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VISUAL ATTENTION AND AGING

Karen E. Groth, and Philip A. Allen

Department of Psychology, Cleveland State University, Euclid Avenue at East 24th Street, Cleveland, Ohio 44115

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1. ABSTRACT

The present review of visual attentional processes and aging focuses on definitions of attention that emphasize some aspect of the control of information processing (selective attention) or the processing resources needed to drive these control processes (attentional capacity). Emphasis is placed on how increased adult age affects attentional mechanisms and how these age differences in attention affect overall information processing. Past research has emphasized that selective attention appears to be resistant to age-related decline. Age-related deficits in attentional capacity or processing resources, however, have been found. A review of more recent psychological research demonstrates the extension of the investigation of attention with emphasis on further defining what is selected in selective attention, and on reexamining the processing resources or capacity issue. Finally, developments in cognitive neuroscience are reviewed in terms of their relevance to attention and aging.

2. INTRODUCTION

Although the self-perceived changes in visual attentional processes may not be as great as the self-perceived changes in everyday memory for older adults, these age-related changes in attention can affect the performance of older adults on cognitive tasks. Theories of cognitive performance have typically used the concept of attention to refer to those processes responsible for the control of information processing (1). Hartley (2), in his review of attention, has refined the definition by stating that attention is responsible for selectively preparing for, maintaining the preparation for and processing certain aspects of experience. Posner and Petersen (3) see attention as functioning as a unified system for the control of mental processing. Although the specific definitions of attention do vary, most emphasize some aspect of the control of information processing (selective attention) or the processing resources needed to drive these control processes (attentional capacity). In the present review, we will discuss the traditional psychological theories that focus on age-related changes in attentional selection and attentional capacity (sections 3-5). The review will then go beyond these traditional theories of selective attention and attentional capacity by discussing space-based versus object-based selective attention and attentional time-sharing (sections 6-8). Also, beyond psychological theories, research in the area of attention within vision science (section 9) and neurophysiology (section 10) will be reviewed. Of interest in this review is how increased adult age affects visual attentional mechanisms and how these age differences affect overall information processing. For example, age-related changes in attention may be a critical component of the often- reported, age-related decline in memory functioning (4).

In much of the early research on visual attentional processes and aging, two aspects were defined: selective attention and attentional capacity. The selective aspect of attention has been defined by Madden (5) as the ability to distinguish relevant from irrelevant information. Attentional selectivity also refers to the specificity with which cognitive resources are allocated to task demands (1). A filtering process, which selects certain information for priority processing, is also attributed to selective attention. Much of the research in the area of attentional selectivity has suggested that many forms of selective attention are resistant to age-related decline. Attentional capacity refers to the limited amount of processing resources that underlie task performance (5). Capacity refers to the amount of processing resources available once attention is focused. Although there is controversy surrounding the use of the concept of attentional capacity, it does seem to evidence an age-related decline (5).

In a review of attention within an aging framework, one is struck by the many varied theoretical explanations for age differences in attentional processes. Hartley (2) discusses several theoretical explanations for age-related differences in attentional functioning. The first theory proposes that with increased age comes a reduction in the energy that fuels cognitive processing. This theory proposes that attention is a resource that enables cognitive processing and this resource is diminished with advanced age. A second theory posited by Hasher and Zacks (6) proposes that older adults exhibit reduced inhibitory functioning. In this view, older adults have attentional deficiencies due to a filtering decrement, resulting in increased levels of intrusions and distractions from irrelevant stimuli. Also, it has been posited that an impairment in spatial localization ability may occur with advanced age (7). This impairment in spatial localization leads to difficulty in suppressing the processing of distractors in visual search tasks.

The third and final theoretical consideration with regard to aging and attention is that age differences in attention are artifacts of more fundamental age differences that can be explained by a generalized slowing model or by the consideration of a reduction in the size of older adults' functional visual field (12). Those who posit a generalized, age-related slowing argue that age-related attentional effects are expressions of a general slowing of all cognitive operations with advanced age (8-11).

Cerella (12) argues that the reduction in the size of older adults' functional visual field or useful field of view, due to reductions in peripheral vision, may be mistaken for attentional changes. Numerous studies have demonstrated that older adults have difficulty processing peripheral targets relative to young adults when the target is embedded in noise (12-17). The findings from these studies are taken as evidence that age differences in visual search are not solely attributable to selective attention deficits.

Due to the lack of an agreed upon theoretical explanation of age-related changes in attentional processes, to the varied findings with respect to attentional selectivity, and the dissatisfaction with the vagueness of the term attentional capacity or processing resources, more recent development in the area of aging and attention has focused on expanding and revising theory on just what is selected in selective attention (i.e., space-based versus object-based attentional selection) and on challenging the concept of attentional capacity and the notion of a limited pool of processing resources that can be devoted to task demands.

Also, rather than positing attentional mechanisms, some vision researchers argue that at least a portion of the selection in visual information processing may be related to the operation of specific visual channels (magnocellular and parvocellular channels) that function on different time courses and analyze differing types of visual information based on spatial frequency content, contrast and chromaticity. Age differences in the sensitivity of these channels have been found and will be discussed later in the review (18-20).

With regard to attentional capacity, much of the research has focused on divided-attention or dual-task performance. It has been assumed that the need to divide the limited pool of attentional resources between two tasks is more detrimental to older adults than to young adults due to a reduction in cognitive resources with increased age. More current work using Pashler's (21) psychological refractory period (PRP) effect is going beyond the controversial notion of limited capacity or resources to empirically demonstrate age differences in the ability to switch attention due to deficits in attentional time-sharing, which has been defined as the ability to serially switch attention between or among tasks (22).

Further development in attention research has come out of research in cognitive neuroscience. The majority of this research has focused on selective attention. It has been stated that the view of attention in terms of capacity or processing resources has hindered the progress of neuroscientific investigation of selective attention (3). In defining selective attention, the neuroscientific literature emphasizes the processes of selection and filtering. Attentional selection selects only a part of the information that is available to an organism. The selection or filtering process is carried out in a system that amplifies relevant information, attenuates irrelevant information, or both (3, 23). Based on this work and its evidence for the modularity of attentional structures and systems, it seems unlikely that there is a general attentional resource that changes uniformly with age (2).

3. AGING AND VISUAL SELECTIVE ATTENTION

Much of the research examining age-related attentional change has employed visual search tasks. The typical visual search task requires subjects to detect target items in a visual display. The typical finding in a visual search task is that as display size increases, there is a linear increase in RT and/or errors which is suggestive of a serial search process (24).

3.1. Evidence for age-related selective attention deficits

Early research investigating age differences in selective attention was conducted by Rabbitt (25, 26). Using a card-sorting methodology in which the participants sorted cards containing letters and digits on the basis of pre-specified categories, Rabbitt found that increasing the number of response categories, the number of stimuli comprising a category, or the number of stimuli on a card led to greater increases in sorting time for older adults relative to younger adults. Based on these data, Rabbitt concluded that the older subjects had difficulty ignoring irrelevant information and were at a disadvantage when searching complex stimuli. Rabbitt's results were interpreted as evidence of an age-related decrement in the selective aspect of attention.

According to Madden (5), though, Rabbitt's results imply limitations in processing resources or attentional capacity or an age-related slowing of the information processing components of the task, rather than an age-related decline in selective attention. Madden (5) states that the card sorting task involves the discrimination of relevant items more so than the discrimination between relevant and irrelevant items. To demonstrate an age-related deficit in selectivity, it would be necessary to find that an explicit dimension distinguishing relevant from irrelevant information was used more effectively by young adults than by older adults.

Further evidence for an age-related deficit in selective attention came from the research of Plude and Doussard-Roosevelt (27) using a visual search task. These authors used a visual search task in which the type of search was manipulated. In the "feature-search" condition the targets and nontargets were perceptually distinct, they did not share any features (a red X target amongst green O nontargets). In the "conjunction-search" condition, the targets shared some features with the nontargets (a red X target embedded in nontargets of red Os and green Xs). The results of this investigation demonstrated that the older adults were at a disadvantage relative to young adults in the conjunction-search condition. This was evidenced by a larger increase in search RT as display size increased for older adults than for young adults. Search RT in the feature search condition was fairly constant over display size for both the older and young adults. Based on these findings, it was concluded that the age differences in the conjunction-search condition were the result of the increased attentional demands of selecting the appropriate target and avoiding the interference from similar nontarget features.

In Madden's (5) review, he concludes that Plude and Doussard-Roosevelt's (27) findings can actually be interpreted as a preservation of selective attention for older adults. According to Madden, the feature search condition provides subjects with the opportunity to discriminate targets and nontargets on a single stimulus dimension. The improvement in search performance in the feature-search condition relative to the conjunction-search condition represents the efficiency of selectivity. In Plude and Doussard-Roosevelt's data, the magnitude of the decrease in the display size effect was larger for the older adults than for the younger adults, suggesting a more efficient use of selective attention.

Allen, Madden, Groth and Crozier (28), using a two-choice, visual search task, found evidence for an age-related deficit in selective attention. Both young and older adult participants responded to letters presented in one to four corners of an imaginary display square. On each trial, one, two, or three instances of a given target letter were presented. In the target only condition (TO), all nontarget corners were left blank. In the target-plus-noise condition (TPN), all nontarget corners of the square were filled with distractor (noise) letters.

The results of this study indicated that older adults exhibited a relatively larger redundancy gain for TPN trials than for TO trials, compared to young adults. A redundancy gain refers to the finding that as the number of redundant targets in a display increases, performance tends to improve. These results were interpreted as a selective attention age decrement due to an inability of the older adults to distinguish relevant from irrelevant information. Older adults had more difficulty in separating the relevant target letters from the irrelevant noise letters. The older adults benefited more from the repetition of the target letters in the display, due to the reduction of noise stimuli in the display. It is believed that increasing the number of noise letters in the display resulted in an increase in interference, particularly for older adults.

In summary, the evidence for age-related selective attention deficits comes from studies which demonstrate an age-related deficit in the ability to ignore irrelelvant or interfering information (25-28). The controversy surrounding such a conclusion comes from the notion that if these studies had provided information which distinguished the relevant and irrelevant items, the older adults would not evidence these age-related attentional selection deficits (29, 30, 31, 32, 33).

3.2. Evidence for age constancies in selective attention

Evidence for age constancies in selective attention has also been reported. The independent variables most often manipulated are the perceptual similarity between the targets and nontargets or the number of items in the display. Nebes and Madden (29) required both young and older adults to respond “yes” or “no” regarding the presence of a prespecified target in a display of six digits. Within the display, three of the items were green and three were red. The assignment of the items and colors was determined randomly. On one-half of the trials a visual color cue was presented 1s prior to the display onset which reliably indicated the presence of the target. On the remaining half of the trials, a cue, which provided no information regarding the target was presented 1s prior to the display. The results of this investigation demonstrated that the magnitude of the decrease in RT associated with the cue was equivalent for both the young and the older adults, suggesting that the older adults were just as effective as the young adults in using the cue to attend selectively to the relevant display items (5). In investigating attentional guidance, Madden, Gottlob and Allen (30) demonstrated that in a conjunction search task, both young and older adults were able to improve search efficiency by attending to a distinct subset of display items.

Older adults have also evidenced improved performance in visual search tasks when a cue for the spatial location of relevant display items is used. When visual markers are presented prior to display onset that reliably predict the location of the target, older adults have demonstrated a decrease in RT associated with target location information that is larger in magnitude than that for young adults (31-33). These findings suggest that the use of selective attention, when provided with cues that distinguish relevant from irrelevant items, is resistant to age-related decline. These findings also point to a preservation of spatial localization ability with advanced age.

Data from filtering tasks has suggested that selective attention is resistant to age-related decline. Eriksen and Eriksen (34) developed an attentional interference task in which subjects were required to make speeded judgments to a small set of targets that appeared in the center of the visual gaze. On some of the trials the target items were flanked on either side by distractor items. The goal of the flankers was to produce perceptual interference. Using the Eriksen and Eriksen (34) filtering task, Wright and Elias (35) found that younger adults were more susceptible to the distractors than were the older adults.

In response to this filtering data, some investigators have suggested that an age-related restriction in the useful field of view may underlie this effect by eliminating the interference from the distractor flankers which fall outside of the older adults more restricted useful field of view (12,15). This explanation of reduced flanker distractibility with age posits that an attentional explanation of such phenomena is not necessary. Plude and Hoyer (33) however, in comparing foveal targets in search versus foveal targets in nonsearch tasks, found that peripheral distractors disrupted the performance of older adults in a search task but not in a nonsearch task. Because foveal targets were used in both conditions, the conclusion that the older adults were insulated from the distractor flankers due to a constricted useful field of view is not fully supported.

In a visual search, divided attention task, Allen, Weber, and Madden (36) using both a two-choice and a go/no-go task in which target letters were presented in one of two corners of a two-corner display found evidence for a preservation of filtering with age. The older adults evidenced larger redundancy gains than young adults, yet this effect did not interact with task type (two-choice or go/no-go) or stimulus type (either target only trials where all nontarget corners of the imaginary square were left blank or target-plus-noise trials in which all nontarget corners of the square were filled with distractor letters) which would be expected if older adults exhibited filtering decrements. If a filtering decrement did exist one would expect to see larger redundancy benefits for TPN trials. This was particularly the case in the go/no-go condition because this task requires the participants to withhold a response to a given stimulus category (e.g., respond to "Fs" but not to "Gs"). This task is a more direct test of the inhibitory control explanation of filtering than is the forced-choice visual search task. In explaining the difference in findings between this study and the Allen, Madden, Groth and Crozier (28) study, it was concluded that when the task uses only two display positions there are few age differences in filtering or selection for visual search tasks because the capacity demands are minimal.

According to Madden (5), young and older adults are equivalent in the ability to distinguish relevant from irrelevant information but an increase in the number of relevant display items either in the target set or in the display impairs search performance more for older adults than for young adults. This increase in age differences as a function of the number of display items to be compared is consistent with an age-related decrease in the amount or the availability of attentional resources or capacity (5) or an age-related slowing of the information processing components of the task (29). However, even though set size effects are suggestive of capacity limitations, they are not conclusive. For example, set size effects can occur for a variety of reasons such as an increase in noise associated with a decision process (37).

4. AGING AND ATTENTIONAL CAPACITY

It has been postulated within cognitive psychology that performance on cognitive tasks is dependent on the availability of a limited pool of processing resources (38). According to Navon (39), in resource theory, the amount of resources invested determines the rate of processing output produced. Variability in task performance is a result of the availability of this limited pool of resources. Numerous empirical effects have been interpreted within the resource framework. Of interest in the area of aging are manipulations of task difficulty, task complexity and dual-task performance. The more difficult or complex a task, the more resources needed. In dual-task performance it is believed that the two tasks are competing for this limited pool of processing resources.

Numerous empirical findings have demonstrated that older adults are at a disadvantage relative to young adults when tasks are difficult, complex or when performing under dual-task conditions (38, 40-44). The explanation for such findings is often related to the notion that older adults are working with a diminished pool of processing resources relative to that of young adults.

Controversy has surrounded the use of attentional capacity or processing resources as an explanation for age differences in cognitive tasks. Salthouse (40, 46) discussed some of the problems inherent to the capacity or resources concept. The problem is that the exact nature of attentional capacity or processing resources has not been specified or measured. According to Salthouse, it is unknown whether the concept of limited capacity or resources refers to limitations in the amount of storage or computation in working memory, limitations in mental energy or effort, or limitations in the speed of information processing.

4.1. Evidence for age-related deficits in attentional capacity

In a review of attentional capacity, Madden (5) states that in visual search tasks, an increase in the number of relevant items either in the target set or in the display impairs search performance more for older adults than for young adults (26, 27, 33, 47). These age differences are consistent with a decrease in the amount or the availability of attentional capacity or processing resources.

Typically, attentional capacity has been assessed using methods that compare automatic versus controlled processing during visual search (48, 49). In search tasks, the demand for automatic versus controlled processing is typically varied by using consistent versus varied mapping. Under consistent mapping conditions, the assignment of target and nontarget items is constant over trials. Under varied mapping conditions, items may serve as targets on some trials and nontargets on other trials. Consistent mapping is thought to entail the use of more automatic detection which is a relatively fast, parallel comparison that is not capacity demanding. Varied mapping requires the use of controlled search processes, which are slow, serial, and capacity demanding. Under consistent mapping conditions it is typically found that RT and error rate do not increase as the number of items to be compared increases (48,49). Under varied mapping conditions, RT and error rate typically increase as a function of the number of items to be compared (48, 49).

Plude and Hoyer (50), using a card sorting task that used both consistent and varied mapping conditions, found that under the varied mapping condition the older adult's sorting time increased more than that of the young adults as the number of items in the target set or on the cards increased and stayed constant over practice. In the consistent mapping condition, however, the influence of the number of items to be compared on sorting time decreased over practice and the effects of display size and target set size were equivalent for the two groups. Other investigations of practice effects with consistent mapping have found support for the notion that the automatic components of search performance are resistant to age-related decline (32, 51-53). The more attention demanding, controlled-search processes are more vulnerable to age-related decline (54).

Dual-task performance has also been used to investigate age-related changes in attentional capacity. Dual tasks typically require subjects to perform two tasks concurrently and make a separate response to each. It is assumed that the two tasks compete for the limited capacity pool of processing resources. Within aging research, dual-task performance has been measured using tasks that involve both a primary and a secondary task. The typical primary tasks require the performance of visual detection or classification (42, 43, 52, 53, 55). Secondary tasks usually include visual search or auditory detection or discrimination (45, 53, 57, 58). The findings from such studies have demonstrated that the impairment of performance associated with dual-task conditions is greater for older adults than for young adults. This suggests that the attentional capacity demands of dual- task performance relative to single task performance are greater for the older adults. These findings suggest an age-related decline in attentional capacity.

Those who argue against an attentional capacity explanation of dual-task procedures state that the increase in age differences in dual-task performance relative to that with single-task performance may result from increases in task complexity. Numerous studies in cognitive aging research have shown that as the complexity of a task increases, the magnitude of the age differences in performance also increases (8, 10, 59, 60). It is believed that age differences in cognitive tasks are the result of a generalized slowing of all cognitive operations.

Allen, Groth, Weber, and Madden (61) investigated potential age differences in attentional resources. Using a visual search, divided attention task in which target letters were presented in one, two, or three corners of a four corner display, evidence for an age-related processing resources decrement was found. Evidence for this age-related resource decrement came from the finding that older adults, relative to young adults, evidenced an even larger redundancy gain for TO trials than for TPN trials. According to Allen, Groth, Weber, and Madden (61), if one assumes that each display corner represents a separate channel, and that the information from each channel can sum to reach a critical target response threshold, then older adults should exhibit a larger redundancy gain for TO trials if they exhibit an age decrement in processing resources. Older adults need more instances of target letters to reach the critical target response threshold. These results were interpreted as evidence for older adults having fewer processing resources because it takes more instances of target letters compared to young adults to reach the critical target response threshold.

5. SUMMARY OF FINDINGS ON ATTENTIONAL SELECTION, ATTENTIONAL CAPACITY, AND AGE

In summary, based on the above research on attentional selection and capacity, it appears to be the case that attentional selectivity is resistant to age-related decline, whereas, attentional capacity is not resistant to age-related decline. When older adults are given advance information that partitions relevant and irrelevant information, they are just as effective as young adults at using that information to selectively attend to the relevant items without distraction from the irrelevant items. In terms of attentional capacity, the summary is more problematic due to the use of the limited capacity or resources concept. If limited attentional capacity is defined as a limitation in working memory space, mental effort or information processing speed, it appears that there are age differences in attentional capacity. Much of the problem arises from the lack of a definition of capacity or resources and of empirical evidence for where the limitations occur.

6. BEYOND TRADITIONAL ATTENTIONAL SELECTION AND CAPACITY THEORIES

More recent psychological research in the area of aging and attention has focused on redefining just what is selected in selective attention (62-66). Also, current research has investigated the possibility of a processing bottleneck under dual-task conditions (21,67) which presumes that age limitations may be due to decrements in attentional time-sharing which refers to the ability to serially switch between or among tasks rather than graded capacity-sharing which involves allocating resources, in parallel, between or among tasks (22). More recent visual search studies, which show age differences in search RT and errors when display size is increased, have been interpreted as being indicative of an age-related slowing of the information processing components of the task rather than being attentional in nature (68-70).

7. WHAT IS SELECTED IN VISUAL SELECTIVE ATTENTION: VARIETIES OF ATTENTIONAL SELECTION

7.1. Space-based selective attention

Selective attention has been described as a spotlight (71), a zoom lens (72), or a spatial gradient (73). All three of these metaphors imply that visual attention corresponds to a focus, a margin and a fringe. Objects that fall within the focus of attention are more effectively processed than objects that fall outside of the attentional window in the margin or the fringe. Theories that have used these three conceptualizations of attention are referred to as space-based theories and they posit that attention is directed to a spatially defined region of an image. The research on aging and selective attention reviewed earlier examined age-related differences in spatial attention.

7.2. Object-based selective attention

More recent research emphasizes that attention can be used to select objects and perceptual groups and that visual attention is object-based (62-65, 74). According to object-based theories of selective attention, attention selects preattentively defined perceptual objects based on the Gestalt principles such as proximity, similarity and common motion (66). Kahneman, Treisman, and Gibbs (64) propose that the visual field is preattentively segregated into perceptual objects and focused attention then selects specific objects for more detailed analysis. What constitutes an object is based on the perceptual grouping process.

Duncan (63) conducted research contrasting space- and object-based notions of selective attention. The stimulus used in Duncan's study consisted of a box with a line running through it. Subjects were required to judge attributes of the stimulus such as the size of the box, the location of a gap in the box, the orientation of the line and the texture of the line. The critical manipulation was whether the target properties appeared on the same or on different objects. According to object-based theories, performance should be better when both properties appear on a single object than when they occur on different objects because objects or perceptual groups are selected in a serial fashion. The results of Duncan's experiment were consistent with an object-based selection mechanism. Additional evidence for object-based attentional selection has been found by Kramer and Jacobson (74), Baylis and Driver (62), and Yantis (66).

7.2.1. Object-based selective attention and aging

In an effort to extend object-based selective attention theory into the aging realm, Kramer and Weber (65) conducted two studies to investigate potential age-related differences in object-based attentional selection. Participants in Kramer and Weber's study were presented with pairs of wrenches and were asked to make one response if two target properties were present in the display and another response if only a single property was present in the display. The manipulation of interest was whether the target properties were present on one wrench or distributed between two wrenches. Object-based selective attention models predict better performance when both target properties appear on a single wrench. Kramer and Weber found evidence consistent with object-based models. Both young and older adults evidenced better performance when the target properties appeared on the same object. Of interest with regard to aging was the fact that the young and the older adults showed similar performance effects suggesting that object-based selective attention is insensitive to aging.

In summarizing the work on aging and object-based selection, Kramer and Weber stated that further research has to extend beyond the simple and uncluttered displays typically used and evaluate older adults' performance with the use of cluttered displays. The use of cluttered displays to evaluate object-based selection and aging is important due to the difficulty older adults have evidenced when searching for targets among heterogeneous distractors (69, 75). Also, given that there is evidence for both space-based and object-based attentional selection, and the possibility that the two types may interact, aging research should focus on whether age differences could be the result of having to shift from one form of selection to another within any given task.

8. BEYOND A GENERAL ATTENTIONAL RESOURCE

The fact that people have trouble performing two tasks concurrently has fueled the emphasis on the notion of a limited pool of processing resources or a limited pool of attentional capacity. In a typical dual-task architecture, a participant carries out two separate discrimination tasks, the stimuli for which are presented sequentially. Task 1 (T1) requires a response to the first-presented stimulus (S1) and Task 2 (T2) requires a response to the second-presented stimulus (S2). Reaction time (RT) and accuracy are typically measured for each task. The responses to S1 and S2 are RT1 and RT2 and R1 and R2. What commonly occurs in this paradigm is a slow down in responding to the second stimulus when the time between S1 and S2 is reduced. The time between S1 and S2 is referred to as the stimulus onset asynchrony (SOA). This slow down in responding is referred to as the psychological refractory period (PRP)effect (21, 67, 76, 78).

8.1. Capacity-sharing

Dual-task interference has been attributed to capacity sharing. According to graded capacity sharing, people share processing capacity among the two tasks leaving less capacity for each individual task, thus impairing performance (38,78). To the extent that processing capacity is allocated to T1, less is available to T2, resulting in the slowing of RT2 when S1 and S2 are presented progressively closer together in time. Graded capacity sharing predicts that RT1 will increase as the SOA between S1 and S2 is decreased. If RT1 increases as SOA decreases and RT2 increases as SOA decreases then this is evidence for graded capacity sharing. If two tasks are competing for the limited capacity or resources, they should both be negatively impacted by reductions in SOA.

8.2. Time-sharing: A third aspect of attention

Rather than graded capacity sharing, Pashler suggests that an alternative theory in dual-task interference is that there exists a “central bottleneck” such that parallel processing may be impossible for certain mental operations. When two tasks need a particular mechanism at the same time the result is a bottleneck and one or both of the tasks will be delayed or impaired. According to this theory, the central processing stages of retrieval and response selection for the two tasks have to be carried out serially and this serial processing produces a bottleneck.

According to Pashler, a bottleneck is a processing stage required by both T1 and T2 that is dedicated to only one task at any particular moment in time. This bottleneck model makes the same prediction for RT2 as capacity sharing, that RT2 will increase as the SOA between S1 and S2 decreases. However, the bottleneck model predicts that RT1 will be either unaffected by the SOA between S1 and S2 or RT1 will decrease as SOA decreases. This theory has been termed serial time-sharing in opposition to parallel capacity-sharing.

8.2.1. Age differences in time-sharing

Allen, Smith, Vires-Collins and Sperry (22) examined whether age differences in time-sharing, defined as the serial switching from one task to another, at the response-selection stage of processing exist. In Experiment 1 of Allen et al. (22), Task 1 consisted of tone discrimination and Task 2 consisted of determining the location of a dot. Older adults showed a larger PRP effect on Task 2 relative to the young adults. In their second experiment, Task 1 was a dot location task and Task 2 was a simultaneous letter matching task. Older adults again showed a larger PRP effect than young adults for Task 2. Also, for both experiments, Task1 performance either became poorer as SOA increased or was unaffected by the SOA between T1 and T2 and these effects were consistent across age. Based on these data, it was concluded that older adults, relative to younger adults, exhibit a decrement in time-sharing at the response selection stage of processing (22). When the SOA between T1 and T2 is reduced, the older adults are at a larger disadvantage because they have not completed T1 response selection before the completion of pre-response-selection processing of T2. The restriction on processing imposed by the bottleneck is more severe for older adults than for younger adults. Note that these PRP data (22) are not consistent with a general capacity limitation because RT1 never decreased as SOA decreased (it either was unaffected by SOA or it increased with SOA).

9. SELECTIVE ATTENTION AND THE MULTICHANNEL MODEL OF VISUAL INFORMATION PROCESSING

The notion of object-based selective attention emphasizes a preattentive selection process and a more focal attention to that which has been preattentively selected. Evidence from vision research has suggested that rather than attention, the selection of certain attributes of objects for further scrutiny is dependent upon the functioning of different spatial frequency channels in the visual system (79). Julesz and Papathomas (80) posit that spatial frequency channels in the visual system aid in the shifting of attention, thus permitting a more detailed look at relevant stimuli.

9.1. The neural basis of visual perception: The multichannel model

Based on behavioral data, there is now evidence to suggest that there are at least two classes of neural channels in the human visual system that respond to different properties of visual stimulation (81-83). The two classes of channels include the transient or magnocellular channels and the sustained or parvocellular channels. Each channel can be distinguished by its temporal response properties and its selectivity for stimuli of different sizes and spatial frequency. The transient or magnocellular channels respond quickly to the onset of stimulation and their response to such stimulation is short-lived (84,85). They respond best to low spatial frequency, global form information. The sustained or parvocellular channels are slower to respond to the onset of stimulation and their response is of longer duration (84, 85). They are most sensitive to high spatial frequency or detail information. The Contrast Sensitivity Function (CSF) provides a summary of the sensitivity of these channels to differing spatial frequencies.

Typically, measurement of a person’s CSF is done to determine the discriminating ability of his or her visual channels to spatial frequency by relating the amount of contrast required to detect a sinusoidal grating to the spatial frequency content of the grating. The more contrast that is required to detect a grating of a particular spatial frequency, the less sensitive that person is to that spatial frequency. The spatial frequency of a grating is defined by the number of repetitions of the sinusoidally varying dark and light bars per degree of visual angle. A low-frequency sinusoidal grating consists of slowly changing dark and light bars, whereas, a high-frequency grating consists of numerous changes between light and dark bars. It is posited that the perception of complex images, which are composed of numerous spatial frequencies, is a function of sensitivity to the pure gratings of the contrast sensitivity test.

9.2. Differences in contrast sensitivity with age

Interest in the effects of aging on the CSF began over 20 years ago. The data of Kline, Schieber, Abusamra and Coyne (18) and Owsley, Sekuler and Siemsen (19) demonstrated an age-related deficit in contrast sensitivity for intermediate- to high-spatial frequencies. Based on these findings and more recent findings (20) it is concluded that older adults, when presented with stationary gratings, show a decrease in sensitivity to medium and high spatial frequency information relative to young adults. This decrease in sensitivity to medium and high spatial frequencies is interpreted as a lack of detail resolution beyond that which is apparent in normal acuity measures. The lack of an age difference in the sensitivity to low spatial frequencies suggests that both young and older adults are equally sensitive to global form information.

9.3. A multichannel model interpretation of empirical findings

Navon (79) investigating the global precedence effect, used stimuli that consisted of large letters made up of small letters (e.g., a large H made up of small Gs). Participants in his study were asked to report the identity of either the small letters or the large letter. These stimuli were used as a method to direct local and global attention. What was found was that young adults could concentrate attention on either the small or the large letters, however, their response to the large letter was quicker than that to the small letters, thus the term the global precedence effect.

According to the multichannel model, the global precedence effect is due to the timing of the two visual channels; the magnocellular or transient channels and the parvocellular or sustained channels. Within the model, low spatial frequency, global form information becomes available in the visual system very quickly after the onset of a stimulus but is of very short duration. Higher spatial frequency information, in the form of more local details, takes a bit longer to become available to the visual system, however, it is of longer duration. In Navon's task, the larger letter was the global form and the smaller letters were the local detail. The young adults had to wait for the local details to become available before they could respond to them.

The typical results of the flankers task, in which a target letter is surrounded by nontargets that are either similar or dissimilar to the target can also be described by hypothesizing the functioning of different channels within the visual system which are sensitive to different spatial frequency information. It has been shown that the time to identify the target letter M in a display such as W M N in which the flankers are similar to the target is longer than that to respond to a target letter M in a display such as O M C in which the flankers are dissimilar (86). In the dissimilar flanker condition, the response can be based on the quickly available global information provided by the transient or magnocellular channels (a sort of pop-out effect). In the similar flanker condition, however, more high spatial frequency information is needed to correctly identify the target.

The findings from these studies suggest that some selection may be based on the functioning of these visual channels rather than being attentional in nature. The difficulty with this hypothesis comes from the reluctance of cognitive psychology, because of its emphasis on independent processing stages (87), to embrace the notion that early visual processing can have an impact on higher order processes.

9.4. The multichannel model and aging

It is known that older adults have reduced sensitivity to medium to high spatial frequencies through measurement of their contrast sensitivity (18-20). Very little research has embraced this finding and investigated it in relation to its impact further in the information processing system. In predicting their performance in either the Navon task or the flankers task, one would expect older adults to show more performance decrements when a response was reliant on high spatial frequency or detail information relative to young adults. Due to reductions in sensitivity to higher spatial frequency information, older adults should be even slower than the young adults in determining the identity of the smaller letters in the Navon task and the target letter in the similar flanker condition.

10. NEUROSCIENTIFIC EVIDENCE FOR AN ATTENTIONAL SYSTEM

The research and theory reported earlier in this paper involve the use of reaction time and accuracy as dependent variables. In the following sections, we will review briefly data obtained from other dependent variables—such as event-related potentials (formed from summed EEGs) or image activation patterns obtained during positron emission tomography (PET) scanning or magnetic resonance imaging (MRI). These more neuroscientifically oriented dependent variables have led some attention researchers to brain models of attention, and how increased adult age affects these systems.

Evidence based on imaging studies and studies of brain-lesioned organisms suggests that there exists a selective attention system that serves a filtering or selection function. The filtering or selection process occurs through the amplification and regulation of the activity of separate processing systems involved in cognitive tasks. Posner and Petersen (3) discuss three hypotheses about attention. First, the attention system of the brain is separate from the data processing system. Second, attention is carried out by a network of anatomical areas. Third, the areas involved in attention carry out different functions which can be specified in cognitive terms. The whole network serves to enhance visual information that occurs at a selected location.

Posner (23) and Posner and Petersen (3) posit that the attention system of the brain consists of two networks. One is responsible for orienting to spatial location (the posterior attention network) and the other is responsible for detecting (the anterior attention network). In terms of attentional selection, it is hypothesized that some areas of the brain can enhance the functioning of individual neurons. This enhancement effect is due to the functioning of the posterior parietal lobe, the lateral pulvinar nucleus of the thalamus and the superior colliculus (3, 23). The anterior attention system is important in regulating cognitive activity (23).

In summarizing the attention system, Posner and Petersen state that the two hypothesized attention systems (posterior and anterior) operate in conjunction with other systems that perform cognitive operations, such as word identification and semantic processing. The goal of attending to a particular location is to assist in the processing of any item that is located there by enabling faster processing or more accurate detection or identification (23, 88-92).

LaBerge (93) postulates an attention system that is directed by the cognitive system. Similar to Posner and Petersen, LaBerge suggests that the pulvinar is the locus of the filtering operation in selective attention. The thalamus produces selective amplification at a target area through the enhancement of target thalamic relay cells, which in turn inhibit neighboring cells. LaBerge proposes a model of the thalamus that consists of enhancement circuits that produce an amplification of the activity of cortical cells that magnifies those cortical cells' advantage over their neighbors. LaBerge refers to this as the Thalamic Enhancement Circuit (TEC). Unlike Posner and Petersen, LaBerge suggests that the original orienting process is conducted by higher order cortical processes.

10.1. Aging and the neuroscientific investigation of attention

Most of the cognitive neuroscience research on age differences in attention has been conducted using event-related potentials (94-96). As noted earlier, event-related potentials (ERPs) are summed electroencephalograms (EEGs) developed from scalp potentials resulting from visual or auditory stimuli. We will limit our present discussion of the ERP literature on aging and attention to visual paradigms. Unfortunately, this eliminates much of the work in this area (96).

Two important ERP papers on age differences in attention that involved visual presentation paradigms will be discussed. Strayer, Wickens, and Braune (97) reported an ERP study on younger and older adults in which P300 waves (positive waves occurring approximately 300 ms after stimulus presentation) showed no age differences in slope across memory set size. However, there were age differences in RT-based slope across memory set size. The lack of age differences in ERP-based slopes, but the existence of age differences in RT-based slopes led Strayer et al. (97) to conclude that there were age differences in response processes (e.g., response selection) but not age differences in memory search. (The P300 wave is not assumed to measure response processes.) These findings replicated an earlier, less comprehensive, memory scanning study reported by Ford, Roth, Mohs, Hopkins, & Kopell (98).

Bashore, Osman, and Hefley (94) reported a meta-analysis of ERP, P300 studies involving age differences. These researchers replicated the Ford et al. (98) and Strayer et al. (97) results on a much wider variety of information-processing tasks than used in the earlier-reported studies. Bashore et al. (94) found that the slope on a Brinley plot derived using P300 latencies (rather than RT latencies) across a wide variety of cognitive tasks showed no age differences (i.e., the slope was not significantly different from 1.00). The RT-based Brinley plot for these very same studies, though, showed a slope significantly greater than 1.00 indicating that older adults slowed down relative to younger adults. Bashore et al. (94) concluded that differential age effects for ERPs relative to RTs suggested that central-process comparison time was not affected by increased adult age, but that response selection was affected by increased age. Also, age differences in the intercepts of the P300-based Brinley plots indicated the presence of peripheral-process (encoding) decrements.

Very little research using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) has investigated attention within an aging framework. Madden, Turkington, Provenzale, Hawk, Hoffman, and Coleman (99) in a PET study of visual search found age differences in search performance when it was necessary to divide attention among display positions. There was an increase in cerebral blood flow in prefrontal cortical regions which was relatively greater for older adults. However, when individuals selectively attended to a known display location, there were no observed age differences. Indeed, there was no cortical activation in either age group when subjects selectively attended to a known display location.

Based on the neuroscientific evidence to date, one can hypothesize about changes in an attentional system with age. According to Hartley (2), it is unlikely, given the dispersion of the attentional system throughout different regions of the brain, that there is a general attentional resource that changes uniformly with age. This architecture is consistent with the idea that there are multiple "pools" of attention resources (100). Psychological research on aging and attention may benefit from tempering the notion of attentional capacity and attentional resources and embracing the knowledge obtained from investigations in cognitive neuroscience.

In an effort to do this, cognitive aging researchers need to employ the methodologies of the neuroscientists such as PET scanning, fMRI, MRI and other imaging techniques. The aging research that has used these imaging techniques has focused on memory tasks (4, 101, 102), mental imagery tasks (103) and indirectly on attentional processes. Some indirect evidence for attentional mechanisms within imaging and memory research has come from the investigation of the effects of practice in a given cognitive task. Madden, Turkington, Provenzale, Denny, Hawk, Gottlob, and Coleman (4), using PET, found evidence for differential regional cerebral blood flow (rCBF) for the first and second halves of a testing session in a recognition memory task. Both Madden et al. (4), and Raichle, Fiez, Videen, MacLeod, Pardo, Fox and Petersen (104) observed that rCBF changes associated with the early stages of practice tended to decline as task performance improved and less attentional control was required. In the Madden et al. (4) study, the effects of practice were more apparent for young adults than for older adults. This age difference was interpreted by Madden et al. (4) as suggesting that the young adults were more efficient at reducing the attentional demands of the recognition memory task.

In conclusion, Madden et al. (4), state that the older adults' retrieval-related changes in rCBF involved both the activation and deactivation of additional brain regions. This recruitment of additional neural regions (i.e., left prefrontal cortex, inferior parietal lobule) may represent the continual allocation of attention to task control which the young adults were able to relinquish with increased practice.

In investigating mental imagery through the use of structural Magnetic Resonance Imaging (MRI) scans, Raz, Briggs, Marks and Acker (103) found more indirect evidence for attentional change with age. Raz, et al. (103) concluded that age-related differences in the speed and accuracy of performance depend on the availability of cognitive and neural resources based in the prefrontal cortex. These resources are dedicated to the executive control of cognitive performance. These researchers concluded that reductions in the volume of the anterior association cortex mediated the age-related decline in mental imagery performance. Unlike the young adults in their study, the older adults showed activation in the prefrontal cortex which has been shown in functional neuroimaging studies to become activated when identification is increasingly difficult. Raz, et al. (103) found evidence that the age-related shrinkage of prefrontal association areas may produce processing deficits in mental imagery tasks.

11. PERSPECTIVE

In his review of attention, Hartley (2) discusses what changes a future review of attention and aging might contain. He predicted that the largest changes and promise for answers would come from research in the area of cognitive neuroscience. What has not changed between the time of his review and the present review is the varied theoretical explanations within psychological research for changes in attentional processes with advanced age and the contradictory findings in terms of both attentional selection and attentional capacity. It is safe to conclude, based on psychological research to date, that older adults are just as effective as young adults at selectively attending to relevant information if information about what is relevant is made available to them. In terms of the capacity aspect of attention, however, no definitive statements can be made with respect to aging due to the continuing controversy surrounding the use of the concept of capacity or resources. There is still no behavioral evidence that specifies what the resources are or where limitations may occur.

Further research is necessary in the area of visual perception to see if the nature of a stimulus at the encoding stage can have an impact further in the information processing system. Of interest is whether the visual deficits of older adults at both the ocular and the neurological levels (spatial frequency channels) impact their information processing performance. What may appear as a resource limitation may actually be due to the higher order processes being impacted detrimentally by visual deficits.

What has changed and is continuing to change is the combining of behavioral evidence from psychological research and neurological evidence from cognitive neuroscience research that has helped to provide converging operations for the existence of a modular attention system that controls cognitive processing. Thus, there is converging evidence (both behavioral and image-based) for something akin to processing resources or limited-capacity. With respect to aging, evidence from studies using PET scanning while subjects perform cognitive tasks has demonstrated a heavier reliance on attentional control by older adults when compared to young adults, particularly when task demands are high. The area involved in this attentional control appears to be the prefrontal cortex. The prefrontal cortex could be the neurological correlate of or the site of processing resources. Further research that combines both behavioral and neurological methods should focus on the impact of age-related attentional differences during cognitive task performance.

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Send correspondence to: Dr Karen E. Groth, Department of Psychology, Cleveland State University, Euclid Avenue at East 24th street, Cleveland, OH 44115, Tel:216-687-9386, Fax:440-687-9294, E-mail: K.Groth@popmail.csuohio.edu

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