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Background/Study Context*: Typical measures for assessing the useful field (UFOV) of view involve many components of attention. The objective of the current experiment was to examine differences in visual search efficiency for older individuals with and without UFOV impairment.*

Methods*: The authors used a computerized screening instrument to assess the useful field of view and to characterize participants as having an impaired or normal UFOV. Participants also performed two visual search tasks, a feature search (e.g., search for a green target among red distractors) or a conjunction search (e.g., a green target with a gap on its left or right side among red distractors with gaps on the left or right and green distractors with gaps on the top or bottom).*

Results*: Visual search performance did not differ between UFOV impaired and unimpaired individuals when searching for a basic feature. However, search efficiency was lower for impaired individuals than unimpaired individuals when searching for a conjunction of features.*

Conclusion*: The results suggest that UFOV decline in normal aging is associated with conjunction search. This finding suggests that the underlying cause of UFOV decline may arise from an overall decline in attentional efficiency. Because the useful field of view is a reliable predictor of driving safety, the results suggest that decline in the everyday visual behavior of older adults might arise from attentional declines.*

Numerous studies have demonstrated that the ability to extract visual information from a scene declines with age. Although some of this age-related visual decline may be the result of changes in low-level vision (e.g., visual acuity), otherwise visually healthy older adults continue to have trouble detecting and discriminating information in the environment (Sekuler & Ball, 1986). Consequently, some age-related declines in visual information processing result from decrements in higher-level visual processes, such as visual attention (Sekuler & Ball, 1986; Ball, Owsley, & Beard, 1990; Ball, Owsley, Sloane, Roenker, & Bruni, 1993). Several studies have claimed that normal aging produces a constriction in attentional breadth or scope, thereby reducing the "useful field of view" (UFOV), which is the area over which observers can process visual information in a single glance (Ball et al., 1993). This idea of a constriction in the functional or useful field of view (Sanders, 1970; Ball et al., 1990) is supported by studies showing that older individuals exhibit decrements in target localization and discrimination, particularly in cluttered or noisy visual environments (Sekuler & Ball, 1986; Scialfa, Kline, & Lyman, 1987; Ball et al., 1990). However, both localizing and discriminating visual targets involves not only the scope of visual attention, but also multiple other attentional processes.

In the current experiment, we use visual search to test for attentional operations that might be associated with declines in the useful field of view. Age-related changes in the UFOV are typically assessed with a standardized, computerized screening task (see Edwards et al., 2005, 2006) composed of subtasks of varying difficulty. There are different versions of the UFOV screening task (see Edwards et al., 2006), but all are similar in that they are composed of several subtests of varying difficulty. Each subtask assesses the exposure duration required to maintain 75% accuracy. The subtests that are predictive of driving and other complex behaviors involve both selective and divided attention. In the four-subtask version of the UFOV screening that we have used in screening for attentional impairments in clinical populations (e.g., Rizzo et al., 2004; Uc, Rizzo, Anderson, Shi, & Dawson, 2005), subtask 1 asks observers tos identify a single shape (car or truck) presented at fixation; subtask 2 requires observers to identify the shape at fixation and to simultaneously localize a peripheral target that appears in an otherwise clear field; subtask 3 is identical to subtask 2, except that the peripheral target appears among distractors; finally, subtask 4 involves reporting if two shapes at fixation are the same or different while performing peripheral localization among distractors.

Performance on subtasks 3 and 4 is sensitive to age-related visual changes: Older adults require longer exposure durations than younger adults to maintain 75% accuracy on these subtasks. Performance on the latter two subtasks is also predictive of driving performance and of everyday functional tasks. Older adults with overall greater UFOV decline than age-matched controls are at greater risk for automobile crashes than adults with less UFOV decline (Owsley, McGwin, & Ball, 1998; Owsley et al., 1998). Accelerated UFOV decline also predicts impairments in nondriving daily activities (e.g., Owsley, Sloane, McGwin, Ball, 2002).

An attentional constriction readily explains UFOV decline on the relevant UFOV screening subtests, and attentional or perceptual constriction are frequently discussed as the underlying cause of attentional impairments during aging (e.g., Ball, Beard, Roenker, Miller, & Griggs, 1988; Kosslyn et al., 1999; Rizzo et al., 2002). If attention becomes narrowed during normal aging, through mild cognitive impairment, or following brain injury, then attention should be limited to the target at fixation. As a result, peripheral target localization would suffer, requiring increased exposure durations to reach performance criteria. However, the relevant UFOV subtasks are complex and tap multiple attentional operations. For example, rather than tapping the scope of attention, the relevant subtasks require attention to be divided between central and peripheral targets. Alternatively, these subtasks could require observers to rapidly shift attention between the central and peripheral stimuli. Further, in the third subtest discussed above, observers must perform visual search for the peripheral target; this search is likely extraordinarily demanding because the target appears among visual noise.

Based on the foregoing considerations, rather than strictly measuring the breadth of attention, the UFOV assay may place demands on basic attentional operations that are important for efficiently extracting visual information from the environment. Thus, UFOV impairment may result from dysfunction in a number of basic control functions, which may include (1) decreased ability to rapidly shift attention between locations or items within a scene, (2) reduced attentional breadth, or (3) an inability to disengage attention from its current focus. Given that basic aspects of attentional function have been shown to decline during normal aging (e.g., Trick & Enns, 1998; Castel, Chasteen, Scialfa, & Pratt, 2003; Rösler, Mapstone, Hays-Wicklund, Gitelman, & Weintraub, 2005; see Kramer & Madden, 2008, for a more extensive review), it is likely that accelerated UFOV decline might also result from difficulties with any number of basic attentional components, and not necessarily to an attentional constriction alone.

In an attempt to better understand the attentional operations that might underlie accelerated UFOV decline, we employed a widely used, speeded visual search task to measure attentional function in participants who either did or did not show UFOV impairments. Based on performance on a standardized UFOV task (Edwards et al., 2005), we classified observers as either "UFOV impaired" or "UFOV unimpaired" using standard criteria for assessing impairment (see Vance et al., 2007). Observers in both groups performed a visual search task (Treisman & Gelade, 1980; Wolfe, 1994) in which they searched for a prespecified target among a varying number of distractors. The targets were defined as either a conjunction of two features (conjunction search) or as a single feature (feature search). In normal observers, features are detected quickly and relatively independently of the number of distractors in the display; conjunction targets are found more slowly, and conjunction target identification slows systematically as distractors are added to a display.

Impairments in different attentional operations make differing predictions for visual search performance. If attention is constricted in UFOV decline, then this constriction should impair both feature and conjunction search because less information could be accrued from the periphery to guide search. Indeed, attentional capture by a salient visual feature during feature search depends on the scope of attention: Only when attention is focused broadly across a display will uniquely colored items attract attention; when attention is constricted via experimental manipulations (e.g., instructional set), salient features no longer capture attention (Belopolsky & Theeuwes, 2010; Belopolsky, Zwaan, Theeuwes, & Kramer, 2007; Theeuwes, 2004). In contrast, if UFOV decline results from ineffective visual search among items in a cluttered scene, then feature search should not differ between UFOV impaired and unimpaired observers. Instead, search rates for conjunction targets would be slowed in impaired observers compared to unimpaired observers; that is, UFOV impaired observers would show a steeper search slope than unimpaired observers.

METHODS

Participants

Eight males and 12 females between the ages of 66 and 87 participated. Ten observers had UFOV impairments (mean age = 79.1, $SD = 5.4$) and 10 did not (mean age = 78.3, $SD = 6.9$). All observers had normal or corrected vision of at least 20/40, and no observers met screening criteria for dementia as assessed by the Mini-Mental State Examination (MMSE). The impaired and unimpaired groups did not differ on contrast sensitivity, measured by the Pelli-Robson chart, or on complex figure copying (Rey-Osterrieth figure). Results from these neuropsychological screening measures appear in Table 1.

The Useful Field of View Classification

The standard UFOV test (see Edwards et al., 2005) has several subtests, as described above. Our observers performed all subtasks. We measured the presentation duration required to maintain 75%

Table 1. Neuropsychological task scores for the impaired and unimpaired groups

	UFOV unimpaired group	UFOV impaired group
MMSE	29.1	28.9
Contrast sensitivity (log contrast)	1.575	1.485
Rey-Osterrieth figure copying (minutes)	1.8	1.8

Table 2. UFOV task scores for the impaired and unimpaired groups

	UFOV impaired group	UFOV unimpaired group
Subtest 1	17.1 ms	17.2 ms
Subtest 2	54.9 ms	95.7 ms*
Subtest 3	294.5 ms	176.2 ms
Subtest 4	500 ms	402.3 ms

Note. Scores are the mean exposure durations required to achieve 75% correct on a subtest.
*The high subtest 2 score for the UFOV unimpaired group was caused by one participant in this group, who had an abnormally long exposure duration. This participant appeared typical for the group on the other subtasks, and when this participant is removed, the average subtask 2 score for the unimpaired group is 45.1 ms.

accuracy in each subtest. To identify participants with UFOV decline, we examined performance on the subtests that required (a) central discrimination and peripheral localization among distractors and (b) central discrimination and peripheral discrimination among distractors (i.e., subtests 3 and 4, respectively). Vance et al. (2007) defined UFOV impairment as a score of 800 ms or higher on the sum of subtests 3 and 4. We defined UFOV impairment less stringently than Vance et al. (2007) because of difficulties recruiting participants who showed that degree of impairment. We defined UFOV impaired individuals as those having a score of 500 ms on subtask 4 and having a subtask 3 and 4 total of 690 or greater. We chose these criteria because participants did not exhibit performance on subtask 3 that would meet Vance et al.'s (2007) inclusion criterion of an 800 ms total. UFOV results for the two groups appears in Table 2.

Stimuli and Procedure

We presented stimuli on a Macintosh G4 computer with a 17-inch CRT (cathode ray tube) monitor to present stimuli and to record responses. The experiment was controlled using MATLAB and the Psychophysics toolbox (Brainard, 1997).

Observers sat 55 cm from the monitor in a dimly lit room and performed a basic visual search task in which search type (feature vs. conjunction) and set size (4, 8, or 12) were varied on a trial-to-trial basis. At the beginning of each trial, a white fixation point (0.35° by 0.35°) appeared for 500 ms on a gray background, followed by a search array, which remained visible until response. The search array consisted of 4, 8, or 12 Landolt squares (one of which was the target) appearing randomly at a location within an imaginary circle (diameter 7.2°). The observers' task was to search for the green Landolt square with a gap in either the left or right side and to report the gap side. The target either appeared as a single green target among red distractors (feature search) or as a green target with left or right gap among red distractors with gaps on their left or right sides and green distractors with gaps in their tops or bottoms (conjunction search). Search displays remained visible until observers responded. Search task and set size were intermixed. Following a 48-trial practice block, participants performed four blocks of 96 trials.

RESULTS

Data from incorrect trials and reaction times (RTs) less than 150 ms or greater than 2.5 *SD*s above the mean were excluded from the analyses; this trimming eliminated less than 3% of the data. Accuracy was uniformly high across all conditions, as shown in Table 3. Observers' mean RT for each condition are shown in Figure 1. The results were analyzed using a mixed-model analysis of variance (ANOVA), with UFOV status (impaired vs. unimpaired) as a between-subjects factor, and set size (4, 8, or 12) and search type (feature vs. conjunction) as within-subjects factors.

We observed no significant main effects or interactions in the accuracy data, $Fs < 1.0$, $ps > 0.47$. However, for RTs, we observed faster RTs for features search than for conjunction search, $F(1, 18) = 375.3$, $p < .0001$, and increased RTs as set size increased, $F(2, 36) = 109.9$, $p < .0001$. The two-way interactions between UFOV status and search type, $F(1, 24) = 5.6$, $p < .01$, UFOV status and set size, $F(2, 36) = 4.9$, $p < .01$, and search type and set size, $F(2, 36) = 145.1$, $p < .0001$, as well as the three-way interaction between UFOV status, set size, and search type, $F(2, 36) = 3.6$, $p < .05$, were also significant.

Table 3. Accuracy of target discrimination

	UFOV unimpaired			UFOV impaired		
	Set size 4	Set size 8	Set size 12	Set size 4	Set size 8	Set size 12
Feature search	99.3 (0.5)	99 (0.6)	97.8 (1.0)	98.3 (0.8)	97.8 (0.8)	97.8 (0.7)
Conjunction search	98.8 (0.7)	98.3 (0.8)	97.0 (1.1)	96.3 (1.1)	97.8 (1.0)	96.5 (1.4)

Note. Standard errors appear in parentheses.

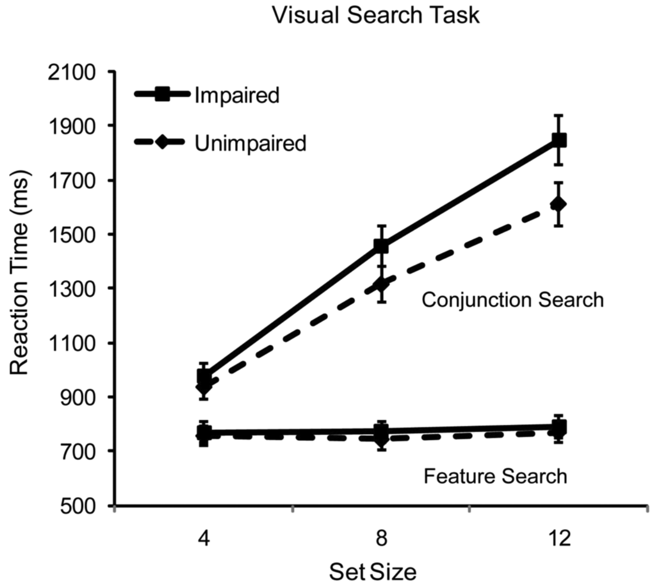

Figure 1. Mean reaction times for feature and conjunction search in both UFOV impaired and unimpaired participants. Error bars represent 95% confidence intervals (Cousineau, 2005; Loftus & Masson, 1994) for each search condition.

To understand the three-way interaction, we analyzed each search type (feature and conjunction) separately, with UFOV status as a between-subjects factor and set size as a within-subjects factor. The results showed a significant main effect of UFOV status in conjunction search, $F(1, 18) = 4.6$, $p < .05$, but no such main effect in feature search, $F(1, 18) = 0.8$, $p = .38$. In addition, there was a significant impairment by set-size interaction in RTs for conjunction search, $F(2, 36) = 3.4$, $p < .05$. Planned comparisons on the search slope for impaired and unimpaired participants in the conjunction search condition revealed that UFOV impaired participants searched significantly more slowly (109 ms/item) than unimpaired participants (74 ms/item), $t(18) = 3.1$, $p < .01$. No other main effects or interactions approached significance.

DISCUSSION

These results demonstrate that older adults with accelerated UFOV decline take longer to search for conjunction targets but not feature targets. Thus, UFOV decline is associated with impairment in searching through a complex display. However, beyond confirming an attentional difficulty in UFOV impairment, the current results point to specific attentional operations that might differ between UFOV impaired and unimpaired observers. Specifically, the fact that feature search did not differ between UFOV impaired and unimpaired observers suggests that the breadth of attention may not differ between these observers. Because attentional capture by a color singleton requires a broad attentional focus (Belopolsky & Theeuwes, 2010; Belopolsky et al., 2007; Theeuwes, 2004), the effective feature search in UFOV impaired older adults suggests that attention may not be overly constricted in these individuals. Instead, the current findings suggest that overall search rates—that is, the amount of time attention remains focused on an item (the "dwell time") and the time to move attention from one item to another—are slower in UFOV impaired observers than UFOV unimpaired observers. Presumably, an inability to rapidly search through a display impairs performance on standardized UFOV measures because attention is unable to disengage from the central target and move quickly to the peripheral target.

The visual search impairments for conjunction search also explain why UFOV decline is associated with impairments in many everyday behaviors, including driving. Visual search is ubiquitous and is required in most visual scenes, whether searching for the ketchup in a refrigerator or merging into traffic on the interstate. A slowing of visual search will, thus, lengthen the time required to complete many everyday tasks. The current results are important for attempts to ameliorate UFOV deficits through behavioral training (Ball et al., 2002). An improved understanding of the attentional operations that contribute to UFOV impairments could lead to more precisely tailored remediation of UFOV decline. For example, based on our results, it is possible that practicing conjunction search may be a more effective intervention than, for example, practicing expanding the attentional window.

Although the current results point to differences in UFOV impaired and unimpaired older individuals, the results raise broader questions about aging in general. Specifically, are there similar differences in visual search performance in younger individuals? Such a question might be difficult to address because younger individuals show less UFOV decline overall. However, experimental manipulations, such as visual degradation or working memory load, could be useful in simulating UFOV decline in younger adults, and simulated UFOV decline in younger adults could shed light on the factors that contribute to UFOV decline in older adults.

One final issue for discussion is the further refinement of the attentional operations associated with UFOV decline. Although visual search allows us to rule out some attentional operations (e.g., attentional scope), search remains a multifaceted process. At a minimum, visual search involves disengaging attention from the current object, tagging that object with an inhibitory tag to avoid revisiting it, and moving or shifting attention to a new object. A difficulty in any of these search components could produce the initial results reported here. In companion work (Cosman et al., submitted), we have reported evidence that suggests UFOV impaired individuals show a specific deficit in disengaging attention. Further work will be necessary to test other specific attentional operations, pinpointing the specific attentional operations that are difficult for individuals with UFOV decline is important for determining appropriate avenues for remediation.

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