RESEARCH BRIEF

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Aging and Top-Down Attentional Control in Visual Search

Project Leads

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Statement of Problem

Many visual tasks, such as airport baggage screening, rely heavily on the ability to accurately and efficiently search for and detect target items amongst distractors. For example, in a luggage X-ray, a weapon such as a knife must be discriminated from visually similar items (McCarley, Kramer, Wickens, Vidoni, & Boot, 2004). It is critical to the mission of the Human Factors/Behavior Sciences Division of the Department of Homeland Security (DHS) to be able to assess and maintain this skill set in those employed as baggage screeners. Basic and applied research in visual search has yielded an extensive body of knowledge regarding the human- and task-dependent variables contributing to search performance. In particular, previous research suggests that the efficiency of visual search varies significantly as a function of increasing adult age. With increasing age, elementary sensory/motor performance (i.e., "bottom-up" processing) declines, whereas reliance on experience and knowledge of task-relevant goals (i.e., "top-down" attention) tends to increase.

In the baggage screening task environment, however, the relevant target (e.g., a weapon) occurs rarely. Studies of visual search have only recently begun to address the issues associated with rare target search, and these studies indicate a dramatically higher miss rate for low-prevalence targets. To date, only studies of younger adult observers have been published. In addition, the relative contributions of top-down and bottom-up variables to rare target search have not been investigated. Thus, to optimize rare target search in applied settings, such as baggage screening, research is needed that investigates the potential contributions of both adult age and top-down attentional control.

Background

Age Differences in Visual Search

Visual search and detection tasks are widely used to determine the cognitive components of visual object identification (Quinlan, 2003; Theeuwes, 1993; Wolfe, 1998). The identification of a predefined *target* object among nontargets (*distractors*) is based on evidence accumulated in an internal representation of the display (i.e., a *master map* of feature activation). Attention is broadly conceived as the set of control systems that bias the gating of this featural information to later processing stages such as object recognition and response selection (Müller & Krummenacher, 2006; Treisman, 2006; Wolfe & Horowitz, 2004). Thus, within an activation map individual features within stimulus dimensions (e.g., shape, orientation, color) are activated as a result of the combined influences of *bottom-up* processing, representing the salience of the local differences among display items, and *top-down* processing, representing the observer's knowledge of the task-relevant features (Shulman, Astafiev, & Corbetta, 2004; Van der Stigchel et al., 2009; van Zoest & Donk, 2004; Wolfe, 1998). Focal attention to activated features begins with the most highly activated feature and continues until either a sufficient match to the target features is found (i.e., a target-present response) or a threshold for terminating search is reached (i.e., a target-absent response). Although distractors that are highly salient may capture attention in a bottom-up manner, top-down control may reduce the magnitude of attentional capture in support of target detection (Bacon & Egeth, 1994; Leber & Egeth, 2006).

The training and maintenance of efficient visual scanning and target detection skills is critical in some applied settings, such as radiological image reading (Kundel & La Follette, 1972; Kundel, Nodine, Conant, & Weinstein, 2007) and airport baggage screening (McCarley, Kramer, Wickens, Vidoni, & Boot, 2004). For example, when multiple targets can occur in a display, the presence of a frequent, easily detected target can lead to a lower ability to detect an accompanying, less salient target. In multiple-target search, setting a threshold to terminate search depends on the relative saliency and frequency of different target types, external pressures of reward and time, and expectation about the number of targets occurring in a display (Fleck, Samei, & Mitroff, in press).

The vast majority of research studies on visual search comprise data collected from younger adult (i.e., college-age) participants. However, significant changes in perceptual and cognitive abilities occur as a function of increasing adult age, even in the absence of significant disease. Age-related differences in cognition are a complex mosaic, with decline being the primary trend for many of the abilities relevant for visual search and attention, especially basic sensory/motor processing operations (Salthouse, 1996; Schneider & Pichora-Fuller, 2000; Scialfa, 2002). Preservation or even enhanced performance as a function of increasing age, however, is also observed, especially for abilities that rely on semantic information, knowledge, and experience (Burke & Shafto, 2008; Horn, 1982).

At what point during adulthood does cognitive change occur? Research studies of cognitive aging most frequently draw conclusions based on a comparison of two age groups, younger and older adults. Studies that have sampled more widely across the age dimension, however, as well as longitudinal studies of the same individuals over time, have confirmed that age-related declines do not appear abruptly, late in adulthood, but instead are relatively linear beginning from 20 or 30 years of age (Hertzog & Schaie, 1988; Salthouse, 1991, 2009; Zelinski & Burnight, 1997). This linear decline is well established for time-dependent tasks that require visual pattern comparison and response selection, skills that contribute significantly to the efficiency of DHS-critical tasks such as baggage screening. However, little is known regarding the degree to which age-related variability in visual search is modifiable. Characterizing this age-related variability is critical for the development of appropriate training and assessment protocols.

To date, research on cognitive aging has emphasized age-related decline. For example, individual differences in bottom-up processing, such as elementary perceptual speed and response selection, account for a significant portion of the age-related variance in many cognitive tasks (Baltes & Lindenberger, 1997; Lindenberger, Scherer, & Baltes, 2001; Madden, Gottlob, & Allen, 1999; Salthouse, 1992, 1996, 2000; Veiel, Storandt, & Abrams, 2006). Further, older adults exhibit some decline in forms of top-down attention, such as the ability to inhibit irrelevant information (Hasher & Zacks, 1988; Lee & Hsieh, 2009; Tays, Dywan, Mathewson, & Segalowitz, 2008) and executive control, defined broadly as the integration, organization, and maintenance of individual information processing components (Gazzaley, Cooney, Rissman, & D'Esposito, 2005; Gazzaley & D'Esposito, 2007; Verhaeghen & Cerella, 2002; Wecker, Kramer, Wisniewski, Delis, & Kaplan, 2000).

At least some forms of executive control, however, remain relatively preserved with age. As a result, age-related differences in visual search performance are not pervasive but rather dependent on the relative contribution of bottom-up and top-down processing demands of the search task (Hommel, Li, & Li, 2004; Kramer & Madden, 2008; Madden, 2007; Madden & Whiting, 2004; Madden, Whiting, & Huettel, 2005). Practice and training can lead to significant improvements in older adults' search performance, although training does not typically eliminate all age-related differences in performance (Becic, Boot, & Kramer, 2008; Madden & Nebes, 1980).

Older adults' reliance on top-down attention may compensate for less efficient components of information processing (Atchley & Hoffman, 2004; Bucur, Madden, & Allen, 2005; Madden, Spaniol, Bucur, & Whiting, 2007). The degree to which search performance improves, based on the (top-down) expectation for a particular target feature, is substantially comparable for younger and older adults (Madden, Whiting, Cabeza, & Huettel, 2004; Madden, Whiting, Spaniol, & Bucur, 2005; Whiting, Madden, Pierce, & Allen, 2005), as is the ability to resist distraction by a salient nontarget (Atchley & Kramer, 2000; Christ, Castel, & Abrams, 2008; Colcombe et al., 2003; Costello, Madden, Shepler, Mitroff, & Leber, in press; Kramer, Hahn, Irwin, & Theeuwes, 1999; Madden, 1983; Pratt & Bellomo, 1999; Whiting, Madden, & Babcock, 2007). Older adults also appear to use a more cautious decision strategy than do younger adults (Madden & Langley, 2003), a practice that may lead to a differential slowing of older adults' responses when a target is not present (Hommel, Li, & Li, 2004; Kramer, Martin-Emerson, Larish, & Anderson, 1996; Scialfa & Thomas, 1994). These findings demonstrate that adults of varying ages may rely on different aspects of visual information processing to achieve comparable levels of task performance.

Search for Low-Prevalence (Rare) Targets

Studies of visual search and aging typically set target prevalence to 50% of the trials; this prevalence rate has the methodological advantage of equating the number of trials associated with target-present and target-absent responses. In tasks such as airport baggage screening or medical image reading, however, the target may have very low prevalence (e.g., less than 1%). The attentional processes involved in detecting low prevalence targets are not well understood, and the available evidence is based entirely on studies of younger adults.

A prominent characteristic of rare target search is an increased rate of missed targets. Wolfe, Horowitz, and Kenner (2005) reported that as target prevalence decreased from 50% to 1%, the miss rate increased from 7% to 30%. But this *prevalence effect* was not simply a result of the decreased frequency of the target-present response; when Wolfe et al. kept the probability of present and absent responses at approximately 50% but varied the prevalence of individual targets, participants still missed a high proportion of the low-prevalence targets. Further, the prevalence effect does not represent a decline in vigilance. The increased miss rate for rare targets occurs early in practice and does not increase significantly as a function of time on task (Van Wert, Horowitz, & Wolfe, 2009). Wolfe et al. proposed that decreasing target prevalence led participants to change their response criterion—that is, to reduce the minimal amount of time required to decide that a target was not present (Chun & Wolfe, 1996). This criterion effect was expressed as a pronounced decrease in reaction time for target-absent responses, but concomitant increase in reaction time for target-present responses, as a function of decreasing target prevalence.

At least some portion of the prevalence effect, however, appears to result from tradeoff between speed and accuracy rather than a shift in response criterion. Highly efficient search (i.e., when target and nontarget items always differ in a single dimension, such as color or orientation) tends to lead to speed-accuracy tradeoffs for rare targets (Rich et al., 2008). But even when targets and distractors are complex objects, and search is inefficient, the speed-accuracy relationship contributes to the prevalence effect. Using an object detection task, Fleck and Mitroff (2007) demonstrated that providing participants with the opportunity to change their response to the display on each trial (i.e., based on the awareness that they had missed the target) led to a dramatic reduction in the magnitude of the prevalence effect.

Synthesis

Given the perceptual and cognitive demands of airline baggage screening, research on visual search and detection is highly relevant to the goals of DHS (McCarley, Kramer, Wickens, Vidoni, & Boot, 2004). In particular, recent studies have identified the prevalence effect, in which the likelihood of missing the search target increases substantially when target prevalence is low, as in baggage screening (Wolfe, Horowitz, & Kenner, 2005). Although vigilance is a critical component of sustained performance in many search tasks, the prevalence effect is not entirely a vigilance problem, because the increased miss rates for rare targets do not vary significantly as a function of time on task (Van Wert, Horowitz, & Wolfe, 2009). Search for rare targets appears to involve some modification of the information processing mechanisms typically engaged during search for prevalent targets, such as the criterion for terminating search (Wolfe et al., 2005) and the relative emphasis on speed versus accuracy (Fleck & Mitroff, 2007). From studies of prevalent (e.g., 50%) targets, research has established that performance entails the interaction of top-down and bottom-up processing (Wolfe, 1998). From the few previous studies available on the prevalence effect, however, it is not yet clear whether top-down attentional control can lead to significant improvements in the pronounced miss rates associated with low-prevalence targets.

Increasing adult age has pronounced influences on many aspects of cognition, especially those related to the speed of information processing, and this influence is relatively linear starting from young adulthood (Salthouse, 1991, 1996). Although age-related decline is evident in some bottom-up components of visual search (Madden, Gottlob, & Allen, 1999; Schneider & Pichora-Fuller, 2000), older adults exhibit preserved ability to use some forms of top-down attention, which may have a compensatory role in search performance (Madden, Spaniol, Bucur, & Whiting, 2007; Madden, Whiting, Cabeza, & Huettel, 2004; Whiting, Madden, Pierce, & Allen, 2005). Thus, on tasks such as rare target search, considerable variation may exist as a function of adult age. Currently, however, the literature on rare target search and age-related effects in visual attention are completely separate. Applied research is necessary to determine whether the top-down attentional control that older adults have exhibited, in other contexts, will also be evident in the case of rare target search.

Future Directions

Given the absence of information regarding age-related effects in rare target search, it would be valuable to compare adults of varying ages in rare target search. For example, significant differences in the bottom-up components of search (e.g., overall feature detectability) should be evident across stratified samples of adults in their 20s, 30s, 40s, 50s, and 60s. Because studies of age-related effects in visual search have most frequently compared just two groups, younger and older adults (Hommel et al., 2004, is an exception), these data would be valuable for cognitive aging research as well. Based on previous studies indicating increased cautiousness and reliance on top-down control as a function of increasing adult age, the ability to detect rare targets may actually become more efficient with increasing adult age. Thus, one direction for future research would be studies that investigate the detection of rare visual targets, using the stratified decade-samples of adults in their 20s through their 60s.

Currently, little is known regarding how the influences of top-down attention, such as the setting of a threshold to terminate search, vary in response to target prevalence. For example, when multiple targets could occur in a display, the presence of a frequent, easily detected target can lead to a decreased detection of additional, less noticeable targets (Fleck et al., in press). Given the role of top-down attention in older adults' search performance generally, the influence of threshold-setting may increase as a function of increasing adult age. Thus, if increasing age is associated with a more cautious response criterion, then the influence of easy-to-detect targets on this threshold may actually decrease in magnitude as a function of increased adult age, as participants develop (with age) more strict decision criteria for deciding that a search can be terminated. This type of research would help to indicate whether instruction and training on the consequences of being influenced by an easy-to-detect target should be geared more towards younger adults, who have not yet developed a more cautious threshold for search termination.

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