Emotional curiosity: modulation of visuospatial attention by arousal is preserved in aging and early-stage Alzheimer’s disease

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Abstract

Previous studies have shown that Alzheimer’s disease, even in its early stages, decreases novelty-seeking behaviors (curiosity) and impairs the shifting of spatial attention to extrapersonal targets. In this study, early-stage probable Alzheimer’s disease patients (PRAD) and young and aging controls were shown pairs of visual scenes, some of which contained emotionally-arousing material, while eye movements were recorded under free viewing conditions. In all three subject groups, emotionally-arousing scenes attracted more viewing time and also became the preferential target of the initial visual orientation. Our findings suggest that the arousing properties of sensory stimuli may overcome some of the AD-related impairments in the distribution of attention to extrapersonal targets. These results may have implications for interventions aimed at improving the cognitive symptoms of PRAD. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

The neuropsychological hallmark of Alzheimer’s disease (AD) is a severe impairment of memory function. However, the adaptive deployment of attention to extrapersonal events is also frequently disrupted early in the course of the disease and interferes with activities of daily living. These attentional deficits are multifaceted and include altered visual search strategies [8,22,24], an inability to disengage the focus of attention [20,23] and reduced orientation to novel and complex stimuli [4]. Furthermore, while AD patients may be able to focus attention globally or locally when each mode is tested in a separate experiment, they have difficulty when required to switch between these processing modes in the same block of experimental trials [7].

One possible strategy for improving attentional engagement in AD is to enhance the emotional impact of environmental stimuli. Several studies have argued for the preservation of emotional processing relative to the cognitive decline in mild AD [1,2,12,25]. Thus, it might be predicted that arousal provoked by emotionally-charged stimuli would deploy attentional resources toward the pertinent sectors of extrapersonal space. The influence of emotional arousal on the regulation of attention in AD has not been directly investigated and is the focus of the current study.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

A total of 42 subjects participated in this study. Nine patients with mild probable Alzheimer’s disease (PRAD) and nine nondemented aging controls (AC) were recruited from the Clinical Core subject registry of the Northwestern Alzheimer’s Disease Center. Subjects
had undergone neurological and neuropsychological examinations to establish the diagnosis of PRAD in the patient group [21] and the absence of cognitive deficits or alterations in daily living activities in the control group. In order to examine the effect of aging, 24 younger volunteer control subjects (YC), recruited through advertisements, also participated. All subjects gave informed consent and were paid for their participation. The experimental protocol was approved by the Institutional Review Board at Northwestern University.

Table 1 presents demographic information and test scores. PRAD and AC subjects did not differ significantly in education (P > 0.05) but the PRAD subjects were significantly older, t(16) = 3.39, P < 0.004. Scores on the Mini Mental State Examination (MMSE) [9] were normal for ACs and in the ‘mildly impaired’ range for the PRAD group. PRAD patients also had abnormal scores on the delayed recall condition of the Logical Memory subtest from the Wechsler Memory Scale-Revised (WMS-R) [28], consistent with the prominent amnesic disorder that characterizes this condition. ACs scored within the normal range for their age and education on all tests. There was no evidence of depression in either the AD or AC groups, as reflected in their total scores on the Geriatric Depression Scale [30].

Seven of the AD subjects in the present sample had also participated in a study of visual target detection reported by Rössler et al. [24]. In this study, subjects were required to detect a target number embedded in an irregular array of distractor letters. The AD subjects (eight in total) demonstrated reduced accuracy (54% correct on average versus 82%) and increased reaction time (almost 6 s per target on average versus 4 s) in comparison to controls. In addition, their search strategies for targets that they did find were distinctly different from those observed in the control subjects. They made more fixations en route to the target and fixation duration was longer on average than that for age-matched controls. These results provide evidence that most of the subjects in the present study were impaired on a visual attention task that involved emotionally-neutral stimuli.

2.1.2. Materials and procedure

Subjects were shown 30 pairs of color visual scenes that varied in emotional content while their eye movements were monitored under free viewing conditions. Subjects were told that some of the images would consist of emotionally-negative (graphic) scenes and they were simply instructed to look at the stimuli in any way they wished. No overt response was required. Emotionally-negative pictures were obtained from the International Affective Picture System (IAPS; Center for Research on Emotion and Attention, Gainesville, FL, 1995) and were chosen based on 9-point arousal and valence scales provided in the IAPS norms (arousal levels ranged between 4.5 and 9; valence levels ranged between 1 and 4). Emotionally-negative stimuli were chosen because they constitute a more homogeneous and reliable arousing category than positive stimuli and the neural systems mediating these stimuli have been investigated more thoroughly [11,15,17,18]. The neutral stimuli were matched for the presence of human figures, global color content and the complexity of the visual scene [15,17]. The 30 scene pairs were displayed on a computer screen for 10 s each and the trials were divided evenly into three left–right pairing conditions: neutral–neutral, negative–neutral and neutral–negative. The scenes subtended 6° of visual angle and the centers of the scene pairs were separated by 15° of visual angle. Each trial was initiated after subjects fixated on a central crosshair and the trials were presented in a pseudorandom order.

Eye movements were recorded using infrared oculography (ISCAN, Burlington, MA) as described previously [16,19,24]. Three regions of interest (ROIs) were drawn around the left, middle and right thirds of the screen. The left and right ROIs contained the two pictures in each trial pair and the middle ROI contained the fixation cross that initiated each trial. The entire vertical dimension of the computer screen was encompassed by the ROIs to compensate for vertical shifts in eye position, which typically occur when tracking eye movements in subjects with bifocal glasses (see the example of PRAD subject in Fig. 1). The ROIs were used to determine the lateral direction of the first saccade directed away from central fixation. In addition, the amount of time spent fixating in each ROI was calculated. The direction of the

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Gender</th>
<th>Education (years)</th>
<th>MMSE</th>
<th>GDS</th>
<th>WMS-R logical memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>YC (n = 24)</td>
<td>26 ± 4</td>
<td>11 M, 13 F</td>
<td>17 ± 2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>AC (n = 9 )</td>
<td>67 ± 5</td>
<td>2 M, 7 F</td>
<td>15 ± 3</td>
<td>29 ± 2</td>
<td>2 ± 4</td>
<td>30 ± 5</td>
</tr>
<tr>
<td>PRAD (n = 9)</td>
<td>76 ± 6</td>
<td>4 M, 5 F</td>
<td>14 ± 3</td>
<td>24 ± 4</td>
<td>7 ± 4</td>
<td>11 ± 6</td>
</tr>
</tbody>
</table>

*a YC, young control; AC, aging control; PRAD, probable Alzheimer’s disease; MMSE, Mini-Mental Status Examination (maximum score = 30); GDS, Geriatric Depression Scale (maximum score = 30; lower scores signify fewer symptoms); WMS-R, Wechsler Memory Scale-Revised (maximum score = 50); n/a, not tested.*
first glance provided a behavioral index of the initial direction of attentional orientation, whereas the fixation times provided a behavioral index of sustained attention over time (e.g., total dwell time). Eye movement data were analyzed using ILAB© software (D.R. Gitelman, Northwestern University Medical School, Chicago, IL) running under the MATLAB environment (Mathworks Inc., Sherborn, MA). Analyses of variance (ANOVAs) were calculated using experimental group (PRAD, AC, YC) as a between-subjects variable and emotional pairing condition (neutral–neutral, negative–neutral, neutral–negative) as a within-subjects variable. Significant main effects were followed up by appropriate post-hoc t-tests. The ANOVAs were computed separately for the attentional orienting and sustained attention measures. Because the attentional orienting responses are directly proportional in each hemispace, only the ANOVAs computed on data from the left ROI are reported. ANOVAs for the sustained attention measures are reported for the left and right ROIs separately, although similar results were obtained when the hemispaces were combined.

2.2. Results

Fig. 1 illustrates the eye movement patterns obtained on single trials from a representative YC, AC and PRAD subject. For neutral–neutral stimulus pairs (top row), subjects showed an initial gaze bias toward the stimulus on the left side (colored line segment), which equilibrated over the time course of picture viewing (black line segment). The leftward bias was more prevalent across trials and persistent in time if an emotional scene appeared in the left hemispace (negative–neutral trials, middle row) and it reversed to a rightward bias if an emotional scene appeared in the right hemispace (neutral–negative trials, bottom row).

Fig. 2 presents the group-averaged data for the initial saccade direction (attentional orienting, top panel) and total dwell time (sustained attention, bottom panel) as a function of emotional pairing condition (neutral–neutral, negative–neutral, neutral–negative). All dependent measures showed significant main effects of the emotional pairing variable (attentional orienting: \( F(2,78) = 29.28, \ P < 0.001 \); sustained attention to the leftward stimulus: \( F(2,78) = 10.77, \ P < 0.001 \); sustained attention to the rightward stimulus: \( F(2,78) = 11.37, \ P < 0.001 \)). In comparison to the baseline condition (neutral–neutral pairs), inspection of the leftward stimulus was significantly increased when an emotionally-negative scene appeared on the left (attentional orienting: \( t(41) = 3.39, \ P < 0.002 \); sustained attention: \( t(41) = 2.75, \ P < 0.01 \)). This effect reversed to a rightward bias when an emotionally-negative scene appeared.
on the right (attentional orienting: $t(41) = 6.20, P < 0.001$; sustained attention: $t(41) = 4.38, P < 0.001$). There were no significant group × emotional condition interactions, indicating that the arousal modulation of visual exploration was consistent across all subject groups. Latency to initiate the first saccade was also analyzed (data not shown) and yielded no significant main effects or interactions.

It is important to consider whether the failure to report significant differences in the AC and AD groups relative to the YC group was related to increased variability in the data. Several observations argue against this possibility. First, visual inspection of the error bars in Fig. 2 does not indicate a substantial increase in variability in these groups. Second, increased spread in the score distribution of these groups would be characterized by significant negative kurtosis, which was not found for any of the dependent measures in either group. Third, we performed an individual subject analysis to determine how many subjects in these groups scored \( > 2 \) S.D. below the YC mean in the degree of the emotional modulation effects. To derive an emotional impact index in the YC group, we converted each dependent measure into percent change scores relative to the neutral–neutral baseline (e.g. leftward dwell time [emotional–neutral] minus leftward dwell time [neutral–neutral]/leftward dwell time [neutral–neutral] × 100). According to this index, only one AC and one AD subject showed impaired dwell times to emotional stimuli on the left and one AD subject showed impaired dwell times to emotional stimuli on the right. None of the other dependent measures showed any outliers relative to the YC group. Altogether, these considerations argue against increased variability in the AC or AD groups as a factor which may have obscured an underlying emotional impairment.

3. Experiment 2

The modulation of visuospatial attention in Experiment 1 is likely related to the arousal properties of the stimuli. It is possible, however, that lower-level perceptual features contributed to the observed oculographic patterns. For example, mere attention to stimulus color could account for the results if the subjects were differentially attending to color information across the stimulus categories. This is important to consider for negatively-valent scenes, as some of them contain images of blood. To address this issue, we conducted a
follow-up study on young healthy subjects using the same stimuli as in Experiment 1, except that the scenes were Gaussian-blurred to appear as abstract images in which color (and other low-frequency visual information) was relatively preserved but object attributes (and other high-frequency visual information) were not discernable.

3.1. Method

3.1.1. Subjects
Ten healthy young adults participated (three male, seven female). The mean (± S.D.) age of the subjects was 29 ± 5 years. All subjects gave informed consent and were paid for their participation. None of the subjects participated in Experiment 1.

3.1.2. Materials and procedure
The stimuli were identical to those in Experiment 1, except that the images were Gaussian-blurred using Adobe Photoshop 4.0 (Adobe Systems, San Jose, CA). The experimental design and analysis was similar to that in Experiment 1.

3.2. Results
The group-averaged data are depicted in Fig. 3. No significant main effects of trial type were found on the attentional orienting or sustained attention measures (P > 0.05), except in rightward dwell time, F(2,78) = 9.71, P < 0.001. Post-hoc t-tests, however, did not show a significant increase in dwell time to the rightward stimulus relative to the neutral–neutral baseline condition (P > 0.05).

4. General discussion
The results of Experiment 1 demonstrate that, in the early stages of AD, patients can direct their attention to environmental stimuli in a normal manner when the stimuli contain negatively-valent emotional content. ‘Emotional curiosity’ as measured within our paradigm contains two components: an early attentional orienting component that directs the first saccade toward the emotionally-arousing cue in the pair and a sustained attention component that keeps the eyes focused on the emotional scene over the entire viewing period. Both of these mechanisms were preserved in the PRAD patients and there was no effect of normal aging on task performance.

The findings are in contrast to our previous report in which PRAD patients were impaired in modulating visual exploration according to variations in the novelty and complexity of emotionally-neutral stimuli using a task design similar to the one in the present study [4]. This dissociation probably reflects differences in the pathological vulnerability of the neural networks that subserve novelty-seeking behaviors versus those that subserve orientation to arousing stimuli.

An alternative
The neural systems that mediate emotional interactions with attention are not well-understood. Given that the amygdala is implicated early in the course of AD [13] and is involved in the perception of negative emotionally-arousing scenes [11,15], it may seem surprising that the AD patients were not impaired on this task. However, it must be emphasized that the neuropathological changes in AD are heterogeneous within amygdala subnuclei [13] and that the amygdala is one node in a distributed network of brain regions sensitive to negative emotional arousal [17,18]. MRI volumetry of the entire amygdala has failed to differentiate early-stage AD patients from control subjects [14], underscoring the regional selectivity and progressive nature of the disease process. Animal studies have shown that motivationally-driven increments of attentional orienting are mediated by the central nucleus of the amygdala [10], which is relatively spared in the neuropathology of AD [13]. It is possible that involvement of other amygdala subnuclei, combined with the recruitment of additional brain regions and neurotransmitter systems, may impair emotional modulation of attention over the course of the disease. Longitudinal behavioral studies combined with in vivo imaging will be required to directly correlate changes in emotion-mediated attentional functions and pathological alterations within the relevant brain networks.

Patients with AD show multiple alterations in the spatial distribution of attention. As discussed above, they fail to show a preferential viewing of novel events [4]. Furthermore, they have difficulty covertly shifting attention to targets at different spatial locations, especially in the presence of distracters or when attention has first been cued to a location that is different from the one at which the target actually appears [23]. They are deficient at visual target search and detection, not only with respect to accuracy and response time, but also with respect to fixation parameters during search [24]. In contrast to these deficits, the present study suggests that visual orientation and sustained attention to emotionally-salient information may remain intact, at least in the early stages of the disease. Our findings may be limited by the small sample size studied. Provided that our findings extend to larger patient groups and other (including positively-valent) stimuli in real-life situations, the results may have potential implications for interventions to overcome the attentional deficits in AD.

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