4)
Middle	613 (8.3)	575 (4.4)	691 (7.3)
Outside	715 (20.8)	594 (7.3)	641 (10.2)

Table 1 continued on the next page.

Stimulus Location

	Center	Middle	Outside
SOA x Cue		Older Adults	
250 ms			
Neutral	1045 (21.6)	1125 (30.1)	1150 (31.8)
Center	1014 (13.6)	1151 (29.6)	1362 (29.6)
Middle	1078 (17.0)	1062 (30.4)	1229 (31.8)
Outside	1170 (19.3)	1133 (26.1)	1144 (31.7)
500 ms			
Neutral	1059 (21.6)	1126 (25.0)	1138 (31.8)
Center	948 (8.4)	1145 (35.2)	1362 (37.5)
Middle	1082 (23.9)	1054 (24.1)	1112 (33.0)
Outside	993 (29.6)	1109 (29.6)	1069 (30.4)
1000 ms			
Neutral	1033 (22.2)	920 (25.3)	998 (33.5)
Center	870 (9.4)	1121 (34.1)	1206 (34.1)
Middle	1091 (27.3)	950 (25.3)	1099 (28.4)
Outside	1026 (22.7)	1065 (29.5)	1008 (29.8)
2000 ms			
Neutral	1155 (25.6)	1118 (34.1)	1206 (27.3)
Center	1000 (9.2)	1336 (30.7)	1442 (34.1)
Middle	1152 (23.9)	1126 (27.0)	1242 (34.1)
Outside	1267 (29.6)	1161 (31.8)	1173 (34.4)

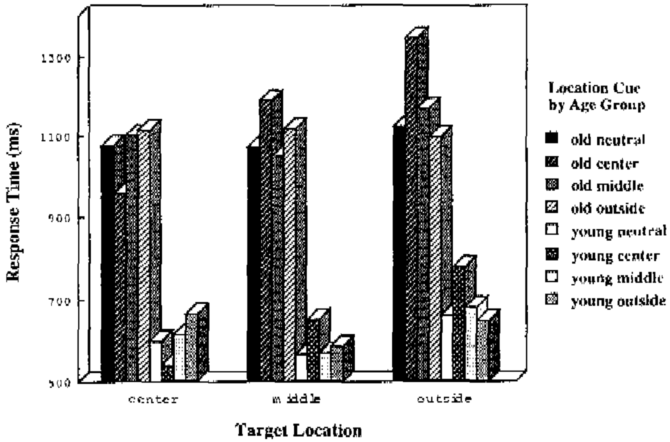

Figure 2a. *Mean response time plotted against actual target location for each age group separately, and, within each group, for the four different spatial cues that were used (Experiment 1).*

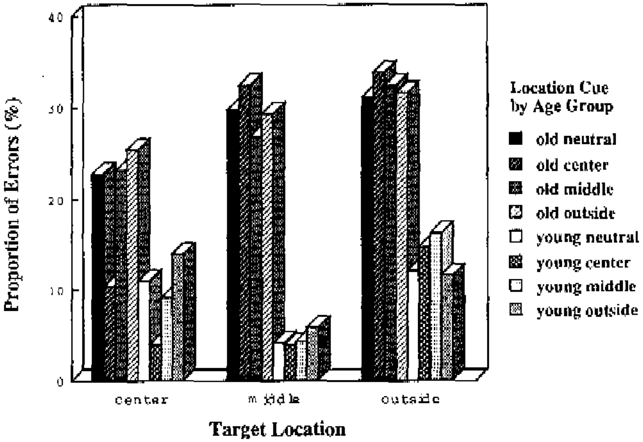

Figure 2b. *Mean percent errors plotted against actual target location for each age group separately, and, within each group, for the four different spatial cues*

that were used (Experiment 1).

All four variables entered into a significant interaction in the RT analysis, F (4,18) = 5.81, $p<.05$. This result indicates that the Cue x Target Location interaction (shown in Fig. 2a) differs for the two age groups across SOA. Although 4-way interactions are difficult to interpret, we provide here one possible source that is explored in more depth in the corresponding model analysis section.

A way to show the possible source of this 4-way interaction is to plot mean costs plus benefits (that is, the average difference between RTs for invalid and valid cue trials) against SOA for the two groups. This plot is presented in Figure 3, which shows that older adults demonstrated larger cue effects than younger adults, and this difference increased with SOA.

It appears as though younger adults showed about the same costs and benefits of cue across all SOAs, whereas older adults showed about a 45% increase in cue effects at larger (1000 and 2000 ms) compared to shorter (250 and 500 ms) SOAs. When the costs-plus-benefits data are divided by the mean RT for the neutral condition at each SOA, in order to assess relative costs plus benefits, the same conclusion is reached (see Table 2).

Error data. The overall error rate for both groups was 15.8%. The proportions of errors per cell were transformed to logits for statistical operations. The ANOVA performed on the error data revealed significant main effects of Age Group, Target Location, and Cue, (F (1, 21) = 22.29, $p< .001$, F (2, 20) = 20.66, $p< .001$, F (3, 19) = 3.83, $p = .0267$, respectively). Cue-display SOA had no effect on the error rates, nor did it enter into any significant interactions. The interaction between Cue and Target Location was not significant (F (6,16) = 1.90, $p = .14$), however, the trend parallels the significant interaction between these two variables in the RT data. A highly significant interaction was also found between Age Group and Target Location (F (2, 20) = 29.60, $p< .001$, see Table 3). Although this interaction is significant, it should be pointed out that both groups showed an increase in error rates from the inside ring to the outside of about 50%.

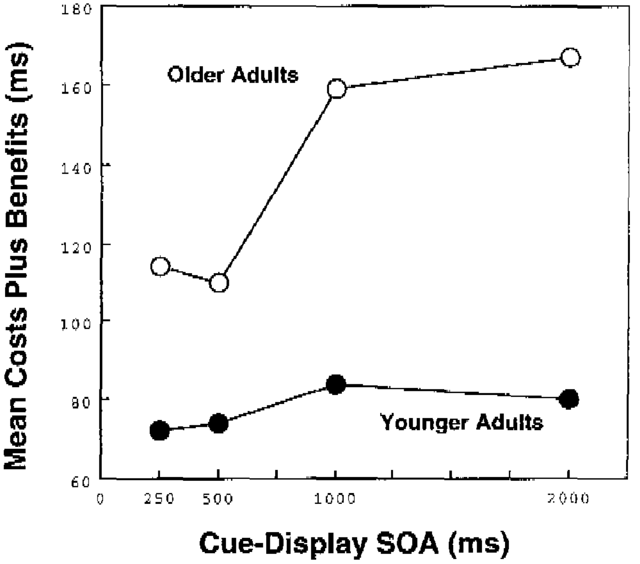

Figure 3. Mean costs plus benefits in the RT data of Experiment 1 plotted against cue-display SOA for younger and older adults separately.

Table 2. Proportional cueing effect (Experiment 1)

	SOA (ms)			
	250	500	1000	2000
Group				
Young	.122	.121	.138	.128
Old	.103	.099	.161	.144

Note: The proportional cueing effect is derived by dividing the overall costs plus benefits by the mean neutral response time at each SOA.

The main difference between groups was that the older subjects showed a consistent eccentricity effect, whereas the younger group had fewest errors for targets in the middle ring.

Table 3. Mean percent errors by target location for Younger and Older subjects (Experiment 1).

	Stimulus Location		
	Center	Middle	Outside
Group			
Young	9.4	4.5	13.5
Old	20.3	29.5	32.2

Summary of results. The results showed that subjects were able to use the cues to produce benefits for valid location cues and costs for invalid cues relative to the neutral cue condition. For both groups, cue effects were strongest for the central cue, indicating that it might have been used more effectively than the middle and outside cues in directing attention. Also, RT data were similar for the neutral and middle cue conditions, indicating that most subjects allocated attention in similar ways for these two types of cues.

The four-way interaction as illustrated in Figure 3 is congruent with evidence that the time course of processing and using the cue differs for the two age groups. The cue effects were proportionately larger for the older adults at the longer SOAs. Although the error data closely paralleled the RT data in general, there was no indication that SOA had any effect on the error rates. Nonetheless, the interaction between age, SOA, and costs-benefits in the RT data (Figure 3) indicates that the older subjects were attempting to make greater use of the cues at longer SOAs, perhaps as a means to compensate for greater difficulty in processing display items, especially as eccentricity increased.

The interaction between age group and target stimulus location in the RT data indicated that peripheral targets were relatively more difficult for the older group to identify (see Table 3). An interpretation of this interaction in terms of attentional allocation would lead us to believe that older adults are less flexible and tend to concentrate resources near the fovea. Another interpretation is that, despite matching the groups as closely as possible for visual acuity, older adults have more difficulty identifying targets that are further from the fovea in a cluttered display. The formal modelling analysis provides a means for differentiating among alternative explanations of the eccentricity effects.

Model-fit analysis. In order to establish whether or not a common theoretical account could explain the results of the two groups, costs and benefits data were fit using three models of attentional allocation. Quantitative models used in this analysis were based on those derived by Juola et al. (1991) for the purpose of comparing hypothetical ways in which attention could be spatially distributed and how these distributions might change over time. The first of these models is the spotlight model in which attention is assumed to be concentrated in a small beam, much like that of a spotlight, that scans items in the visual field in a serial, self-terminating manner, continuing until the target item is located or the search is completed. This serial search is assumed to start in the cued ring. In the neutral condition the scan is assumed to begin at a strategically determined point. Also tested were a zoom lens and a resource allocation (ring) model. Both of these models allow a much broader and more flexible expanse of attentional distribution. The difference lies in the amount of flexibility predicted for each. In the zoom lens model, attention spreads out from the foveal area, expanding and contracting to encompass the area indicated by the cues (LaBerge, 1983). The ring model, (Egly and Homa, 1984; Juola, Crouch, & Cocklin, 1987) predicts still greater flexibility of attentional allocation than the zoom lens model in that attention is distributed only in the cued area. This means that attention is presumed to separate from the foveal area whenever the middle or outer rings are cued, thereby providing a greater concentration of resources than if the center area had been included, as in the zoom lens model. Both the zoom lens and the ring models assume the possibility of parallel processing of objects within the attentional field if the target-distractor difference is great enough (e.g., Duncan & Humphreys, 1989).

In its simplest form the zoom lens model predicts that valid cues will enhance processing of objects within the entire area bounded by the outer edge of the cued rings, resulting in the greatest benefit for the center where resources are more concentrated, a smaller benefit for the middle ring when resources are more diffuse, and no benefit for outer ring cues as compared to the neutral condition. In the latter case, both types of cues would result in a spread of attention over the entire field. Costs would only be apparent for targets appearing in areas outside a cued ring, as attention would then have to spread out from a more foveal area. The ring model, in contrast, predicts benefits for all validly cued conditions as attention is assumed to detach from the foveal area for middle and outside cues and to concentrate in the cued ring. Invalid cue conditions should result in costs of varying magnitudes depending on whether the target lies one or two rings away, either to the inside or the outside of the cued ring. Juola et al. (1991) found strong support for the ring model in similar experiments using young adult subjects.

In both the ring and the zoom lens models, four parameters were estimated from the data using a least-squares method. These included T, a baseline response time, B, a benefit parameter subtracted from T on valid cue trials, C, a cost parameter added to T on invalid cue trials, and E, an eccentricity parameter added to response times for targets appearing in the outermost circle(s). The only difference between the two models was in the assignment of costs and benefits; the ring model limits benefits to the cued ring only, and assigns costs to targets located in rings inside or outside the cued ring. The zoom lens model, on the other hand, assigns benefits to the validly-cued inner ring, and to both inner and middle rings, although with a value diminished by half, when the middle ring is cued. Costs are incurred only for targets occurring outside the cued area. In the spotlight model, a baseline response time, T, is estimated along with a scanning time parameter, c, to approximate the time to search each display item in a serial, self-terminating way until the target is found. The number of items searched depends on the order in which the rings are scanned. The order was determined for each subject group to yield the best overall fit to the data. The data collapsed across SOAs and the fits of the models are shown in Table 4.

In order to test the effects of SOA on model fits and parameter estimates, both the ring and zoom lens models were fitted to the RT data for both groups at all four SOAs. The data are shown in Table 5.

The same models were fitted to the error data, and the results are shown in Table 6. Here F, for "failure rate", replaces T in the set of parameters estimated for the ring and zoom lens models. There is no simple way to generate error rate predictions from the spotlight model directly, so the method used by Juola et al. (1991) was used here. The assumption is that subjects perform a serial scan of the display items until a time is reached when the image fades. If this temporal criterion is reached, and the target has not yet been found, the subject guesses, and makes an error half of the time. The expected number of guesses and the temporal criterion were estimated using a least-squares procedure and Gaussian approximations to the right-hand sides of the search-time distributions, with their means predicted by the spotlight model for the RT data (see Juola et al., 1991).

Table 4. Response Time data (in ms) and predictions of the Ring, Zoom Lens, and Spotlight Models of Attention (Experiment 1).

	Stimulus Location		
	Younger Adults		
Cue	Center	Middle	Outside
Neutral	599	564	659
Center	539	650	776
Middle	614	567	678
Outside	662	585	646
	Ring Model[a]		
Neutral	T+C=592	T+E=576	T+2E=628
Center	T-B=532	T+C+E=643	T+2C+2E=761
Middle	T+C=591	T-B+E=584	T+C+2E=694
Outside	T+2C=658	T+C+E=643	T-B+2E=635
	Zoom Lens Model[b]		
Neutral	T=610	T+E=617	T+2E=674
Center	T-B=547	T+C+E=682	T+2C+2E=754
Middle	T-B/2=579	T-B/2+E=593	T+C+2E=689
Outside	T=610	T+E=617	T+2E=624
	Spotlight Model[c]		
Neutral	T+12.5c=628	T+4.5c=571	T+20.5c=686
Center	T+4.5c=571	T+12.5c=628	T+20.5c=686
Middle	T+12.5c=628	T+4.5c=571	T+20.5c=686
Outside	T+20.5c=686	T+12.5c=628	T+4.5c=571

Table continued on the next page.

Stimulus Location

Older Adults

Cue	Center	Middle	Outside
Neutral	1073	1072	1123
Center	958	1188	1343
Middle	1101	1048	1170
Outside	1114	1117	1098

Ring Model[a]

Neutral	T+C=1073	T+E=1061	T+2E=1133
Center	T-B=963	T+C+E=1145	T+2C+2E=1299
Middle	T+C=1073	T-B+E=1035	T+C+2E=1216
Outside	T+2C=1157	T+C+E=1145	T-B+2E=1106

Zoom Lens Model[b]

Neutral	T=1100	T+E=1100	T+2E=1100
Center	T-B=988	T+C+E=1207	T+2C+2E=1315
Middle	T-B/2=1044	T-B/2+E=1044	T+C+2E=1207
Outside	T=1100	T+E=1100	T+2E=1100

Spotlight Model[c]

Neutral	T+8.5c=1076	T+8.5c=1076	T+20.5c=1200
Center	T+4.5c=1035	T+12.5c=1117	T+20.5c=1200
Middle	T+12.5c=1117	T+4.5c=1035	T+20.5c=1200
Outside	T+16.5c=1159	T+16.5c=1159	T+4.5c=1035

[a] Parameter values: Young: T=524.9, B=-7.6, C=66.6, E=51.5; Old: T=989.8, B=26.5,C=83.4, E=71.4.
Percent variance accounted for: Young= 86.8; Old= 89.6.

[b] Parameter values: Young: T=610, B=62.7, C=65.2, E=6.9; Old: T=1100, B=111.8, C=107.6, E=-0.30.
Percent variance accounted for: Young= 74.6; Old= 90.1.

[c] Parameter values: Young: T=538.6, c=17.7; Old: T=988.7,c=10.3.
Percent variance accounted for: Young=57.3; Old=50.5.

Table 5. Model Fits x SOA for Experiment 1 Latency Data.

		Young		Old	
Model		Ring	Zoom	Ring	Zoom
SOA					
250	T	490.5	579.2	992.5	1100.2
	B	- 19.0	49.7	2.0	85.0
	C	79.5	79.9	85.0	91.5
	E	65.8	16.6	82.9	22.0
	V	97.0	80.3	92.9	85.0
500	T	539.2	612.7	1002.1	1053.4
	B	5.2	67.0	58.6	68.8
	C	61.1	64.8	42.8	98.9
	E	52.0	7.5	80.2	24.9
	V	89.7	76.9	66.7	75.5
1000	T	555.1	620.9	924.0	1043.6
	B	15.8	62.1	29.0	122.2
	C	57.0	62.5	90.4	107.6
	E	45.0	2.8	47.7	-26.9
	V	84.0	67.2	78.7	71.5
2000	T	544.8	627.8	1040.4	1203.3
	B	- 0.9	73.8	16.2	171.5
	C	68.6	54.7	115.1	132.2
	E	43.3	0.4	75.5	-20.6
	V	91.4	58.9	84.5	86.2

Note: T = baseline response time, B = benefit, C = cost, E = eccentricity, and V = %variance explained.

Table 6. Error data (proportions of incorrect responses) and predictions of the Ring, Zoom Lens, and Spotlight Models of Attention (Experiment 1).

	Stimulus Location		
	Younger Adults		
Cue	Center	Middle	Outside
Neutral	10.9	4.0	12.0
Center	3.9	3.9	14.6
Middle	9.1	4.2	16.2
Outside	13.8	5.7	11.5
	Ring Model[a]		
Neutral	F+C=6.8	F+E=5.8	F+2E=7.8
Center	F-B=4.3	F+C+E=9.0	F+2C+2E=17.7
Middle	F+C=6.8	F-B+E=5.8	F+C+2E=11.9
Outside	F+2C=10.4	F+C+E=9.0	F-B+2E=7.7
	Zoom Lens Model[b]		
Neutral	F=8.2	F+E=8.6	F+2E=9.1
Center	F-B=4.1	F+C+E=9.9	F+2C+2E=11.8
Middle	F-B/2=5.8	F-B/2+E=6.1	F+C+2E=10.4
Outside	F=8.2	F+E=8.6	F+2E=9.1
	Spotlight Model[c]		
Neutral	8.8	6.0	12.2
Center	6.0	8.8	12.2
Middle	8.8	6.0	12.2
Outside	12.2	8.8	6.0

[a] Percent variance accounted for: Young= 43.7; Old= 70.8.

[b] Percent variance accounted for: Young= 25.7; Old= 84.2.

[c] Percent variance accounted for: Young= 60.0; Old= 25.8.

Table continued on the next page.

	Stimulus Location		
	Older Adults		
Cue	Center	Middle	Outside
Neutral	22.7	29.7	31.1
Center	10.2	32.4	33.8
Middle	23.0	26.7	32.4
Outside	25.3	29.3	31.6
	Ring Model[a]		
Neutral	F+C=22.1	F+E=27.4	F+2E=34.8
Center	F-B=15.9	F+C+E=28.7	F+2C+2E=37.7
Middle	F+C=22.1	F-B+E=21.1	F+C+2E=36.3
Outside	F+2C=23.2	F+C+E=28.7	F-B+2E=27.5
	Zoom Lens Model[b]		
Neutral	F=25.7	F+E=29.0	F+2E=32.3
Center	F-B=13.7	F+C+E=30.1	F+2C+2E=34.5
Middle	F-B/2=19.7	F-B/2+E=23.0	F+C+2E=33.4
Outside	F=25.7	F+E=29.0	F+2E=32.3
	Spotlight Model[c]		
Neutral	29.3	24.8	33.6
Center	24.8	29.3	33.6
Middle	29.3	24.8	33.6
Outside	33.6	29.3	24.8

Note: Predicted values have been directly obtained by logits and retransformed to probabilities for the ring and zoom lens models.
Parameter values can only be indirectly related to probabilities due to the logit transformation and therefore are not given here. Error predictions for the spotlight model were derived using the method of Juola et al (1991) (refer to text).

Discussion

As can be seen in Table 4, the ring model provided the best fit to the mean RT data for the young adult group, but the zoom lens model gave the best fit to the mean data for the older adults. The spotlight or serial scanning model, did an inferior job of fitting the data for both subject groups. A second, four-parameter, version of the spotlight model was developed to improve the fit and provide a fairer comparison to the other two four-parameter models. This new version took into account the effect of distance of the cued ring from fixation thus the four parameters consisted of a base time and three different scan speeds corresponding to either the center, middle or outside cue area. As the various scan speeds behaved very erratically, and as the fit remained worse than either the four-parameter zoom lens or the resource model, results of this version will not be further reported.

When fitted to the error data, the ring model again performed a better job for the data for the younger subject group than the zoom lens model, however, the fit was not better than that of the spotlight model in this case. The superior fit for the spotlight model is due to the fact that the younger adults' error data show a slightly different pattern than the RT data, as errors were decidedly less frequent for targets in the middle ring. Whereas the zoom lens and ring models are essentially the same for both sets of data, the spotlight model for the error data adds a common standard deviation parameter, and an extra temporal criterion parameter, estimating the average time when the subject has been unable to find the target and has to guess. The advantage for the spotlight model is somewhat of an anomaly, however, as it has not been found in our earlier research (Juola et al., 1991) nor in Experiment 2 of the present paper. The important point to make here is that the data from the two age groups are best described by different models. The older adults' data are best fit by the zoom lens model, whereas the younger adults seem capable of separating attention from the foveal region when cued to do so and more flexibly allocating it within the cued area.

The RT and error data suggested that in the neutral cue condition, young adults rest their attention away from the fovea in anticipation of the display. That is, both RTs and error rates are lowest for targets occurring in the middle ring in the neutral cue condition. A similar phenomenon had been described earlier by Posner (1980), who argued that subjects appeared to prepare for a peripheral stimulus if they were not told in advance whether the stimulus would appear in the foveal area or in the periphery. The lack of benefit for a valid cue to the middle ring, as in the data of the young group (see fig. 2), is consistent with this strategy. In this situation attention is concentrated in a similar way in the neutral and middle cue conditions, thereby resulting in similar RTs and error rates for neutral and valid middle cue conditions. The ring model, as used for the analysis of Experiment 1 data, incorporates this strategy, reflecting the effect described by Posner (1980). The older subjects, on the other hand, show no such effects; RTs and error rates show no advantage for the middle ring but rather a general increase with eccentricity.

The results of the model fits to the overall RT and error data further suggest that younger and older adults are using different attentional allocation patterns for processing the displays. Young adults generally are able to concentrate their attention on the cued ring, whereas older adults spread their attention over a wider area from the fovea outward, generally including regions inside the cued ring in their span of visual attention. Older adults also apparently need more time to allocate attention in response to the cues, as cue effects (measured by costs plus benefits) increased from 250 to 1000 ms SOA, whereas younger adults showed no SOA effects. However, the results of the model analyses by SOA cast some doubt on this interpretation of differential time course of processing between the two groups.

When the data were analyzed by SOA, the error data indicated that both the spotlight and the ring models were superior to the zoom lens model at all SOAs for the younger subjects. In contrast, the zoom lens model fitted the older adults' data best at all four SOAs. The RT results were less clear in this respect. As SOA increased, the ring model did a consistently good job of fitting the data for the younger subjects, but the ring and zoom lens models gave alternately better fits for the older adults. Whereas the younger adults showed relative stability in the parameter estimates across SOA, the older subjects showed a more consistent growth in cost and benefit with increasing SOA.

What becomes clear from the formal model analysis of the RTxSOA results is that there are some unsatisfactory properties of the behavior of the zoom lens model. It is unreasonable to assume that the older adults would have a smaller eccentricity effect than the younger adults yet the zoom lens model results in unacceptably low, in fact negative, eccentricity parameter values for the older group at both the 1000 and 2000 ms SOAs. As described earlier, the zoom lens model predicts reduced processing resources for any cue to the outer area and would therefore interpret high visual eccentricity costs as a good fit. This confounding of visual and attentional resources renders some parameter estimates of the zoom lens model highly unstable whenever visual eccentricity is a factor. Thus, the model analysis by SOA is inconclusive as to whether there is actually an age difference in the time course of processing the cue. Nonetheless, if we were to rely on the MANOVA results (see Fig. 3), we would conclude that the older adults become relatively more adept at employing the cues as SOA increases, whereas younger adults make nearly equal use of the cues at all SOAs.

It is possible, however, that one cause for apparent processing differences between the age groups could simply be greater eccentricity effects for the older subjects. It can be seen in both the RT and the error data that the older subjects were having greater overall difficulty with identifying targets than were the younger subjects. Although the difficulty did not appear to be concentrated in the periphery, older subjects reported having far more difficulty with the outermost targets during the experimental sessions. It was also the case that the eccentricity parameter took on different values for young and old subjects and was nearly always substantially higher for the older adults (see Table 5). It is possible that the older adults have relatively more difficulty in identifying the outermost targets, and they adjust their voluntary allocation of attention differently (i.e., over a wider gradient) than the younger subjects in an attempt to compensate for this difficulty. These relative acuity/attentional differences in older subjects could explain the better fit of the zoom lens model for older adults. Since the zoom lens model confounds eccentricity effects of reduced acuity with attentional effects, it predicts increased response times and errors for targets appearing in the outer area. This prediction is the consequence of thinning resources resulting from a wider spread of attention. Therefore it was necessary to control for eccentricity effects by covarying stimulus size with eccentricity in Experiment 2.

2.3 Experiment 2

Experiment 2 was designed to control for eccentricity/acuity effects which might have contributed to overall age differences in Experiment 1. That is, since elderly subjects might show greater differences between foveal and peripheral acuity effects than younger subjects (e.g., Cerella, 1985), performance interactions with age might be due to visual, and not attentional, effects. If care is then taken to minimize older persons' visual problems, they might exhibit the same patterns of attentional allocation as younger adults. Anstis (1974) found that acuity (as measured by letter recognition accuracy) declined linearly with eccentricity up to about 30 degrees of visual angle. Based upon this finding he specified the sizes that letters should be to be equally discriminable and above threshold across a range of eccentricities. In addition, Cerella (1985) found that there is a shrinking, by approximately one third, of the effective visual field with age. Therefore, based upon these measures a target display for Experiment 2 was developed in which the targets and distractors were 7.5 times threshold size, as described by Anstis (1974), as this was considered more than adequate to compensate for the reduced acuity of the elderly. The total extent of the display remained 12 degrees of visual angle in diameter, which should be within the restricted range for older subjects as described by Cerella (1985).

In addition to controlling for visual effects, the SOA range was narrowed. As older adults' data were nearly asymptotic at the 1000 ms SOA in Experiment 1, in Experiment 2 the SOAs were changed to 250, 500, 750, and 1000 ms.

Method

Subjects. An additional 24 subjects who had not participated in Exp 1 were run in the second study. The younger group (mean age = 21.8 years, range = 19-24) consisted of 9 males and 3 females chosen from the subject pool at the Institute for Perception Research/IPO and from the university community at large. The older group (mean age = 67.2 years, range = 63-73) included 8 males and 4 females, also chosen from the IPO subject pool. All subjects had normal or corrected-to-normal near and far visual acuity measured in the same manner, resulting in the same range of acuity as in Experiment 1. All subjects also had self-reported good to excellent health and were matched for educational level.

Apparatus. The stimuli were presented on the video screen of a Macintosh IIcx computer. The Macintosh IIcx controlled the timing of stimuli presentation and recorded participants' responses as in Experiment 1. As a different computer and screen were used in Experiment 2, screen luminance and refresh rate were tested to insure comparable presentation. Both measures were found to be virtually identical to those of Experiment 1. In the present study two buttons on the keyboard were programmed to record responses in a way comparable to Experiment 1. Subjects viewed the screen from a distance of 57 cm.

Materials. All materials for the second experiment were identical to those of the first with the exception of changes in the size of characters in the target display. Targets and distractors were all 0.55 cm in Experiment 1, whereas in the present study, stimuli in the center area were 0.5 cm in diameter, in the middle cue area they were 1.0 cm and in the outer cue area 1.5 cm. Targets and distractors were all placed on their respective presentation axes so as to appear centered at about 1, 3, and 5 degrees of visual angle from the fixation point and within their corresponding cue areas.

Procedure. The procedure was identical to that of Experiment 1 with the exception of substituting the 2000 ms SOA with a 750 ms SOA. The same instruction manual was presented to the subjects with only the example of the target and distractor display changed and the instruction to press a key on the keyboard replacing that of the button press. The ' V ' and ' M ' keys were programmed to record the left and right responses, respectively, and small pieces of tape with copies of the appropriate targets were placed on the keys.

Results. Prior to analysis, outliers were removed from the data as in Experiment 1 (< 0.1%). The mean RT and error data are shown in Table 7 for each SOA and for both groups of subjects. The same data collapsed across SOAs are shown in Figure 5, a and b.

Response times. Analysis of variance of mean RTs for each cell of the design revealed significant main effects of age group, $\underline{F}$ (1, 22) = 41.13, $\underline{p} < .001$; stimulus location, $\underline{F}$ (2, 21) = 22.09, $\underline{p} < .001$; cue, $\underline{F}$ (3, 20) = 4.50, $\underline{p} = .014$; and SOA, $\underline{F}$ (3, 30) = 4.69, $\underline{p} = .012$. Both subject groups responded somewhat faster at the shorter SOAs than at longer SOAs. The mean RTs for the 250 to 1000 ms SOA conditions were 587 ms, 628 ms, 631 ms, and 609 ms, respectively for younger subjects, and 854 ms, 846 ms, 921 ms, and 888 ms for the older subjects. The interaction between cue and target location was also significant, $\underline{F}$ (6, 17) = 3.32, $\underline{p} = .0237$ confirming subjects' use of the cues to direct attention.

Table 7. Mean Response Times (RT) and Percent Errors (PE- in parentheses) for all conditions of Experiment 2.

	Stimulus Location		
	Younger Adults		
SOA x Cue	Center	Middle	Outside
250 ms SOA			
Neutral	620 (17.7)	547 (1.0)	559 (1.6)
Center	568 (5.1)	597 (4.2)	638 (3.1)
Middle	626 (15.6)	552 (2.2)	575 (6.3)
Outside	655 (18.8)	550 (3.1)	555 (2.0)
500 ms SOA			
Neutral	689 (25.0)	559 (2.6)	567 (2.1)
Center	591 (10.5)	620 (4.2)	671 (6.3)
Middle	706 (14.6)	555 (2.7)	617 (1.0)
Outside	809 (26.0)	580 (7.3)	566 (2.5)
750 ms SOA			
Neutral	689 (25.5)	588 (4.2)	577 (2.6)
Center	598 (8.2)	671 (1.0)	671 (5.2)
Middle	683 (20.8)	525 (2.1)	622 (4.2)
Outside	737 (25.0)	638 (10.4)	570 (3.1)
1000 ms SOA			
Neutral	670 (21.4)	573 (2.6)	589 (1.6)
Center	591 (6.5)	605 (5.2)	666 (6.8)
Middle	644 (18.8)	567 (2.1)	588 (2.1)
Outside	686 (26.0)	564 (4.2)	567 (1.7)

Table continued on the next page.

	Stimulus Location		
	Older Adults		
SOA x Cue	Center	Middle	Outside
250 ms SOA			
Neutral	924 (38.5)	835 (16.7)	790 (9.4)
Center	807 (17.4)	890 (10.4)	886 (9.4)
Middle	932 (43.8)	775 (13.8)	799 (7.3)
Outside	996 (36.5)	824 (16.7)	782 (8.5)
500 ms SOA			
Neutral	991 (35.4)	793 (11.5)	770 (7.8)
Center	804 (15.6)	860 (19.8)	917 (14.6)
Middle	946 (33.3)	763 (13.0)	792 (12.5)
Outside	928 (31.3)	835 (15.6)	754 (8.7)
750 ms SOA			
Neutral	1040 (33.9)	839 (15.6)	837 (7.3)
Center	887 (22.0)	946 (14.6)	917 (12.5)
Middle	1038 (43.8)	822 (16.0)	847 (5.2)
Outside	1076 (38.5)	959 (16.7)	837 (7.8)
1000 ms SOA			
Neutral	1094 (41.1)	841 (18.8)	816 (5.2)
Center	846 (23.3)	934 (17.7)	928 (12.5)
Middle	953 (33.3)	744 (14.5)	870 (7.3)
Outside	981 (41.7)	845 (16.7)	799 (10.7)

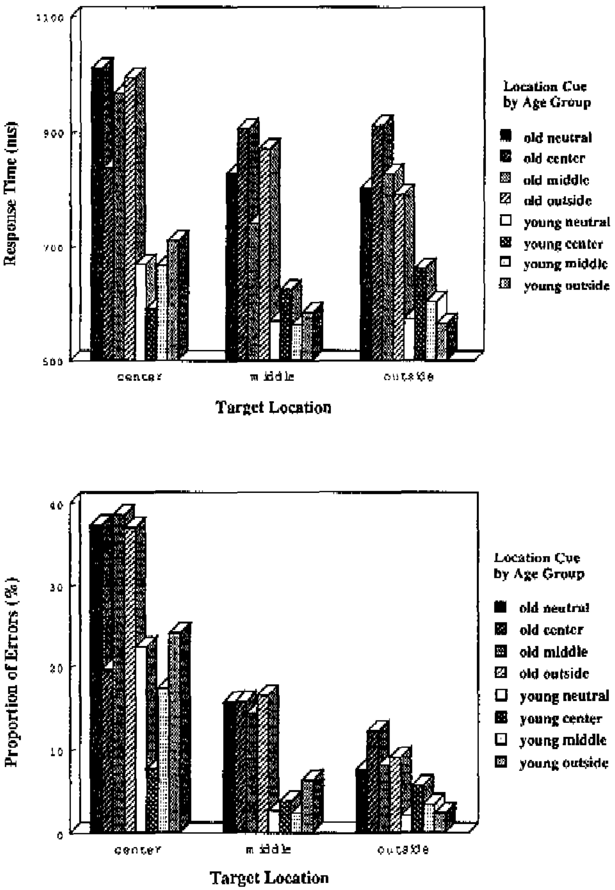

Figure 5. Data for the older and younger adults collapsed across SOA's.

Error data. The overall total error rate for both groups was 11.2%. The error rates per cell were transformed from proportions to logits for statistical analyses as in Experiment 1. The ANOVA revealed significant main effects of age group, F (1,22) = 21.79, $p < .001$, target location, F (2,21) = 58.72, $p < .001$, and cue, F (3,20) = 6.14, $p = .0039$, but not of SOA. The interaction between cue and target location was also significant (F (6,17) = 4.65, $p < .0057$) paralleling the RT results. Finally, an interaction between age, cue, and SOA (F (9,14) = 3.06, $p < .03$) reached significance. This interaction reflects the differential use of the outside cue by the older and younger adults at the 500 ms SOA only and not a systematic trend. Therefore, it is not readily interpretable in terms of our hypothesis.

Summary of MANOVA results. Significant RT results generally paralleled those of Experiment 1 with the exception of the main effect of SOA which was not found for Experiment 1. In addition, the main effect of age group was significant in the RT data, as it was for Experiment 1, but age no longer interacted with cue, target location, or SOA. These findings suggest that the effect of SOA in Experiment 1, implying a difference in the time course of cue processing between the two groups, was a result of visual difficulties experienced by the older adults. It is possible that, given more time, older subjects used the cues to gather more resources to the cued area in an attempt to offset visual acuity deficits. At short SOAs they were unable to gather as many resources as they were at longer SOAs but this does not necessarily mean that there was any difference in the time course of processing the cue itself. Additionally, the lack in Experiment 2 of any interactions with Age Group is an indication that the visual effects of eccentricity, which might have contributed to the age differences found in Experiment 1, were indeed controlled in Experiment 2.

Age differences in the mean RT patterns for the neutral cue condition are of interest as well. The long RT of the center location in the neutral condition might be related to the phenomenon described by Posner (1980) in which subjects attend away from the fixation area if they know that peripheral stimuli might be presented. In this way, they allow the fovea to "take care of itself" while attending to stimuli that they expect to be more difficult to see. It seems that the effect is much larger for the old group, and while it might represent a strategic age difference, this "avoidance" of the center area also occurs when an invalid cue is given suggesting it is due to more than just the effect described by Posner (1980). Two other possible causes of the lower performance in the center area are the relatively small size of the center targets and visual interference.

First, although the center targets were approximately the same diameter as those in Experiment 1, line thickness was reduced so as to prevent the middle and outside characters from appearing too bold due to the proportional size increase with eccentricity. Under conditions of screen presentation, the center target and distractors apparently were somewhat degraded in relation to their size due to pixel density as compared to those of the middle and outside characters.

Second, it is also possible that the lower performance in the center area represents an effect of visual interference due to the distractors. This type of visual interference is known to affect word identification outside the fovea where the most outward letter is more visible than the most inward letter (Andriessen & Bouma, 1976; Bouma, 1973). There is also recent evidence that visual interference in the extrafoveal visual field is far greater for older adults than for younger adults (van den Heuvel, 1994). This is a separate phenomenon from reduced peripheral vision and is not likely to be controlled with the increase in stimuli size with eccentricity as is peripheral visibility. Increased visual interference outside of foveal vision is therefore a likely cause for much of the performance deficit in the center area, which acts in combination with the additional effects of a small degradation of center stimuli visibility, and that described by Posner (1980).

In the center condition where the cue was valid, the cue enabled the older subjects to achieve a benefit of 175 ms in the valid center condition as compared to the 78 ms benefit for the younger subjects. This result indicates that visual discrimination abilities across age groups are not determined solely by visibility (e.g., Anstis, 1974), but also by flexible processes of attention which show age-related changes in themselves.

Model fit Analysis. Overall RT data were fit by three models of attentional allocation as in Experiment 1 with some changes (Table 8), discussed below. The spotlight model, a two parameter model, remained as it was. The original zoom lens and ring models predicted increased RTs for all targets appearing in the middle and outer areas due to the effect of eccentricity. It was assumed that these predicted eccentricity effects would be balanced to zero by the linearly increasing size of the targets and distractors used in Experiment 2 and were therefore removed from both the zoom lens and the ring model by removing the fourth parameter E. In the case of the ring model the cost remained for the neutral center condition in accordance with the finding of Posner (1980) that subjects tended to distribute attention away from the foveal area (as was also done in Experiment 1) when no informative cue was given. However, an additional unit of cost was added to each of the center location conditions to reflect the observed suppression apparently due to visual interference and degradation factors. Thus, the cost parameter reflected: 1) suppression of the center cue area due to visual effects, 2) predicted costs due to invalid cues, and 3) the avoidance effect described by Posner (1980). As the theoretical basis of the zoom lens model does not allow for attention to be concentrated away from the foveal area no logical changes could be made other than the removal of the eccentricity parameter. The best fit to the RT data was shown to be the ring model for both younger and older subjects. The spotlight model did not give as good a fit as the ring model and the zoom lens model gave an extremely poor fit. A similar result was attained for both groups in fitting the zoom lens model to the error data (see Table 9). However, in contrast to the RT data results, the spotlight model appeared to fit the error data of the older adults equally well as the ring model.

Table 8. Response Time data (in ms) and predictions of the Ring, Zoom Lens, and Spotlight Models of Attention (Experiment 2).

Stimulus Location

Younger Adults

Cue	Center	Middle	Outside
Neutral	667	567	573
Center	589	623	661
Middle	665	562	601
Outside	710	583	564

Ring Model[a]

Neutral	T+2C=659	T=565	T=565
Center	T-B+C=603	T+C=612	T+2C=659
Middle	T+2C=659	T-B=556	T+C=612
Outside	T+3C=706	T+C=612	T-B=556

Zoom Lens Model[b]

Neutral	T=610	T=610	T=610
Center	T-B=598	T+C=628	T+2C=645
Middle	T-B/2=604	T-B/2=604	T+C=628
Outside	T=610	T=610	T=610

Spotlight Model[c]

Neutral	T+20.5=669	T+8.5c=585	T+8.5c=585
Center	T+4.5c=558	T+12.5c=613	T+20.5c=669
Middle	T+20.5c=669	T+4.5c=558	T+12.5c=613
Outside	T+20.5c=669	T+12.5c=613	T+4.5c=558

Table continued on the next page.

Stimulus Location

Older Adults

Cue	Center	Middle	Outside
Neutral	1012	827	803
Center	837	904	912
Middle	967	740	827
Outside	995	871	791
	Ring Model[a]		
Neutral	T+2C=948	T=811	T=811
Center	T-B+C=835	T+C=879	T+2C=948
Middle	T+2C=948	T-B=767	T+C=879
Outside	T+3C=1016	T+C=879	T-B=767
	Zoom Lens Model[b]		
Neutral	T=879	T=879	T=879
Center	T-B=834	T+C=886	T+2C=892
Middle	T-B/2=857	T-B/2=857	T+C=886
Outside	T=879	T=879	T=879
	Spotlight Model[c]		
Neutral	T+20.5c=968	T+8.5c=827	T+8.5c=827
Center	T+4.5c=779	T+12.5c=874	T+20.5c=968
Middle	T+20.5c=968	T+4.5c=779	T+12.5c=874
Outside	T+20.5c=968	T+12.5c=874	T+4.5c=779

[a] Parameter values: Young: T=565.2, B=9.2, C=47.0; Old: T=810.8, B=44.3, C=68.4.
Percent variance accounted for: Young=94.4; Old=86.0.

[b] Parameter values: Young: T=610.0, B=11.2, C=17.9; Old: T=879.3, B=45.4, C=6.3.
Percent variance accounted for: Young=0.07 ; Old=0.04.

[c] Parameter values: Young: T=526.0, c=6.98 ; Old: T=726.0, c=11.8.
Percent variance accounted for: Young=83.7; Old=82.2.

Table 9. Error data (proportions of incorrect responses) and predictions of the Ring, Zoom Lens, and Spotlight Models of Attention (Experiment 2).

	Stimulus Location		
	Younger Adults		
Cue	Center	Middle	Outside
Neutral	22.4	2.6	2.0
Center	7.6	3.6	5.7
Middle	17.4	2.3	3.4
Outside	24.0	6.3	2.3
	Ring Model[a]		
Neutral	F+2C=12.1	F=2.0	F=2.0
Center	F-B+C=6.3	F+C=5.0	F+2C=12.1
Middle	F+2C=12.1	F-B=2.5	F+C=5.0
Outside	F+3C=26.4	F+C=5.0	F-B=2.5
	Zoom Lens Model[b]		
Neutral	F=5.8	F=5.8	F=5.8
Center	F-B=7.5	F+C=4.9	F+2C=4.1
Middle	F-B/2=6.6	F-B/2=6.6	F+C=4.9
Outside	F=5.8	F=5.8	F=5.8
	Spotlight Model[c]		
Neutral	12.2	5.8	5.8
Center	3.7	6.5	12.2
Middle	12.2	3.7	6.5
Outside	12.2	6.5	3.7

Table continued on the next page.

		Stimulus Location	
		Older Adults	
Cue	Center	Middle	Outside
Neutral	37.2	15.6	7.4
Center	19.6	15.7	12.2
Middle	38.5	14.3	8.1
Outside	37.0	16.4	8.9
		Ring Model[a]	
Neutral	F+2C=24.9	F=9.3	F=9.3
Center	F-B+C=19.0	F+C=15.1	F+2C=24.9
Middle	F+2C=24.9	F-B=11.5	F+C=15.1
Outside	F+3C=37.3	F+C=15.1	F-B=11.5
		Zoom Lens Model[b]	
Neutral	F=17.8	F=17.8	F=17.8
Center	F-B=23.5	F+C=13.5	F+2C=10.2
Middle	F-B/2=20.5	F-B/2=20.5	F+C=13.5
Outside	F=17.8	F=17.8	F=17.8
		Spotlight Model[c]	
Neutral	31.2	17.7	17.7
Center	13.1	22.2	31.2
Middle	31.2	13.1	22.2
Outside	31.2	22.2	13.1

a Percent variance accounted for: Young=82.7; Old=55.7.
b Percent variance accounted for: Young=0.03; Old=0.13.
c Percent variance accounted for: Young=64.2; Old=57.9.

Note: The ring and zoom lens models have been run with the logit transformed error rates and probabilities shown are the resulting retransformations of corresponding logits. As parameter values can only be indirectly related to probabilities they are not given here. Error predictions for the spotlight model were derived using the method of Juola et al (1991, refer to text).

Thus, it remained to determine which of the two models actually best described the behavior of the older adults as reflected by the error data. However, before this was done, a correlation analysis was performed between the response time data and the error data in order to insure there was no evidence of a speed accuracy trade-off which would invalidate the use of the models due to unstable data. Results of the analysis for the younger adults (r = .85) and for the older adults (r = .83) indicate that RTs and error rates are positively correlated and are thus essentially measuring the same phenomenon. This provides evidence that, despite high error rates, the response time data of the elderly is stable.

Next, it was suspected that the reduction of performance in the center location (suppression cost) was greater for the older subjects than for the younger subjects due to greater visual interference and degradation effects than attentional effects. This was a reasonable supposition based on our knowledge of the possible degradation of the center stimuli, the effects of visual interference on older adults, as well as the results of Experiment 1 which suggested that the older adults were more vulnerable to visual difficulties than the younger adults. This hypothesized, age-related, difference presumably had not noticeably affected the model fits of the RT data as response time is a finer measurement than error rates and subtle differences do not strongly affect the fit of the models. Errors are a discrete type of measurement and create larger effects in the model fits.

It was therefore hypothesized that differential effects of the two sources of cost for the older subjects (recall that costs for center location conditions were thought to encompass the costs of visual factors, costs for invalid cues, and the effect described by Posner, 1980), had resulted in a lowered fit to the ring model. In other words, if costs generated by visual factors are greater for the older subjects, then the combination of all possible costs into one parameter, as in the three parameter model, would have constrained visual effects, resulting in a lowered fit by the ring model to the less sensitive error data. Therefore, a four parameter ring model with visual factors (suppression cost) and attentional factors (invalid cue cost, and the avoidance effect described by Posner, 1980) as separate parameters was compared with the spotlight model. The four parameter ring model explained 79.0% of the variance in the error data of the older adults as compared to the 57.9% explained variance of the spotlight model. In order to make a fair age comparison, the error data of the younger adults was also fit to the four parameter ring model. Where the three parameter ring model explained 82.7%, the four parameter version explained 95.2% of the variance in the error data of the younger adults. We therefore conclude that the ring model provides the best explanation of the behavior of both groups when visual factors are specifically taken into account.

In order to compare the relationship of the cost for an invalid cue and the cost due to suppression of the center area for both age groups, the four parameter ring model was fit to the RT data. (The explained variance was thus 94.4% for the younger group and 85.5% for the older group.) Results of the new model fits revealed that the RT parameter value estimates for the two cost parameters (visual and attentional) were nearly equal (invalid cue = 45.5 ms, suppression of the center area = 48.9 ms) for the young group. However, the cost for an invalid cue (plus the effect described by Posner, 1980, which will not be further discussed separately from the effect of invalid cues as it only affects the neutral center condition and therefore does not account for a major portion of the overall attentional effects) for the older group was estimated to be far smaller (43.8 ms) than the cost for suppression (102.0 ms) of the center area. Therefore, our hypothesis was confirmed; older and younger adults were clearly different in their response to targets in the center area, most likely due to visual factors.

Discussion

The interpretation of the RT analysis by formal models is straightforward. When the size of the targets and distractors is increased with eccentricity, response time data of both younger and older adults are best explained by the ring model.

The model analysis of the error data of the older adults led to the development of a four parameter ring model that gives separate estimations of the cost for invalid cues and the cost of center area presentation due to (presumably) visual factors. The most important result of the exercise of using the four parameter model was the discovery of a clear age difference in the avoidance of the parafoveal center area. Using the same four parameter model, an analysis of the RT data provided a quantification of the effects of an invalid cue and the effects of presentation in the center area, outside the fovea. From the resulting parameter values it was apparent that older adults do not have as great a cost for an invalid cue as do the younger adults. This outcome can be interpreted in terms of a reduced inhibition hypothesis where a decreased ability to inhibit uninformative areas of the attentional field results in lowered costs for invalid cues (e.g. Hartley, 1992). The very high value of the avoidance parameter for the older adults suggested that visual effects, whether due to decreased visibility of the center stimuli, or to visual interference, are affecting the behavior of the older adults more than the younger adults. However, as the older adults showed a greater benefit for the validly cued center condition as compared to the younger adults, despite visual effects, it can be concluded that they are able to use attention to offset detrimental effects of either visibility or interference. Additionally, as the ring model predicts far higher cue benefits for the older adults in general, it is apparent that they utilize the cue to a greater extent than the younger adults.

2.4 General Discussion and Conclusions

The two experiments reported here found large and consistent differences between young and elderly adults in the speed and accuracy with which they located and identified a single target character embedded in a 24-character display. Some of these differences were due primarily to aging effects on peripheral visual factors alone, as changes in the size of display characters had greater effects on elderly adults' performance than for the younger adults. In the first experiment, in which all characters were the same size independent of eccentricity, elderly subjects were relatively slower and less accurate than in the second experiment in which image size increased linearly with eccentricity. These results indicate that some of the differences between search performance in young and elderly adults can be minimized if care is taken to reduce the typical difficulty that many elderly adults have in processing peripheral characters in a cluttered display.

Further differences between results for the two age groups were revealed by fitting several models of attentional distribution to the RT and error data. All subjects in both experiments showed large and consistent costs for invalid spatial cues and benefits for valid cues, but the best-fitting models were not the same in the two experiments. Specifically, a serial, self-terminating (spotlight) model was tested against the data and rejected in all cases. The younger subjects' data from both experiments and the older subjects' data from Experiment 2 were best fit by a resource allocation model which proposes that attention can be allocated to a ringlike region around the fovea in response to a cue indicating that the target should appear within a particular ring. The data from the older group of subjects differed in Experiment 1, from that of the younger group, and was best fit by a zoom lens model which proposes that attention energizes a circular area capable of spreading out from the fovea in response to ringlike cues. When systematic increases in character size with increasing eccentricity were introduced in Experiment 2, however, the elderly adults' data were best fit by the resource allocation (ring) model, just as they were for the younger subjects. That is, by making special allowances for reduced peripheral acuity in elderly adults, their data more closely resembled the data from younger subjects both quantitatively and qualitatively.

The model fitting results for the data from Experiment 2 revealed further, more general, differences between the age groups. Despite the fact that the data of both groups was best explained by the same (ring) model, an expansion of the model parameters indicated that older adults had more difficulty in identifying targets in the center area as compared to the younger adults when the cue did not direct attention there. It cannot be determined whether this was an effect of degraded stimuli or of visual interference, however, the older adults were able to compensate for this, apparently visual, difficulty to a great extent. Compensation was apparently the result of increased attention as shown by the very high benefit of a valid cue to the center area. In addition, the overall benefit for a valid cue was much higher for the older adults than for the younger adults indicating that the older subjects made greater use of the cues, possibly in order to offset greater visual difficulties in the center area that occurred despite matching the groups for general visual acuity.

Results of the Experiment 2 model analysis also revealed that older adults had lower costs for invalid cues than the younger adults, possibly reflecting a decreased ability to inhibit uncued areas of the display. As mentioned earlier, the selective processes of attention are thought to include both a focusing component where attention is concentrated on the to-be-processed item, and an inhibitory component that suppresses response to distracting, or irrelevant, items in the visual display. In the case of the present study, the benefit for a valid cue can be assumed to reflect the focusing aspect of attention where a greater benefit represents a higher concentration of processing resources. In this view, the cost for an invalid cue reflects the strength of suppression, or inhibition, of the items in the uncued areas of the visual display. Therefore, the increased benefits for valid cues, and the decreased cost for invalid cues, as shown by the older adults, is interpreted as evidence for an age-related differential relationship of the two component processes of attention. The finding that cost is reduced in relation to benefit for older adults as compared to younger adults is consistent with other findings of reduced inhibitory functioning with age (e.g. Hasher, Stoltzfus, Zacks & Rypma, 1991; Hasher & Zacks, 1988; McDowd & Filion, 1992; McDowd, & Oseas-Kreger, 1991; Stoltzfus, Hasher, Zacks, Ulivi & Goldstein, 1993).

Other differences between the experiments showed up in the overall effects of age. In order to eliminate attentional effects from consideration, and thereby any strategic differences between younger and older subjects, data from neutral-cue trials only will be considered first. These data show nearly equivalent levels of performance for the younger subjects: mean RT = 607 ms and 602 ms in Experiments 1 and 2, respectively; mean error proportion = 9.0 in both experiments. The proportional character size increase with eccentricity in Experiment 2 had a large effect on the data for the older subjects, however: mean RT = 1089 and 881; mean error proportion = 27.8 and 20.1, for Experiments. 1 and 2, respectively.

When the data for valid and invalid cue trials are considered, it is clear that the benefits and costs of these cues are about the same for Experiments 1 and 2 for the younger subjects (both the actual data and the model parameter estimates for costs and benefits differed by no more than 20 ms between experiments). For the elderly adults, however, benefits increased and costs decreased substantially from Experiment 1 to 2. Furthermore, the costs and benefits showed a large SOA effect only for the older subjects in Experiment 1. Apparently the greater visual difficulty caused by the displays used in the first study resulted in a compensatory attentional strategy adopted by the older subjects. This strategy takes about 1000 ms to effect its full result, and produces much of the cost-benefit difference between younger and older subjects observed in Experiment 1.

One of the reasons that the zoom lens model fit the data better than the ring model for the older subjects in the first experiment is probably due to a confounding of visual and attentional effects in the parameters of that model. That is, the zoom lens model describes attention as a beam which disperses its resources more thinly as it expands from the central area when increasingly peripheral cues are used. The data for the older subjects also indicated that increasing eccentricity reduced target discrimination accuracy. Thus, the drop in performance from near to far targets could be interpreted as either a visual or an attentional problem, and the parameters of the zoom lens model cannot separate these two effects. When eccentricity was eliminated as a problem by the display changes made in Experiment 2, the ring model fit all data better for both young and old subject groups. This result makes a strong methodological point that studies of aging effects in visual search studies have to attempt to separate visual from attentional and other cognitive components of overall performance. Further, this result supports the conclusion that the ring model gives a more accurate description of the kind of control that observers have over attentional resources when the process is not severely data-limited (see Juola et al., 1991). When the known difficulty that older adults have in processing peripheral stimuli in a complex scene is somehow minimized, elderly and young adults appear to be equally flexible in attending to visual cues. Both groups show largely the same pattern of costs and benefits in visual search but with a somewhat different ratio with the older subjects relying less on inhibitory than selective processes. However, some age-related visual differences apparently remain but do not severely affect the flexibility of attentional distribution. These differences can be partially offset by an increase in attentional concentration by the older adults when a cue is provided.

In summary, the results of this study indicate that older adults retain the ability to flexibly distribute attention, but show some evidence of a lowered ability to inhibit areas of the visual field which may contain distracting information. However, the most important outcome of the study is the finding of large and various visual differences between younger and older adults that interact with attention. This leads us to the conclusion that visual differences associated with aging might have been underestimated, or undervalued, in many previous age-related studies of attention (as suggested by Cerella, 1985). The present study has made clear the importance of gaining a better understanding of the visual changes associated with age, especially eccentric vision and visual interference, and incorporating what is known into developing future paradigms for the study of attention and aging. In addition, the use of a quantitative modelling technique has been shown to offer a viable means of separating out visual effects from attentional effects in order to provide a more sound age comparison of selective attentional distribution.

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Chapter 3

Aging and Mechanisms of Visual Selective Attention: Effects on Word Localization and Identification[2]

Abstract

The present study investigated age differences in attentional allocation in a word localization and identification task. Response times for valid and invalid spatial cue conditions were compared for each of two age groups under two SOA conditions: 500 ms and 1000 ms. Very high benefits for valid cues in terms of response time were found for both groups. Results indicated that attention was more important for words when compared with similar earlier studies using a simple shape identification task. A sensitive model fitting technique was used to compare the cost and benefit of selective attention to words and revealed that attention can be concentrated away from the fovea to benefit in word identification in much the same manner for both age groups. The model fit analysis also revealed that attention for word identification, and perhaps any more complex visual stimuli, is more diffuse than for simple shape identification. In addition, older adults are more likely to avoid the foveal area in order to distribute attentional resources to the periphery and are able to increase these effects of selection at the longer SOA. This suggests that older adults are using attention to offset visual processing deficits for peripheral information such as letter information in the reading process. The results support a two process view of attention where attention consists both of selection and inhibition and provide evidence to support a theory of reduced inhibitory processes as a cause for cognitive slowing associated with aging.

3.1 Introduction

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[2] This chapter has been accepted in this form for publication: McCalley, L.T. (in press). Visual Cognition.

Recent age comparison studies by McCalley and Bouwhuis (1992, in press) have indicated that, when acuity is controlled, a single resource allocation model of attention can explain the behaviour of both old and young adults. Nevertheless, within the model, differences in strategies between the two groups can be identified, possibly reflecting visual and cognitive interactions. Specifically, older adults were more likely to direct attention to the periphery of the visual field in anticipation of a target stimulus than younger adults who concentrated attention closer to the fovea. The studies mentioned above required the localization and identification of a specific geometric figure among similar non-target figures. The present study extends the theoretical model to word localization and identification in an effort to explore whether the strategic differences in attentional allocation between the age groups, apparent in the earlier studies, would also occur with printed text. An exploration of attentional processes in word recognition in the elderly is a starting point for developing an understanding of the reading processes of older adults and a means of assessing the function and the demands of attention allocation in a complex visual environment.

Little research has addressed the reading processes of the elderly, and the existing literature normally concentrates on specific optical, or visual, pathologies associated with aging. Visual word recognition, however, seems to be one fruitful area of investigation as delayed word recognition associated with aging has been reasonably well established (Aberson & Bouma, 1993; Allen, Madden, & Crozier, 1991; Bowles & Poon, 1985; Madden, 1992). Little is known though as to the reason for the slowing of word recognition with age.

The findings of Johnson, Adams, Adams and Lewis (1988) and those of Elliott, Whitaker and MacVeigh (1990) suggest that optical factors are not the primary cause of age related visual processing decline. According to Aberson and Bouma (1993), it is likely that age effects found in visual word recognition are due to a central operating deficit. A recent study by Allen, Madden, Weber and Groth (1993) has concluded that the cognitive component which causes older adults to take significantly longer to recognize words than younger adults lies at the peripheral-processing level affecting word encoding processes. Madden and Plude (1993) also state that age differences in the visual sensory processes involved in information processing tasks lie beyond the level of the retina. One component of these processes may be visual selective attention.

Attention. Visual attention is known to aid perception, especially in complex environments (Engel, 1974) by controlling the selection of information needed for further processing and is assumed to encompass two distinct operations (Juola, Bouwhuis, Cooper & Warner, 1991). That area of the visual field to which visual attention is directed receives visual information processing benefits (enhancement or optimization), and, concomitantly, information in the unattended areas of the visual field is suppressed. The suppression mechanism prevents unselected information from interfering with the processing of the selected information (Juola et al., 1991). In the search for attentional deficits as an underlying cause of cognitive decline with age, both enhancement and suppression mechanisms are important issues to address. In addition, a time course difference in enhancement and supression mechanisms would provide a strong argument against the general slowing theory of cognitive aging and in favour of a more refined and predictive theory of cognitive aging (see Hartley, 1992, for a review and discussion of attentional theories and aging).

The Role of Parafoveal Vision. The importance of parafoveal word recognition in reading has been long established (see Aberson & Bouma, 1993, for a review of the topic). According to Balota and Rayner (1991), abstract letter code information can be utilized parafoveally (see also Blanchard, Pollatsek & Rayner, 1989). Furthermore, parafoveal processing is likely to be influenced not only by visual acuity, but also by the cognitive resources of the individual. Parafoveal processing decreases with foveal load implying an attentional effect which creates a kind of tunnel-vision, shrinking the functional field of view (Balota & Rayner, 1991). If we view this phenomenon as a narrowing of a beam width which is dependent upon the quantity of resources necessary to process a foveal image then we have a near analog of the zoom lens model of attentional distribution (Eriksen & St. James, 1986; LaBerge, 1983). It could then be proposed that the attentional mechanism controls the allocation of visual processing resources implying that visual processing and visual attention are closely linked. However, the picture is more complex than this as Juola et al. (1991; see also Engel, 1971) found that the distribution of attention can occur independently of the foveal area to allow the concentration of resources in the parafoveal region.

The effects of aging on parafoveal vision itself must also be considered. It has often been observed that older subjects have more difficulty with targets presented in the parafoveal area than younger subjects. Some researchers have suggested that observations interpreted as age differences in attentional distribution might instead be artifacts of visual differences between the age groups (Hartley, 1992). However, a prior study by McCalley and Bouwhuis (in press) has shown that stimulus properties in the parafoveal region can play a role in how the attentional distribution mechanism behaves. In a location and identification cuing task with same-sized targets and distractors, an analysis of response times and error rates by quantitative modelling revealed different attentional distribution patterns between younger and older adults. It was found that when stimulus size increased linearly with eccentricity in a visual display of 12 degrees, this controlled for visual eccentricity effects associated with age (McCalley & Bouwhuis, in press). Further analyses by modelling revealed that the older subjects were able to concentrate attention away from the fovea to speed response to a target in the parafoveal area in much the same manner as the younger subjects. Thus, older adults were different from young adults in how they allocated attention when targets and distractors were the same size. When the targets and distractors were increased in size with increasing eccentricity then the attentional allocation of the older adults became much more like that of the younger adults.

However, older adults still showed some differences in that they utilized the cue more and directed attention away from the fovea to a greater extent than the younger adults.

Models of Attention. Two previous studies of age-related effects of visual selective attention by McCalley and Bouwhuis (1992, in press) discussed results in terms of three theoretical models; the spotlight, the zoom lens, and the ring models, adapted from a study by Juola et al. (1991). Juola et al. (1991) tested and compared formal versions of these models which originated from the research of Eriksen & Yeh and Tsal (1985, 1983, respectively, spotlight model), Eriksen & St. James and LaBerge & Brown (1986, 1989, respectively, zoom lens model), and Egly & Homa and Juola et al. (1984, 1991, respectively, gradient or ring model). The zoom lens and the ring models, only, were selected for the analyses of this study as the spotlight model did not perform well in the McCalley and Bouwhuis studies (1992, in press). In addition, the zoom lens and the ring models are directly comparable on the bases of number of parameters and method of parameter estimations.

As interpreted by Juola et al. (1991), the zoom lens and the ring models are both forms of gradient models. The zoom lens model assumes that attention spreads from the point of fixation to encompass the attended area where the ring model allows more flexibility whereby attention can concentrate away from fixation while still surrounding the foveal area. Table 1 shows the predictions of these two hypothetical models.

Table 1. Predicted costs and benefits for the zoom lens and the ring hypotheses in terms of comparison with a neutral cue condition.

	Stimulus location		
	Zoom lens		
	Center	Middle	Outside
Cue			
Center	benefit	cost	cost
Middle	benefit	benefit	cost
Outside	none	none	none

	Stimulus location		
	Ring		
	Center	Middle	Outside
Cue			
Center	benefit	cost	cost
Middle	cost	benefit	cost
Outside	cost	cost	benefit

The focus of the present study is the age-comparison of flexibility of attentional allocation as it relates to the identification of words, or other meaningful stimuli. The ring model, the most flexible of the two models used in the present study, derives its name from the type of display used by Egly and Homa (1984) where the task demands a ring-like allocation of attention. However, as a flexible resource allocation model of attention the 'ring' can predict costs and benefits of a spatial cue for any size or shape of area designated as long as the area is contiguous (refer to Juola et al., 1991). Egly and Homa (1984, Experiment 3) compared two qualitative models similar to those of this study in a letter localization task. Subjects were required to identify a central fixation letter and the location of a second target letter which could appear in one of three ring-shaped areas. Costs and benefits for error rates for valid and invalid cue conditions were predicted on the basis of whether or not attention could be focused away from fixation. Results of their study confirmed the ring hypothesis of attentional distribution demonstrating that attention can be directed to general areas in the visual field. Juola et al. (1991) used a similar task, but with more complex displays which included distractors in order to strengthen the effect of the cue. In addition, the task was made easier than that of the Egly and Homa (1984) study by reducing the number of target letters to two from nine, and linearly increasing the size of the targets and distractors with eccentricity. This allowed for a substantial reduction in the error rate as compared to that found by Egly and Homa (1984) where the error rate for invalid cue conditions reached 80% for the outside ring. In addition, Juola et al. (1991) developed sensitive quantitative models in order to test three hypothetical models, the spotlight, zoom lens and ring, of attentional allocation. Again, the ring model was found to best fit the data.

Later studies by McCalley and Bouwhuis (1992, in press) extended the use of the quantitative models developed by Juola et al. (1991) to age-related studies of attentional allocation. The use of formal models, as recommended by Salthouse (1988), allows for more detailed analyses of age-related changes in visual selective attention as effects are represented by quantifiable parameters. McCalley and Bouwhuis (1992) compared attention allocation patterns of younger and older adults using a simple shape identification task. Subjects were asked to locate and identify a Landolt figure as to whether the opening in the figure faced right or left. The figure appeared among a group of 23 similar distractors and all 24 figures were evenly distributed over three concentric rings which were the possible cue areas. Predicted costs and benefits in response time and error rate for a spatial cue were compared for three allocation models, the spotlight, the zoom lens and the ring. Results of the younger adults best fit the more flexible gradient model, the ring, and results of the older group best fit the zoom lens model. However, a later study (McCalley & Bouwhuis, in press) as previously mentioned, revealed that a more flexible allocation model best explained the data for both age groups when the effects of eccentric vision were controlled. Moreover, the quantitative parameters of the model allowed for a finer analysis which revealed some attentional distribution differences between the two groups. Model parameters revealed that older adults were more likely to allocate attention to the periphery in anticipation of the cue. It was argued that the differing results of the two studies probably reflect visual and cognitive interactions whereby, with acuity controlled, older adults rely more on attention to gather information parafoveally. Both earlier studies were based on a paradigm requiring the localization and identification of a simple geometric figure among similar nontargets. The present study was conducted to explore whether the strategic differences in attentional allocation, revealed by quantitative modelling in the previous studies, can be extended to word localization and identification in the two age groups which may, in turn, affect reading processes.

3.2 Experiment

Method

Subjects. The subjects were two groups of twelve individuals. The younger adult group consisted of five female and seven male volunteers, ranging in age from 19 to 24 years (mean age = 22.4), selected from the subject pool at the Institute for Perception Research/IPO and from the university community at large. The younger subjects were either students of the University of Technology, Eindhoven, or were students of high vocational training institutes in the same area. The older adult group included four female and eight male volunteers, ranging in age from 63 to 73 years (mean age = 66.5), recruited from the IPO subject pool, and all had been educated to the high vocational level or above. All subjects had normal or corrected-to-normal near and far visual acuity and all had self-reported health as good to excellent.

Apparatus and Materials. The stimuli were presented on the video screen of a Macintosh IIcx computer. The Macintosh IIcx controlled the timing of stimulus presentation and recorded participants' responses via two keys on the keyboard which were programmed to correspond to the two possible subject responses.

Each trial of the experiment consisted of a sequence of six frames (Figure 1). The first frame consisted of two concentric circles with a fixation cross in the centre and was presented for 2000 ms.

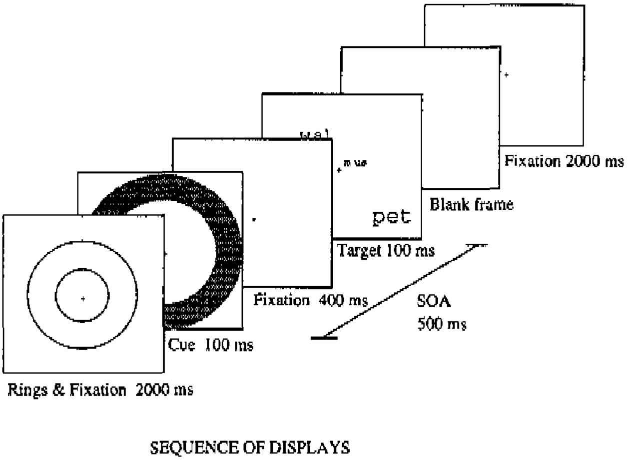

Figure 1. Sequence of frames for the experiment. The example shown is the 500 ms condition with the target word pet appearing in the outside ring. The cue condition is valid.

The circles served to indicate three ring-like areas to be attended to as cued; one within the inner circle, one between the inner and the outer circle, and one outside the outer circle. The second frame was presented for 100 ms and contained the cue which appeared as a distinct greying of the white screen corresponding to one (centre, middle or outside cue conditions), or all (neutral or uninformative cue condition), of the three circular areas. The third frame held a fixation cross which was centered in the display field. The duration of this display was varied across the four experimental sessions run with each subject so as to give the desired Stimulus Onset Asychrony (SOA) between cue and target. The fourth frame, shown for 100 ms, consisted of three three-letter Dutch words of equally high lexical frequency, one in each of three possible cue areas. In each trial one of two target words, pet or pot (cap and pot in English), appeared and the other two words served as distractors. The words were positioned along invisible axes, horizontal, vertical and diagonal, centered on the fixation cross in a visual field divided into an unseen circular grid containing 45 degree sectors and segments. The words were semi-randomly varied in position so that the three words never fell in the same quadrant. The total display was 12 cm in diameter; at the viewing distance of 57 cm, one degree of visual angle corresponded to about 1 cm. One word was centred 1 cm from the fixation point, the second at about 3 cm from fixation, and the third lying at about 5 cm from the fixation point. In this way each of the three possible circular cue areas contained a word. The words increased linearly in size with eccentricity. Those presented closest to the centre of the display were approximately 0.75 cm in length ("x" height = 4 mm), those appearing in the middle area being approximately 1.0 cm ("x" height = 5 mm), and those presented in the outer area were approximately 1.5 cm ("x" height = 6 mm). After the stimuli were presented, the field remained blank (the fifth frame was blank) until the subject made a response. The sixth, and final, frame consisted of a 2000 ms presentation of the fixation cross on a blank field. It appeared only after the subject pressed one of the response keys, indicated the end of the trial, and provided a rest period between trials. Thus, the intertrial interval was 2000 ms.

Procedure. The experimental task consisted of a two-alternative forced choice identification task in which subjects were required to indicate with a key press which of the two target words, pet or pot, appeared in the target display. The keys corresponded to the "m" and "v" positions on the keyboard and were marked with tape on which was written the appropriate target word. Subjects were instructed to fixate on the center cross in the first frame and not to move their eyes. They were then instructed to focus their attention on the ring(s) as indicated by the cue and were told that the cue would help them to detect and identify the target, as it would most likely appear in the cued area. In fact, the cue was valid on 80% of the non-neutral cue trials. Subjects were told to make the appropriate button response as quickly, but accurately, as possible and to guess if they were not certain of whether they had detected or properly identified the target.

Subjects attended a total of five sessions, each lasting approximately 2 hours. The first session was a training session in which subjects were read a training manual and subsequently given training blocks of 24 trials each until they had completed either 6 blocks or had reached a performance rate of 90% correct responses; whichever came first. The four remaining sessions consisted of the counter-balanced, randomized presentation of two different SOA conditions of 500 and 1000 ms. Sessions were blocked by SOA. At the beginning of each session the subject was given a practice block of 24 trials. Following the practice block subjects were given 4 full blocks of 72 trials each which included 48 valid, 12 invalid, and 12 neutral cues, all of which were randomized for all cue by target conditions. They were encouraged to rest for approximately 10 minutes between blocks at which time they were also given feedback as to the number of errors they made in the block.

Results and Discussion

Trials with RTs < 100 ms or on which the response time was more than twice the mean of the cell were considered outliers and removed. Fewer than 0.5% of the data were discarded in this way. Mean response times, calculated across subjects, revealed costs for invalid cues and benefits for valid cues as illustrated in Figure 2, a and b.

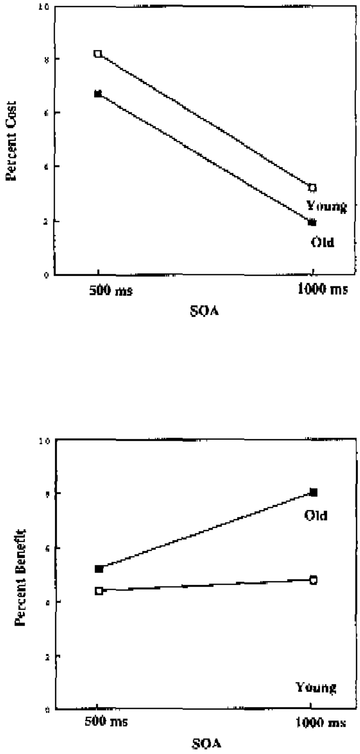

Figure 2. Percent cost (a) and percent benefit (b) in response time as a function of age and SOa.

Data were subjected to multivariate analyses of variance (MANOVAs) on response times (RTs) and on error rates (logit transformed) in a 2 (age group) x 3 (target location) x 4 (cue) x 2 (SOA) mixed model design prior to a model fitting analysis.

Response Time Data. The RT MANOVA revealed main effects of age, cue, and target location (F (1,22) = 37.86, p<.0001, F (3,20) = 13.16, p<.0001, and F (2,21) = 10.19, p< .001, respectively). The main effect of SOA was not found to be significant (F<1). There was an interaction between cue and location (F (6,17) = 16.87, p<.0001), between SOA and cue (F (3,20) = 3.34, p< .05), and between SOA, target location, and age (F (2,21) = 4.25, p< .05). Furthermore, there was a highly significant four way interaction between SOA, cue, target location, and age (F (6,17) = 4.59, p< .01). The four way interaction was further analyzed revealing a trend towards significance (F (1,22) = 8.03, p<.09) for the interaction of age and SOA, and, most importantly, the interaction of age with cue was highly significant (F (1,22) = 3.02, p<.01).

Error Data. The mean overall error rate was 12.6%. The MANOVA analysis of the error logits per cell of the design found significant main effects for age and target location (F (1,22) = 8.20, p<.009, F(2,21) = 48.89, p<.0001, respectively). The main effect of cue showed a trend towards significance (F(3,20) = 2.32, p<.11). A highly significant interaction of cue by location was also revealed (F(6,17), p<.0005).

Model Fits. Data were compared on the basis of two different models of allocation of attention. A model of flexible resource allocation (the ring model) was found to best fit the data of both the older and the younger adults (Table 2). Details of the analysis are discussed in the following section.

MANOVA Analysis. MANOVA was employed to trace the significant effects that could subsequently be modelled in a detailed fashion by mathematical analysis techniques.

In general, effects in the error data are not as strong as those in the response time data. However, these data provided converging evidence for the main findings serving to limit arguments for evidence of differential speed-accuracy trade-offs. No further analyses of the error data were considered necessary. However, it should be noted here that in preparation for previous similar studies (e.g. McCalley & Bouwhuis, 1992) pilot data of younger subjects indicated that unless the task was demanding enough, effects of attentional manipulation would be low. Thus, displays have been designed to create a level of difficulty that is attention demanding for younger adults while still manageable for older adults. This has the effect of creating high error rates in the data of the older group. However, as can be seen in Fig. 3, the pattern of errors by target location for both groups was nearly identical.

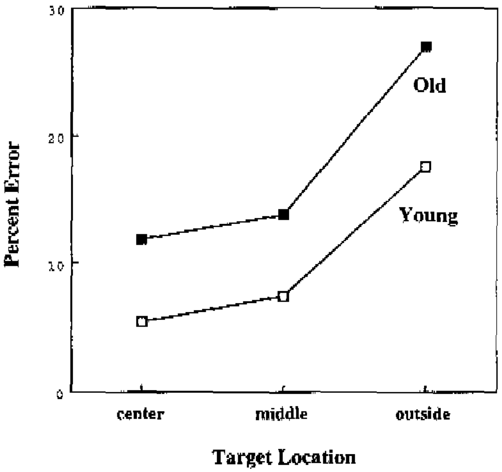

Figure 3. Percent of errors as a function of age and target location.

In comparing the overall error rate for the older subjects in this study with that of the younger subjects of Juola et al. (1991, Experiment 1) at 7.9% and that of Egly and Homa (1984, Experiment 3) at about 50% (and reaching 80% in one condition), it is obvious that data of this study fall within previous accepted error rates for similar studies. In addition, the robust MANOVA results indicate that the response time and the error data are stable.

Response times (RTs) and error rates in the present study indicate that both older and younger adults were able to use the cue to direct attention to a specific area of the visual field, thereby reducing errors and speeding responses to a word target. The effects of the cue on RTs for identifying a word in a particular area are shown in figures 4a, 4b, 5a and 5b. RTs are generally faster, showing a benefit, for a valid cue condition and slower, showing a cost, for an invalid cue condition for both groups when compared to the corresponding RT in the neutral cue condition.

Interactions between SOA and cue, SOA, target location and age, and, most importantly, SOA, cue, target location and age reflect differing strategic shifts by SOA in the use of the cue for both age groups. Figures 2a and 2b illustrate that both groups have similar overall proportional cue effects at 500 ms SOA but there is a large difference in the relationship of cost to benefit. The older subjects have a lower proportion of cost and a higher proportion of benefit as compared to the younger subjects. Within the context of the present experiment the interpretation of the results assume that suppression of uncued areas results in a cost for an invalid cue and selection of the cued area results in a benefit for a valid cue. This is in accordance with a large body of literature which argues for a dual process view of attention proposing that suppression of irrelevant information and selection of to be processed information are both components of the attentional mechanism (eg. Hasher, Stoltzfus, Zacks & Rypma, 1991; McDowd & Filion, 1992; McDowd & Oseas-Kreger, 1991; Stoltzfus, Hasher, Zacks, Ulivi & Goldstein, 1993). At the 1000 ms SOA cost drops dramatically for both groups but remains about the same proportionally between the two groups.

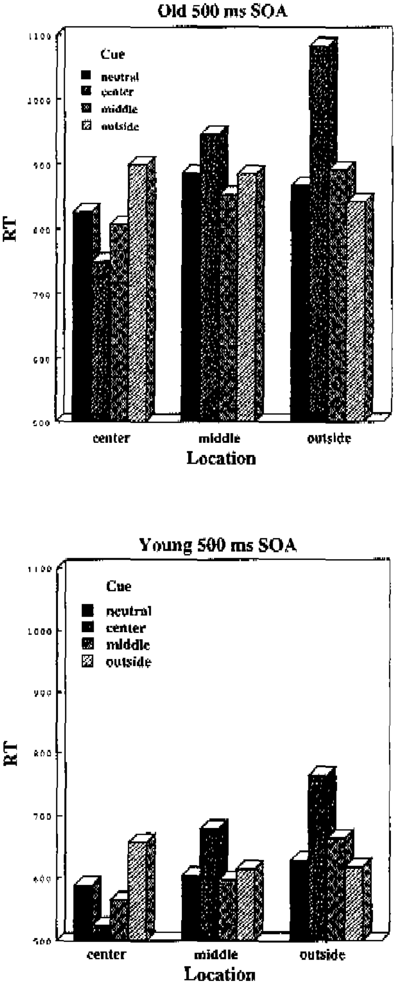

Figure 4. Response time for targets as a function of cued locations at 500 ms SOA for older adults (a) and younger adults (b).

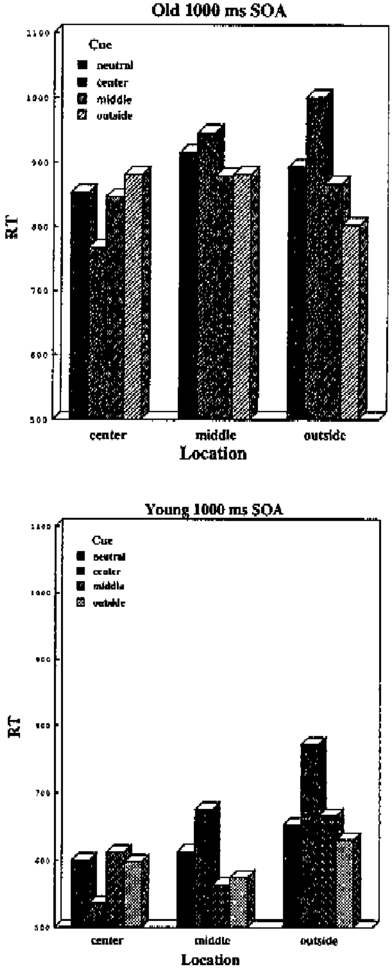

Figure 5. Response time for targets as a function of cued locations at 1000 ms SOA for older adults (a) and younger adults (b).

However, the proportion of benefit, while remaining nearly the same over SOA for the younger adults, increases for the older adults. This difference in benefit will be discussed in greater detail in the discussion of the formal model analysis where model fits provide actual quantitative parameters.

The analysis of the four-way interaction revealed that the effect of SOA was significant for the older group in the specific condition of the invalid cue to the center where the target appeared in the outside ring. In this condition there was a significant drop in the RT (resulting in a rise in benefit) for the older adults from the 500 ms cue condition to the 1000 ms cue condition. Furthermore, the interaction analysis showed that the effect of the cues for the outside location was different for the older group at the 1000 ms SOA as compared to the 500 ms SOA condition. These effects can be seen clearly in Figures 4a and 4b, and 5a and 5b, and indicate that, with time, older adults use the cue to gain higher benefits in the periphery through both a reduction in suppression and an increase in selection to the outside area.

Model Analysis.

Quantitative models were developed to estimate predicted costs and benefits. To predict response times, both the zoom lens and the ring model had four parameters: a base response time to a neutral cue (T), benefit for a valid cue (B), cost for an invalid cue (C), and cost for the eccentricity of the target in the visual field (distance from fixation, E). Although an attempt was made to control for peripheral acuity effects by enlarging the words with eccentricity, error rates for both age groups indicated some effect of target distance from the fovea (Fig 3). Thus, the eccentricity parameter was added to test for the effect of presentation in the far periphery. Parameter estimates were obtained from the data by using a least-squares procedure. The predictions of both models for the mean response time data are shown in Table 2.

Table 2. Mean Response Time data (in ms) and predictions of the Ring and Zoom Lens, Models of Attention.

	Stimulus Location		
	Younger Adults		
Cue	Center	Middle	Outside
Neutral	594	608	640
Center	529	678	768
Middle	564	605	666
Outside	626	594	624
	Ring Model[a]		
Neutral	T+C=581	T+E=593	T+2E=653
Center	T-B=531	T+2C+E=690	T+2C+2E=750
Middle	T+C=581	T-B+E=592	T-B+2E=652
Outside	T+2C=630	T-B+E=592	T-B+2E=652
	Zoom Lens Model[b]		
Neutral	T=602	T+E=614	T+2E=625
Center	T-B=538	T+C+E=679	T+2C+2E=755
Middle	T-B/2=570	T-B/2+E=582	T+C+2E=690
Outside	T=602	T+E=614	T+2E=625

[a] Parameter values: Young: T=532.4, B=1.3, C=48.6, E=60.4; Old: T=768.3, B=21.6,C=65.6, E=125.4.

[b] Parameter values: Young: T=602.0, B=64.2, C=65.0, E=11.7; Old: T=876.5, B=96.1, C=77.0, E=-8.5.

Table continued on the next page.

Stimulus Location

Older Adults

Cue	Center	Middle	Outside
Neutral	839	900	880
Center	758	946	1042
Middle	826	866	878
Outside	890	883	821
		Ring Model[a]	
Neutral	T+C=834	T+E=894	T+E=894
Center	T-B=747	T+C+E=959	T+2C+E=1025
Middle	T+C=834	T-2B+E=851	T-B+E=872
Outside	T+2C=899	T-B+E=872	T-2B+E=850
		Zoom Lens Model[b]	
Neutral	T=876	T+E=868	T+2E=859
Center	T-B=780	T+C+E=945	T+2C+2E=1013
Middle	T-B/2=828	T-B/2+E=820	T+C+2E=936
Outside	T=876	T+E=868	T+2E=859

As can be seen in Table 2, there are some differences in the modelling of attentional distribution for the two groups. Both the zoom lens and the ring formulae for each group reflect the respective theoretical differences hypothesized for each model. However, adjustments have been made for possible age-related strategy differences. Although both groups had benefits for each valid cue condition, not every invalid condition resulted in costs. In some conditions it is apparent that attention has spread from the cued ring to the adjacent ring as can be seen, for example, in Figure 5a and 5b. In this case, for the invalid outside cue where the target was located in the middle ring area, there is still some benefit as compared to the neutral cue condition for the middle ring area. In addition, total costs and benefits in RT for the younger adults are lower in proportion to the overall RT for the outside cue conditions as compared to the data of the older group. This indicates that the eccentricity of target presentation might have a greater effect on the younger subjects (or attention is allocated in a different, and less advantageous manner, in the periphery for the younger adults). One interpretation of this result is that attention is used by the older adults to offset the effects of diminished visual processing in the periphery where the younger adults do not need to use as much attention in the periphery. Therefore, the ring model for both groups was modified to reflect a lower resolution of attentional resources than assumed in previous versions (Juola et. al., 1991; McCalley & Bouwhuis, 1992, in press) while still maintaining theoretical integrity by predicting costs for invalid cues to the outside ring. Results of the model fits for mean response time, presented in Table 2, confirm that the data of both age groups can be explained with a single theoretical account of the distribution of attention; the ring model.

Previous research has shown that in some tasks older adults are apparently able to make greater use of prior information than younger adults (e.g. Folk & Hoyer, 1992; Hartley, Kieley & McKenzie, 1992; Hartley, Kieley & Slabach, 1990; Nissen & Corkin, 1985). Therefore the cost and benefit parameters were weighted for particular cells to reflect more control of attention for the older adults and a more diffuse spread as well as lower benefits in the outside cue condition for the young. The eccentricity parameter was also weighted to predict a higher cost for all outside conditions for the younger adults in comparison to the older adults (see Table 3).

Results of the present study provide some evidence to support a theory of reduced inhibitory processes. According to Hartley (1992), a finding of lowered costs of invalid cues for older adults as compared to younger adults would provide evidence for the acceptance of such a theory to account for age-related cognitive decline. The parameter values given by the best fitting model (Table 3) show a much lower ratio of cost to benefit for the data of the older adults as compared to that of the younger adults. The extremely high costs for an invalid cue in comparison to a negligible benefit for a valid cue indicate that younger subjects depended on suppression, or inhibition, of the uncued areas to locate the target. In contrast, the benefit parameter value for the older subjects was robust in comparison to the cost parameter value.

In addition, the interaction analysis revealed that the significant differences between the younger and older adults lie in the response to stimuli in the outer area which improved for the older adults with more time despite evidence for a reduction of suppression at the longer SOA. This is also reflected in the small decrease in goodness of fit to the ring model at the 1000 ms SOA (Table 2) for the older adults due to a drop in the predicted high costs for an invalid cue. This is an important point as it is known that, for the reading of text, letter information can be processed in the periphery (Balota & Rayner, 1991).

Evidence from several studies indicates that older adults are less able to suppress or ignore irrelevant information (e.g. Rabbitt, 1965; Stoltzfus et al., 1993; Tipper, 1991). This should put them at a disadvantage in many situations requiring a high speed of visual search, especially for textual material (Bouma, 1978). However, despite evidence of age-related slowing of word recognition, Aberson and Bouwhuis (1994) report that there is little evidence of age-related slowing in the actual reading of text as a result of aging per se. In addition, a study by McDowd and Oseas-Kreger (1991) using a letter reading task to investigate age differences in negative priming found that some older subjects were able to read the letter lists faster than some of the young subjects despite evidence of reduced suppression processes in the older subjects. Stoltzfuz et al.

(1993) used this same procedure to explore age differences in inhibition and found that despite a lack of suppression older adults were able to perform a selection task with no more interference from a distractor than the young group. This finding indicates that inhibition is not always necessary to concurrent selection. The results of these studies are in accordance with those of the present study where enhanced processing in the periphery occurred for the older group at the longer (1000 ms) SOA despite a reduction in suppression and where selection seemed to act independently of suppression. These results suggest that in older adults attention can be used to compensate for other reduced resources such as a general decline in visual processing. This might explain why reading rates can be maintained until a very late age (Aberson & Bouma, 1993).

As previously mentioned, both groups were compared on the basis of two models of attentional allocation, the zoom lens and the ring, and the ring performed best for both groups. However, for the younger adults, the zoom lens model also performed well, although not quite as well as the ring model. The reason for this is quite clear. The zoom lens model predicts a depletion of benefit for a valid cue condition to the outermost cue area due to a thinning of attentional resources. An effect of eccentricity would have the same effect and therefore the zoom lens model will interpret, for example, difficulty due to visual processing at increasing distance from the point of fixation as an effect of attentional thinning.

In the present study, the diffuse spread of attention indicated by the data of the younger adults, which can best be seen at 1000 ms SOA (Fig. 5b), is interpreted by the zoom lens model as a dilution of resources due to spread over the whole field. Yet, at 500 ms SOA (Fig 4b), the ring effect is clear. When the data are examined closely it becomes apparent that the ring model gives the best explanation for the performance of the younger adults as benefits for a valid cue condition to the outside area are always greater than for an invalid cue to the same area for a target word appearing in either the middle or the center area confirming that attention has been directed away from the point of fixation and concentrated in the outer area. This response pattern is very similar to that reported in Juola et. al. (1991), Egly and Homa (1984) and McCalley and Bouwhuis (1992, in press). However, in the earlier studies of McCalley and Bouwhuis (1992, in press) where a shape identification task was used, it was the older adults who experienced difficulty in relationship to the eccentricity of presentation. As mentioned previously, this was found to be correctable with an increase in the size of the stimuli with distance from fixation indicating a visual and attentional interaction.

Present data of the older subjects match more closely to the predictions of the ring model than the data of the younger subjects showing more distinct costs and benefits for the middle and outside cue conditions indicating a greater shift of attentional resources in response to the cue. The present data also reveal that the cuing and selection of the outside conditions takes much more time than found in the previous studies (McCalley & Bouwhuis, 1992, in press), especially for the older adults. However, the older subjects appear to have equal difficulty with eccentricity over the middle and the outer rings as compared to the younger adults who have more difficulty with the furthest ring than with the middle ring as indicated by the weighting of the distance, or eccentricity, parameter of the ring model. This finding supports earlier indications that visibility in the parafoveal region alone does not explain attentional differences between the age groups but is related to attention and is, to some degree, dependent upon whether the task is shape or word identification.

The unusually high benefits for valid cue conditions in the present study, as compared to the earlier McCalley and Bouwhuis studies (1992, in press), suggest that word identification benefits more from attention than simple shape identification, irrespective of location in eccentric vision. The selection of the outside locations take more time for word identification than for simple shape identification, and this is more evident for the older group. It is interesting to note that in the development of this experiment, pilot studies, using six young adults (mean age = 23 years), indicated that not more than two distractor words could be used before the identification task became too difficult to perform.

3.3 Conclusions

In comparison to the abovementioned studies which yielded nearly perfect symmetric costs for invalid cue conditions and benefits for valid cue conditions, ring selection was not nearly as well defined. This indicates that attention allocation changes when word perception, or perhaps any more meaningful or complex visual pattern perception, is required. The present study confirms that a more flexible theoretical model of attention best describes the behavior of both old and young adults which is supported by the phenomenon that attention is controlled in a more diffuse manner for word localization and identification than for simple shape localization and identification. Furthermore, differences still exist between the two groups at a higher level of visual processing as indicated by the effect of SOA. Older adults evidence lower levels of suppression of irrelevant information as compared to younger adults and, after some time, are able to increase the effects of selection of information. Older adults are also more likely to avoid the foveal area in order to allocate attentional resources to the periphery. This suggests that the older adults are using attention to offset a decline in the processing of parafoveal and peripheral information which may have consequences for the use of letter information in the reading process.

The use of quantitative model analysis in the present study has allowed a far more detailed exploration of age differences in the allocation of attention than the traditional statistical analysis techniques. Model analysis has revealed that older adults retain a great deal of flexibility of resource allocation and can use this flexibility to increase processing in selected spatial areas as shown by the weighting of specific parameters. Furthermore, the use of quantitative parameters has revealed the precise magnitude of the relationship between cost (suppression) and benefit (selection) for both younger and older adults.

Although results presented here strongly support a two process view of attention, there is little evidence that lowered inhibitory processes greatly reduce the overall ability of older adults to focus attention in the reported task. Further research is necessary to determine the relationship between the two processes and how they behave in more complex environments.

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Chapter 4

Age Changes in the Distribution of Attention on Pictorial Backgrounds[3]

Abstract

Older adults appear to be at a disadvantage in the performance of everyday activities which require the localization and identification of words in complex visual environments. It was hypothesized that older people have more trouble than younger people in allocating attention to words in the parafoveal visual field when a task must be carried out on a pictorial background. Results of the experiment reported in this study reveal that the demands of a complex pictorial background reduce the useful field of view for both age groups, however, effects are significantly greater for the old, confirming the hypothesis. In addition, the spatial allocation of attention was more disrupted for the old when the task was performed on a moving video background than on a still background. Quantitative modelling procedures support a theory of reduced inhibition for both externally, and internally driven attentional processes of the older adults. Some changes to text for video overlay and for road signs that might aid the elderly in the performance of daily tasks are suggested.

4.1 Introduction

Older people often report increasing difficulty in detecting objects in complex, distracting environments (Ball, Beard, Roenker, Miller & Griggs, 1988). This is especially true for tasks involving the search for, and identification of, words among other distracting stimuli in everyday tasks such as reading a street sign surrounded by other street signs (Sekuler & Ball, 1986), reading television credits and reading in general (Kosnik, Winslow, Kline, Rasinski & Sekuler, 1988) and, in parts of Europe, the reading of subtitles on

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[3] This chapter has been submitted for publication as McCalley, L.T.

television (d'Ydewalle & Gielen, 1994). Ball et al. (1988) found that performance on a localization task (used by Sekuler & Ball, 1986) which required visual search in the peripheral field was predictive of reported difficulty with everyday tasks of older people. This indicates that the self-reported everyday problems of the elderly could be a result of an inefficient processing of parafoveal information.

Two domains of study have provided the bulk of literature addressing the problems older people report having with tasks involving parafoveal object or word recognition in a visually cluttered environment. One domain addresses visual performance in the useful field of view (UFOV) and the other seeks to explain cognitive deficits of the elderly as due to the inability to ignore, or inhibit, irrelevant information.

Useful Field of View. The useful field of view is defined by Ball et al. (1988) as, "the visual area in which information can be acquired within one eye fixation". According to Ball et al. (1988) the useful field of view can be affected by age, number of distractors, a foveal task demand, and the eccentricity of target presentation.

Many researchers have found that when a target is presented in an empty field, eccentricity of presentation generates no age-related deficits (Ball et al, 1988; Cerella, 1985; Sekuler & Ball, 1986; Scialfa, Kline & Lyman, 1987). However, age-related deficits appear when the target is embedded in noise. This effect increases when a foveal task is included (Ball et al., 1988; Sekuler & Ball, 1986; for a review see Hartley, 1992). For example, in the Sekuler and Ball (Experiment 1, 1986) study a cartoon representation of a human face served both as the target and as a central fixation object. Subjects were asked to indicate at which location the target face appeared. Targets were presented at three eccentricities (5, 10, or 15 degrees of visual angle) in conditions with or without distractors and with or without a foveal task. Older subjects were found to perform badly in comparison to the younger subjects under the distractor condition. The addition of a foveal task differentially decreased processing efficiency at the greatest eccentricity of the older subjects. In a similar study by Ball et al. (1988) it was reported that, with practice, older subjects could increase their useful field of view by approximately 10 degrees visual angle (stimuli were presented at 10, 20, and 30 degrees visual angle).

It is possible to interpret the above effects in terms of attentional age changes affecting the useful field of view. The fact that age differences related to the eccentricity of target presentation appear only when distractors are added to the display can be interpreted in terms of the reduced inhibition hypothesis (Hartley, 1992) of attention as further discussed in the following section.

In addition, the finding by Ball et al. (1988) that the useful field of view can be increased with practice for all age groups, including the older group, has an explanation in terms of the allocation of attentional resources. Juola, Bouwhuis, Cooper, & Warner (1991, see also Egly & Homa, 1984) found that attentional resources can separate from the fovea allowing a concentration of processing resources in the periphery in response to a spatial cue. In the case of the Ball et al. (1988) study, it is possible that all three age groups developed an attentional strategy with practice that allowed them to distribute attentional resources to the furthest periphery of the display and away from the center in order to reduce error rates. As the study did not present any targets within the center 10 degrees of visual angle it can be neither confirmed nor disproved that attention was shifted away from the fovea. However, studies by McCalley, Bouwhuis and Juola (in press), and McCalley (in press) have shown that older adults retain a highly flexible allocation of attention enabling them to shift attention away from the fovea for certain tasks. In the McCalley (in press) study, where a three letter target word among similar distractor words was presented at three eccentricities, both older and younger adults adopted a strategy of eccentric allocation of attentional resources when so cued which speeded response and reduced errors to targets appearing in this area. When targets were invalidly cued to the most eccentric area of the display, high costs were found for locating and identifying a target in the area closest to the fovea indicating that attention for both age groups was allocated away from this center area. In McCalley et al. (in press) similar results were obtained using Landolt figures among ring distractors of the same thickness and diameter. It would therefore seem plausible that what Ball et al. (1988) interpreted as recovery of a broad UFOV through training, which had previously shrunk due to an unspecified effect of aging, was in fact evidence that subjects learned to apply a more advantageous attentional allocation strategy through practice.

It has become clear, then, that attention plays an important role in determining the amount of information that can be processed in the parafoveal area in a single fixation by influencing the useful field of view. Additionally, some age differences found in studies of the useful field of view can be explained in terms of a theory of reduced inhibition. Thus, in order to understand age differences in performing visual search tasks in the visual environments of everyday task performance, the question of whether or not older adults are indeed less able to ignore irrelevant information in the visual field must be further addressed.

Inhibition of Irrelevant Information. The inhibition hypothesis supposes that older adults are less able to inhibit their response to unselected stimuli thus interfering with their ability to selectively attend to a target (Hasher, Stoltzfus, Zacks, & Rypma, 1991). For example, Rabbitt (1965), using a card sorting task, found that the addition of (irrelevant) distractor letters around the (relevant) target letters caused an age-related slowing in task completion. Rabbitt (1965) was one of the earliest researchers to suggest that older people may have more difficulty in ignoring irrelevant information than younger people. The idea of reduced inhibitory processes was then formalized in later studies (e.g. Hasher & Zacks, 1988) which suggest that selective inhibition declines with age.

Although the Rabbitt (1965) study used a visual search task where eye movements were allowed and the Ball et al. (1988) study did not, the same interpretation of the inability to ignore irrelevant information can be applied. In the Ball et al. (1988) study the addition of a foveal task to the peripheral task resulted in large response decrements for older subjects as compared to young and middle-aged subjects. An hypothesis of reduced inhibitory processes would predict that older subjects would have difficulty in inhibiting one task while completing the other, thus resulting in a performance deficit in the old group as compared to the young as, indeed, found by Ball et al. (1988).

In spatial cuing tasks where advance information is provided as to the most likely area for the target to appear one would expect older adults to show lower costs for an invalid cue if they were unsuccessfully inhibiting the uncued area. This is in accordance with the two process view of attention (e.g. Hasher, Stoltzfus, Zacks & Rypma, 1991; McDowd & Filion, 1992; McDowd & Oseas-Kreger, 1991; Stoltzfus, Hasher, Zacks, Ulivi & Goldstein, 1993) where it is assumed that suppressing uncued areas results in costs for invalid cues and selection of the cued area results in a benefit for a valid cue. Until recently, lowered costs for older adults as compared to younger adults for invalid cues had not been found. However, in the aforementioned spatial cuing study by McCalley (in press) older adults were found to have lower costs in relation to benefits as compared to younger adults suggesting a comparative reduction of inhibition. When comparing response times at two different stimulus onset asynchronies (SOAs) of 500 and 1000 ms, evidence for reduced inhibition was found only at the 1000 ms SOA. However, the decrease in cost (inhibition) at 1000 ms SOA did not result in a lower overall performance of the older adults as compared to the 500 ms SOA implying that reduced inhibitory functioning may not necessarily impede performance. Furthermore, it is possible that increased selection processes compensated for the reduction in the inhibitory processes in this task.

If reduced inhibition does not impair performance in such a visual search task as would be expected, then a general reduction of inhibition must be questioned as the source of the visual search problems that older people so often report. What the McCalley (in press) study has in common with all the other studies discussed thus far is that the display was presented on a uniform background. When carefully examining the demands of an everyday visual search task at least two different levels of necessary inhibition of irrelevant information are frequently required due to the presence of visually cluttered backgrounds.

The first is an internal, voluntary, or goal-directed inhibition concomitant with the controlled orientation of attention as in the McCalley (in press) study. In studies of selective attention, controlled orientation of attention is thought to be generated by a central cue which gives information about where a target is most likely to appear (e.g. Müller & Rabbitt, 1989; Koshino, Warner & Juola, 1991). The subject then orients to the cued area in response to the informative cue in anticipation of the target. Analogous to the experimental situation is the task of attending to a freeway sign while driving, where many city directions might be listed and a particular one is needed. In this case the sign serves as the cue indicating the general area to search for the appropriate information among several distractors which must be inhibited or ignored.

The second level of inhibition is externally driven by constantly changing environmental demands and is related to "attracted attention" (Rock & Mack, 1994). In the example of the freeway sign, this would be the necessary inhibition of all surrounding environmental distractors in the fore- and background. The experimental analog to this is a selective attention study where a peripheral cue such as a flash of light or the abrupt onset of a potential target can cause a capture of attention, thought to be automatic (Jonides, 1981; Müller & Rabbitt, 1989; Koshino et al., 1991). In a study by Juola, Koshino, Warner and McMickell and Fiori, (1993), the results indicated that older adults were less successful in ignoring an abrupt onset of a stimulus in the periphery than younger adults. It is thus possible that when confronted with a dynamic background containing visual transients, older adults experience difficulty in suppressing the ensuing automatic orientation of attention resulting in a less efficient controlled response to task specific search areas. This would mean in simple terms that a background in which abrupt and/or unanticipated movements are common is more distracting for older persons.

The Separation of Visual Planes. Implicit in the above hypothesis is the assumption that human beings are able to selectively allocate attention to a single plane or grouping among two or more planes or groupings. Furthermore, it is assumed that, once selected, spatial allocation of attention can proceed on this plane with minimal reference to the inhibited plane. It is unquestioned that humans can separate their visual world into planes and the Gestaltists long ago provided rules to describe the phenomena of how foreground is separated from background (Goldstein, 1984). In addition, experimental studies have indicated that attention can be directed to one of two superimposed forms (e.g. Duncan, 1980; Rock & Gutman, 1981; Tipper, 1985). Aging studies have also shown that older subjects are capable of performing tasks which require separating superimposed visual stimuli on both static (Somberg & Salthouse, 1982) and moving (Ponds, Brouwer & Wolffelaar, 1988) backgrounds. The abovementioned studies establish that both younger and older individuals are able to attend to a single perceptual group in a cluttered visual field.

However, the question remains as to whether or not attention can be distributed in a spatial manner in a more complex visual environment. The concept of spatial attention in dynamic visual environments has been challenged by Driver and Baylis (1989). Driver and Baylis (1989) found that far distractors which shared a common motion with the target produced more interference than near, but stationary, distractors. In addition, when near distractors shared a common movement and the target and far distractors remained stationary, the far distractors produced the most interference indicating that shared movement overrode the effect of proximity (Driver & Baylis, 1989). The authors concluded that attention is assigned to perceptual groups rather than to contiguous areas of the visual field which would argue against spatial metaphors of visual attention such as the zoom lens (e.g., Eriksen & St. James, 1986; LaBerge & Brown, 1989), spotlight (e.g., Eriksen & Yeh, 1985; Tsal, 1983), and ring (e.g., Egly & Homa, 1984; Juola et al., 1991) models of attentional allocation. However, Driver and Baylis (1989) allow that a "spotlight" of attention might function on "nonspatial dimensions", such as motion, but that metaphors which imply strictly spatial distribution should not be used. Unfortunately they do not provide alternative terms and, for the purpose of this study, spatial terms are retained.

However, other researchers have found evidence that selective attention can be distributed to either objects or locations (e.g. Monheit & Johnson, 1994); at least in static environments. As many everyday tasks require a spatial allocation of attention in cluttered visual fields, such as reading subtitles on film backgrounds which necessitates that attention be allocated to specific areas of the field in order to identify words, it is not unreasonable to assume that attention can be spatially cued in such a dynamic setting.

Thus, the primary focus of the present study is to explore the spatial allocation of attention with word stimuli superimposed on pictorial stimuli in an effort to make findings more generalizable to real life tasks with which older people report having difficulty. Few, or no, studies have sought to test whether older adults do indeed respond differently than younger adults in spatial cuing tasks with realistic visual background transients, at least not in a controlled laboratory setting.

4.2 Experiment

Introduction

The present study sought to test whether changing the background conditions would have differential effects on the attentional allocation patterns of younger and older adults. The assumption is made that the backgrounds used are in some way unique to the rest of the display enabling the subjects to separate them from further processing while attention is then spatially distributed in response to a cue within the foreground stimulus display. In Gestalt terms, a still background can be thought of as being grouped by the Law of Prägnanz, or by the Law of Similarity (Goldstein, 1984) where a moving background might be grouped by either of these, or by motion alone. In the present study pilot research established that the task stimuli and the background stimuli are dissimilar enough to be perceived as separate groups, presumably based on these laws.

Method

Subjects. The subjects were two groups of twelve individuals. The younger adult group consisted of five female and seven male volunteers, ranging in age from 20 to 25 years (mean age = 22.8), selected from the subject pool at the Institute for Perception Research/IPO and from the university community at large. The younger subjects were either students of the University of Technology, Eindhoven, or were students of high vocational training institutes in the same area. The older adult group included seven female and five male volunteers, ranging in age from 65 to 73 years (mean age = 68.2) recruited from the IPO subject pool, and all had been educated to the equivalent of current high vocational training or above. All subjects had normal or corrected-to-normal near and far visual acuity and all had self-reported health as good to excellent.

Apparatus and Materials. Stimuli were drawn in CorelDraw on a Dell Optiplex 433/L personal computer in "Switzerland 70" font. The VGA-video signal of this computer was converted to normal video format with an IMAX Media Scan converter and overlaid onto the video frames of a normal VHS video utilizing a tape of a nature documentary film. For the moving background condition the intact documentary was used and for the still background condition selected frames of the same documentary were used. The overlay procedure was accomplished by mixing the normal VHS frames with the converted computer images of the drawn stimuli with two video editors; a Panasonic Production Mixer WJ-MX 30 and a Sony Editing Control Unit PVE-500. As each full (European) video frame lasts exactly 40 ms, the presentation time of each stimulus was precisely determined by a count of the frames. Each trial sequence of frames was then marked at the beginning of the target display with a 1000Hz tone using a Philips PM 5110 RC generator. The tone served as an indicator for the data collection computer to begin measuring the response time. Finally, the mixed images and tones were recorded on a Sony Betacam/sp VCR uvw-1800P video recorder and this recording was then converted to VHS with a Philips Matchline VHS type VR 833 video recorder. Subject responses were collected and stored with a two button pad connected to a SUN "SPARCstation" IPC with a temporal resolution of 1 ms for each response. The stimuli were presented on a Philips 60 cm diagonal television screen with a Philips VHS type VR 332 video recorder.

Each trial consisted of a sequence of five images overlaid on either of two backgrounds; moving and still (Fig. 1). The first stimulus was presented for 2000 ms and consisted of four white outline boxes (40 mm x 28 mm) placed 2.5 cm apart in a row centered in the lower third of the television screen. Centered between the inner two boxes, but 7 cm above the row of boxes, was a fixation dot.

The boxes served as indicators of the possible locations of the cue, target, and distractors. The second image was identical to the first except that either the two inner (inside cue) or the two outer (outside cue) or all four (neutral cue) boxes appeared as solid white.

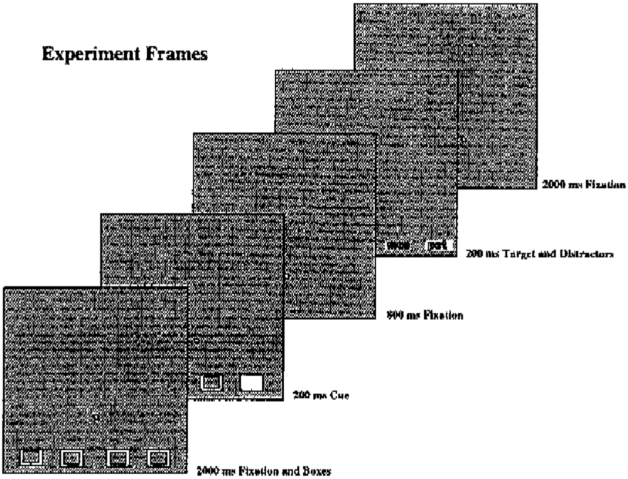

Figure 1. Sequence of stimulus frames used in the experiment. This is a schematic drawing and boxes and words are not to scale.

The whitened boxes served as the spatial cue and were shown for 200 ms. The third image contained only the fixation dot, lasting 800 ms, which served to set the Inter Stimulus Interval (ISI) creating a Stimulus Onset Asynchrony (SOA) of 1000 ms. The fourth image, presented for 200 ms, was again the fixation dot with a three-letter word of equally high lexical frequency as compared to the others now occupying the areas where the boxes previously appeared. One area contained the target word which could be either pet or pot, and the other three contained distractor words. All words were white text appearing on the pictorial background which was in color. The fifth, and final, image contained only the fixation dot and was presented for 2000 ms allowing time for the subject to respond and indicating the end of the trial. Immediately after this stimulus a new trial began.

Subjects were seated two meters from the television screen at which distance the target and distractor words (actual "x"-height = 18.5 mm, or 0.5 degree visual angle at 2 m), or the four boxes, viewed together, subtended a total of seven degrees visual angle. The placement of the fixation dot slightly above the boxes did not change the visual angle and served to make the display more like that normally encountered in subtitling (with which the Dutch subjects were familiar). In addition, the location of fixation corresponded to the area where individuals most often fixate in anticipation of a subtitle (d'Ydewalle & Gielen, 1994).

Procedure

The experimental task consisted of a two-alternative forced choice task in which subjects were required to indicate with a button press which of the two target words, pet or pot, appeared in the target display. The two buttons were on the button pad connected to the SUN station and were each marked with the appropriate target word. Subjects were seated in a comfortable chair with their eyes at a distance of 2 meters from the television screen and were handed the button box and asked to place each thumb over one of the buttons.

Subjects were then instructed to fixate on the fixation dot in the first frame and not to move their eyes throughout each trial. In this case there would be no advantage for a subject to move their eyes as the targets were equally likely to appear on either side of fixation. However, the task would have been easier if subjects had made a single eye fixation downwards in order to fixate at the same level as the boxes. This was discouraged by the experimenter who was seated next to the television screen during training and asked subjects to fixate on the dot then "tested" their proper fixation by asking them to make an eye movement down to the box level and back up to the dot. In this way, subjects were led to believe that the experimenter was able to monitor their eye position. This same procedure was used throughout the experimental sessions to encourage fixation on the dot. The short (200 ms) presentation of the target display also made an eye movement unlikely, although not impossible, but the use of an eye tracking device would have made the task uncomfortable and unfamiliar counter to the goals of the experiment. As no systematic variations were observed in the data that would indicate that the task had suddenly become easier for a subject, the faux "test" of fixation was considered to be successful.

Subjects were instructed to focus their attention on the boxes as indicated by the cue and were told that the cue would help them to detect and identify the target, as it would most likely appear in the cued area. In fact, the cue was valid on 80% of the non-neutral cue trials. Subjects were told to make the appropriate button response as quickly, but accurately, as possible and to guess if they were not certain of whether they had detected or properly identified the target.

Subjects attended a total of three experimental sessions. The first was a practice session which lasted approximately 1 hour where subjects were given a training manual to read after which they were given training blocks of 12 trials each until they had completed either 16 blocks or had reached a performance rate of 90% correct responses; whichever came first. The two remaining sessions consisted of the counter-balanced pre-randomized presentation of two different background conditions; moving and still. At the beginning of each session the subject was given two practice blocks of 16 trials each. Following the practice blocks subjects were given 2 full blocks of 120 trials each which included 80 valid, 20 invalid, and 20 neutral cues, all of which had been randomized for all cue by target conditions before being overlaid on the video background. Trials were blocked by background condition and subjects received one of each background block in each session. After each block there was a break of approximately 10 minutes in which time subjects were given feedback as to the number of errors they made in the block and encouraged to rest.

Results

Trials with response times $<$ 100 ms or on which the response time was more than twice the mean of the cell were considered outliers and removed. No responses exceeded the allowed 2000 ms and fewer than 0.7% of the data were thus discarded.

Data were subjected to multivariate analyses of variance (MANOVAs) on response times (RTs) and on error rates (logit transformed) prior to a quantitative model fitting analysis. A 2 (age group) x 2 (target location) x 3 (cue) x 2 (background) mixed model design was used where age was the between subject factor, and target location, cue, and background were within-subject factors.

Response Time Data. The RT MANOVA revealed a main effect of age (F (1,22) = 12.16, p <. 002) but not of background (F< 1). The main effect of target location was also found to be significant (F (1,22) = 71.77, p < .001), but that of cue was not (F< 2). There was a very significant interaction between cue and location (F (2,21) = 76.10, p <.0001) and between background, cue and location (F (2.21) = 3.35, p <.05). The four way interaction between ground, cue, target location, and age proved not to be significant (F< 2).

Error Data. The mean overall error rate was 13.7%. The MANOVA analysis of the error logits per cell of the design found no significant main effects of age (F< 1) nor background. The main effects of cue and target location were, however, highly significant (F (2,21) = 5.07, p< .02, F (1,22) = 56.22, p< .0001, respectively). The interactions between age and cue, target location and cue, and age, target location, and cue (F (2,21) = 4.78, p< .02, F (2,21) = 35.64, p< .0001, F (2,21) = 3.66, p< .04, respectively) all reached significance, however, the interaction between age and target location (F (1,22) = 3.82, p< .06) only approached significance. A further test of the simple age by target location interaction did not reveal significance for either the neutral or inside cue conditions, however results were significant for the outside cue condition (F (1,22) = 7.61, p< .01). Furthermore, the interaction of age by target location, with cue condition "outside" held constant, for the moving background was highly significant (F (1,22) = 11.65, p< .003).

Model Fits. Data were compared on the basis of two different models of the allocation of attention. A model of flexible resource allocation (the ring model) was found to best fit the data of both the older and the younger adults. Details of the analysis and the corresponding tables are discussed in the following section.

Discussion

MANOVA Analysis. It can be expected that older adults experience some slowing with age, but because of their reading experience, they would be expected to retain a level of word recognition much like that of the younger adults (Aberson & Bouma, submitted). Thus, what we find is a significant RT main effect of age which reflects the expected response time differences, and no main effect of age for the error rates. In order to insure that this interpretation was correct, correlations between mean RTs and error rates were calculated. RTs and error rates were found to be highly, positively, correlated for the younger and older groups in both the moving ($r_{.01}(4) = .917$, $r = .96$, $r = .99$, respectively) and still conditions ($r_{.01}(4) = .917$, $r = .98$, $r = .97$, respectively) thus indicating no evidence of a speed-accuracy tradeoff for either age group.

Both the RT and the error analyses shared a highly significant interaction between target location and cue indicating that both age groups were able to successfully distribute their attention in response to a spatial cue in such a way as to reduce both response time and error rates in valid cue conditions as compared to the neutral cue condition. An increase in RTs and errors was also evident for both groups in response to an invalid cue when compared to the neutral cue conditions. This confirms the hypothesis that attention can be spatially allocated to a single plane when a pictorial background, either moving or still, is used (Figure 2a and 2b).

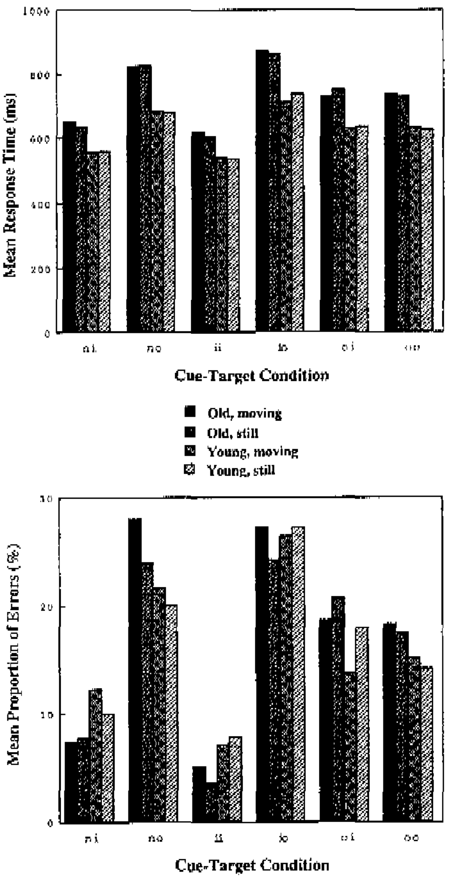

Figure 2. Mean response time for all cue-target combinations (a) and mean error proportions for all cue-target combinations (b) for younger and older subjects for the still and moving background conditions. Note: cue conditions: n=neutral, i=inside, o=outside; target location: i=inside, o=outside.

The significant main effect of target location in both RT and error analyses reflects the finding that both age groups take longer and make more errors when they are required to identify a target appearing in the outer area of the display (Figure 2a and 2b). This effect was significantly greater for the older subjects as confirmed by a test of the age by target location interaction (outside cue condition) in the error rate analysis. This robust finding implies that both pictorial backgrounds, moving or still, made the distribution of attention more difficult for older adults than for the younger adults when the outer area was cued. Thus, both highly complex backgrounds apparently interfered with the ability of the older subjects to activate the outer area. As the interaction was cue-dependent (on the "outside" cue) then it is likely due to an internal, goal driven, attentional process, and not to visual factors. However, the exact interpretation of this particular interaction can only be demonstrated by a formal model fit, and is therefore discussed in a later section.

The significant RT interaction between target location, cue, and background suggests that younger and older adults responded differently to the cue when the background condition was manipulated. The error rate analysis for the same interaction did not reach significance. However, a test of the significant interaction between age, target location and cue seen in the error rate analysis was found to be highly significant when the cue "outside" was held constant and tested separately for each background. This was accomplished by a General Linear Model simple test of significance for the MANOVA. The test revealed a highly significant age effect of the moving background indicating that the older adults experienced more difficulty in identifying the target when the background was moving, but once again the outcome was dependent on whether or not the cue was to the outer area. It is therefore difficult to interpret whether all of the difficulty in identifying the outer targets experienced by the older adults was cue-dependent or whether a portion was due to a reduction in the ability to inhibit visual transients in the moving background. If it could be confirmed that older adults were hindered independently by the moving background in addition to the cue-dependent reduction of internally driven inhibition, then this would show an age-dependent reduction of externally driven inhibition as well. Thus, further analyses using a quantitative modelling technique were carried out in order to establish whether or not age differences in the response to the moving background could be explained in terms of an inability of older adults to suppress response to visual transients in the background.

Model analysis. Initially two different models of attentional allocation were compared in order to establish that both groups were distributing attention in the same manner. A previous study of age-related effects of visual selective attention by McCalley (in press) discussed results in terms of two theoretical models; the zoom lens, and the ring models, adapted from a study by Juola et al. (1991). Juola et al. (1991) tested and compared formal versions of these models which originated from the research of Eriksen and St. James (1986, zoom lens model), and Egly and Homa (1984) and Laberge and Brown (1989) (gradient or 'ring' model). The zoom lens and the ring models are directly comparable on the basis of number of parameters and method of parameter estimation.

The zoom lens and the ring models, as interpreted by Juola et al. (1991), are both forms of gradient models. The zoom lens model assumes that attention spreads from the point of fixation to encompass the attended area where the ring model predicts more flexibility, allowing attention to concentrate away from fixation while still surrounding the foveal area. Table 1 shows the predictions of these two hypothetical models. The ring model, the most flexible of the two models used in the present study, derives its name from the type of display used by Egly and Homa (1984) where the task demanded a ring-like allocation of attention. However, as a flexible resource allocation model of attention the 'ring' can predict costs and benefits of a spatial cue for any size or shape of area designated as long as the area is contiguous (refer to Juola et al., 1991).

Table 1.

Theoretical Models

	Target Location	
	Inside	Outside
	Ring	
Cue		
Inside	benefit	cost
Outside	cost	benefit
	Inside	Outside
	Zoom lens	
Cue		
Inside	benefit	cost
Outside	no cost or benefit	no cost or benefit

In a series of spatial cuing experiments using simple shape stimuli McCalley et. al. (in press) had found that when the size of the targets and distractors remained the same despite increased eccentricity of presentation, attentional allocation of older adults appeared to differ from that of younger adults. Although McCalley et al. (in press) established that this was primarily an artifact of the zoom lens model which confounds visibility in the periphery with attentional effects, the degree of furthest eccentricity of the present experiment was thought to be small enough to avoid the confound and thus provide a sound comparison of the models. As the present experiment was designed to be as ecologically valid as possible, the outer boxes and the words appearing in the corresponding areas were not increased in size with eccentricity in order to offset distance effects.

The models used to test results of the experiment each consisted of four parameters. These were base response time (T) or base error rate (F), benefit for a valid cue (B), cost for an invalid cue (C), and the effect of distance from fixation (E). Predictions of the models were based upon the theoretical models shown in Table 1. Both models share the assumption that attention can be allocated in response to a spatial cue. The difference between the two lies in the flexibility of the distribution. The ring model assumes that attention can be distributed independently of the foveal area in response to a spatial cue thereby allowing resources to be focused in the cued areas furthest from fixation. The zoom lens model assumes that attention is distributed from fixation outwards, never completely detaching from the foveal area. These different predictions can be tested by using a neutral cue where attention is presumed to spread evenly over the field from fixation outwards when no prior location information is given. Thus, the ring model predicts that a valid cue will always produce a benefit (reduced RT or errors), and an invalid cue will always produce a cost (increased RT or errors) when compared to the corresponding neutral cue condition. Like the ring model, the zoom lens models predicts that a cue to the "inside" area will result in a benefit when it is valid (the target appears in the inside area) and in a cost when it is invalid (the target appears in the outside area). However, in contrast to the ring model, the zoom lens model predicts that attention, in response to an "outside" cue, will spread from fixation over both the inside and outside areas thereby behaving in much the same manner as attention to the neutral cue. For this reason, the zoom lens model predicts no benefit, and no cost, to an "outside" cue. Parameters of the models were estimated by means of a least squares minimization technique. The proportion of explained variance was thus computed as a measure of goodness of fit.

Results of the model analyses for both response times and error rates (Tables 2, 3, 4, & 5) show that attention distribution for

Table 2. Response Time data (in ms) and predictions of the Ring and Zoom Lens Models of Attention for a moving background.

	Stimulus Location			
	Younger Adults		Older Adults	
	Inside	Outside	Inside	Outside
Cue				
Neutral	556	681	650	824
Inside	535	711	617	868
Outside	627	631	728	735
	Ring Model[a]			
Neutral	T=568	T+E=669	T=665	T+E=809
Inside	T-B=532	T+C+E=720	T-B=604	T+C+E=870
Outside	T+C=618	T-B+E=634	T+C=726	T-B+E=748
	Zoom Lens Model[b]			
Neutral	T=592	T+E=656	T=689	T+E=780
Inside	T-B=535	T+C+E=711	T-B=617	T+C+E=868
Outside	T=592	T+E=656	T=689	T+E=780

[a] Parameter values: Young: T=567.7, B=35.5, C=50.5, E=101.7; Old: T=665.0, B=61.0, C=61.0, E=144.0.
Percent variance accounted for: Young=98.1 ; Old=98.3.

[b] Parameter values: Young: T=591.5, B=56.5, C=55.0, E=64.5; Old: T=689.0, B=72.0, C=88.5, E=90.5.
Percent variance accounted for: Young=83.9 ; Old=85.0.

Table 3. Response Time data (in ms) and predictions of the Ring and Zoom Lens Models of Attention for a still background.

	Stimulus Location			
	Younger Adults		Older Adults	
	Inside	Outside	Inside	Outside
Cue				
Neutral	559	677	634	821
Inside	532	735	600	861
Outside	634	624	750	728
		Ring Model[a]		
Neutral	T=566	T+E=670	T=657	T+E=780
Inside	T-B=526	T+C+E=736	T-B=593	T+C+E=877
Outside	T+C=633	T-B+E=630	T+C=735	T-B+E=735
		Zoom Lens Model[b]		
Neutral	T=597	T+E=651	T=692	T+E=775
Inside	T-B=532	T+C+E=735	T-B=600	T+C+E=861
Outside	T=597	T+E=651	T=692	T+E=775

[a] Parameter values: Young: T=566.2, B=40.0, C=66.5, E=103.7; Old: T=656.5, B=63.5, C=78.0, E=142.0.
Percent variance accounted for: Young=99.4 ; Old=97.0.

[b] Parameter values: Young: T=596.5, B=64.5, C=84.5, E=54.0; Old: T=692.0, B=92.0, C=86.5, E=82.5.
Percent variance accounted for: Young=84.9 ; Old=78.7.

Table 4. Error data (in ms) and predictions of the Ring and Zoom Lens Models of Attention for a still background.

	Stimulus Location			
	Younger Adults		Older Adults	
	Inside	Outside	Inside	Outside
Cue				
Neutral	9.9	20.0	7.7	23.9
Inside	7.9	27.1	3.6	24.2
Outside	17.9	14.2	20.6	17.4
		Ring Model[a]		
Neutral	F=10.6	F+E=18.8	F=8.6	F+E=21.8
Inside	F-B=7.8	F+C+E=28.5	F-B=4.9	F+C+E=33.1
Outside	F+C=16.9	F-B+E=14.3	F+C=14.3	F-B+E=13.3
		Zoom Lens Model[b]		
Neutral	F=13.4	F+E=16.9	F=12.8	F+E=20.5
Inside	F-B=7.9	F+C+E=27.1	F-B=3.6	F+C+E=24.2
Outside	F=13.4	F+E=16.9	F=12.8	F+E=20.5

[a] Percent variance accounted for: Young=98.6 ; Old=83.6.

[b] Percent variance accounted for: Young=78.2 ; Old=80.9.

Note: Predicted values have been obtained by logits and retransformed to probabilities for the ring and zoom lens models. Parameter values can only be indirectly related to probabilities due to the logit transformation and therefore are not given here.

Table 5. Error data (in ms) and predictions of the Ring and Zoom Lens Models of Attention for a moving background.

	Stimulus Location			
	Younger Adults		Older Adults	
	Inside	Outside	Inside	Outside
Cue				
Neutral	12.2	21.6	7.4	27.9
Inside	7.2	26.3	5.1	27.1
Outside	13.7	15.1	18.6	18.3
	Ring Model[a]			
Neutral	F=11.7	F+E=22.4	F=8.9	F+E=23.9
Inside	F-B=7.4	F+C+E=26.0	F-B=5.8	F+C+E=34.3
Outside	F+C=13.9	F-B+E=14.8	F+C=14.0	F-B+E=16.4
	Zoom Lens Model[b]			
Neutral	F=12.9	F+E=18.1	F=11.9	F+E=22.7
Inside	F-B=7.2	F+C+E=26.3	F-B=5.1	F+C+E=27.1
Outside	F=12.9	F+E=18.1	F=11.9	F+E=22.7

[a] Percent variance accounted for: Young=99.6 ; Old=89.5.

[b] Percent variance accounted for: Young=92.7 ; Old=79.0.

Note: Predicted values have been obtained by logits and retransformed to probabilities for the ring and zoom lens models. Parameter values can only be indirectly related to probabilities due to the logit transformation and therefore are not given here.

both younger and older adults is best explained by the ring model, rather than the zoom lens model. The zoom lens model does not capture the effects present in the data nearly as well as the ring model which provides a nearly prefect fit. Despite decreasing the eccentricity of presentation (maximum 3.5 degrees visual angle) as compared to the earlier studies (maximum 5.5 degrees visual angle) (McCalley, in press; McCalley et al., in press) a confounding of visual and attentional effects by the zoom lens model is apparent. The predicted RT parameter values of the zoom lens model (Tables 2 & 3) indicate that eccentricity values remain high and are interpreted by the model as cost for thinning of attentional resources over the visual field. In other words, the confound of eccentricity remained despite the attempts to avoid it by decreasing the distance of the furthest target from fixation. Therefore, further discussion will address only results of the best fitting ring model.

The extremely high fit of the ring model in comparison to earlier studies (McCalley & Bouwhuis, 1991; McCalley, in press; McCalley et al., in press) indicates that attentional allocation in response to a spatial cue is not only possible when the task is overlaid on a pictorial background, but such a background is more compelling for cue response. This can also be seen in the near perfect distribution of RT costs and benefits in response to the cue where, in comparison to the corresponding neutral cue condition, both error rates and latencies are higher for an invalid cue and lower for a valid cue (Tables 2, 3, 4, & 5). Although the earlier studies generally found symmetrical costs and benefits for a similar spatial cue, costs and benefits were not as stable as in the present study.

In the moving and still backgrounds, an age effect is revealed in the comparison of the RT cost and benefit parameter values of the best fitting (ring) model. In the still background condition, the ratio of cost to benefit is high for both age groups but in the moving condition, cost and benefit are equal for the older group while cost remains high in comparison to benefit for the young, corresponding to the actual data (refer to parameter values, Tables 2 & 3).

If the assumption is made that cost for an invalid cue can be interpreted as inhibition of the uncued area (e.g. Hartley, 1992) and benefit as selection of the cued area (McCalley, in press), then it appears that in the moving condition, older adults have more difficulty in inhibiting the uncued area. In general, the overall parameter values suggest that the older adults are making more use of the cue to guide attention and optimize performance than the younger adults under both background conditions. The proportional RT cueing effects shown in Table 6 give additional support for this interpretation. Furthermore, a finding of increased cue dependence by older subjects is consistent with previous research using plain backgrounds which has shown that in some tasks older adults are apparently able to make greater use of prior information than younger adults (e.g. Folk & Hoyer, 1992; Hartley, Kieley, & Mckenzie, 1992; Hartley, Kieley, & Slabach, 1990; Nissen & Corkin, 1985).

Table 6. Proportional Cueing Effect

	Background	
	Moving	Still
Group		
Young	.139	.176
Old	.166	.195

Note: The proportional cueing effect is derived by dividing the overall costs plus benefits by the mean neutral response time under each background condition.

As the model fits suggest that older adults have more difficulty in inhibiting the uncued areas in response to the cue, a more in-depth model analysis of the MANOVA interaction of age and location in the moving background condition (with the effect of the outside cue held constant) was undertaken. In comparing error rates for the older adults as predicted by the model with the actual error rates (Figure 3) it can be seen that the deviations occur whenever the target appears in the outside area and this is most pronounced in the moving background condition. It is apparent that the older group had more difficulty than the younger group in responding to the cue in the outside area in the presence of either pictorial background (refer to Figure 2) resulting in the disparate fits of the models for the data of the older group (89.5% explained variance) and the younger group (99.6% explained variance).

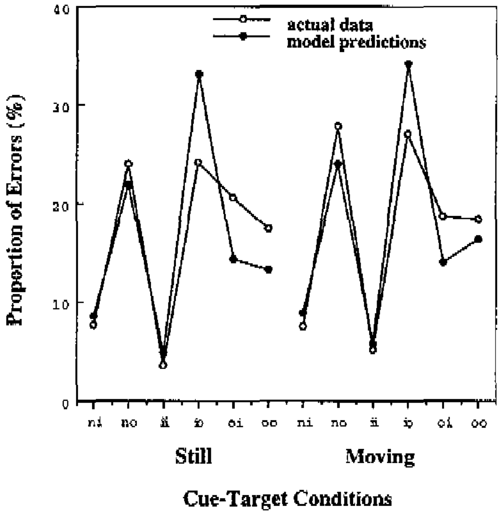

Figure 3. Actual percent errors of the older group and percent errors predicted by the ring model for the older group plotted against the separate cue by target location conditions for the still and the moving background conditions. Note: cue conditions: n = neutral, i = inside, o = outside; target location: i = inside, o = outside.

It was hypothesized that the lower fit to the model of the older group reflected an inability to inhibit the outside cue area in the presence of either background. This was tested by removing predicted cost (inhibition) from the model for the older adults only in this cue-location condition. Thus the model was adjusted to reflect lowered inhibition in response to the (outside) cue and as the inhibition is cue-dependent it is interpreted as being internal, or controlled.

It was further hypothesized that the deviation of the actual and predicted error responses in the two outside cue conditions ("oi" and "oo") was the result of interference from the moving background as implied by the MANOVA. In this case the higher-than-predicted error rates suggested that the older group was experiencing more interference than the younger adults in activating the outer area in the presence of the moving background thus shrinking the field of attentional distribution. As the interference is dependent on the moving background only, it is interpreted as externally generated inhibition or interference.

The model was then adjusted by adding a fifth parameter for the background conditions with the parameter weighted to reflect increased difficulty in the outside area due to the interference of the moving background. The two background condition models were combined to one five parameter model for the combined twelve data cells in order to strengthen the resulting model fits. Thus, the adjustments reflected a reduced internal inhibition of cued areas in the presence of either pictorial background and reduced external inhibition of only the moving background. The explained variance of the model to test the interaction increased from 89.5% for the unadjusted model to 98.7% for the adjusted model (Figure 4), thus confirming the exact location of the interaction.

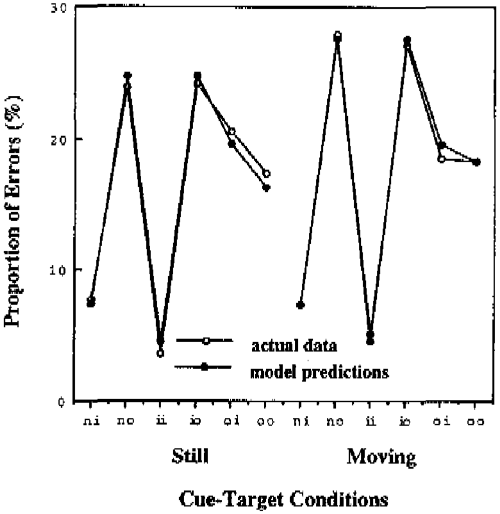

Figure 4. *Actual percent errors of the older group and percent errors predicted by the adjusted ring model for the older group plotted against the separate cue by target location conditions for the still and the moving background conditions. Note: cue conditions: n = neutral, i = inside, o = outside; target location: i = inside, o = outside.*

In summary, both groups had difficulty in responding to the outside cue when the background was either still or moving, but the difficulty became greater with a moving background. It is also interesting to note here that in a previous study (McCalley et al., in press) when the cue was neutral (no prior location information was given as to where the target would appear), both younger and older adults located a target appearing in the middle area faster than one in the center area. Thus, in anticipation of the target, both groups strategically distributed their attention away from the fovea in a position to give equal advantage to a target appearing in either the center or the outside area. This was consistent with an earlier finding by Posner (1980) who suggested that, when given no prior location information, subjects used a strategy whereby they "let the fovea take care of itself". In the case of the present study, this effect was not found. It is possible that the addition of the interfering background shrunk the useful field of view in the foreground plane to the extent that all allocation of resources was forced to operate close to the fovea. It is also possible that the placement of the fixation dot slightly above the inner boxes encouraged subjects to use a different strategy than found in the earlier studies (McCalley et al., in press; Posner, 1980). In the present study, it would be most advantageous to shift attention slightly downwards rather than outwards. In addition, the present study required only two areas of spatial allocation, as compared to the three required in the prior study, and little would have been gained by a strategy of allocation further to the periphery.

As indicated by the MANOVA analysis, the response was different for each group in the moving condition. For the older adults, all outside locations were generally more difficult in the moving background condition than in the still which was not true for the younger adults. This was confirmed by adjustments to the model where a cost for an invalid inside cue (the target appears in the outside) was removed to reflect reduced inhibitory processes in the outside area, and a different (smaller) cost parameter was added to reflect increased difficulty with every outside presentation whether the cue was neutral, inside, or outside. The resulting higher fit to the model by the adjustment of parameters reflecting decreased inhibition suggests that older adults might indeed be more disadvantaged in the distribution of their attentional resources by irrelevant, or distracting, information in the visual field.

4.3 Conclusions

As previously stated, it is well known that people can read film subtitles and that reading requires attention to guide saccades

(Humphreys & Bruce, 1989), thus it is not unreasonable to assume that attention can be spatially cued in such a setting. Results of both the MANOVA and the model analyses confirm that attention can be allocated in response to a spatial cue by both younger and older subjects even when a highly structured pictorial background is present.

The success of a spatial cuing paradigm in a multi-plane environment, as in the present study, suggests that when the planes are sufficiently different to allow for parsing, then attention can behave in a manner consistent with a spatial metaphor in a single plane. However, movement does not appear to aid in the grouping process thereby allowing for better parsing of a pictorial background. Instead, it causes more interference with the foreground than a still background for older subjects who, in the moving background condition, had significantly more difficulty in responding to a target appearing in the outside boxes than did the younger subjects.

Earlier findings by McCalley et al. (in press) indicated that, when targets and distractors were the same size at all eccentricities, both older and younger subjects could make use of a spatial cue for a presentation field of up to approximately 11 degrees visual angle in diameter. However, the effect of the backgrounds in the present study narrow the use of the cue to a field of less than 7 degrees visual angle. The present findings are consistent with the interpretation that the demands of the background limit the useful field of view in the attended plane for both age groups, shrinking it so that targets appearing in the furthest area of the plane become more difficult to identify. However, the field shrinks more for the older adults than for the younger. Additionally, the effectiveness of the attentional mechanism is constricted for both groups, but more so for the older group when the background is moving. It can be concluded from this finding that older adults do experience more interference from a background with visual transients which is consistent with the finding of Juola et al. (1993). Findings thus support an hypothesis of reduced inhibition of older adults for information external to the attended plane.

There is also evidence that controlled inhibition, dependent only on the cue, is reduced for the older subject group in the present study when the background was either moving or still. This was confirmed by a test of the location by age interaction for the outside cue condition with a moving background suggesting that problems of controlled inhibition were related only to the outside cue on a moving background. However, a more detailed analysis, using a quantitative modelling technique, indicated that the response of the older adults to the cue was also affected in the inside cue condition for both backgrounds.

In summary, both older and younger adults are able to allocate attention in a manner that is best explained by a ring-like spatial metaphor when the task is performed on a pictorial background. However, the effect of background, whether moving or still, causes the field of view for the task to constrict when compared to a similar task performed on a plain white background, especially for the older adults. Changes to the overall best fitting model can adjust the fit of the data of the older group to be nearly identical to that of the younger group if more cost for the outside location in the moving background condition, and no cost for an invalid inside cue (to the outside), are predicted. Results of changes to the model for older subjects that reflect the effect of the moving background provide evidence to support an hypothesis of reduced externally driven inhibition. The results of the additional age-related changes to the model reflecting cue-dependent responses support a hypothesis of reduced internal inhibition for the older adults which is also supported by statistical analyses.

The findings of the present study suggest that older people have more difficulty in performing everyday tasks in cluttered visual environments due to an inability to suppress or inhibit both responses to unexpected visual transients generated by a dynamic environment and expected, but superfluous, information in the attended field when task performance must be carried out on a highly structured pictorial background. Apparently, parafoveal word recognition suffers for older adults whenever a visually complex background is added to the task suggesting that reduced inhibition of unattended areas of the visual field can account for at least part of the self-reported everyday problems of the elderly when performing such tasks as reading subtitling and highway and street signs.

Findings of this study suggest that important textual information appearing on complex backgrounds should be presented in a shortened, or condensed manner (e.g. fewer words) for older people, where possible. This would allow for the text to more easily fall within the field of attentional distribution which has become smaller due to the interference of the background. Thus, shortened text would be especially commendable for interactive video applications where there is usually a highly graphical dynamic background. In some cases a constriction of the text itself might aid older individuals in tasks which require word recognition, such as in reading road signs. However, further research is necessary to establish the proper text spacing in order to optimize visibility while avoiding interference from flanking words.

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Chapter 5

Age Effects on the Processing of Words and Shapes in the Left and Right Visual Fields[4]

Abstract

We examined age differences in left and right visual field advantage for verbal (word) and nonverbal (shape) information. Data from two experiments using a either a word or a simple shape identification task were compared. In both cases the target appeared equally often in either visual field. Older and younger adults were found to have a response time advantage for verbal information presented in the right visual field, however, only younger adults had an advantage for nonverbal information in the left visual field. Older adults showed a significant increase in response time for words presented to the left visual field indicating a possible slowing of interhemispheric transfer time. In addition, older adults showed evidence of a more generalized processing of shapes over both hemispheres as compared to the apparently more specialized processing of the younger adults. For the word data, results are interpreted in terms of a componential slowing of systems involved in cognitive processing. An interpretation of the shape data takes into account the influence of attention and reduced inhibitory processes on nonverbal information processing. The appropriateness of the statistical analyses used are emphasized in relation to similar studies and to the recommendations of other researchers and a case is made for the use of MANOVA in combination with Hierarchical Regression Analysis for this type of study.

5.1 Introduction

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[4] This chapter has been submitted for publication as McCalley, L.T., Solso, R. L., & van Hoe, R.

Until recently, a theory of generalized slowing of cognitive processing associated with aging has held a powerful position in the literature. There is no denying that a slowing of all speeded response positively correlates with age (Salthouse, 1990) and that to attribute cognitive slowing to this phenomenon is attractive, however, questions concerning the validity of the attribution remain (Hartley, 1992). Earlier proponents of a generalized slowing hypothesis sought to explain cognitive slowing with age as an artifact of the overall slowing associated with aging. However, Cerella, one of the earlier supporters of generalized slowing (e.g. Cerella, 1985), has concluded that a single factor of slowing is not adequate to explain the reduced rate of information processing of older adults (Cerella, 1994), but is domain- specific.

The focus of this study is thus to analyze the age-related performance differences in two visual processing tasks in an effort to relate slowed processing associated with aging to a specific structure. Our purpose is to parcel out the contribution of slowing effects associated with one site to the observed overall rate of slowing. We proceed on the assumption that cognitive slowing is not a general phenomenon that affects all processes equally, but that it reflects a differential slowing of component processes. This assumption does not rule out the possibility that there is a sort of generalized slowing of neuronal processes (e.g. Birren, 1974; Birren, Woods & Williams, 1980) that represent a base upon which site-specific slowing is added when a particular task requires the use of the site in question. However, it is also possible that the impaired integrity of one or more specific structures which are universally involved in cognitive processing can account for much of the slowing associated with age.

Recent experiments by McCalley, Bouwhuis, and Juola (in press) and McCalley (in press) that dealt with age changes in the distribution and extent of visual selective attention have provided us with extensive data with which to pursue questions related to cognitive slowing. Data from two experiments, using nearly identical paradigms, allow us a unique opportunity to investigate age-related slowing of cognitive processing as a function of hemispheric specialization.

It has long been acknowledged that each hemisphere of the brain is somewhat specialized in function. The left hemisphere (LH) is associated with speech and phonetic analysis, motor functions, and emotion (Hoptman & Davidson, 1994) as well as word identification and reading (Kinsbourne, 1970), and local processing (high spatial frequencies) (Posner & Petersen, 1990, Jacobs & Kosslyn, 1994). The right hemisphere (RH) is associated with visuospatial functions, prosody, components of attention (Hoptman & Davidson, 1994), especially sustained attention, global processing (low spatial frequencies) (Posner & Petersen, 1990, Jacobs & Kosslyn, 1994), and pictorial shape recognition (Kinsbourne & Byrd, 1985). However, the brain does not function as two separate hemispheres, but functions as a whole, with interhemispheric communication provided primarily by the corpus callosum (CC).

The CC is a fiber tract connecting the hemispheres and transfers information back and forth between the hemispheres, with the transfer from RH to LH being slightly faster then LH to RH (Hoptman & Davidson, 1994). Interhemispheric transfer time (IHTT) is frequently measured by subtracting RTs for ipsilateral trials from those for contralateral trials. The IHTT is thus a measure of the speed of information transfer which is thought to be important in cognitive performance. If the IHTT is either too fast or too slow response output will be affected (Hoptman & Davidson, 1994).

The size of the CC is reduced with age (Cowell, Allen, Zalatimo, & Denenberg, 1992), suggesting the possibility that fewer fibers are available for interhemispheric transfer as the brain ages. A slowing of transmission between the two hemispheres due to reduced fiber pathways would likely result in deficits in higher order functions involving both hemispheres.

Research addressing adult age differences in hemispheric functioning has been primarily concerned with assessing whether or not there are age-related decrements in one hemisphere or the other.

No age-related studies of interhemispheric transfer time have been located. Of the studies of age-related lateralization differences we have located only two using an age comparison paradigm for visual information processing which are in any way comparable to our own. The first, by Kinsbourne and Byrd (1985), investigated age differences in the hemispheric processing of nonverbal (geometric) shapes. The results showed that older and younger adults both demonstrated a right-hemisphere-left visual field (RH-LVF) advantage in a shape recognition task. This is evidence that older and younger adults share the well established hemisphere-visual field advantage for simple shape recognition and leads us to believe that they would thus also share the established left-hemisphere-right visual field (LH-RVF) advantage (e.g. Kinsbourne, 1970; Eng & Hellige, 1994; Kim, submitted, as reported in Eng & Hellige, 1994) for word information. Results of the second study, by Byrd and Moscovich (1984), tend to confirm our supposition. In this task older and younger adults were presented three letter words to either the right or the left visual fields which were followed by a mask. In both peripheral and central mask conditions older adults were found to have a right visual field advantage equivalent to that of the younger adults.

When a word appears in either the RVF or the LVF it is processed by the LH. Then, because the connection of the RVF to the LH is direct, there is usually both a speed and accuracy advantage over a LVF presentation. It is supposed that this advantage is due to the fact that verbal information from the LFV to be processed in the LH first must travel to the RH and cross over to the LH via the corpus callosum, causing a small delay (Hoptman & Davidson, 1994). Since simple shapes are processed predominantly in the RH, then there is a LVF advantage for shape information, similar to the RVF-LH advantage for words.

If there is slowing of interhemispheric transfer of information due to an aging effect on the corpus callosum, then we would expect older adults to show differential slowing in the crossover conditions in tasks that require either shape or word processing. For example, if a shape is presented to the LVF, both young and old subjects should show the expected LVF-RH advantage, but when the shape is presented in the RVF, older adults should show increased slowing (a larger disadvantage) as compared to the young if the corpus callosum is impaired with age. The opposite should be true for the processing of words.

5.2 Experimental Data

Introduction. As stated earlier, data collected by McCalley et. al. (Experiment 2, in press) and McCalley (in press) allow a direct comparison of the processing of shapes and words by older and younger adults in relation to the different visual fields. In the first experiment (McCalley et al., Experiment 2, in press) response time (RT) and error data were collected using a shape identification task, and in the second experiment (McCalley, in press) RT and error data were collected using a word identification task. These experiments were conducted to assess differences in the covert orientation of attention of older and younger adults. As IHTT is the usual measure for assessing the functioning of the CC we use only response time in the present analysis.

Subjects. Of the 24 subjects who participated in the shape experiment, 12 ranged in age from 19-24 (mean age = 21.8) and 12 from 63-73 (mean age = 67.2) and of the 24 who participated in the word experiment, 12 ranged in age from 19-24 (mean age = 22.4) and 12 from 63-73 (mean age = 66.5). All younger subjects were either students of the University of Technology, Eindhoven, or students of high vocational training institutes in the same area. Older subjects in both studies had been educated to the high vocational level or above, thus matching the educational level of the younger subjects. All subjects had normal or corrected-to-normal near and far visual acuity, and had self-reported health as good to excellent. Subjects were free of neurological and visual field disorders according to self-reports and all older subjects had undergone visual examinations within a year prior to the experiment in addition to the near and far visual acuity tests performed on both age groups by the experimenters.

In neither study was handedness checked, however, based on the estimate of the population being approximately 90% right-handed (Benson & Zaidel, 1985), we would expect no more than a total of 5 subjects to be left-handed. According to a recent review of the topic by Hoptman and Davidson (1994), there is no consistent behavioral evidence of handedness effects in interhemispheric interaction. Furthermore, in the cases where handedness effects have been reported, the patterns of asymmetry are similar for both groups with the performance asymmetry being just slightly smaller for left-handers than for right-handers (Hellige, Bloch, Cowin, Eng, Eviatar, & Sergent, 1994). Thus, we conclude that the inclusion of 10% left-handers in our group would only serve to lower the chances of reaching significance for weak interactions, with results, however, being in the expected direction.

Visual Tasks. Both experiments were conducted using the same basic paradigm, based on that of Egly and Homa (1984) and Juola, Bouwhuis, Cooper, and Warner (1991), and both used a two-alternative forced-choice design with a key press response required. In both cases, the task was to identify a specified target among distractors. Targets and distractors were presented in three circular and concentric areas of the visual field centered around a fixation point as in Figure 1 ("Shape" experiment).

Stimuli were centered at approximately 1.5, 3.5, and 5.5 degrees visual angle from fixation for the center, middle, and outer areas respectively. In the shape experiment, each area contained eight figures, twenty-three of which were circles (distractors), and one of which was a broken circle in the form of a Landolt "C" matching its neighbors in diameter and thickness. The target and the distractors were enlarged in accordance with the eccentricity of the area within which they appeared from fixation.

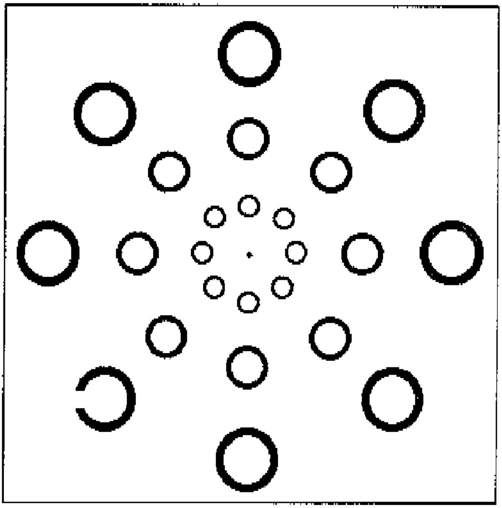

Figure 1. Target display for the shape experiment. Targets were either right or left facing landolt figures. The example shown is a left-facing target in the outside area.

Based on the equally visible display of Anstis (1974) stimuli were approximately 0.5 cm, 1.0 cm, and 1.5 cm for the center, middle, and outer areas of presentation, respectively, in height and width. The target could appear in any one of the four quadrants of each circular area and appeared equally often to the right of fixation as to the left in a random fashion.

In both experiments, a sequence of six frames was presented consisting of (1) a fixation cross and delineation of three possible circular cue areas (2000 ms), (2) a greying of all (neutral cue) or one (center, middle, or outside cue) of the delineated areas (150 ms), (3) a fixation cross, (4) a target display with one target and either 23 (shape experiment) or two (word experiment) distractors (150, and 200 ms, respectively), (5) a blank screen (until a response was made) and (6) a fixation cross (2000 ms) indicating the end of the trial and serving as a short break between trials.

In the word experiment, targets and distractors were three letter words of equally high lexical frequency. Each circular area contained only one word, thus in each trial there was a target word and two distractor words. Earlier pilot studies had shown that this was the maximum number of words that could be used in each target display before the interference from the distractors became too great to perform the task. Target and distractor words were presented in the same manner as the shapes at the same eccentricities and with approximately the same increase in size with eccentricity (Figure 2).

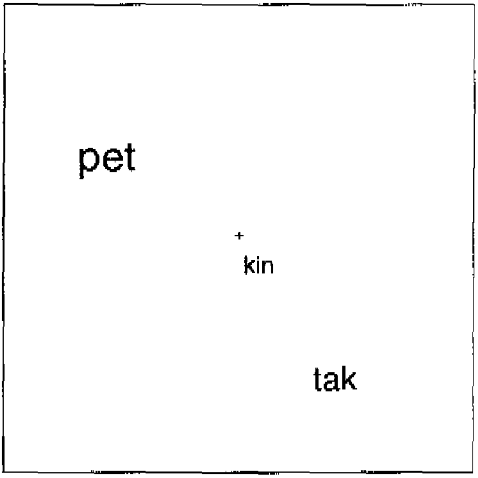

Figure 2. Target display for the word experiment. Targets were either the word "pet" or "pot" (cap and pot, respectively, in the Dutch language), and were of equally high lexical frequency. The example shown is the target word pet in the outside area.

Again, targets appeared equally often to the left of fixation as to the right.

In each target display of each experiment, distractor figures and words appeared simultaneously in both visual fields, however, the target only appeared in either the right or the left visual field. As the target appeared randomly to the left or right of fixation the best strategy would be to maintain central fixation. Thus the methodology is consistent with that used to specifically test hemispheric processing differences (e.g. Kinsbourne & Byrd, 1985).

Location of Targets. As mentioned previously, targets and distractors fell at three different eccentricities from fixation. Targets that fell closest to fixation (1.5°) were likely to have entered both visual fields due to their foveal proximity and therefore data from this location were expected to not show a visual field advantage and to serve as a control. Targets that fell further from fixation, in the middle area (3.5°) and the outer area (5.5°), were expected to yield visual field advantages, with those in the outside showing the clearest advantage.

5.3 Results

Methodology

The Experimental Design Model. The approach for analyzing the results of the word and shape experiments was as follows. First, the experimental design (linear model) of each experiment is described. The designs of the word experiment and the shape experiment have been described in detail in McCalley (in press) and McCalley et al. (in press), respectively. However, the design model of each experiment for the current data-analysis is derived from a single basic design. This design model is identical for both experiments and consists of a mixed between-within subjects design: Age x Visual Field x Position. Age is a between-subjects variable with two levels: young and old. Visual field is a within-subjects variable with two levels: left visual field (LVF) and right visual field (RVF). Stimuli were presented to the left or right of fixation with position as a within-subjects variable with three levels: center, middle, and outside, as described earlier. Reaction time (RT) served as the dependent variable. Second, the results of the general linear model (GLM) analysis of the experimental design model are presented. The effects of interest are the main effect of visual field and the interaction effects in which visual field is involved.

General Linear Model. In general, we advocate a GLM approach rather than the traditional Analysis of Variance (ANOVA) for analyzing experimental design models, and for aging studies in particular. (We will not discuss the GLM approach here in detail, however, for an excellent review, see McCullagh and Nelder, 1983). There are three primary reasons for using the GLM approach in aging research. First, the GLM approach is the best for all cases of unbalanced designs (Keren, 1993), whether for general, or aging research. Second, it is also the best method for use with repeated-measures designs (O'Brien & Kister Keiser, 1985; Lewis, 1993) which are frequently used in studies of aging. It is generally accepted that if an ANOVA is used to analyze a design that is not balanced, the validity of the output is questionable (Keren, 1993). A third, and practical, reason for using the GLM approach, is that it is more flexible. The GLM method is based on least-square regression methods and therefore regression analysis techniques can be easily carried out. Regression analyses are indeed frequently used in aging research (e.g. Cerella, 1985; Madden, 1992; Salthouse & Coon, 1994). In fact, in the third part of the results section we apply and evaluate the regression technique as proposed by Salthouse and Coon (1994) for analyzing and interpreting differential age-related influences. Salthouse and Coon (1994) discuss the difficulties involved in interpreting Age x Variable interactions in studies of aging and propose that in the case of a significant Age x Variable interaction effect an additional hierarchical regression analysis, used to infer the presence or absence of differential age-related influences, should be performed.

Hierarchical Regression. Salthouse and Coon (1994) argue that three different interpretations can be drawn from a significant Age x Variable interaction. Assuming that Age and Variable both have two levels, the most frequent interpretation of an Age x Variable interaction would be that one theoretical process (as measured by Variable 2) is more age-sensitive than the other theoretical process (as measured by Variable 1). A second, alternative, interpretation is that age-related influences do not selectively affect two different processes, but that those processes differ in the demands they make upon a common processing resource that is related to age. A third interpretation is that both variables are determined by the same processes, and therefore share a large proportion of their systematic age-related variance and, thus, there is little unique variance in one that is independent of the variance in the other.

For these reasons, Salthouse and Coon (1994) suggest that additional types of analyses are needed to determine whether Age x Variable interactions should be interpreted in terms of a differential deficit on the relevant theoretical processes. They consequently propose the following procedure (Salthouse & Coon, 1994, p. 1173):

1. Determine whether the Age x Variable interaction is significant.
2. If the interaction is significant, examine the amount of unique age-related variance in the variable with the greater age difference by determining the increase in variance associated with age after the variance in the other variable has been controlled. If the residual age-related variance is significant, then a conclusion that the processes were selectively and independently influenced by age would be warranted.

Shape Experiment

Model. The data of the shape experiment were analyzed as an Age x Visual Field x Position design with Subjects as a nested factor within the factor Age according to the general linear model approach[5].

Reaction times greater than twice the mean of the corresponding condition were removed as outliers. Applying this rule, 1.2% of the original dataset was considered as outliers. After removing the outliers, the design was unbalanced as the number of RT measures differed per subject, hence, the GLM method was indicated (Keren, 1993). The mean number of RT measures per subject in the final dataset was 1019.75 which allowed for a very powerful test of the Visual Field effects of interest.

Split-Plot General Linear Model Analysis. The results of the split-plot GLM analysis are presented in Table 1.

In reference to the Visual Field effects that are of interest to this analysis, there was no main effect of Visual Field. The mean RT for the RVF was 687.65 ms and 689.57 ms for the LVF.

The results of the AGE x Visual Field interaction are depicted in Figure 3.

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[5] In general, a multivariate GLM analysis of repeated-measures designs is to be preferred (Lewis, 1993; O'Brien & Kister Keiser, 1985). The only drawback of this approach is that in the case of no more subjects than degrees of freedom for the repeated measures main effects and interaction effects, multivariate tests cannot be carried out (Lewis, 1993). That is the case in the current situation if we were to analyze the dataset according to a MANOVA repeated-measures design model. In those cases, an adjustment of the degrees of freedom according to Greenhouse and Geisser (1959) and Huynh and Feldt (1976) are recommended. However, for the current design (both for the word and the shape experiments) no differences are to be expected between a multivariate GLM approach and a split-plot GLM approach which is the one used in the present study. This is because all experimental variables except Position, have two levels. Therefore, the adjusted degrees of freedom will only be mentioned for the variable Position.

Table I. ANOVA table for the shape experiment.

Source	SS	df	MF	F
Between blocks				
Age	335272524.99	1	335272524.99	80.48*
Subjects(Age)	91641456.02	22	4165520.73	
Within blocks				
Visual Field	12384.52	1	12384.52	0.05
Age x Visual Field	731614.04	1	731614.04	2.93**
Visual Field x Subjects(Age)	5493139.67	22	249688.17	
Age x Visual Field x Position	10999648.96	8	1374956.12	6.06***
Visual field x Position x Subjects(Age)	19979681.83	88	227041.84	

* P≤ .05
** P≤ .01
*** P≤ .001

The Age x Visual Field x Position interaction is represented in Figure 4. As can be seen, there are no visual field differences between the younger adults and the older adults for the targets in the center and middle locations. For the outside location, however, the younger subjects process targets faster in the LVF than in the RVF while the reverse holds for the older subjects. Hence, the results pattern found for the Age x Visual Field interaction (Figure 4) can be explained by the Age x Visual Field result pattern found for the outside location condition.

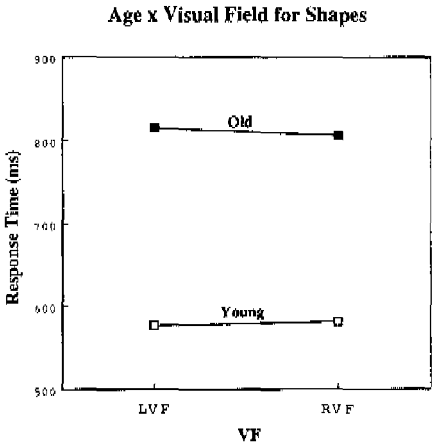

Figure 3. The significant Age by Visual Field interaction, as indicated by lower mean response time to shape targets in the LVF of the younger subjects, and the RVF of older subjects.

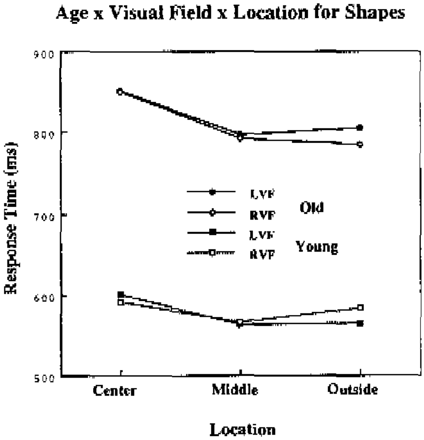

Figure 4. Effect of target location for both age groups as assessed by the shape identification task for each visual hemifield.

Hierarchical Regression Analysis. The Hierarchical Regression Analysis is of relevance here as the differences in processing of items in the left versus right visual field are typically interpreted in terms of different and/or additional hemispheric and interhemispheric processes (structures).

The age difference was largest for the LVF condition for the Age x VF interaction (Figure 4). Therefore, an analysis was run in which the effect of age on the LVF reaction times was evaluated with the effect of RVF being controlled. The effect of age was found to be highly significant (F (1,22) = 59.32, p< 0.0001) and accounted for 16% of the residual variance in the LVF variable.

Of primary interest, was the Age x Visual Field interaction in the Outside location conditions, thus the same type of analysis was run to explore this particular effect. Again, the age difference was greatest for the LVF condition, so the effect of age was evaluated with the effect of RVF controlled and was found to be highly significant (F(1.16) = 36.33, p < 0.0001) with 17% age-related residual variance.

Discussion

The interaction between age and visual field shows that shapes are processed differentially by the older and younger subjects. Contrary to the findings of Kinsbourne and Byrd (1984), our analysis shows that older adults do not have an advantage for shape information presented in the left visual field as the younger adults do. However, the results of Kinsbourne and Byrd (1984) can only be compared to our own on the basis of their non-memory condition where five geometric shapes were presented to each visual field to each of 40 subjects for identification. Thus, their data is based upon only five trials per subject for the visual field advantage in question in contrast to the 576 trials per subject for each visual field in the present study (before removal of outliers). In addition, Kinsbourne and Byrd (1984) used no control for eye movements during each presentation which varied from 10 s to 20 s. It is therefore possible that, despite the fact that the target was as likely to appear to the right as to the left of fixation, eye movements biased the results. In our study, eye movements were controlled by limiting the presentation of the target stimuli to 100 ms for shapes, and 150 ms for words. Under these circumstances, an eye movement would be unlikely as the average latency for an eye movement is approximately 175 to 200 ms (Rayner, 1984).

It is possible that the preferential processing of information in the RVF of the older subjects reflects a shift in laterality from the RH to the LH. A laterality shift from the RH to the LH in processing non-verbal information has been observed in several prior studies where age differences have not been examined (Kinsbourne & Bruce, 1987). In the Kinsbourne and Bruce (1987) study young subjects (age range = 17-22 years) were shown non-verbal (geometric shape) stimuli in either the left or the right visual fields. Over 40 trials the expected LVF-RH advantage was neutralized by improved RVF performance in the second 20 trials in each single block suggesting that the "dominant" hemisphere will take over in a task where hemisphere specialization is weak or where both hemispheres can perform the task. This lateralization shift might reflect a strategy to optimize processing related to attentional bias (Jacobs & Kosslyn, 1994; Kinsbourne, 1970), or, as suggested by Kinsbourne and Bruce (1987), subvocalization. If subjects have a tendency to subvocalize during the task, then the task might shift to a more verbal mode of processing best carried out in the LH. The proposition that subvocalization caused the lateralization shift for older adults in this study can be neither confirmed nor denied as subvocalization was not controlled. Aditionally, the targets used in the shape experiment were not pure geometric forms but Landolt "C"s and might thus have been interpreted as right- and left-facing versions of the letter C. Either subvocalization or identification of the verbal form of the shape by the older adults might have then biased the processing for the left hemisphere. Why this would occur for only older subjects is unclear, but nonetheless, such interpretations cannot be ruled out without further investigation. Evidence from Kinsbourne and Bruce

(1987, Experiment 4), using young adult subjects, did not support a subvocalization hypothesis of lateralization shift. Furthermore, if it is indeed true that the older adults processed the target stimuli as verbal information, then we would expect the data of the word experiment to closely resemble the data of the shape experiment, which it does not. We must also therefore consider the possibility that the lateralizaton shift seen in the older group is related to attention.

Jacobs and Kosslyn (1994), reporting on a study of hemispheric specialization for spatial information, suggest that attention is the overriding factor which determines whether the expected RH advantage will be apparent. In the Jacobs and Kosslyn (1994) study it was shown by computer simulation that both hemispheres are capable of detecting shape information. However, the RH bias was weak, which is consistent with other empirical research (e.g. Christman, Kitterle, & Hellige, 1991) leading the authors to suggest that attention determines where the processing takes place (Jacobs & Kosslyn, 1994).

It was then decided to further analyze our own results for an effect of the factor Trial in order to see if the outcome might support an interpretation of the age differences in hemispheric processing as being due to attention. If attention was affecting the lateralization effects of the older subjects then we would expect to see an interaction of age and trial as older adults enhance their use of attention over the blocks of trials. Furthermore, as our data showed the expected LVF-RH advantage for the young adults, we did not expect to find evidence of a lateralization shift for this age group as found by Kinsbourne and Bruce (1987) in their study. The shape identification task of Kinsbourne and Bruce (1987), using a polygon target among differing polygon distractors, was probably more attention demanding than our own using a Landolt figure among circles. If attention is indeed the deciding factor determining hemispheric processing, then our task was probably not taxing enough for the young to trigger a lateralization shift. The expectation that attention plays a stronger role for older adults in the task being analyzed is supported in the literature and is discussed in more detail in a later section.

Although in the data of the present paper the younger adults showed the expected LVF advantage, it was decided to check the blocks of trials to see if there was an indication of the trial effect for either age group as found by Kinsbourne and Bruce (1987). The design of the analysis was Age (young and old) x Visual Field (left and right) x Position (target location = center, middle, or outside area of the stimulus field) x Trial (first and second halves of each trial block). Each block consisted of 72 trials before removal of outliers, thus the first half was defined by 36 trials less outliers, and the second block was defined in the same manner.

Results of a GLM analysis revealed a main effect of the factor Trial (F (1,22) = 15.58, $p <$ .0001) indicating that RT for the first half of the block of trials was significantly different from the second half. This outcome is explained by the Age x Trial interaction (F (1,22) = 18.13, $p <$ .0001) where it can be seen that the older subjects were significantly faster to respond to the target in the second half of each trial block. Response times for the younger subjects for the first and second half blocks were 577.7 ms and 578.4 ms, respectively, and for the older subjects, 820.3 ms and 802.4, respectively. As there was no interaction for Age x Visual Field x Trial ($F < 1$), it was apparent that the change in speed by half-block for the older adults was independent of visual field. Thus, the older subjects were faster in responding to targets in both the left and right visual fields in the second half of the blocks. An unanticipated outcome of the analysis was a significant interaction between age, target position, and trial (F (2,22) = 3.75, $p <$ .02) as the older subjects became faster in identifying targets in the middle area of the stimulus field.

The significant interaction between age and trial cannot be interpreted in terms of a shift of lateralization of the older group as RT decreased for both visual fields over half-blocks. A shift in lateralization would require that RT decrease for targets in only one VF over half-blocks indicating a shift in processing advantage from one hemisphere to the other. However, the significant outcome can be interpreted in support of our argument that the behavior of the older adults is differentially affected by attention. Kinsbourne (1970) suggested that subjects may adopt a set for processing in the hemisphere best adapted to the task. In the present case, it would be expected that attentional set for shape identification would be for information entering the LVF. As the RH responds in its orienting function, then the LH would be inhibited (Kinsbourne, 1970). If older people are less able to inhibit the functioning of the LH then it (the less advantageous hemisphere) will share processing. Although the attentional system in older people is not well understood, it is known that both the locus coeruleus and the norepinephrin (NE) system, which are thought to influence attention, degenerate with age (e.g. Coull, 1994). As both the locus coeruleus and the NE system are thought to function to reduce the signal to noise ratio and allow the suppression of irrelevant information, then their reduced function in the elderly provides a likely explanation for shared processing over the hemispheres.

The gain in performance over both visual fields as indicated by the Age x Trial interaction may also reflect the increased use of attentional resources by the older subjects. We know from our own studies, using attentional cueing paradigms, such as those used for the collection of the present data (McCalley, in press; McCalley et al., in press), and from those of other researchers (e.g. Hartley, Kieley & Slabach, 1990; Hoyer & Familant, 1987; Madden, 1984; Nissen & Corkin, 1985) that older adults are as likely, or more so, to benefit from spatial cues. Therefore, older adults apparently rely more on attentional resources for target identification. Furthermore, our own studies have shown that, in some cases, older adults adopt different patterns and strategies in the spatial allocation of these attentional resources (McCalley et al., in press). Therefore, increased attention over trials, consistent with these earlier findings, could explain the significant reduction of RT by the older group over half-blocks.

The significant interaction between age, target position, and trial is consistent with our earlier finding that older adults first distribute attention to the most peripheral areas of the stimulus display with attention shifting inward to the middle area over time (McCalley, in press). The previous finding was based on within, and not between, trial data as in the present case, yet the behavior appears to reflect a consistency in the strategy of the older adults. Although we can give no explanation for why this behaviour should occur, the convergent results reinforce that this particular age difference is robust, affects processing over trials as well as within trials, and is therefore of interest for future investigation.

Our primary concern, however, was whether older adults would show slowed responses as compared to the younger adults for conditions in which spatial information had to cross the corpus callosum for processing in the right hemisphere. We were not able to ascertain whether this occurred as the older subjects probably did not process the spatial information exclusively in the right hemisphere as had been predicted.

Word Experiment

Model. The data of the word experiment were analyzed in exactly the same manner as for the shape experiment with an Age x Visual Field x Position design with Subjects again as a nested factor within the factor Age in accordance with the general linear model approach.

As in the shape experiment data, reaction times greater than twice the mean of the corresponding condition were removed as outliers. By application of this rule, 1.16% of the original dataset was considered as outliers. The mean number of RT measures per subject in the final dataset was 996.21 which again allowed for a very powerful test of the Visual Field effects of interest.

Split-Plot General Linear Model Analysis. The results of the split-plot GLM analysis are presented in Table 2.

Table 2. ANOVA table for the word experiment.

Source	SS	df	MF	F
	Between blocks			
Age	346897853.69	1	346897853.69	58.12*
Subjects(Age)	131309503.57	22	5698613.80	
	Within blocks			
Visual Field	11439906.02	1	11439906.02	40.69*
Age x Visual Field	1982425.55	1	1982425.55	7.05**
Visual Field x Subjects(Age)	6184623.42	22	281119.25	
Age x Visual Field x Position	47404412.53	8	5925551.57	25.34*
Visual field x Position x Subjects(Age)	20579188.78	88	233854.42	

* $P \leq .05$
** $P \leq .01$
*** $P \leq .001$

In reference to the Visual Field effects that are of interest to this analysis, the main effect of Visual Field was highly significant. The mean RT for the LVF was 728.77 ms and 691.72 ms for the RVF.

The results of the Age x Visual Field interaction are depicted in Figure 5.

The mean RT for the LVF stimuli is significantly higher than for the RVF stimuli for the both older and younger adults, but this difference is significantly greater for the older subjects.

The Age x Visual Field x Position interaction is represented in Figure 6.

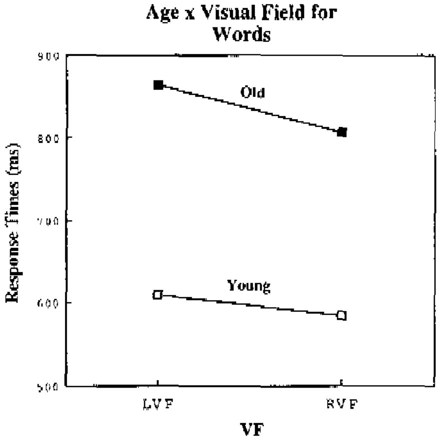

Figure 5. The significant Age by Visual Field interaction, as indicated by a proportionally higher mean RT to word targets by the older subjects than the younger subjects in the LVF.

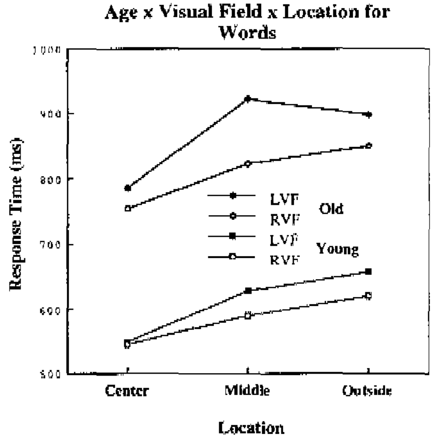

Figure 6. Effect of target location for both age groups as assessed by the word identification task for each visual hemifield.

Older adults and younger adults both showed a significant RVF-LH advantage for the middle and outside positions. However, the RVF versus the LVF differences were significantly larger for the older subjects as compared to the younger subjects.

Hierarchical Regression Analysis. The crossover conditions (LVF-LH) were further analyzed with a Hierarchical Regression Analysis. This sort of analysis is of particular relevance because, for the processing of words in the LVF, a CC-mediated transfer process was hypothesized. The same process was not hypothesized for the processing of words in the RVF as the visual word information is thought to travel directly to the LH, as discussed earlier, thus not involving CC transfer.

As the age difference was largest for the LVF condition, shown by the Age x VF interaction, an analysis was run in which the effect of age on the LVF reaction times was evaluated with the effect of RVF controlled. The effect of age was found to be highly significant ($F(1,22) = 36.85$, $p < 0.0001$) with a residual age-related variance of 9%.

In the case of the Age x VF x Position interaction, a Hierarchical Regression Analysis was not necessary as the variable Position was significant for both the middle and outside locations, as expected.

In order to quantify the effect of interhemispheric slowing in the older subjects a regression model was fitted to the data for both the RVF and the LVF conditions. The model consisted of Old (response times) as the dependent variable and Young (response times) as the independent variable. No intercept term was included in the model. For the RVF condition, the model explained 91% of the variance and the least-squares estimation of the slope parameter was 1.33. For the LVF condition, the model explained 88% of the variance and the estimation of the slope parameter was 1.37. Hence, we derived that the response times of the older adults in the crossover conditions (O2) was linearly related to the reaction times of the older adults in the non-crossover conditions (O1) in the following way: $O2 \approx 1.03O1$. Thus, in the crossover condition for the older subjects, the interhemispheric transfer caused a slowing of 0.03.

Discussion

Consistent with the findings of Byrd and Moscovich (1984), older adults demonstrated the predicted RVF-LH advantage for words in much the same manner as the younger adults. It is also clear from the analyses that older adults were significantly slower in the crossover conditions suggesting that the corpus callosum was not transmitting information from the LH to the RH as rapidly as for the young. As Byrd and Moscovich (1984) did not measure IHTT and only presented error data, results of their study cannot be directly compared to our own regarding this issue.

We also must consider another interpretation of the data. Rather than viewing the data of the older subjects as representative of slowed processing of information entering the LVF as compared to the RVF, we might also consider that information to the right of fixation is processed faster than that to the left of fixation. Such an interpretation would imply that the results of the older adults are indicative of attentional bias to the right of fixation rather than the slowing of IHTT. Yet there are three arguments against this interpretation. The first is that if attention is causing a bias then we would expect to see the same bias for targets appearing to the right of fixation in the center and middle locations as we do for those appearing in the outside location for older adults only, but this is not the case. The second argument is that we would expect to see the same pattern af results for the shape data as for the word data which we do not. The third argument is that if the decrease in response time over the trial blocks for the older adults in the shape experiment is due to incresed attention, then the result is an enhanced processing of targets appearing to either side of fixation. This means that the attentional resources of the older subjects are spread over the entire cued area without a bias to the right of fixation. This interpretation is also supported by the attentional shift analyses in McCalley et el. (in press) where older adults are shown to spread attention equally in ring-like areas around fixation with no bias to the right of fixation. We thus favor the interpretation of the data as showing evidence for a slowing of IHTT in the older subjects for the crossover conditions.

The age-related slowing of interhemispheric transfer in the present study represented a proportional slowing of 0.03, thus for a response time of 1000 ms, 30 ms could be accounted for as site-specific slowing associated with age-changes in the CC.

5.4 Conclusions

In this study methodological and statistical issues were emphasized in order to present the best possible arguments for our points and to serve as an example for future research in an area where small (albeit important) results are common. These methodological issues are often neglected in related studies, whether age-related or not. For example, Lewis (1993) reviewed 58 articles, nonsystematically selected from major psychology journals, and found that 55 of the 58 articles reported at least one questionable repeated-measures F test. In order to avoid weakening data analysis results in such a manner we advocate a general linear model approach which is particularly relevant in the case of repeated-measures and unbalanced designs typically used in aging research. In our analyses of Age x Variable interactions, we further applied the hierarchical regression approach as recommended by Salthouse and Coon (1994) to test the residual age-related variance. According to this approach, evidence was found for differential age-related influences for both the shape and the word experiments.

Results of the analyses of the shape experiment indicate that the processing of shapes is different for older and younger adults. Older adults do not show the expected LVF-RH advantage and therefore the crossover condition cannot be assessed as to whether or not the CC is implicated in age-related slowing of shape processing. Although neither subvocalization nor the processing of the Landolt "C"s as verbal information by the older adults can be ruled out, the literature and the data do not strongly support these interpretations. It is also possible that the age-related difference in the processing of shapes reflects attentional effects that mask the slowing of the IHTT.

The LVF-RH advantage for the processing of shapes is not robust and is thought to be easily overcome by attentional factors (Jacobs & Kosslyn, 1994). The present data indicate that the older subjects use both hemispheres to process shapes which is consistent with a theory of reduced inhibition of the less specialized hemisphere due to age-related degradation of the NE and the locus coeruleus which influence attention. In addition, the older adults increased processing over both visual fields within any block of trials consistent with a frequently observed (e.g. Hartley, Kieley, & Slabach, 1990; Hoyer & Familant, 1987; Madden, 1984; Nissen & Corkin, 1985) differential use of selective attention resources by older, as compared to younger, adults. Therefore, it is more likely that the difference in hemispheric processing of shapes between the two age groups is due to age-related attentional differences affecting hemispheric specialization rather than to subvocalization or the processing of the target shapes as the letter C.

Findings from the analyses of the word experiment suggest that the integrity of the corpus callosum is compromised with age resulting in a slowing of the interhemispheric transfer of information that can account for a portion of cognitive slowing associated with aging. This further suggests that cognitive slowing is differentially affected by various sites in the nervous system which may slow at different rates and therefore provides support for a view of age-related cognitive slowing that posits age-sensitive components and, thus, does not assume that the latencies of older adults is a linear function of the latencies of younger adults.

Although it can be inferred from the results of the analyses of the word experiment data that age-related slowing of the IHTT would also be present in the shape recognition task, the result of this slowing is questionable. If older adults process shape information in both hemispheres, information from each visual field is processed via the corresponding (direct) hemisphere connection therefore, no, or little, information must pass through the CC.

In the introduction to this paper we proposed to relate age-associated changes in the speed of processing to a specific structure in the neural system in an effort to establish that slowing can occur in a componential manner and that the influence on processing can be parsed on this basis. We proceeded by analyzing data from a shape identification task and a word identification task. In this manner we hoped to account for a portion of the well established overall slowing known to occur with age. The analyses of data from the word identification experiment provided evidence of a straight-forward influence of age-related slowing in the interhemispheric transfer of information which can account for a 30 ms slowing for every 1000 ms of response time of older adults. However, analyses of the data from the shape identification task indicated that not all tasks are necessarily influenced by slowing of interhemispheric transfer. Older adults possibly process shape information in a manner that is more influenced by attention and less reliant on communication between the hemispheres of the brain than younger adults. In this case other neural systems are implicated as possible sites of cognitive slowing through their influence on attentional resources. We conclude from these results that cognitive slowing associated with age is due to the composite effect of component processes which differ for different tasks.

In summary, the brain of older adults appears to process information in a manner unlike that of younger adults under some conditions. Word information seems to be processed by older and younger persons in a similar manner but is subject to interference when the information must be processed via the visual field ipisilateral to the left brain hemisphere. Shape information is apparently processed in a different manner for younger and older persons. In younger adults shape information is processed primarily by the hemisphere most specialized for non-verbal information. In older adults both hemispheres appear to share processing of shapes which could be the result of attentional factors (e.g. see Jacobs & Kosslyn, 1994), of increased subvocalization; or of processing the targets as verbal information. Although this still remains to be determined, it is known that there is an age-related degradation of the norepinephrine system and the locus coeruleus influencing attention (Coull, 1994) which may prevent the inhibition of the hemisphere less specialized for non-verbal information processing (see Kinsbourne, 1970) thus resulting in shared hemispheric processing.

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Chapter 6

Conclusions

6.1 Introduction

The primary goal of this dissertation was to establish a basis for understanding the source of reading problems that affect the everyday functioning of older adults. Word identification in the field of vision away from fixation was identified as a particular source of difficulty for the elderly. This is of primary relevance as many daily tasks, for example driving and reading subtitles as well as the reading of text, require that word information be acquired in the outer areas of the visual field. As prior research had established the importance of attention in such tasks, the study focused on the effects of aging on visual selective attention and on its influence on word recognition in the parafoveal visual field.

The sequence of experiments began with addressing basic theoretical issues of how attentional selection and distribution changes with age. The general findings of the research presented here indicate that older people retain a high degree of flexibility in the distribution of attention, much like that of younger people. However, the relationship of the processes of selection and suppression that underlie attention was found to change in a systematic fashion relative to the type of visual stimuli presented, the background of presentation, and age. These changes though could not explain a major portion of the slowed responses and reduced accuracy of the older subjects. However, an analysis of the data from the second shape experiment (Chapter 2, Experiment 2) and the word experiment (Chapter 3) indicated that changes in interhemispheric transfer time (IHTT) and other central processes affecting attention might influence processing speed and accuracy. A more detailed summary of the findings and conclusions of the study follows.

6.2 Research results

Attention Theory

One of the most important findings of this research is that older people have a different relationship than younger people between the selection and inhibition processes underlying attention. Furthermore, the change in the relationship between selection and inhibition is primarily associated with word identification rather than with simple shape identification (Chapter 3).

Many previous studies have indicated that older adults suffer from a decrement in their ability to inhibit irrelevant or interfering visual information (e.g. Madden, 1983; Plude & Hoyer, 1985; Rabbitt, 1965; Scialfa, Kline & Lyman, 1987). However, the evidence for age-related reduced inhibition has generally come from studies using negative priming (e.g. Hasher, Stoltzfus, Zacks, & Rypma, 1991; McDowd & Oseas-Kreger, 1991), dual task experiments, and visual or memory search tasks (Hasher & Zacks, 1988; also see Hartley, 1992). Prior to the research presented here, the expected evidence of reduced costs for an invalid cue for older subjects due to reduced inhibition of non-cued areas in location cuing tasks in support of a theory of reduced inhibitory processing had not been found.

The question then arises as to why the particular word identification experiments used in this study produced the missing evidence when others were unsuccessful in obtaining it. The answer to the question lies primarily in the method of the data analysis used here and not in the experimental paradigm. If it is recalled that a spatial cue is a stimulus providing target location information prior to the onset of the stimulus display, then it is expected that a valid cue will produce a benefit in performance and an invalid cue will produce a decrement, or cost, in performance, when compared to a corresponding neutral cue condition. Previous studies which sought to compare the effects of aging on attention either added performance costs and benefits in order to achieve a measure of the total magnitude of response to the cue (e.g. Hartley, Kieley & Slabach, 1990; Hartley, Kieley, & McKenzie, (1992), or relied only on an analysis of benefits (e.g. Hoyer & Familant, 1987; Madden, 1983). However, cost and benefit data from the experiments presented in Chapters 2, 3, and 4 were analyzed separately based on the assumption that first, benefit for a correct cue reflects the selective processing of the cued target area, and second, that cost reflects the inhibitory processes which suppress response to interfering information in the uncued regions of the display (Cowan, 1988; Hartley 1992; Kinchla, 1992; Plude, Enns, & Brodeur, 1994; Posner & Snyder, 1975; see also Jonides & Mack, 1984). The use of mathematical models of the distribution of attention allowed a quantification of the separate effects of costs and benefits, allowing a precise measurement of the relationship between selection and inhibition for younger and older adults. In addition, different SOAs were used to establish the development, over time, of this relationship. By this method, it was discovered that older adults used selective and inhibitory processes in much the same manner as younger adults at shorter SOAs (< 500 ms). However, at longer SOAs (> 1000 ms), they were shown to rely far more on the selective processes, presumably as a compensation for an inability to sustain inhibition. As the total amount of cost and benefit changed little over SOA, a simple addition of the effects, as done in prior studies, would have led to the erroneous conclusion that attention did not change with age. Thus, by using the models, age-related changes in inhibitory processing could be plausibly established and detailed, lending support to the reduced inhibition theory.

Models of Attention

In addition to contributing to a theory of age-related cognitive slowing, the formal modelling method also provided a means to test which of three prevalent theories provided the best description of attentional distribution for age groups at opposite ends of the lifespan continuum. These three theories were represented by visual metaphors that describe how attention might be distributed in response to a spatial cue appearing in the visual field. On a superficial level these models do not appear to be mutually exclusive therefore a brief description follows.

The first theory used the metaphor of a spotlight with the corresponding model assuming a serial self-terminating scan of each object in a display field. The beginning of the scan was assumed to be governed by the cue and in the case of a neutral cue was assumed to be random. As the scan times are by definition additive the spotlight model is consequently additive. The second and third theories used the metaphors of a zoom lens and a ring respectively. The zoom lens and the ring models assumed parallel processing of objects in the cued area of an experimental display and in the case of the neutral cue the entire display was assumed to be processed in a parallel manner. These models too were additive[6]. The spotlight model is capable of generating effects similar to both the zoom lens and the ring models because a scan of a cued area enhances processing in much the same way as a general distribution of attention over the same area. However, because it is a serial processing model, it is incompatible with the other two parallel

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[6] By definition, all three models are additive (linear) and thus cannot describe anything but additive effects unless extra parameters are included. If RT models contain multiplicative components then RT must consequently be transformed into a variable containing multiplicative components. This, however, necessitates nontrivial transformations which would, in the case of the present study, require additional parameters. As an additive model is the simplest conceivable model, and considering the ratio of parameters to degrees of freedom, parsimony was retained by refraining from the addition of multiplicative components. A similar argument holds for the treatment of the error scores, but interestingly, a form of multiplicative model must be used as probability components are not additive. The simplest model extant for probability analysis is the logit strength model of Luce (1959) which requires that effects be additive on the logit scale. This implies that the effects are multiplicative on the probability scale but an additive type of description can be applied.

processing models. Furthermore, the spotlight model constrains the parameters to such an extent, allowing only a base time and a scan time, that it cannot hold in view of the data. The zoom lens model may be considered a special case of the ring model, but with much less flexibility. Yet, due to its inflexibility, the special case of the zoom lens model within the ring model cannot account for outside ring activation apparent in the experimental results that occur in conjunction with suppression of the center ring area. Therefore, it must be concluded that the zoom lens is incompatible with the data, and consequently, with the ring model. The results outlined in Chapter 2 indicate that a flexible resource allocation model of attention that allows for attention to concentrate outside the foveal area best explains the data of older and younger adults. In comparing the zoom lens and the ring models, it became apparent that the zoom lens model confounds attention and visual processing in peripheral vision. This suggests that previous research which concluded that attention spreads from the fovea to encompass an attended area must be viewed with some scepticism. In the hope of allowing for a fair comparison of the zoom lens and the ring model an attempt was made to compensate for reduced peripheral vision of the older adults by increasing the size of stimuli in accordance with visual eccentricity. The size increase was not successful in equating the groups' attentional distribution according to the models when the task was to locate and identify a simple shape (Chapter 2, Experiment 2) nor was the same technique for words (Chapters 3 & 4) successful. This lead to a rejection of the zoom lens model as a viable model for the distribution of attention as attention could not be identified separately from visibility.

The necessity of including an eccentricity parameter in the ring model demonstrated that, despite increasing the visibility of word stimuli in the outermost areas of the experimental displays, older adults retained a disadvantage for identifying peripheral stimuli. This finding is important as it implies that many studies of age-related changes of attention have possibly underrated the peripheral visibility of targets for older adults thus confounding

attention and visibility.
Cerella (1985) had earlier warned of this possibility, however experimenters continued to mistakenly assume that a match of simple distance acuity for the different subject groups would allow for fair age comparisons to be made. The models, as used in this study, lend support to the Cerella (1985) findings, and provide a quantifiable comparison of the effect of eccentricity between older and younger subjects.

Performance Related to Everyday Tasks

As previously stated in this thesis, older adults report difficulty in performing everyday activities which require that information be gathered from a cluttered visual environment. The results of the experiment requiring the identification of words on pictorial backgrounds (Chapter 4) has provided the control of a laboratory setting with the ecological validity of using a task similar to one that is often present in daily activities. The word identification task was designed to test the effect of both moving and still backgrounds on the distribution of attentional resources to words, and thus to the processing of words, in extrafoveal vision. As the words appeared on a video background, the moving background task shared many similarities with the reading of television subtitling. In addition, the use of pictorial backgrounds, in general, made the data more generalizable to everyday tasks.

Results of the experiment showed that older adults had proportionately more difficulty than younger adults in identifying a word on either the still or moving backgounds. In addition, the older group was especially disadvantaged when the target word appeared on a moving background. It was apparent from the data analyses that the older adults were less able than the younger adults to suppress responses both to unexpected visual transients in the moving background, and to expected, but irrelevant, information in the visual field. Therefore, it appears that word recognition suffers for older adults whenever a visually complex background is added to the task. This suggests that at least some of the self-reported problems of the elderly, such as reading subtitling or street signs, are due to reduced inhibition of unattended areas of the visual field.

Interhemispheric Age Differences

Although evidence for an age-related change in the relationship of cost and benefit (inhibition and selection) was found, this could not, by itself, explain the overall increase in response time and error rates observed in the older group. This study had thus far provided evidence for reduced inhibition in older adults in the expectation that reduced inhibition was the underlying cause for cognitive slowing as proposed by the proponents of the Reduced Inhibition Hypothesis. Yet, in those conditions where a reduction in inhibition of the older adults was evident, response times and errors did not differ from the conditions where inhibition remained intact for the older group. It thus remained to address whether a hypothesis of general slowing could be falsified. If it could be shown that a specific component of cognitive processing was sensitive to slowing due to age-related factors then the status of slowing as being general would be questionable. It was then hypothesized that if opposing visual field advantages could be established for the data from the simple shape and word experiments (Chapter 2, Experiment 2, and Chapter 3) as suggested by neuropsychological studies, then the role of interhemispheric transfer, as a component process in slowing, could be explored.

The experimental paradigm used for the abovementioned experiments, where targets appeared in either the right or left visual fields, provided an opportunity to explore possible age differences associated with interhemispheric transfer. This transfer occurs via the corpus callosum which transmits information from one brain hemisphere to the other. The study of age-related transfer differences was possible due to the same number of presentations of the experimental targets in both visual fields in the second shape experiment and the word experiment. Each visual field shows a processing advantage for different types of stimuli. A right visual field advantage is thought to reflect preferential processing of verbal (e.g. word) information by the left brain hemisphere, and a left visual field advantage reflects preferential processing of spatial (shape) stimuli. When stimuli are presented to both eyes (binocularly) then verbal information coming from the right visual field travels directly to the left hemisphere for processing, while verbal information from the left visual field travels first to the right hemisphere, then passes along the corpus callosum to the left hemisphere for processing. Thus, a word appearing in the right visual field is processed faster than a word appearing in the left visual field as the right visual field information does not have to first cross the corpus callosum. The opposite is true for spatial (shape) information.

Briefly, results of the data from the simple shape and the word experiments showed that the brain of older adults may process information in a manner unlike that of younger adults in some conditions. Word information seems to be processed by older and younger persons in a similar manner but is subject to interference when the information must be processed via the visual field ipisilateral to the left brain hemisphere. Shape information may be processed in a different manner for younger and older persons. In younger adults shape information is processed primarily by the hemisphere most specialized for non-verbal information. In older adults it seems likely that both hemispheres share processing of shapes, which could be the result of either a greater propensity for subvocalization by older adults or attentional factors (e.g. see Jacobs & Kosslyn, 1994). Although subvocalization cannot be ruled out, there is no evidence in studies which do not examine age differences to suggest that it is a factor (Kinsbourne & Bruce, 1987). The effect of attentional factors can only be speculative here, however, it is known that there is an age-related degradation of the norepinephrine system and the locus coeruleus influencing attention (Coull, 1994) which may prevent the inhibition of the hemisphere less specialized for non-verbal information processing (see Kinsbourne, 1970). An interpretation based on reduced hemispheric inhibition provides a good explanation for the bi-lateral processing of shapes by the older adults. Although the apparent shared hemispheric processing of shape information by older adults pre-empted an analysis of interhemispheric transfer time it provides evidence that slowing is not general. The concept of generalized slowing assumes that all processing proceeds in a uniform manner, only slower, which is apparently not the case, as is evident from the shape and word analyses results.

6.3 Summary

Major Findings

The above sections highlight the more important findings of the research presented in this thesis. However, the study resulted in many interesting insights into the distribution of attention, especially to words, of the two age groups studied. It is therefore useful to review all major findings of the study.

The most important findings regarding age-related changes in cognitive processing from the research presented here are that (1) older individuals retain a high flexibility of attentional resources and use information presented prior to a task (e.g. a cue) to allocate those resources in apparently greater quantities than younger adults, (2) difficulty in the visual processing of objects is perhaps underrated for older adults, (3) older adults appear to use more selective processing rather than inhibitory processing than younger adults when they are given ample time to identify a target, and (4) some of the observed slowing of cognitive processing attributed to the effects of aging might be due to a weakening of the transmission of information across the hemispheres of the brain and to differences due to age-related changes in brain systems related to the inhibitory aspect of attention.

More general findings of the research provided evidence that (1) a theory of attentional distribution that allows for attention to be separated from the foveal area in order to allow maximum visual processing in the extrafoveal visual field best explains the behavior of older and younger adults, (2) attention is best described as the interaction of two processes; selection and suppression or inhibition, (3) word identification benefits more from attention than the identification of simple shapes, (4) attention can be distributed in a spatial manner to information overlying a complex pictorial background, and (5) attention to words in the extrafoveal region is constricted in scope when a complex pictorial background is present.

Overview and Suggestions for Future Research

The research presented here has provided a more detailed understanding of the attentional processes involved in the identification of words in the extrafoveal region of the visual field. The theoretical implications of the study lie both in its contribution of evidence to a theory of reduced inhibitory processing and in the findings that suggest the value of further exploration into the effects of age on the areas of the brain involved in information processing. The results of this study leave little doubt that the relationship of the inhibitory and selective processes of attention change with age, yet the overall effect is clearly more complex than that predicted by a simple theory of reduced inhibition. As commonly presented, an hypothesis of reduced inhibition suggests that older adults are less able to ignore irrelevant information and that this is the underlying cause of an attentional deficit which itself underlies a slowing of cognitive processing in the elderly. However, the present study has provided little evidence that reduced inhibition is clearly a cause for the ubiquitous age-related slowing.

According to the results presented in this thesis, the hypothesis of general slowing which assumes an equal, or nearly so, rate of slowing for all tasks, does not fare well either as an explanation of the increased response times and errors of older adults observed in this study. Findings of an analysis of visual field-brain hemisphere interactions (Chapter 5) imply that some of the slowing of cognitive processing associated with aging might be due to obstructions of the pathway that connects brain hemispheres, but this pathway is not always involved in information processing. Some tasks reflect this slowing component, and some do not; therefore slowing cannot always result from the same general cause.

What can be said regarding theory specific to the study of aging, is that the reduced inhibition hypothesis is the most fruitful to pursue, but that many other factors must be taken into consideration. It is probable that the selective aspect of attention remains intact, or even increases, with age, allowing older adults a means to compensate for reduced inhibition in many circumstances. It is clearly evident from this study that older adults maintain a remarkable flexibility in distributing their attentional resources and appear to use them to enhance otherwise impaired visual processing. However, this mechanism is vulnerable to environmental demands as exemplified by the different background conditions used in the final experiment (Chapter 4). It is therefore up to future research to develop a comprehensive understanding of the roles of the inhibitory and selective processes of attention and how they are influenced by the visual environment as well as their relationship to brain structures.

Methodological advancements have also been presented here as the use of mathematical modelling techniques has been shown to enable a better identification and more accurate measurements of the influences of visual distractors in the environment. In addition, a flexible resource allocation model of attention has been shown to best explain the behavior of both age groups used in this study which contributes to the assessment of a general theory of attentional distribution. The model analyses also indicated that one of the more prevalent general theories of attentional distribution, the zoom lens model, confounds attention and visual processing and has, therefore, no identifiable parameters in the present paradigm. In addition, the spotlight model, which assumes serial processing, was rejected as it performs erratically when scanning speed must be adjusted for distance. Future research using a similar methodolgy of quantitative modelling techniques would be useful for the detailing of the relationship of selective and inhibitory processes in many visual environments, including everyday settings such as television and computer screens. In this way thresholds of visual complexity might also be better set and understood for older users.

With regard to what this thesis has contributed to understanding the role of visual selective attention in the everyday environment, it has been found that word identification benefits more from attention than simple shape identification. Therefore, it follows that any disturbance to the effective use of attentional resources by older adults would likely result in an impairment of word identification. Results of the final experiment (Chapter 4) indicated that a complex pictorial background did indeed disturb the distribution of attentional resources more for older adults than for younger adults and thus impaired word identification. In addition, a dynamic background, comparable to those encountered in everyday task performance, caused significantly more shrinkage of the functional field of view and the attentional field for older subjects than for younger subjects. This suggests that future research should determine if the interfering effects of cluttered and moving backgrounds on word identification could be offset by changing the backgrounds where possible, and optimizing word readability by using less text when the background cannot be changed.

As the results and conclusions of the study presented in Chapter 4 are based on costs and benefits for valid and invalid cues using a consistent target and distractor display, there is little, or no, doubt that attention is what is measured. However, it is also possible that increased visual interference associated with aging also plays a significant role in the everyday functioning of older adults. There is evidence that older people suffer far more visual interference from distractors in extrafoveal vision than young people (Van den Heuvel, 1994). The exact nature of this interference is not yet understood, and was not addressed in the present study as attention was chosen as the major focus of research. However, a future extension of this research is recommended where, using the same general paradigm as used in the studies presented here, the number of distractors are systematically changed in order to determine the effect of visual interference.

Applications of new technology, such as car navigation systems using visual displays, which are currently expected to provide much needed aid to older drivers, must take into account the extra visual clutter that will be created. Alternatives to additional visual information should be sought in order to avoid compounding the already too complex visual environment of older adults. Results of the analyses of hemispheric processing differences between older and younger adults also indicate that older adults process shapes in a different manner than words from that of younger adults. Although it has not yet been determined whether this manner is significantly less successful than that of the young it must be presently assumed so, as it likely represents a less effective use of resources to inhibit areas of the brain less specialized for shapes. It might therefore be the case that the use of shapes (i.e. icons) as a form of communication used on computers, televisions, stereo equipment, road signs, and public restrooms, to name just a few of the myriad applications, should be rethought. For older people, it appears that the use of simple text in everyday settings, with as simple a background as possible, is the optimal presentation of information for the old.

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Summary

The experiments were designed as a sequence of age comparison studies to, first, investigate the effects of attention on the localization and identification of simple shapes in extrafoveal vision, and then, second, proceed to more complex visual stimuli (words) on a plain background, then, third, to words on complex pictorial backgrounds. Finally, data from the plain background experiments for simple and complex shapes were analyzed as to whether observed slowing of visual processing by older adults could be related to age-related slowing of interhemispheric transfer in the brain.

Chapter 2 reports and compares the results of the first two experiments in the series. Results of Experiment 1, using simple shapes as stimuli, revealed that older adults were much slower and less accurate than younger adults in locating and identifying a target in extrafoveal vision. Additionally, older adults made greater use of a spatial cue in order to guide attention. Different SOAs were used to test a theory of age-related general attentional slowing which predicted that there would be no difference between the two age groups in the speed of use of the cue. However, differential behavior of the two groups at different SOAs suggested a possible time course difference.

A quantitative model analysis was used to test which of three theories of attentional distribution in response to a cue would best fit the data of the two age groups and revealed that the distribution of attention was different for older and younger adults. This led to the realization that the zoom lens model of attention confounds attention and visual processing in the peripheral visual field. Experiment 2 was then designed as a replication of Experiment 1 with an increase in size of the stimuli consonant with the eccentricity of presentation. The resulting increased visibility of extrafoveally presented stimuli served as the added control for the peripheral visual processing deficit of the older adults. A model analysis of the results of Experiment 2 demonstrated that, with a control for the visibility of peripheral stimuli, the attentional

distribution of older adults was similar to, and as flexible as, that of the young adults. In addition, with visibility controlled, there was no longer evidence of a time course of cue processing differences between the two groups.

Chapter 3 extends the comparison of attention for shapes in the periphery to more complex stimuli in a report of Experiment 3. Experiment 3 was designed to observe whether attention for words was the same as for simple shapes and whether age differences would emerge with the use of more meaningful and complex stimuli. A quantitative model analysis was again used to reveal that older and younger adults distributed attention in much the same way. However, attention for words was distributed in a more diffuse manner than for simple shapes. In addition, higher costs and benefits for invalid and valid cues revealed that word identification benefits more from attention than shape identification. Although data of both the older and younger adults fit the same model of attentional distribution, older adults showed a greater shift of attention in response to the cue and had a greater tendency to shift attention away from the foveal area in response to the cue. Most importantly, age-related differences in response to the cue at different SOAs suggested that older adults are less likely to suppress irrelevant information than younger adults and use increased selection processes to offset the decline in suppression. This finding, as yet unreported in other research, lends support to an hypothesis of reduced inhibition put forward to explain cognitive slowing with age. Evidence from Experiment 3 also suggests that older adults are able to use attention to compensate for other reduced resources such as a general decline in visual processing.

Chapter 4 reports the results of Experiment 4 which extends the investigation of age differences in the use of attention for the identification of words from simple blank background presentations to complex pictorial background presentations. Experiment 4 was designed to assess attention for words in a context that would allow generalization to everyday tasks. The use of both moving and still video backgrounds were found to reduce the useful field of view of both younger and older adults. A moving background was found to be more interfering for older adults than for younger adults under cue-independent presentations (externally initiated attentional shifts). Additionally, under cue-dependent conditions (internally initiated attentional shifts) older adults were disadvantaged as compared to younger adults whether the background was still or moving. Results of a quantitative model analysis supported this interpretation and provided support to a theory of reduced inhibition for cognitive slowing.

Chapter 5 provides an analysis and comparison of response to nonlinguistic and linguistic visual stimuli appearing in either the left or the right visual fields. Although prior experiments (Experiments 3 & 4) provided evidence of reduced inhibition of irrelevant visual information in older adults, reduced inhibition could not explain all the observed slowing. Due to the data collection method and consistent use of a single experimental paradigm in Experiments 2 and 3 a different type of analysis provided a means of comparing one aspect of brain functioning that might explain another portion of the overall slowing. Lateralization of the functioning of the right and left hemispheres of the brain allowed an investigation of age-related functioning of the corpus callosum which serves to transmit information between the brain hemispheres. Older adults evidenced slowing of the cross hemispheric transfer of information suggesting that the corpus callosum may be one possible site of degeneration causing slower cognitive processing.

Samenvatting

Het onderzoek is opgezet als een serie van experimenten waarin aandachtsstrategieen van verschillende leeftijdsgroepen werden bestudeerd. Het eerste experiment was gericht op het effect van aandacht op lokalisatie en identificatie van eenvoudige vormen in het parafoveale gezichtsveld. In de daarop volgende experimenten werden eerst meer complexe visuele stimuli (woorden) op een neutrale achtergrond gebruikt en tenslotte werden woorden op achtereenvolgens stilstaande en bewegende beelden geprojecteerd. Een nadere analyse is uitgevoerd met de data van de experimenten waarbij een neutrale achtergrond werd gebruikt, teneinde een relatie aan te tonen tussen de waargenomen langzamere visuele informatieverwerking bij ouderen en de mogelijke toename van overdrachtstijd tussen beide hersen hemisferen.

Hoofdstuk 2 beschrijft en vergelijkt de resultaten van de eerste experimenten. Het experiment waarbij eenvoudige vormen werden gebruikt liet zien dat ouderen veel minder snel en accuraat waren dan jongeren in het lokaliseren en identificeren van parafoveale stimuli. Daarnaast maakten ouderen meer gebruik van de aanwijzingen, voorafgaand aan de stimulus, om hun aandacht te richten. Deze resultaten komen overeen met bevindingen van onderzoekers die uitgingen van soortgelijke paradigmata. Tijdsvariaties tussen het aanbieden van de vooraanwijzing en de feitelijke stimulus werden gebruikt om een theorie van leeftijdsgerelateerde algemene vertraging van aandachtsprocessen te toetsen. Verschillende prestaties tussen beide leeftijdsgroepen suggereerden echter een verschil in de tijd die ouderen ten opzichte van jongeren nodig hebben om gebruik te maken van de vooraanwijzing.

Een kwantitatieve model analyse werd uitgevoerd om te toetsen welke van drie mogelijke theorieen van aandachtsverdeling de experimentele data van de beide leeftijdsgroepen het best benaderde. De analyse toonde aan dat er een verschil bestaat in aandachtsstrategieen tussen ouderen en jongeren. Dit verschil zou echter verklaard kunnen worden door een mogelijke vermenging in het zoom lens model van aandacht en visuele waarneming in het perifere gezichtsveld. Het tweede experiment was derhalve een herhaling van het eerste met dien verstande dat de stimulusgrootte toenam met toenemende excentriciteit. Deze vergroting van de perifere stimuli verbeterde de visuele informatieverwerking van de ouderen. De model analyse van het tweede experiment toonde aan dat wanneer voor stimulusgrootte werd gecompenseerd de aandachtsverdeling van ouderen vergelijkbaar is met die van jongeren. Ook de oorspronkelijke tijdsverschillen die bestonden tussen ouderen en jongeren in het gebruik maken van de vooraanwijzing verdwenen door deze compensatie.

Hoofdstuk 3 rapporteert over het derde experiment waarin werd getoetst in hoeverre de aandachtsverdeling voor woorden hetzelfde is als voor simpele vormen en of leeftijdsverschillen zouden optreden wanneer meer complexe of betekenisvolle stimuli werden gebruikt. De kwantitatieve analyse toonde aan dat ouderen en jongeren een nagenoeg gelijke wijze van aandachtsverdeling hanteerden. De aandachtsverdeling voor woorden was echter duidelijk meer diffuus dan voor simpele vormen. Daarenboven werd aangetoond dat identificatie van woorden meer dan identificatie van vormen een aandachtsproces is. Dit wordt verklaard uit de respectievelijke hogere kosten en baten bij het gebruik van foute dan wel correcte vooraanwijzingen. Hoewel ouderen en jongeren blijkbaar dezelfde aandachtsverdeling lieten zien werd aangetoond dat de ouderen de vooraanwijzing meer gebruikten en dat vooral wanneer de vooraanwijzing meer perifeer was. Een belangrijke constatering is dat ouderen meer moeite blijken te hebben met het onderdrukken van niet relevante stimuli en in toenemende mate gebruik maken van selectie processen om aldus te compenseren voor de afname van het kunnen negeren van het niet relevante. Dit nog niet eerder in de literatuur gepresenteerde resultaat ondersteunt een hypothese van gereduceerde inhibitie als een mogelijke verklaring voor cognitieve achteruitgang. Daarnaast werd in dit experiment aangetoond dat ouderen met aandachtsverdeling kunnen compenseren voor bijvoorbeeld teruggang in visuele informatieverwerking.

In hoofdstuk 4 wordt het experiment beschreven waarin het effect wordt onderzocht van een natuurlijke achtergrond ten opzichte van de bij de eerdere experimenten gebruikte neutrale achtergrond, teneinde een indruk te krijgen van aandachtsverdeling in meer dagelijkse omstandigheden. De in dit experiment gebruikte stilstaande en bewegende achtergronden veroorzaakten zowel bij ouderen als bij jongeren een afname van het functionele of bruikbare gezichtsveld. Wanneer geen vooraanwijzing werd gegeven bleek een bewegende achtergrond voor ouderen een negatief effect op het verdelen van hun aandacht te veroorzaken. Wanneer vooraanwijzingen werden gegeven scoorden ouderen slechter dan jongeren zowel in het geval van stilstaande als van bewegende achtergronden. De resultaten van de kwantitatieve model analyse ondersteunden deze bevindingen en daarmee de theorie van gereduceerde inhibitie als verklaring voor cognitieve achteruitgang.

Hoofdstuk 5 geeft een analyse en vergelijking van reacties op vormen en woorden die werden aangeboden in het rechter dan wel linker gezichtsveld. Hoewel eerdere experimenten een afname lieten zien van de mogelijkheden om irrelevante stimuli in het perifere gezichtsveld te onderdrukken, kon niet de volledige afname hiermee verklaard worden. Het gebruik van hetzelfde paradigma en de identieke wijze van data verzameling in experiment 2 en 3 maakten het mogelijk om een nader aspect van het functioneren van de hersenen te analyseren waarmee mogelijk een gedeelte van de langere reactietijden verklaard kon worden. Toekenning van functies aan de linker en rechter hersen hemisfeer maakte een studie naar het leeftijdsafhankelijke functioneren van het corpus callosum mogelijk. Aangetoond werd dat bij ouderen het informatie transport tussen beide hemisferen is vertraagd waarmee is aangegeven dat het corpus callosum mogelijk van invloed is op leeftijdsgerelateerde veranderingen in cognitieve processen.

Curriculum vitae

Lorna Theo McCalley was born on November 17, 1947, in Fresno, California, United States of America. She obtained the B.A. degree in Anthropology with a minor in Design at the University of California, Berkely, in 1970. She worked as an interior design consultant until 1986 when she joined the staff of the University of Nevada-Reno (UNR). While teaching in the design department of UNR she continued her post graduate studies in both Design and Psychology, receiving a M.Sc. in Design in 1988. Having completed two years in the Ph.D. program of the Department of Psychology, UNR, she joined the Cognition and Communications Group of the Institute for Perception Research (IPO), Eindhoven, in 1990 as a Research Assistant. From March of 1990 to the present she has been working on a project entitled 'Visual Selective Attention and Aging'.

Stellingen

behorende bij het proefschrift
Visual selective attention and aging
van L. T. McCalley

I

The use of log-transformed response time data in age-related studies, as advocated by Allen et al. (1992), is neither necessary nor defensible.

Allen, P. A., Madden, D. J., Groth, K. E., & Crozier, L. C. (1992). *Impact of age, redundancy, and perceptual noise on visual search.* Journal of Gerontology: Psychological Sciences, 47, 69-74.

II

One theory attributes lowered intellectual functioning with age to a reduction in cognitively stimulating interaction with the environment due to lowered sensory functioning (Sekuler & Blake, 1987). This sensory deprivation theory is less compelling than a 'common cause' hypothesis which attributes both lower sensory and lower cognitive performance with age to loss in the integrity of brain physiology (Lindenberger & Baltes, 1994).

Sekuler, R., & Blake, R. (1987). *Sensory underload.* Psychology Today, 21, 48-51.

Lindenberg, U., & Baltes, P. B. (1994). *Sensory functioning and intelligence in old age: A strong connection.* Psychology and Aging, 9, 339-355.

III

In order to develop ecologically valid real-life studies of the effects of aging on attention, it would be better to develop a theoretical framework based on the purpose(s) of attention rather than the effects of attention as is currently used in laboratory studies.

Allport, A. (1989). *Visual attention.* In M. Posner (Ed.), Foundations of Cognitive Science. Cambridge, Mass: MIT Press.

IV

Adoption of a program to extend the useful field of view (UFOV) of older drivers in order to reduce auto accidents, as suggested by Owsley (1994), will most likely have the opposite effect.

> Owsley, C. (1994). *Vision and driving in the elderly.* Optometry and Vision Science, 71, 727-735.

V

The current path taken by the field of medical technology, which advocates technology-driven design for the elderly, is not compatible with a future of less institutionalized health care where the elderly are active, rather than passive, consumers of technology.

> Soldo, B. (1990). *Household types, housing needs, and disability.* American Psychologist, May.

VI

The amount of personal space that each individual requires is culturally determined and may be based upon the density of the population from which a culture develops. Thus the wide open spaces left in a queue by a visitor from the Wild West acts as a vacuum to be filled by the entire Dutch population.

VII

Gerontologists and Ornithologists share a common problem; the subjects of both fly south for the winter.