Published in final edited form as:
Curr Dir Psychol Sci. 2007 April ; 16(2): 70–74. doi:10.1111/j.1467-8721.2007.00478.x.

Aging and Visual Attention

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Abstract

Older adults are often slower and less accurate than are younger adults in performing visual-search tasks, suggesting an age-related decline in attentional functioning. Age-related decline in attention, however, is not entirely pervasive. Visual search that is based on the observer's expectations (i.e., top-down attention) is relatively preserved as a function of adult age. Neuroimaging research suggests that age-related decline occurs in the structure and function of brain regions mediating the visual sensory input, whereas activation of regions in the frontal and parietal lobes is often greater for older adults than for younger adults. This increased activation may represent an age-related increase in the role of top-down attention during visual tasks. To obtain a more complete account of age-related decline and preservation of visual attention, current research is beginning to explore the relation of neuroimaging measures of brain structure and function to behavioral measures of visual attention.

Keywords

visual perception; adult development; cognition; reaction time; neuroimaging

The frequently quoted observation by William James that ''Every one knows what attention is'' (James, 1890/1950, p. 403) is also applicable to the topic of visual attention, because ''everyone knows'' that there is age-related change in visual attention. Scientific research on attention over the past 100 years has continued to expand the definition of attention. Similarly, research on adult age-related differences, conducted over a more recent period, has provided additional insight into the changes in attention that occur during adulthood. The results of this research are important because they challenge the assumption that decline is the only form of age-related change. In addition, neuroimaging studies are providing a wealth of information regarding the brain mechanisms of attention. Thus, current accounts of age-related changes in attention reflect two influences: behavioral research focused on defining the role of attention in task performance and neuroimaging research directed towards identifying the relevant neural systems.

FEATURES OF ATTENTIONAL GUIDANCE

Continuum of Search Efficiency

In navigating the visual environment, people must attend to some objects and ignore others. Guiding attention to the relevant object is easy in some instances, as when noticing a red wine stain on a white carpet, but more difficult in others, as when attempting to identify objects in a blurry photograph. To quantify how attention is used in these perceptual tasks, behavioral research has relied extensively on analyses of *visual search*, in which observers attempt to find a predefined target item in a display of accompanying nontarget (distractor)

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items. The measure of interest is often the change in reaction time (RT) or accuracy for detecting the target, in relation to an increasing number of display items (display size). As illustrated in panel A of Figure 1, the search target (e.g., an upright T) may be a featural *singleton*, defined as an item that differs from all of the distractors in a particular feature (e.g., color, shape, or size). Detection of a singleton target is highly efficient, and RT is relatively unaffected by the number of distractor items. In contrast, when the target and distractors share features (Fig. 1, panel B), search is less efficient, and target detection requires additional time as display size increases.

Current theories of visual attention characterize the difference between panels A and B in Figure 1 in terms of a continuum of search efficiency, rather than as categorically different forms or stages of information processing (Wolfe & Horowitz, 2004). Search is highly efficient (as in panel A) when driven entirely in a *bottom-up* manner—that is, by salient differences among the features of the display items. In highly efficient search, the observer has the impression that the target pops out of the display, capturing attention automatically. Successful performance in more difficult search tasks (as in panel B) relies on *top-down* processing—that is, the observer's knowledge of the target and how it differs from the distractors. In this type of inefficient or difficult search, there is typically a direct increase in RT as a function of increasing display size, and thus the slope of the line of RT plotted against display size (or the RT×Display Size function) is useful as a metric of search efficiency.

Most instances of visual search, however, involve a combination of bottom-up and top-down effects. These effects do not occur in entirely separate processing stages but instead interact to determine performance. Top-down, knowledge-based processing can influence attentional guidance even when search is highly efficient (Wolfe, Butcher, Lee, & Hyle, 2003). Similarly, top-down knowledge of the relevant target feature can help observers to reduce or eliminate distraction from salient but irrelevant display items (Leber & Egeth, 2006).

Age-Related Changes in Attentional Guidance

In difficult search tasks such as those illustrated in panel B of Figure 1, the slope of the RT×Display Size function is typically higher for older adults than for younger adults, suggesting an age-related decline in the efficiency of search processes (Madden & Whiting, 2004). One goal of research on aging and attention is to clarify the relative contribution of the bottom-up and top-down components of age-related changes in visual attention. Older adults show declines in bottom-up visual processing at the sensory level, even when tested under best-corrected conditions (i.e., with glasses). When the visual target is a featural singleton, however, older adults typically exhibit the independence between RTand display size indicative of highly efficient search (Plude & Doussard-Roosevelt, 1989;Whiting, Madden, Pierce, & Allen, 2005). Thus, although age-related decline in bottom-up visual processing contributes to an overall slowing of perceptual processing speed for older adults, there is also some preservation of bottom-up attention, providing a basis for highly efficient search.

Cognitive-aging research has documented age-related decline in top-down attention, although researchers have expressed this conclusion in various ways. Several theories have been developed around the idea of age-related decline in executive processing, defined as processes involved in maintaining and updating information in working memory, in inhibiting irrelevant information, and in time sharing between tasks (Verhaeghen & Cerella, 2002). Older adults appear to be less successful than younger adults at using a top-down attentional set (i.e., maintaining mental preparation) for avoiding attentional capture by a salient but task-irrelevant display item (Colcombe et al., 2003). These findings suggest that older adults' decreased performance in visual-search tasks is not attributable entirely to bottom-up processing and includes some decline in top-down attentional control.

Other forms of top-down attention, however, do not completely conform to the predictions of executive-control theories, instead exhibiting a substantial degree of constancy as a function of adult age. In highly efficient search tasks, in which RT is independent of display size, advance knowledge of the target-defining feature leads to comparable levels of improvement in search performance for younger and older adults (Whiting et al., 2005).

Older adults are also successful in using some forms of top-down attention in more difficult search tasks. Madden, Whiting, Cabeza, and Huettel (2004) varied the probability that the target would be a color singleton (a red letter among gray letters). This was a difficult search task in which each display contained either four or six letters, and participants responded as to which one of two target letters (E and R) was present in the display. Across blocks of trials, participants performed two task conditions: ''neutral,'' in which there was low probability (.17–.25) that the color singleton would be the E/R target, and ''guided,'' in which there was higher probability (.75–.83) of singleton–target correspondence. Attending immediately to the singleton in the guided condition will thus facilitate identifying the target, and it will delay finding the target on those trials when it is not the singleton. The results indicated that the changes in search RT related to the target singleton were substantially greater in the guided condition than in the neutral condition, implying top-down attention to the target-relevant feature (color). The magnitude of this effect, in terms of the proportional change in RT, was comparable for the two age groups. Thus, although other forms of executive control exhibit age-related decline, older adults' top-down attention exhibits some degree of preservation.

The benefit in search performance associated with frequently occurring targets is due to two factors: the observer's conscious expectation that a particular feature or item will occur, and priming effects associated with repeating a particular feature across successive trials, independently of whether the observer is aware of that repetition. These two aspects of top-down attention are difficult to separate entirely. From the results of visual-search tasks that systematically varied the repetition priming of target and distractor features, it appears that both the repetition-priming and conscious-expectation aspects of top-down attention are preserved for older adults and that older adults place additional emphasis on the expectation of target-relevant features (Madden, Spaniol, Bucur, & Whiting, in press). This increased reliance on top-down attentional guidance may represent a compensatory response to age-related decline in bottom-up sensory processing.

COGNITIVE NEUROSCIENCE OF AGING AND ATTENTION

Brain Mechanisms of Attention

The age-related changes in visual attention discussed up to this point have been assessed in behavioral measures of visual search. How are the behavioral findings related to the brain mechanisms of attention? Neuroimaging studies of younger adults have led to some agreement on the broad outlines of these mechanisms (Kastner, 2004; Shulman et al., 2003). Much of this research has involved positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), both of which measure the activation of cerebral gray matter, during the performance of cognitive tasks. A *frontoparietal network*, spanning the frontal and parietal lobes, on the lateral surface of the brain, appears to mediate performance in visual-search and detection tasks. Within this network, the dorsal regions (those on the upper surface) of the frontal and parietal lobes are particularly important for top-down attentional guidance during visual search. The network also contains a ventral component (on the lower surface of the frontal and parietal lobes), especially in the right hemisphere, mediating bottom-up attention. The ventral component acts as a ‘‘circuit breaker’’ that orients attention to unexpected or particularly relevant events.

Age-Related Changes in the Attentional Network

Neuroimaging studies of older adults have yielded evidence of age-related change within the dorsal component of the fronto-parietal network. Activation of regions of the frontal lobe during cognitive tasks, for example, tends to increase as a function of adult age, which may reflect older adults’ increased emphasis on the top-down attentional-control processes mediated by these regions (Cabeza, 2002; McIntosh et al., 1999). Less is known regarding age-related effects in the ventral component of the network. Activation of cortical regions mediating visual processing, situated in the occipital lobe (at the back of the brain), is often lower for older adults than it is for younger adults, which may reflect age-related decline in the quality of the bottom-up sensory input. Consistent with this type of decline, studies of nonhuman-primate brain anatomy have reported age-related degradation of white matter in the optic nerve, including both loss of axons (the extensions of nerve cells that conduct impulses to other nerve cells) and abnormalities of axons’ myelin sheaths (the insulating coating that facilitates conduction). Neuro-imaging studies also suggest, however, that age-related decline in the volume of gray matter (nerve cells) is greater in the frontal lobe than it is in other brain regions. Thus, the relations between these structural and functional changes in the frontoparietal network, and their influence on attention, have not yet been completely defined.

In a recent fMRI study (Madden et al., 2007), my colleagues and I demonstrated that age-related changes in frontoparietal activation were associated specifically with top-down attentional guidance during visual search. In this experiment we used a letter-search task in which, as described previously, the probability that a color singleton would correspond to the search target was either high (guided condition) or low (neutral condition). One of the main findings, illustrated in Figure 2, was that activation in the frontal and parietal lobes was correlated with search performance for older adults, whereas activation in the occipital lobe was correlated with search performance for younger adults. Because this pattern held only in the guided condition (i.e., when the color singleton predicted target location) and not in the neutral condition, these data support the view that older adults’ increased frontoparietal activation represents top-down attentional control.

In addition to measures of cortical activation from fMRI, we (Madden et al., 2007) also obtained measures of white-matter integrity from diffusion tensor imaging (DTI; a structural imaging measure that is sensitive to the rate and directionality of diffusion of water molecules in tissue). DTI provides a measure of the integrity of white-matter tracts, such as the degree to which axons are oriented in the same direction and possess intact myelin sheaths. We found that white-matter integrity was lower for older adults than for younger adults, particularly in prefrontal regions, although this effect was statistically independent of the age-related change in search performance. Further investigations of aging and DTI will be valuable, however, because age-related changes in white matter that lead to disconnections between components of the frontoparietal network may be an important source of age differences in visual attention. The type of age-related increase in frontoparietal activation we reported (Madden et al., 2007), for example, may represent a compensatory response to decline in the bottom-up input from sensory pathways.

CONCLUSION AND FUTURE DIRECTIONS

Behavioral research on age-related change in visual attention suggests that decline occurs in bottom-up visual sensory processes and in some aspects of executive processing related to task control. Some forms of top-down attentional guidance, however, remain operative in older adulthood and may even play a larger role in the performance of older adults. Thus, one direction for future research is to determine the distinguishing features of top-down attention that separate it from executive processes exhibiting age-related decline. A related question is whether the age-related increase in top-down attention that has been observed in some visual-search tasks is a compensatory response to the decline in sensory processing. Neuroimaging findings lead to a compensatory interpretation, but additional evidence linking age-related increase in frontoparietal activation with higher levels of behavioral performance is needed. In addition, within the frontoparietal network, age-related changes are observed most frequently in the dorsal component mediating top-down attention. Little is known regarding age-related change in the ventral component mediating the detection of target-relevant features. Developing a more comprehensive account of aging and visual attention will involve integrating data from structural imaging (e.g., white-matter integrity), functional imaging, and cognitive performance.

Beyond these basic theoretical issues, researchers are also actively addressing the question of translation between laboratory and applied settings. In the case of visual attention, several studies have demonstrated correlations between laboratory measures of attention and automobile-driving performance (e.g., accident rates). Reports are also emerging to indicate that various forms of interventions designed to improve physical and cognitive vitality may lead to corresponding improvements in both the behavioral measures of attention and the brain structures related to them.

Recommended Reading

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Acknowledgments

Supported by Research Grants R37 AG02163 and R01 AG011622 from the National Institute on Aging. This article reports work conducted in collaboration with Scott Huettel, Roberto Cabeza, James Provenzale, Leonard White, Barbara Bucur, Julia Spaniol, and Wythe Whiting.

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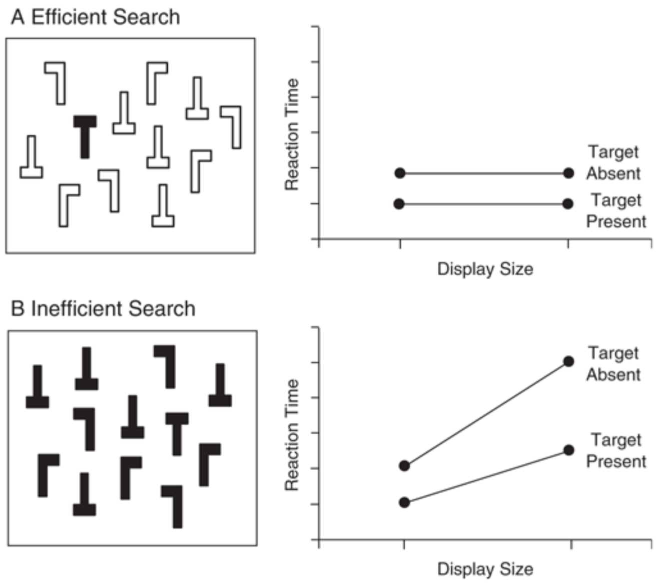

Fig. 1.

Efficient (A) and inefficient (B) visual-search performance. In both cases, the target is an upright T. In the upper left panel, the target differs from the nontarget display items in a unique feature, color; as a result, target detection is highly efficient and reaction time is independent of the number of distractor items (display size; upper right). In this case, search is influenced primarily by the bottom-up process of feature salience. In the lower left panel, the nontarget features are similar to those of the target, leading to a less efficient, attention-demanding search process. The observer must search through the display items individually, leading to pronounced increase in reaction time as a function of display size (lower right). In this case, because the target cannot be distinguished from the nontarget items by local feature differences, performance is determined by the observer's top-down guidance of attention to the target.

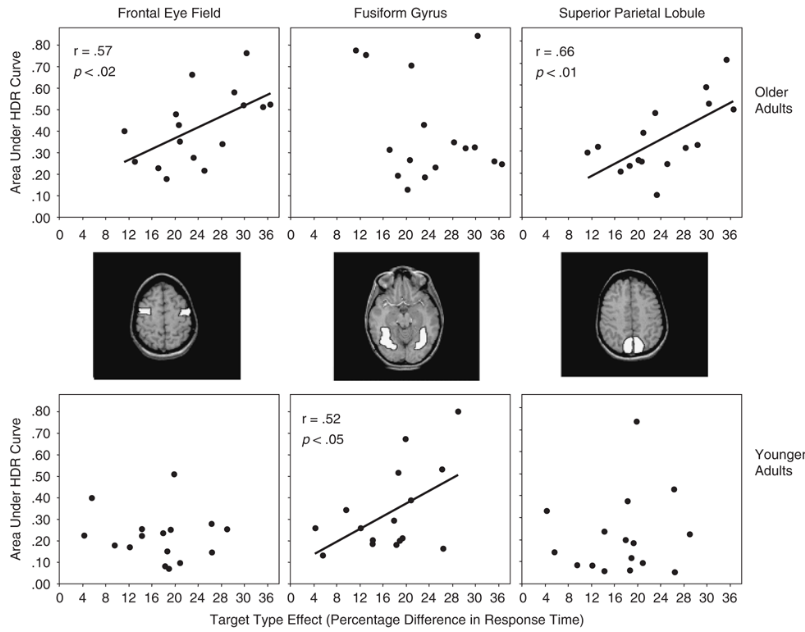

Fig. 2.

Difference in the activation of three brain regions during top-down visual search for older (top) and younger (bottom) adults. Regions of interest included the frontal eye field (in the upper surface of the frontal lobe; left), the fusiform gyrus (in the lower surface of the occipital lobe; middle), and the superior parietal lobule (in the upper surface of the parietal lobe; right). Area under the HDR curve refers to the measure of activation during functional magnetic resonance imaging, defined by the area under the hemodynamic response (HDR) curve. The target-type effect refers to a behavioral measure of visual-search performance, the percentage change in reaction time for target-letter identification when the target is presented in a unique color (e.g., a red letter among gray letters), relative to when one of the nontarget items is presented in a unique color. The figure illustrates the finding that, when search involves top-down attention (i.e., the observer’s expectation regarding the probability of the target’s color), activation of the frontal and parietal regions (frontoparietal network) was correlated with search performance for older adults but not for younger adults. (Modified with permission from Madden et al., 2007.)