Dynamic Allocation of Attention in Aging and Alzheimer Disease

Uncoupling of the Eye and Mind

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Context: Visual attention can be distributed focally, in the direction of gaze, or globally, throughout the extrapersonal space. Aging, and especially Alzheimer disease (AD), may influence global attention, resulting in shifts of gaze to attend to the global workspace.

Objective: To determine if subjects who have AD and cognitively intact older subjects shift their gaze more often than young subjects while viewing a dynamic stimulus that emphasizes global attention.

Design: Experimental study of eye fixation patterns in response to a simulated driving scene with stationary and moving distractors.

Setting: Urban, medical school, National Institute on Aging–funded Alzheimer’s Disease Center.

Participants: Thirteen subjects with mild probable AD, 13 age-comparable cognitively intact older control subjects, and 11 young control subjects.

Main Outcome Measure: Proportion of eye fixations within and outside of a central region of interest encompassing the “road” surface.

Results: Young controls made significantly more eye fixations (mean number of eye fixations, 47.5) than either of the other 2 groups (older controls mean, 33.2; patients with AD mean, 32.2). However, 76% of their fixations remained within the central region of interest. Older controls and subjects with AD made proportionately fewer fixations within this region (48% and 49%, respectively) than young controls and moved their eyes more often to the periphery but did not differ from one another.

Conclusions: Young controls maintain central eye position regardless of peripheral distraction. Older controls move their eyes to the periphery, presumably to widen the window of attention. Subjects with mild AD did not experience an additional disadvantage beyond that associated with aging.

Arch Neurol. 2001;58:1443-1447

The limited information processing capacity of the brain creates a situation where only parts of the environment can become the focus of attention at any given time. In the visual modality, global attention encompasses the entire extrapersonal space and is used for the rapid detection of novel events. Such events can then attract a more focused sort of attention for detailed assessment. These shifts of visual attention can occur overtly, through shifts in gaze, or covertly, without eye movements.

Shifts between global and local allocation of attention have been studied experimentally in patients with Alzheimer disease (AD). In these and other studies, the stimuli have been static or appear suddenly in one of several cued or uncued locations. One common daily circumstance in which there is a premium on rapid and dynamic covert shifts of attention between local and global levels occurs while driving an automobile. In this situation, it is necessary to maintain eye position within a relatively circumscribed area, “on the road,” while global attention and covert shifts of attention move flexibly within the extrapersonal space to detect events related to traffic and road conditions. Alterations of attention in part account for a higher frequency of motor vehicle collisions in older drivers in situations where there is great demand on attentional resources, such as at intersections and traffic circles. Aging and, to a greater extent, AD may influence the ability to inhibit shifts of gaze causing gaze to be diverted to extraneous locations and objects.

The goal of this study was to characterize visual attention strategies in su-
SUBJECTS AND METHODS

SUBJECTS

The subjects consisted of 13 patients with mild probable AD, 13 age- and education-matched cognitively intact ONCs, and 11 young control subjects (YNCs). The patients and ONCs were recruited from the Clinical Core subject registry of the Northwestern Alzheimer’s Disease Center, Chicago, Ill. They had all undergone neurologic and neuropsychological examinations to verify the absence of neurologic disease, cognitive deficits, and alterations in daily living activities in the ONC group and to establish the diagnosis of “probable AD” in the patient group.7 The absence of dementia and preservation of daily living activities in the ONC group was also verified in an interview with a designated informant, as part of the Northwestern Alzheimer’s Disease Center registry procedures for enrolling subjects. Young controls were recruited from advertisements placed around the university and were screened using a telephone interview for exclusion criteria prior to participation. Exclusion criteria for the present study were (1) the use of psychoactive medications, (2) unusual corrective lenses that might interfere with the collection of eye movement data, (3) corrected visual acuity worse than 20/40 in either eye, and (4) visual field deficits on neurologic examination.

The following neuropsychological tests had been administered to the patients with AD and ONCs as part of the Northwestern Alzheimer’s Disease Center Clinical Core methods for establishing a diagnosis: Mini-Mental State Examination, Digit Span, Logical Memory and Visual Reproduction subtests from the Wechsler Memory Scale—Revised, the Boston Naming Test, Verbal Fluency (animal list generation), and the word list and constructions subtests from the battery of the Consortium to Establish a Registry for Alzheimer’s Disease, and Judgment of Line Orientation.8-12 The YNCs were graduate students and did not undergo additional testing. The study was approved by the institutional review board of Northwestern University, Chicago, Ill. All subjects gave informed consent.

PROCEDURE

An infrared-based eye tracking system (model RK-426PC; ISCAN, Burlington, Mass) recorded eye position, sampling at a rate of 60 Hz, while subjects looked at an animation simulating the view from the perspective of the driver in a moving automobile. The animation was displayed on a 21-in monitor subtending a visual angle of 23°. Eye position was recorded in 2-dimensional space and saved to a personal computer (Macintosh; Apple Computers, Cupertino, Calif) for analysis using custom-designed software (ILAB, Chicago, Ill) running in the MATLAB environment (Mathworks, Natick, Mass). A standardized calibration procedure preceded the experimental task to ensure accuracy of eye position within the display.

Movement of a car down a 2-way street was simulated by displaying 300 still frames of digitized images at the rate of 15 frames per second, approximating a speed of 30 mph. Subjects viewed three 20-second simulations that differed with respect to the density of stationary distractors flanking the street (eg, buildings, pedestrians, trees, etc). In addition, moving vehicles approached from the periphery at each of 2 intersections, but the traffic lights in the direction of simulated travel remained green so that automatic motoricity responses related to slowing or braking would not be provoked. Although the simulations were not representative of real driving conditions, they could be compared with light traffic situations that might be encountered in rural or suburban areas during daytime hours.

Based on reports by Cole and Hughes,14,15 a region of interest (ROI) for a primary location of attentional focus for safe driving was operationally defined as the area occupied by the street in the direction of the heading on the display monitor (Figure). In the experimental task this ROI occupied the same relative visual position on the screen throughout the 20-second duration of each simulation. Subjects were instructed to view the simulations as if they were safely driving to emphasize reliance on a more global attentional strategy.

DATA ANALYSIS

Eye fixations are accepted as a valid measure of attentional allocation13,14 and constituted the dependent variable in this study. A fixation was defined as eye position remaining within a 6-pixel horizontal by 4-pixel vertical area on the display for at least 100 milliseconds.20,21 The mean total number of fixations and mean fixation duration within the ROI were calculated for each of the three 20-second animations and a grand mean was derived for each measure for each subject. Three separate 1-way analyses of variance (ANOVA)s with planned contrasts of group means (YNCs vs ONCs, ONCs vs subjects with AD) were used to compare the groups for the average total number of fixations, average duration of fixations, and average percentage of fixations that fell within the defined ROI while viewing the animations.

RESULTS

SUBJECT DEMOGRAPHICS AND NEUROPSYCHOLOGICAL TEST SCORES

Table 1 lists demographic information, Mini-Mental State Examination scores, and scores from the delayed recall condition of the Logical Memory subtest from the Wech-
Sler Memory Scale–Revised for the 2 older subject groups. Subjects with AD and ONCs did not differ significantly from one another for age. Mean years of education differed among the 3 groups (F2,34=6.5, P=.004), but post hoc comparisons showed that the only statistically significant difference was between the YNCs and the subjects with AD (P=.005). Scores on the Mini-Mental State Examination were normal for ONCs (mean [SD], 28.2 [1.5]) and in the mildly impaired range for subjects with AD (24.3 [3.1], P=.003). Subjects with AD also had abnormal scores on the delayed recall condition of the Logical Memory subtest from the Wechsler Memory Scale–Revised, consistent with their prominent amnestic disorder. All ONCs scored within the normal range on the neuropsychological battery and were performing normally in all activities of daily living, as corroborated by their designated informants.

Although this study was not aimed at predicting actual driving skill, subjects were asked about their driving experience because this could potentially influence performance. All subjects had driving experience, and 10 of the 13 subjects with AD were continuing to drive at the time of the study. Three subjects with AD had not driven for the previous 2 to 3 years, 1 because of physical limitations, and 2 who were relying on others for transportation over the same interval. All ONCs and YNCs were current drivers, but many stated that they often relied on public transportation.

**EXPERIMENTAL TASK**

Group mean scores for each dependent variable are given in Table 2. The omnibus ANOVAs for average total number of fixations and average percentage of fixations within the ROI were statistically significant (75.7 [15.3]) and in the mildly impaired range for subjects with AD (24.3 [3.1], P=.003). Subjects with AD also had abnormal scores on the delayed recall condition of the Logical Memory subtest from the Wechsler Memory Scale–Revised, consistent with their prominent amnestic disorder. All ONCs scored within the normal range on the neuropsychological battery and were performing normally in all activities of daily living, as corroborated by their designated informants.

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**Table 1. Subject Characteristics**

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of Subjects (M/F)</th>
<th>Age, y</th>
<th>Education Level, y</th>
<th>MMSE Score†</th>
<th>Logical Memory WMS-R Score‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>YNCs</td>
<td>11 (5/6)</td>
<td>27.4 (3.9)</td>
<td>16.8 (1.3)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>ONCs</td>
<td>13 (4/9)</td>
<td>73.9 (4.0)</td>
<td>15.7 (1.7)</td>
<td>28.2 (1.5)</td>
<td>25.6 (9.3)</td>
</tr>
<tr>
<td>Subjects with AD</td>
<td>13 (4/9)</td>
<td>75.7 (5.7)</td>
<td>13.8§ (2.9)</td>
<td>24.3</td>
<td>(3.1)</td>
</tr>
</tbody>
</table>

*MMSE indicates Mini-Mental State Examination; WMS-R, Wechsler Memory Scale–Revised; YNCs, young control subjects; ONCs, cognitively intact older control subjects; NA, does not apply; and AD, Alzheimer disease.
†Total raw scores from the MMSE with a possible score of 30.
‡Raw score from the delayed recall condition of the Logical Memory subtest from the WMS-R with a possible score of 50.
§Statistically significantly different from the YNCs (P=.005, 1-way analysis of variance [ANOVA]).
¶Statistically significantly different from the ONCs (P=.003, ANOVA).

**Table 2. Results of Analysis of Fixation Variables**

<table>
<thead>
<tr>
<th>Group</th>
<th>Total No. of Fixations</th>
<th>Fixations in ROI, %</th>
<th>Fixation Duration, ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>YNCs</td>
<td>47.5† (12.8)</td>
<td>75.7‡ (15.3)</td>
<td>336.7 (148.7)</td>
</tr>
<tr>
<td>ONCs</td>
<td>33.2 (13.7)</td>
<td>48.0 (28.7)</td>
<td>586.7 (406.0)</td>
</tr>
<tr>
<td>Subjects with AD</td>
<td>32.2 (16.0)</td>
<td>49.3 (32.5)</td>
<td>536.3 (321.4)</td>
</tr>
</tbody>
</table>

*All data are given as mean (SD). ROI indicates region of interest; YNCs, young control subjects; ONCs, cognitively intact older control subjects; and AD, Alzheimer disease.
†Statistically significantly different from ONCs (P=.01, 1-way analysis of variance [ANOVA]).
‡Statistically significantly different from ONCs (P=.02, ANOVA).
2 groups, the difference was not statistically significant. This is perhaps because of the large variability in this measure in the 2 older groups.

The planned comparisons revealed that the YNCs made significantly more eye fixations overall while viewing the simulations than the ONCs ($P = .01$). In addition, significantly more of the eye fixations of the YNCs fell within the ROI when compared with those of the ONCs ($P = .02$). That is, a greater proportion of eye fixations of ONCs fell outside the ROI, directed at the periphery of the scene. There was no statistically significant difference between the ONCs and the subjects with AD on any of the 3 dependent measures.

Patients with mild probable AD and cognitively intact ONCs make frequent eye movements to the periphery of a dynamic scene that simulates the driver’s view in a moving automobile. Younger controls, in contrast, make more frequent eye movements but the excursions are small and the eyes remain within a circumscribed area analogous to the surface of the road directly ahead of them.

The infrequency of eye movements made by YNCs outside the ROI, even in the presence of peripheral distractors, leads us to suspect that they were able to attend to the periphery without also shifting gaze, although we did not specifically test their awareness of events in the periphery. In contrast, subjects with mild AD and ONCs moved their eyes, presumably along with their attention, to locations in the periphery, suggesting diminished capacity for the flexible interplay between covert and overt shifts of attention. This interpretation may be challenged by many reports of the absence of a significant impairment of covert shifts of attention in cognitively intact ONCs. However, these studies used static stimulus displays with targets that occurred in predictable locations. The dynamic scene used in our study places rapidly changing demands on the attentional system and may, therefore, reduce the efficiency of covert shifts of attention in nondemented older subjects.

One measure of the visuospatial allocation of attention that has been applied to driving is the useful field of view (UFOV). The UFOV is defined as the area of the visual field in which information can be most readily processed without eye or head movements. It is tested by having subjects maintain central fixation and monitor central events while responding to targets that suddenly appear in a stationary display at various eccentricities from fixation. This window of visual attention reflects 3 different factors—visual processing speed, the ability to divide attention, and freedom from distractibility. Although deficits in each of these domains can occur with aging, these components can operate independently of each other and additively to alter the UFOV. Several studies have shown that the percentage of reduction in the UFOV, combined with overall mental status scores, has a high predictive value for motor vehicle collisions in elderly persons. Recently, patients with AD were found to be impaired relative to age-matched controls on all components of the UFOV.

One consequence of a reduction in the UFOV during an activity such as driving or other similar attention-demanding activities might be an increase in the number of overt changes in eye position needed to attend to peripheral events. Although YNCs made more fixations than the 2 older subject groups while viewing the dynamic experimental scene, these fixations remained within a limited area. Thus, small deviations in eye position within the ROI could have been sufficient for the YNCs to covertly monitor the full extent of the scene in the periphery. In contrast, although the ONCs and the subjects with AD made fewer fixations, more fixations left the ROI in a way that may have diverted focal attention away from the direction in which the road was heading. These results are, in part, consistent with the UFOV model and demonstrate the effects of aging on visual attention to a dynamic stimulus.

There are several limitations of our study. The sample size is small because of a need to use subjects with mild dementia and also to fulfill inclusion-exclusion criteria for recording accurate eye data. Thus, the results may not generalize to a larger sample. In addition, the driving scene was used as a metaphor for a condition in which both global and local modes of attention were required in quick succession. Therefore, this was not a study of driving—actual driving skill was not measured—and so findings cannot be directly translated to predictions for driving safety. We also did not inquire about differential experiences in driver training. Older subjects may have learned to drive before standardized driver education courses were instituted and the instruction to drive safely during this task may have evoked different strategies in each subject group based on prior training. Finally, the experimental task excluded many features of driving that further increase the attentional load in the naturalistic setting, including street sounds, the sound of a car radio or a cellular phone, the presence of a passenger, information in rearview and side view mirrors, and unexpected events. Despite these limitations, however, the similarity in visual attention strategies between nondemented ONCs and older subjects with mild dementia in our study may provide information that helps to explain why some patients with AD may retain the ability to drive safely, at least in the early stages.

The age-related changes in visual attention demonstrated in this study may have several roots. First, this may reflect an alteration of the neurologic mechanisms of attention in aging. Second, it may represent increased caution in older subjects, who may need to compensate for generally reduced reaction time by more extensive scanning with the eyes. Furthermore, while attention strategies may differ in younger and older individuals, the changes may not necessarily be adverse for activities such as driving. One way to explore the relationship between these findings and driving safety would be to compare fixation patterns in individuals with good and poor driving records. The findings of our study may have some implications for how elderly individuals can correct for reduced flexibility in shifting among different forms of attentional allocation. For example, training older individuals to detect targets in the periphery, while maintaining central fixation, could possibly improve global attention.
This study emphasizes the need to distinguish age-associated from dementia-related changes in visuospatial attention. The debate over driving and the elderly population has evolved into a highly charged issue in this country, in part because our society places such a premium on personal independence and the freedom conferred by having an automobile. It is clear that a visual acuity test is insufficient to assure safe driving and that cognitive deficits impair the strategic deployment of attention that is necessary for successful driving. The many components of visuospatial attention, each of which may show differential vulnerability to aging and to different stages of AD, may provide a sensitive probe for deficits that could impair driving safety.

Accepted for publication May 4, 2001.

This work was supported in part by grants RO1-AG14068 (Dr Weintraub) and AG13854 from the National Institute on Aging, Bethesda, Md, to the Northwestern Alzheimer’s Disease Center, and by a Bucher Summer Gerontology Fellowship to the Northwestern University Medical School (Dr Mapstone).

We thank Marsel Mesulam, MD, for his helpful comments on the manuscript and Kathy Schelble for technical assistance in recruiting and testing the subjects.

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