

## **Attention to semantic and spatial information in aging and Alzheimer's disease**

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In two experiments we explored the patterns of attention to semantic and spatial information in younger adults, older adults, and patients with Alzheimer's disease (AD). In the first experiment, a semantic priming task measured age- and AD-related changes in attentional sensitivity to semantic information. In the second experiment, the semantic priming task was modified to additionally serve as a spatial inhibition of return (IOR) task. The combined semantic and spatial task measured (a) age- and AD-related changes in sensitivity to spatial cues as well as to semantic primes, and (b) interactions between the networks that subserved attention to semantic and spatial information. The results of both experiments revealed group differences in the utilization of semantic primes as a function of prime validity, suggesting that both older adults and AD patients were less likely than younger adults to generate controlled attention-dependent expectancies for semantically related information. Spatial IOR effects in Experiment 2 were evident in the performance of all three groups, but were of reduced magnitude in AD patients. Younger adults' performance reflected interactions between semantic priming and spatial cuing effects. These findings are consistent with conclusions that (a) selectivity via semantic primes and via spatial cues reflect separate attentional mechanisms, and (b) semantic and spatial aspects of attention are mediated by different but closely interconnected neural networks.

**Key words:** Attentional neural networks, attention deficits, aging, Alzheimer's disease.

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Multiple aspects of attention are necessary for successful selection and utilization of visual information, including alertness for upcoming events, spatial localization of visual stimuli, and discrimination of stimuli related and unrelated to current goals. Research addressing changes in selection abilities have documented that certain aspects of attention are relatively preserved with both normal aging and Alzheimer's disease (AD), while other aspects are compromised (see reviews by Hartley, 1992; Madden & Plude, 1993; Parasuraman & Haxby, 1993; Perry & Hodges, 1999). However, selection processes are infrequently assessed concurrently (Gunter, Jackson, & Mulder, 1996; Hartley, 1993; Perry, Watson, & Hodges, 2000; Rizzo, Anderson, Dawson, Myers, & Ball, 2000). Simultaneous assessment of different selection processes allows exploration of the relative resistance or susceptibility of these processes to the effects of aging and disease. Direct comparison reduces the influence of task differences and subject variability and allows stronger inferences regarding the source of dissociations in performance.

The present study focused on two processes of selection: (a) attention to semantic information and (b) attention to spatial information. The neural bases for the processing of these types of information appear to be at least partially independent (David & Cutting, 1992; Mecklinger & Meinshausen, 1998; Wilson, Clare, Young, & Hodges, 1997), with spatial processing being more dorsally-based (e.g., parietal areas) and semantic processing being more ventrally-based (e.g., temporal areas). Some evidence suggests that the attentional networks associated with these types of information processing are also largely independent (Dark, Vochatzer, & Van Voorhis, 1996; Posner & Dehaene, 1994; Posner & Petersen, 1990). The potential separability of these types of attention suggests that the processes underlying them may be differentially affected by aging and AD. The following sections address these two types of attention, as well as the effects of aging and AD on each.

### **Attention to Semantic Information**

Attention to the context-appropriate meanings of words and symbols is necessary for the successful execution of many verbal and visual tasks. The cuing properties of semantic information enhance anticipation for and comprehension of subsequently presented information (such as the first words of a sentence cuing the last word). Semantic priming tasks assess the cuing properties of word meanings by presenting pairs of words under valid, invalid, and neutral priming conditions. In the valid condition, a target word is preceded by a semantically related prime word (e.g., the word "doctor" preceded by the word "nurse"). In the invalid condition, the target is preceded by a prime word that is unrelated to the current target (e.g., the word "doctor" preceded by the word "shoe"). Finally, in the neutral condition, the prime stimulus is a nonword or a word that evokes no particular meaning (e.g., "XXXXX" or "blank").

If attention is directed to the meaning of the prime word, responses to the target word should be faster in the valid condition than in the neutral

condition, because attentional processes are thought to influence activation within the semantic network so that related items receive enhanced processing. On the other hand, responses to the target word should be slowed when it is preceded by an invalid prime word, because attention must be disengaged and redirected from the expected meaning of the word. This facilitation and slowing in performance due to valid and invalid primes has been termed "benefits" and "costs," respectively.

Caution must be exercised in interpreting benefits and costs within the semantic priming task in terms of attentional processing, because research has shown that two separate processes contribute to semantic priming performance (Neely, 1977; Posner & Snyder, 1975): One is a controlled attention-dependent process, and the other is an automatic activation process. The controlled attention-dependent process involves conscious allocation of attention to areas within the semantic network based on prime-generated expectancies. Participants generate expectancies when they learn that prime stimuli are regularly paired with semantically related target stimuli. The conscious strategy to expect a target word to be related to the prime word, and to prepare a response accordingly, facilitates performance (i.e., a benefit is experienced) when the prime is valid. However, expectancies inhibit performance (i.e., a cost is experienced) when the prime is invalid, because previous pairings cause the presented target to be unexpected.

The automatic activation process involved in semantic priming occurs without conscious awareness. Instead, activation of a semantic representation of a stimulus spreads automatically within the semantic network to closely associated words and concepts. Automatic activation facilitates performance when words are related, but it cannot inhibit performance when words are unrelated. Therefore, automatic activation processing affects semantic benefits but not semantic costs. As a result of the concurrent influence of controlled attention-dependent expectancies and automatic activation processes on semantic priming performance, attempts must be made to distinguish these effects when examining the influence of aging and AD on attention-dependent processes of priming.

Certain task manipulations encourage the development of controlled expectancies during semantic priming (Neely, 1977; Posner & Snyder, 1975). Based on the finding that controlled expectancies are slower to develop than automatic activation processes (i.e., it takes time to generate an expectancy), studies interested in invoking the use of expectancy strategies during priming have interposed an interval of at least 400 ms between presentation of the prime and the target (De Groot, 1984; Milberg, Blumstein, Katz, Gershberg, & Brown, 1995; Neely, 1977). With such a delay, both semantic benefits and semantic costs are evident in priming performance. At shorter delays, participants often demonstrate semantic benefits but not semantic costs, because automatic activation of related concepts is fast and does not inhibit responding. In addition to an appropriate delay interval, use of a high proportion of valid trials encourages the development of controlled attention-dependent expectancies, because participants soon detect the consistent semantic relationship between the prime and the target. Finally, instructions

that delineate the semantic relationship of primes and targets also encourage an expectancy strategy.

Although the above methods encourage the development of controlled attention-dependent expectancies, they do not preclude the influence of automatic activation processes on priming performance. Examination of semantic costs versus semantic benefits helps isolate the influence of controlled processes on priming performance, because costs reflect controlled attention-dependent processes alone, whereas benefits reflect the influence of both automatic and controlled processes. Although there are potential difficulties in obtaining a truly “neutral” condition (Balota, Black, & Cheney, 1992; de Groot, Thomassen, & Hudson, 1982; Jonides & Mack, 1984), the neutral condition is instrumental in distinguishing costs from benefits. With a neutral condition, age- and AD-related changes in attention-dependent priming effects can be assessed independent of the influence of automatic activation processes.

#### **Attention to Semantic Information in Older Adults**

Under conditions favoring automatic semantic activation (short prime-target interval, equal probability of valid and invalid trials), older adults have demonstrated semantic priming effects (faster responses to targets following valid primes than to targets following invalid primes) that were similar in magnitude to those of younger adults (Balota & Duchek, 1988; Burke, White, & Diaz, 1987; Chiarello, Church, & Hoyer, 1985; Ober, Shenaut, Jagust, & Stillman, 1991; but also see Bowles, 1994). This evidence suggests that processes of automatic activation in semantic priming are unaffected by aging. Studies that have manipulated task conditions to encourage controlled attention-dependent processing (e.g., long prime-target interval, high proportion of valid trials, instructions delineating the prime-target relationship) have reported significant costs as well as significant benefits in older adults' priming performance (Burke et al., 1987; Chiarello et al., 1985; Hartman, 1991; but also see Balota et al., 1992; Milberg et al., 1995). Moreover, these priming effects were similar in magnitude to those of younger adults (Burke et al., 1987; Chiarello et al., 1985). Therefore, older adults appear as able as younger adults to direct their attention toward anticipated semantic outcomes based on learned prime-target relationships.

#### **Attention to Semantic Information in AD Patients**

Under conditions that encourage processes of automatic activation, semantic priming effects have been shown to be at least as great in the performance of AD patients as in that of older adults, and in some studies have been even greater (Balota & Duchek, 1991; Chenery, Ingram, & Murdoch, 1994; Nebes, Martin, & Horn, 1984; Shenaut & Ober, 1996). Therefore, automatic semantic activation processes appear intact in AD patients. Few studies have included the proper conditions (prime-target interval over 400 ms, high percentage of valid trials, a neutral condition) to isolate controlled attention-dependent processes in the semantic priming

performance of AD patients. Studies that have included such manipulations have found that AD patients are less likely to form controlled attention-dependent expectancies. For instance, Hartman (1991) concluded that AD patients activated semantic associations automatically, as evidenced by intact semantic benefits. However, patients failed to make use of semantic information contained in primes to anticipate target words, as demonstrated by a lack of semantic costs. Similarly, Chenery et al. (1994) found semantic facilitation under automatic activation conditions (short prime-target interval, low percentage of related trials) in both older adults and AD patients, but they found evidence of controlled expectancies under attention-dependent processing conditions (prime-target pairs repeated predictably across trials) only in older adults. Albert and Milberg (1989) used long prime-target intervals and found both reduced costs and reduced benefits in AD patients compared to older adults.

### **Attention to Spatial Information**

Attention to spatial information is necessary for creating mental representations of the environment and for manipulating objects within that environment. Spatial cues often exist in visual scenes to direct attention to items most relevant to the task at hand. Research by Posner and colleagues (Posner, 1980; Posner & Cohen, 1984; Posner, Cohen, & Rafal, 1982) has demonstrated that searching for task-relevant stimuli is facilitated when spatial cues direct attention to the upcoming location of a stimulus (e.g., an outline box briefly highlights the location of a subsequent target). However, search performance is hindered when spatial cues provide incorrect information regarding the location of a target stimulus (e.g., an outline box highlights a location and the subsequent target is presented elsewhere). This slowing of performance is thought to result from incorrect attentional shifts toward cued locations, from which attention must be disengaged and redirected once targets are presented elsewhere.

Another demonstrated attentional effect of spatial cues is *inhibition of return* (IOR). In an IOR paradigm, after attention is drawn by a spatial cue to a peripheral location, it is drawn away again before the target is presented. Targets subsequently presented at the peripheral location that had been cued are detected *more slowly* than targets presented at a peripheral location that had not been cued. This pattern of performance appears contradictory to the spatial cuing results described above. However, this slowed detection of targets at cued locations is thought to represent a consequence of the initial withdrawal of attention from the cued locations. Once a location is searched without a target being found, the withdrawal of attention from that location is accompanied by an inhibitory tagging of that location. Posner and colleagues (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985) have proposed that IOR facilitates visual search by promoting preference for novel unsearched locations.

### **Attention to Spatial Information in Older Adults**

Most evidence indicates that attentional sensitivity to spatial cues changes little with normal aging. The search performance of older adults is as likely as that of younger adults to be (a) facilitated by spatial cues that correctly direct attention to the locations of targets, and (b) hindered by spatial cues that direct attention away from the locations of targets (Atchley & Kramer, 1998; Gottlob & Madden, 1999; Greenwood, Parasuraman, & Haxby, 1993; Nissen & Corkin, 1985).

Spatial IOR patterns also appear to be preserved with aging. When attention is drawn from a cued peripheral location to a cued central location, older adults are slower to return attention to the previously cued peripheral location than to an uncued peripheral location. Age equivalence in the magnitude of IOR effects is observed on both detection tasks and discrimination tasks (Hartley & Kieley, 1995) and with intrinsic as well as extrinsic shifts of attention (Faust & Balota, 1997). Additionally, older and younger adults exhibit a similar temporal pattern of IOR (Faust & Balota, 1997; Hartley & Kieley, 1995).

### **Attention to Spatial Information in AD Patients**

Findings are mixed regarding the preservation of IOR patterns in AD patients. Faust and Balota (1997) used a long interval rather than a second cue to draw attention away from a cued peripheral location. They found that AD patients, unlike older adults, produced facilitated rather than inhibited responses to targets subsequently presented at the peripherally-cued location, suggesting a failure to intrinsically return attention to fixation before the target appeared. In contrast, Danckert, Maruff, Crowe, and Currie (1998) used a similar single-cue paradigm and found intact IOR effects in AD patients. With a double-cue task (a peripheral cue followed by a central cue), which promotes extrinsic shifts of attention (Faust & Balota, 1997; Langley, Fuentes, Hochhalter, Brandt, & Overmier, 2001), AD patients exhibited the same IOR pattern as older adults, at least on a simple detection task. However, on a two-choice categorization task, AD patients demonstrated reduced IOR effects (Langley et al., 2001). This suggests that increased cognitive demands revealed IOR deficits associated with AD.

Other spatial cuing tasks have revealed AD-related deficits in spatial attention that vary with response requirements. Patients' performance is facilitated as much as that of older adults from spatial cues that correctly indicate the location of a subsequent target (Faust & Balota, 1997; Oken, Kishiyama, Kaye, & Howieson, 1994; Parasuraman, Greenwood, Haxby, & Grady, 1992; Wright, Cremona-Meteyard, Geffen, & Geffen, 1994). Although shifting and engagement abilities appear intact, AD patients have greater difficulty with spatial disengagement (i.e., shifting attention from a cued location to a target location when the cue had incorrectly predicted the location of the target) than younger adults on tasks that require a discrimination response (e.g., indicate whether the located target is a consonant or a vowel; Oken et al., 1994; Parasuraman et al., 1992). In

contrast, difficulties with disengagement are not observed on tasks that require only a detection response (e.g., press a button when the target is detected; Faust & Balota, 1997; Parasuraman et al., 1992; Wright et al., 1994).

### **Present Study**

In the following two experiments, we examined changes related to aging and AD in attentional sensitivity to semantic primes and spatial cues. We used a semantic priming task in the first experiment to assess changes in the ability to attend selectively to the semantic attributes of a word as a function of its prime validity. We modified the semantic priming task in the second experiment so that it served as a spatial IOR task as well as a semantic priming task, with the intention of assessing changes in the ability to inhibit shifts of spatial attention. The semantic and spatial components of attention tapped by the combined task are thought to belong to independent attentional networks, one associated with attention to linguistic stimuli, and the other associated with spatial orienting (Fuentes, Carmona, Agis, & Catena, 1994; Fuentes, Vivas, & Humphreys, 1999a; Posner & Petersen, 1990; Posner & Raichle, 1994; Posner, Sandson, Dhawan, & Shulman, 1989). Although the attentional networks are proposed to be independent, it is possible that the neural connections in the brain areas involved in the two networks permit a coordination of semantic and spatial attention. Consistent with this hypothesis, recent behavioral and neuroimaging evidence suggests that the two types of attention interact (Fuentes, Vivas, & Humphreys, 1999a, 1999b; Lambert & Sumich, 1996; McCarthy & Nobre, 1993; Stolz & McCann, 2000; Vivas & Fuentes, 2001). To illustrate, Fuentes et al. (1999a, 1999b) found that IOR affected semantic attentional processing of stimuli. Both positive semantic priming effects and flanker interference effects were reversed when primes and distractor flankers, respectively, were presented at spatially cued locations (Fuentes et al., 1999b). Furthermore, attentional effects of semantic inhibition and semantic facilitation vanished when targets were presented in locations subject to IOR (Fuentes et al., 1999a). These results suggest that one aspect of spatial attention, IOR, interacts with various aspects of semantic attention in complex ways. Experiment 2 permits exploration of possible changes associated with aging and AD in the interactions between semantic and spatial processes of attention.

## **EXPERIMENT 1**

In the two-choice semantic priming task of Experiment 1, younger adults, older adults, and AD patients categorized target words as exemplars of *animals* or *trees*. Target words were preceded by prime stimuli that were either semantically-valid (named the category of the target word), invalid (named the other category), or neutral (XXXXX). To promote the generation of controlled attention-dependent expectancies, we: (a) used a stimulus onset asynchrony (SOA) of 950 ms between the prime stimulus and the target word to allow sufficient time for expectancies to develop, (b) paired the prime word

with an exemplar from its category on a high percentage (75%) of non-neutral trials, and (c) told participants that the prime word named the category of the target word on most trials.

Predictions of age and AD effects were as follows: Because most evidence suggests that older adults are able to form controlled attention-dependent expectancies for semantically-related word pairs (Burke et al., 1987; Chiarello et al., 1985; Hartman, 1991), both older adults and younger adults were predicted to respond more slowly to invalidly-primed targets than to neutrally-primed targets (semantic costs). In contrast, the performance of AD patients was predicted to reflect reduced costs, because AD patients have difficulty forming controlled attention-dependent expectancies (Albert & Milberg, 1989; Chenery et al., 1994; Hartman, 1991). All three groups were predicted to benefit from valid primes (faster responses to validly-primed targets than to neutrally-primed targets) because benefits reflect automatic activation of related items as well as controlled attention-dependent expectancies for consistently paired items.

An alternative prediction for the performance of AD patients was derived from spatial cuing findings of AD-related difficulties in the disengagement of spatial attention (Oken et al., 1994; Parasuraman et al., 1992). If disengagement difficulties also characterize semantic attention, AD patients might be able to form attention-dependent expectancies for semantic information, but they also might be unable to disengage attention when the prime that initiated the expectancy proves to be invalid (i.e., an unexpected target is presented). According to this hypothesis, the RT performance of AD patients, compared to that of older adults, should be disproportionately slowed by invalid primes. Alternatively, the increase in error rates from the neutral condition to the invalid condition should be greater for AD patients, if they are less able to stop expectancy-based responses to unexpected targets.

## METHOD

**Participants.** Fifteen younger adults, 14 older adults, and 15 AD patients participated in Experiment 1. Younger participants were undergraduate students from the University of Minnesota. Older participants were spouses of AD patients and volunteers from a retirement condominium near the university. AD patients were referred by the director of the Alzheimer's Disease and Related Disorders Clinic at the University of Minnesota Hospital. All participants were native English speakers. Some younger adults received course credit for their participation; the remaining younger adults, as well as the older adults and AD patients, received \$15 for participation in both Experiments 1 and 2.

Patients were diagnosed with probable AD by a neurologist according to the guidelines of the National Institute of Neurological and Communicative Disorders and Stroke, and the Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA, McKhann et al., 1984). A health screening questionnaire (Christensen, Bowes, Armson, & Kern, 1992) identified



participants with self-reported histories of physical or psychological problems known to impair cognition. No histories of heart condition, stroke, serious head injury, psychiatric illness, learning disability, or drug abuse were reported. All participants had normal or corrected-to-normal vision as assessed by a near visual acuity test. Median scores were 20/15 (range 20/15 - 20/25), 20/20 (range 20/15 - 20/40), and 20/25 (range 20/15 - 20/30) for younger adults, older adults, and AD patients, respectively.

Four AD patients were eliminated from the study for their RT performance, as described in the Results section. Table 1 presents the mean age, years of education, and scores on several psychometric tests for the remaining participants. Older adults and AD patients did not differ significantly in age. There was no difference among the three groups in years of education. Younger adults performed reliably better than older adults on tests of immediate and delayed verbal recall; older adults performed reliably better than AD participants on all psychometric tests,  $p < .05$  by  $t$  test. AD patients' scores on the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) ranged from 17 to 27, indicating mild to moderate levels of cognitive impairment.

**Table 1.** Demographic Data and Psychometric Test Results (*SDs* in parentheses).

	Younger adults	Older adults	AD patients
<i>N</i>	15	14	11
Age	23.2 (3.6)*	69.0 (7.6)	71.0 (8.2)
Yrs. of education	14.7 (1.0)	14.3 (1.5)	14.4 (3.9)
MMSE <sup>a</sup>	29.5 (0.6)	29.2 (0.9)	23.0 (3.1)*
Verbal fluency <sup>b</sup>	14.5 (3.1)	14.4 (4.4)	10.3 (4.1)*
CERAD immediate recall <sup>c</sup>			
Trial 1	7.7 (1.2)*	5.6 (2.2)	2.7 (1.8)*
Trial 2	9.4 (0.6)*	7.5 (1.7)	4.1 (1.2)*
Trial 3	9.6 (0.6)*	8.4 (1.3)	4.7 (1.6)*
CERAD delayed recall <sup>c</sup>	9.2 (1.0)*	7.3 (2.1)	1.3 (1.7)*
Trails A (sec) <sup>d</sup>	24.5 (8.4)	36.9 (10.2)	72.4 (40.7)*
Trails B (sec) <sup>d</sup>	60.5 (30.8)	91.6 (24.3)	188.7 (92.7)*

<sup>a</sup> MMSE = Mini Mental State Examination. MMSE scores range from 0-30, with lower scores indicating poorer performance.

<sup>b</sup> Verbal fluency scores represent the number of words beginning with the letter "F" correctly produced in one minute.

<sup>c</sup> CERAD = Consortium to Establish a Registry for Alzheimer's Disease. CERAD recall scores represent the number of words recalled from a list of 10.

<sup>d</sup> Scores on Trails A and B represent the number of seconds required to complete the trails. Maximum score was 300 sec.

\* Mean scores differed significantly from older adults with  $t$  test,  $p < .05$

**Apparatus and Stimuli.** Stimuli were presented on a color monitor of an IBM/PC compatible computer. A button box interfaced with the parallel port of the computer was used to record participants' responses. Two buttons were arranged vertically on the box with removable labels ("Animal" and "Tree") positioned immediately above the buttons. The stimulus displays were white and red on a black background. The displays contained three white unfilled boxes arranged horizontally, subtending visual angles of  $5.4^\circ$  by  $1.3^\circ$ . The inner sides of the two peripheral boxes were located  $4.9^\circ$  from central fixation. The category names *ANIMAL* and *TREE* served as the prime words for the valid and invalid conditions. A string of five Xs served as the prime stimulus for the neutral condition. The target stimuli consisted of the words *horse, lion, cat, dog, elm, oak, pine, and maple*. Prime stimuli were printed in uppercase, and target stimuli were printed in lowercase, both in a white sans serif font. Letters subtended an average of .48 by .38 degrees of visual angle at a viewing distance of 60 cm.

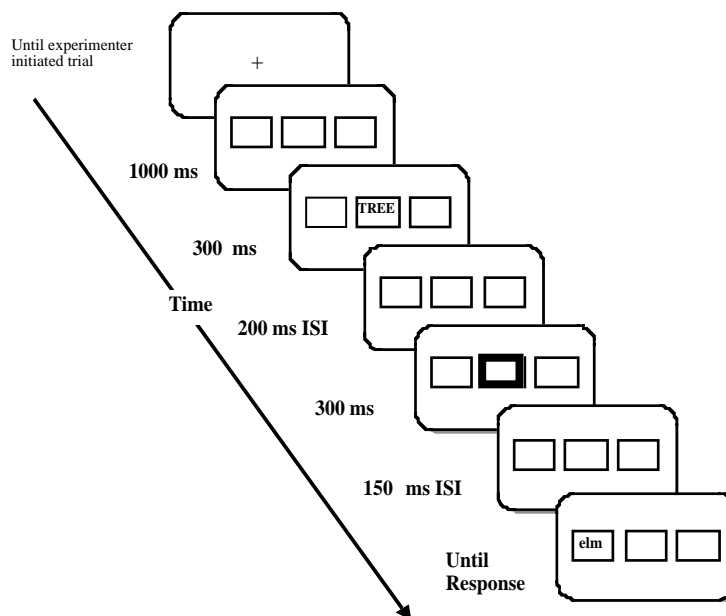
Trials were of three types, corresponding to three semantic priming conditions: (a) the valid condition, in which the target word was preceded by a prime word naming its category (e.g., ANIMAL-dog); (b) the invalid condition, in which the target word was preceded by a prime word naming the other category (e.g., TREE - dog); and (c) the neutral condition, in which the target word was preceded by a prime stimulus of five Xs (e.g., XXXXX - dog). There were 24 practice trials and 96 test trials. One-third of the trials (8 practice trials, 32 test trials) were from the neutral condition. Of the remaining trials, 75% (12 practice trials, 48 test trials) were from the valid condition, and 25% (4 practice trials, 16 test trials) were from the invalid condition. For the valid and invalid conditions, the prime word was ANIMAL for half the trials and TREE for the remaining trials. The eight target words were used an equal number of times within each of the three semantic priming conditions.

**Procedure.** To ensure that all participants (particularly AD patients) were familiar with the target words, participants were asked to categorize aloud each of the eight words as an animal or as a tree. All participants correctly categorized the words.

The experimenter explained the task to participants using a drawn representation of the stimulus events. Participants were instructed that on those trials in which a category word preceded the target word, "most of the time, but not all of the time," the target word would come from the named category. Participants were told to categorize the target word as quickly as possible while avoiding errors.

A trial proceeded as follows (see Figure 1). A fixation cross was presented in the center of the screen until the experimenter initiated the trial by pressing a key on the keyboard. Three horizontally-arranged white boxes replaced the fixation cross and remained on the screen for the duration of the trial. After 1000 ms, the center box changed to red and the prime stimulus (ANIMAL, TREE, or XXXXX) appeared in the box for 300 ms. The three boxes reverted to white for 200 ms, after which the center box changed to red

for 300 ms, to ensure attention was maintained at the center location. With an SOA of 950 ms between the prime stimulus and the target word, the target word was subsequently presented in either the left or the right peripheral box, and remained on the screen until the participant responded. The target was an exemplar of one of the two categories, and the participant classified the target word by pushing the corresponding labeled button on the button box. The assignment of responses to buttons was counterbalanced across participants. Trials from the three priming conditions (valid, invalid, and neutral) were intermixed and presented in random order. The target words in each semantic priming condition were presented on half the trials in the left peripheral box and on half the trials in the right peripheral box. Participants rested one thumb on the top button and the other thumb on the bottom button of the button box throughout testing.



**Figure 1.** Sequence of events for the semantic priming task in Experiment 1. Note that the prime stimulus (ANIMAL, TREE, or XXXXX) was presented in the center box, and the target stimulus (horse, lion, cat, dog, elm, oak, pine, or maple) was presented in either the left or the right peripheral box. Stimuli were presented in white against a black background. The spatial cue, represented by a bolded box here, was a change in the color of the box from white to red. Stimuli were presented in one of three semantic priming conditions: valid (the target word was an exemplar of the category named by the prime word), invalid (the target word was an exemplar of the other unnamed category), or neutral (the prime stimulus was a row of Xs). Displays are not presented to scale.

**Data Analysis.** A systematic linear relationship is often found between the response latencies of younger adults, older adults, and AD patients (Madden, in press; Nebes & Brady, 1992; Nebes & Madden, 1988; Salthouse, 1985). Across a variety of cognitive tasks, older adults' mean RTs and AD patients' mean RTs are roughly a multiplicative factor of younger adults' mean RTs. This factor is approximately 1.50 for older adults (Cerella, 1985; Lima, Hale, & Myerson, 1991; Myerson, Ferraro, Hale, & Lima, 1992) and 2.25 for AD patients (Madden, Welsh-Bohmer, & Tupler, 1999; Nebes & Brady, 1992). As a result of this monotonic relationship, older adults and AD patients may produce larger condition effects than younger adults independent of the influence of the particular cognitive process under investigation. As Faust and Balota (2000) have demonstrated, group differences in general processing speed may exaggerate some group interactions but obscure others. RT transformations have been developed to take into account the contribution of group differences in baseline processing speed (Faust, Balota, Spieler, & Ferraro, 1999; Madden, in press). One such transformation scales each individual's condition effects as a proportion of his or her baseline RT. The transformed scores identify task-specific group differences that are independent of baseline RT differences.

We used the following transformation to calculate semantic benefits and costs in the RT performance of each participant, using their median RTs:

$$\text{Semantic Benefit} = (\text{Neutral RT} - \text{Valid RT}) / \text{Neutral RT} \times 100$$

$$\text{Semantic Cost} = (\text{Invalid RT} - \text{Neutral RT}) / \text{Neutral RT} \times 100$$

Using these percentage change scores, we were relatively confident that any observed group differences in patterns of semantic benefits and costs resulted from attentional differences rather than general RT differences. Untransformed median RTs were analyzed only when comparisons were limited to differences between priming conditions within a group; all comparisons between groups were made with transformed RT scores.

## RESULTS

Participants were eliminated from the data analysis if their mean RT was greater than 4000 ms, if a mean percentage change score was more than 2.5 *SDs* above or below the group mean, or if their percentage errors were greater than 33%. Two AD patients were eliminated from the data analyses because of mean RTs greater than 4000 ms. Two additional AD patients were eliminated because of outlier percentage change RT scores. None of the younger or older adults had outlier RT or error scores based on the above criteria.

**RTs.** Table 2 presents means of median RTs and mean percentage errors as a function of semantic priming condition. Figure 2 presents the derived benefits and costs as represented by percentage change scores. As depicted in the figure, the RT performance of all three groups reflected

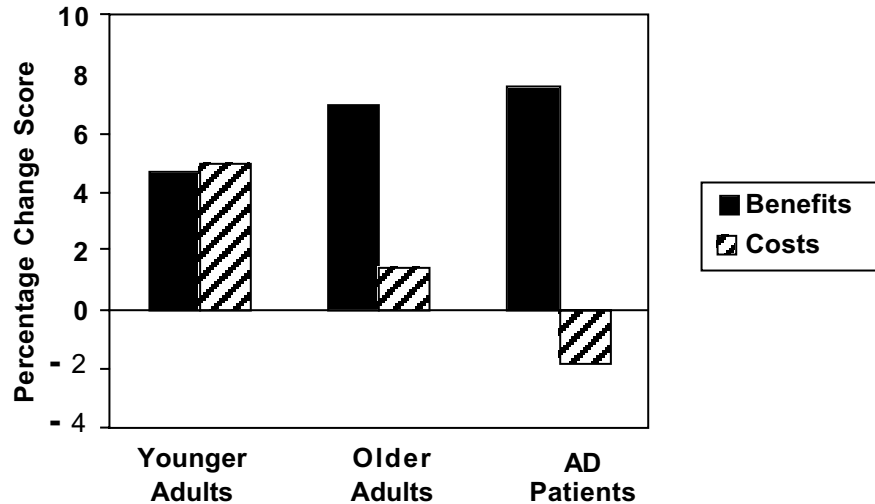
semantic benefits of valid primes, but only the younger adults' performance reflected semantic costs of invalid primes. Percentage change scores were submitted to a 3 x 2 mixed analysis of variance (ANOVA), with group (younger adults, older adults, and AD patients) as the between-subjects variable and semantic priming effects (benefits and costs) as the within-subjects variable. The semantic priming effect was significant,  $F(1, 37) = 9.77$ ,  $p < .01$ , indicating that semantic benefits were larger in magnitude than semantic costs when averaged across groups. In addition, there was a Group x Semantic Priming Effect interaction,  $F(2, 37) = 3.23$ ,  $p < .05$ .

**Table 2.** Mean RTs (ms) and Errors (%) as a Function of Semantic Priming Condition in Experiment 1.

	Semantic priming condition		
	VALID	NEUTRAL	INVALID
Younger adults ( $n = 15$ )			
<i>M</i> RT	566	593	622
( <i>SD</i> )	(70)	(53)	(59)
<i>M</i> errors	3.8	3.5	5.4
( <i>SD</i> )	(3.6)	(3.9)	(7.0)
Older adults ( $n = 14$ )			
<i>M</i> RT	700	754	765
( <i>SD</i> )	(60)	(64)	(83)
<i>M</i> errors	0.6	1.3	1.3
( <i>SD</i> )	(1.3)	(2.1)	(2.7)
AD patients ( $n = 11$ )			
<i>M</i> RT	1088	1182	1163
( <i>SD</i> )	(316)	(354)	(360)
<i>M</i> errors	4.9	5.1	10.8
( <i>SD</i> )	(6.1)	(4.7)	(7.4)

**Note.** RT = reaction time

To explore the interaction, effects of semantic priming condition were examined within each group, using untransformed RTs. Condition effects were significant in all three groups: younger adults,  $F(2, 28) = 16.02$ ,  $p < .0001$ ; older adults,  $F(2, 26) = 11.26$ ,  $p < .001$ ; and AD patients,  $F(2, 20) = 7.25$ ,  $p < .01$ . For younger adults, LSD *t* tests indicated that valid RTs were significantly faster than neutral RTs, which in turn were significantly faster than invalid RTs, reflecting semantic benefits and semantic costs, respectively. For both older adults and AD patients, valid RTs were significantly faster than neutral RTs, but neutral RTs did not differ from invalid RTs, reflecting semantic benefits but not semantic costs, respectively.



**Figure 2.** Semantic benefits and semantic costs as represented by percentage change scores in Experiment 1. Semantic benefits were calculated on each participant's median RTs using the formula  $(\text{Neutral RT} - \text{Valid RT}) / \text{Neutral RT} * 100$ . Semantic costs were calculated using the formula  $(\text{Invalid RT} - \text{Neutral RT}) / \text{Neutral RT} * 100$ .

**Errors.** Percentage errors were submitted to a Group (younger adults, older adults, and AD patients) x Semantic Priming Condition (valid, neutral, and invalid) mixed ANOVA. There were main effects of group,  $F(2, 37) = 8.49, p < .001$ , and semantic priming condition,  $F(2, 74) = 6.77, p < .01$ , as well as a Group x Semantic Priming Condition interaction,  $F(4, 74) = 2.40, p < .05$ . LSD  $t$  tests indicated that both AD patients and younger adults committed more errors than older adults, and invalid errors were greater than neutral and valid errors,  $ps < .05$ . To explore the interaction, error patterns were examined separately within each group. Condition effects were not significant for either younger adults,  $F(2, 28) = 1.15, p > .30$ , or older adults,  $F(2, 26) = 0.55, p > .50$ . In contrast, the effect of semantic priming condition for AD patients,  $F(2, 20) = 5.03, p < .05$ , was characterized by higher error rates in the invalid condition than in either the neutral or valid conditions.

## DISCUSSION

The semantic priming performance of older adults and AD patients differed from that of younger adults in patterns of benefits and costs. With an RT analysis, all three groups exhibited benefits of a valid prime, but only younger adults exhibited costs of an invalid prime. These RT results suggest that automatic processes of semantic activation remained relatively stable with both aging and AD, as reflected in intact benefits, but controlled attention-

dependent processes necessary for forming semantic expectancies were either compromised or less than fully utilized with aging and with AD, as reflected in reduced costs.

The absence of semantic costs was anticipated in the performance of AD patients, but not in the performance of older adults. The lack of significant costs suggests compromised development of controlled attention-dependent expectancies with normal aging, which stands in contrast to the findings of other studies that found age constancies in patterns of costs and benefits (Burke et al., 1987; Chiarello et al., 1985). The discrepancy in findings may be due to differences between studies in task requirements. Past studies did not require semantic processing of the target word, but instead used lexical decision or word naming tasks. In contrast, this experiment used a categorization task, which required participants to access their knowledge of semantic attributes of target words. The heavier emphasis on semantic processing may have revealed age-related deficits in expectancy-dependent performance not revealed with tasks requiring only lexical processing. However, Milberg et al. (1995) used a lexical decision task and also found no semantic costs in the priming performance of older adults.

Another possible explanation for the age-related change in semantic costs was that older adults were able to develop attention-dependent expectancies for related targets, but they chose not to use an anticipation strategy. Older adults tend to respond more cautiously than younger adults, preferring accuracy over speed. Cautiousness was reflected in the lower overall error rates for older adults compared to younger adults or AD patients. If older adults thought that anticipating the target word based on the semantic content of the prime word would increase errors in the invalid condition (perhaps due to difficulties with disengagement), they may have chosen to ignore, to the extent possible, the predictability attributes of the prime word, and responded based fully on the target word. If this were true, it is possible that under circumstances that encouraged a riskier strategy, there would be evidence of expectancy development in the older groups. Younger adults, on the other hand, perhaps more comfortable in their ability to disengage from their expectancies when necessary, chose to attend to and utilize the predictive information contained in the primes.

As expected, for younger adults and older adults, error rates did not differ across the three semantic priming conditions. AD patients, on the other hand, committed more errors in the invalid condition than in the neutral or valid conditions. The RT data were consistent with the interpretation that AD patients did not form controlled attention-dependent expectancies, whereas the error data supported the conclusion that AD patients formed expectancies for related targets but had difficulty disengaging these expectancies when primes proved to be invalid. To further explore this discrepancy between RT and error patterns, we examined the relationship between RT costs and error costs. Although there was no correlation between RT costs and error costs for younger adults,  $r = .02, p > .20$ , or for older adults,  $r = -.07, p > .20$ , there was a positive correlation for AD patients  $r = .70, p < .02$ . This suggests that AD patients who exhibited RT costs also exhibited error costs. An examination of

individual scores revealed that only three AD patients had RT costs of any magnitude, and these three AD patients were also the only patients to have notably high error costs (over 10%).

As a further test of whether this subgroup of AD patients developed attentional expectancies, we compared their RTs for error trials with their RTs for correct trials in the invalid condition. This analysis was limited to the three participants noted above because errors were too few (two or less) for other participants. Error RTs ( $M = 750$  ms) were faster than correct RTs ( $M = 1545$  ms), suggesting that on some trials, this subgroup responded quickly but incorrectly based on their expectancies, and on other trials, they took the additional time needed to disengage attention from their expectancies. Expectancies for this group of AD patients were expressed both in RTs and in errors, whereas expectancies for the younger adults were expressed only in RTs. This pattern suggests that expectancy formation in AD patients, when it occurs, is accompanied by difficulties with disengagement.

Error-related costs for the remaining AD participants were similar to those for younger adults (2.0% vs. 1.9%, respectively). Therefore, the majority of AD patients failed to develop controlled attention-dependent expectancies. Note that the positive correlation between RT costs and error costs for AD participants argues against a speed-accuracy trade-off that would be anticipated if semantic costs were being realized through high errors *rather than* slowed RTs. Instead, the same AD subgroup that showed evidence of semantic expectancies through longer latencies also showed it through increased errors. It is also worth noting that AD patients' MMSE scores (a measure of dementia severity) did not correlate with semantic costs as measured by either RT scores,  $r = -.12$ , or error scores,  $r = -.27$ .

## EXPERIMENT 2

In Experiment 1, the observed patterns of benefits and costs in semantic priming performance were consistent with the hypotheses that (a) automatic semantic activation processes are preserved with both aging and AD (intact benefits), and (b) controlled attention-dependent expectancy processes are impaired with aging and AD (reduced costs). A goal of Experiment 2 was to replicate the pattern of semantic priming effects observed in Experiment 1.

A second goal of Experiment 2 was to explore age- and AD-related changes in spatial attention. Studies have found unaltered patterns of spatial IOR in older adults (Faust & Balota, 1997; Hartley & Kieley, 1995), but inconsistent patterns in AD patients. AD patients demonstrate deficits in IOR on discrimination tasks (Langley et al., 2001) but not on detection tasks (Danckert et al., 1998; Faust & Balota, 1997; Langley et al., 2001). As a result, because the present task required a categorization response, we predicted that both younger adults and older adults would demonstrate normal IOR patterns (slower responses to targets presented at previously cued locations than to targets presented at previously uncued locations), but that the RT performance of AD patients would reflect diminished IOR.



A third goal of Experiment 2 was to examine the interaction between semantic priming effects and spatial cuing effects. The networks of semantic attention and of spatial attention, when activated simultaneously, might interact in such a way as to reveal features of attentional change in older adults and AD patients that would not be observed when the attentional networks were activated individually. To examine both semantic priming effects and spatial IOR effects within the same task, the semantic priming task of Experiment 1 was modified. The location of the prime stimulus, which had remained constant in Experiment 1 (always in the center box), now varied between the left and the right peripheral boxes, so as to serve as a spatial cue as well as a semantic prime. Next, the center box was cued to direct attention away from the peripheral prime, after which the target was presented either at the same peripheral location at which the prime stimulus had been presented (the *cued location*) or at the other peripheral location (the *uncued location*). At the same time that the locations of the prime and target stimuli were varied to measure spatial IOR effects, the semantic relationships of the prime and target stimuli were varied to measure semantic priming effects.

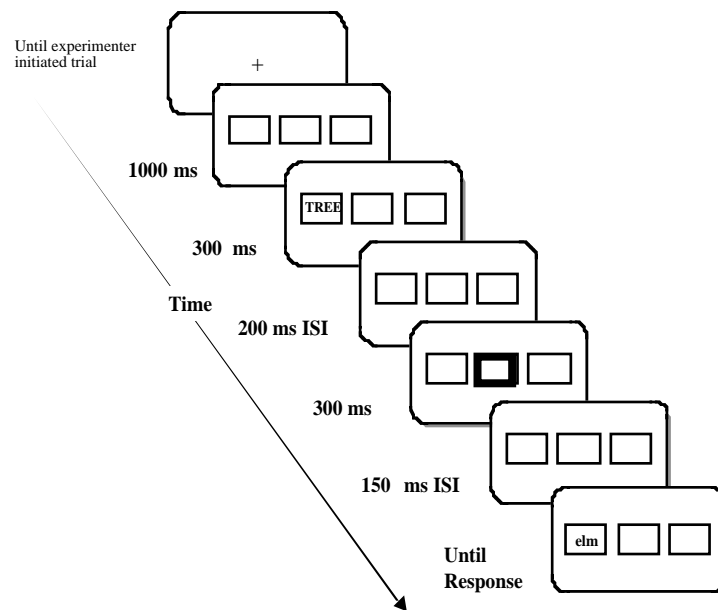
## METHOD

**Participants.** Participants from Experiment 1 also completed Experiment 2. An additional younger adult and an additional AD patient were eliminated due to unacceptably high errors in the invalid condition (over 33%).

**Stimuli.** The equipment and stimuli were the same as those used in Experiment 1. Participants completed 60 practice trials and 192 test trials. As in Experiment 1, one-third of trials (20 practice trials, 64 test trials) were from the semantically-neutral condition (e.g., XXXXX - elm). Of the remaining trials, 75% (30 practice trials, 96 test trials) were from the valid condition (e.g., TREE - elm), and 25% (10 practice trials, 32 test trials) were from the invalid condition (e.g., ANIMAL-elm). Within the three semantic priming conditions, half the trials were cued location trials (the target stimulus was presented in the same peripheral box as the prime stimulus) and half were uncued location trials (the target stimulus was presented in the other peripheral box). In each combination of semantic priming and spatial cuing conditions (e.g., valid prime, cued location), prime and target stimuli were presented an equal number of times in the left and right peripheral boxes.

**Procedure.** In contrast to the procedure of Experiment 1, the prime stimulus in Experiment 2 was presented (for 300 ms) in one of the two peripheral boxes rather than in the center box (see Figure 3 for the trial sequence). The peripheral box in which the prime stimulus was presented turned red simultaneously with presentation of the prime. As in Experiment 1, at the offset of the prime stimulus, the three boxes returned to white for 200 ms, and then the center box turned to red for 300 ms. After the three boxes

returned to white for 150 ms, the target word was presented either in the same peripheral box as the prime stimulus (the cued location) or in the other peripheral box (the uncued location). Participants categorized the target word as quickly as possible by pressing the corresponding button on the button box. As in Experiment 1, participants were instructed that on those trials in which a category word preceded the target word, “most of the time, but not all of the time,” the target word would belong to the named category.



**Figure 3.** Sequence of events for the combined semantic priming and spatial cuing task in Experiment 2. The prime stimulus and the target stimulus were presented in either the left or the right peripheral box. In the spatially-cued condition, the target word was presented in the same box as the prime stimulus. In the spatially-uncued condition, the target word was presented in the other peripheral box. The spatial cue that followed the prime stimulus was always presented in the center box. Stimuli were presented in white and red against a black background. The identities of the prime and target stimuli depended on the semantic priming condition (valid, invalid, or neutral). Displays are not presented to scale.

**Data Analysis.** For each participant, we calculated semantic benefits and costs in each spatial cuing condition (cued and uncued) using the percentage change formulas of Experiment 1:

$$\text{Semantic Benefit} = (\text{Neutral RT} - \text{Valid RT}) / \text{Neutral RT} \times 100$$

$$\text{Semantic Cost} = (\text{Invalid RT} - \text{Neutral RT}) / \text{Neutral RT} \times 100$$

Additionally, we calculated spatial IOR scores in each semantic priming condition (valid, neutral, and invalid) using the percentage change formula:

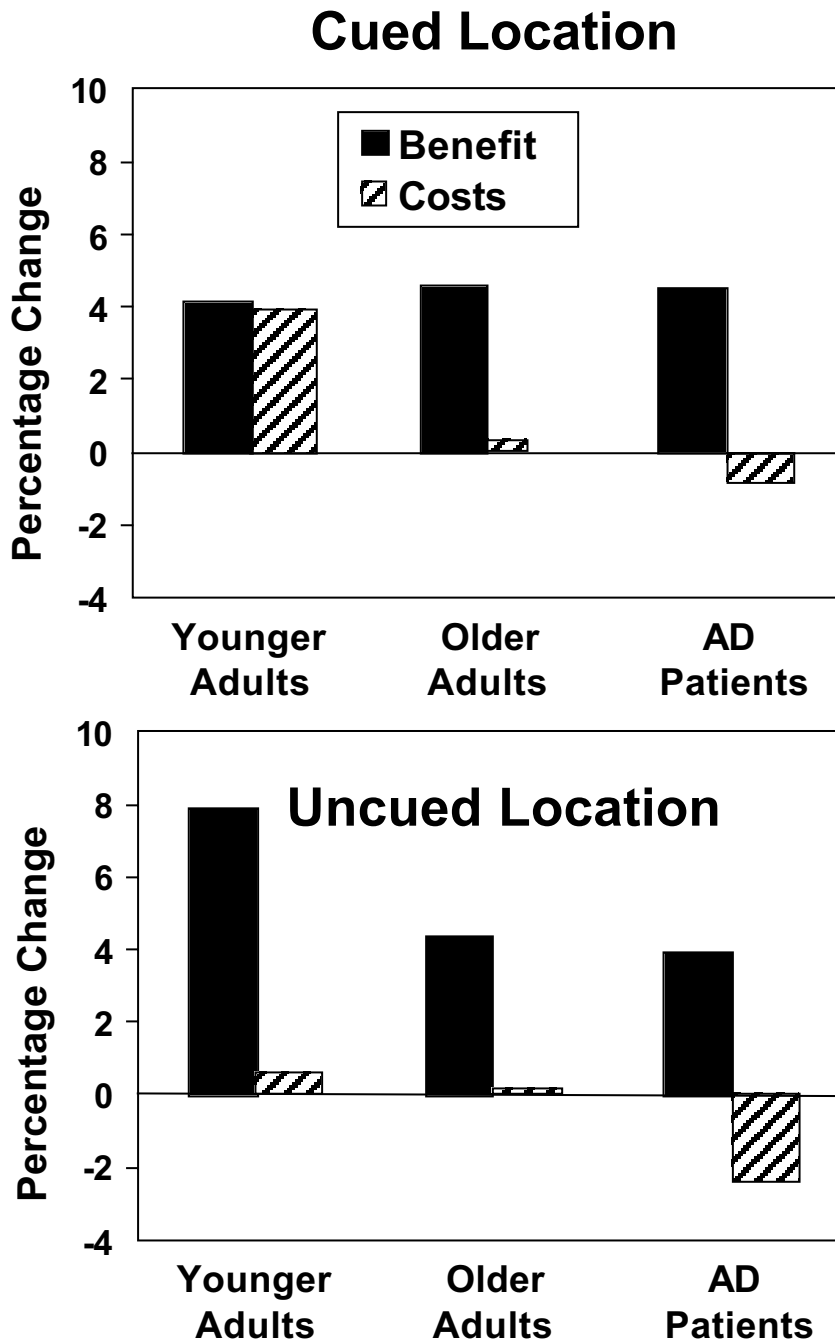
$$\text{Spatial IOR} = (\text{Cued RT} - \text{Uncued RT}) / \text{Uncued RT} \times 100$$

## RESULTS

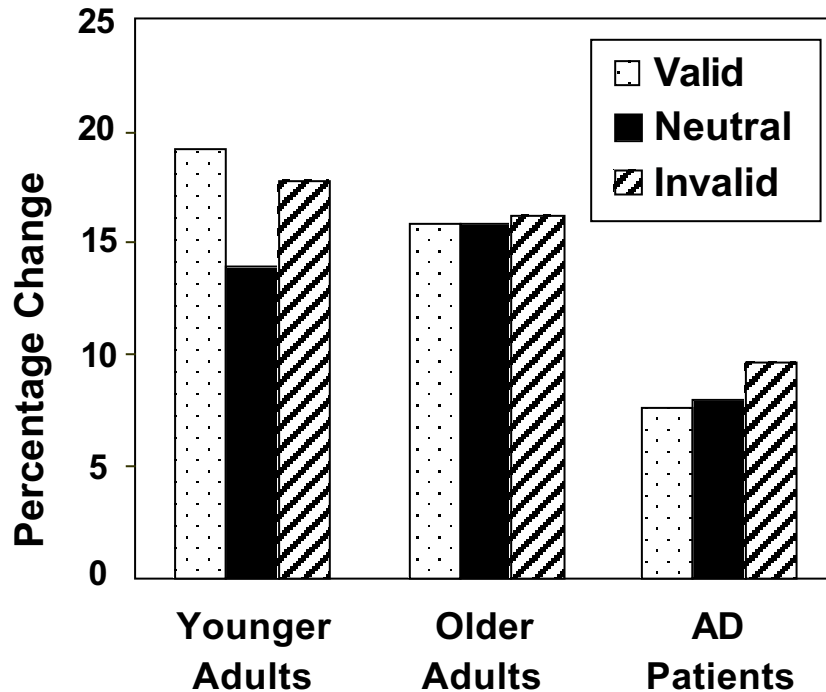
Table 3 presents means of median RTs and percentage errors as a function of semantic priming (valid, neutral, and invalid) and spatial cuing (cued and uncued) conditions. Figure 4 depicts percentage change scores representing semantic benefits and semantic costs at spatially cued and uncued locations. Figure 5 depicts percentage change scores representing spatial IOR effects in semantically-valid, neutral, and invalid conditions. The mean scores suggest that, similar to Experiment 1, the priming performance of all three groups reflected semantic benefits (faster RTs in the valid condition than in the neutral condition), but only younger adults' performance reflected semantic costs (slower RTs in the invalid condition than in the neutral condition). Interestingly, semantic costs for younger adults were observed *only* at the cued location, not at the uncued location (Figure 4), suggesting an interaction between semantic priming and spatial cuing effects for this group. Additionally, spatial IOR effects (slower RTs to targets presented at cued locations than to targets presented at uncued locations) were evident in the performance of all three groups, although the magnitude of this effect was reduced in AD patients (Figure 5). There also appeared to be an interaction between IOR effects and semantic priming condition for younger adults, in that spatial inhibition was greater when targets were preceded by category primes than when targets were preceded by nonword primes.

**RTs. Semantic priming effects.** Percentage change scores representing benefits and costs were submitted to a 3 x 2 x 2 mixed ANOVA with group (younger adults, older adults, and AD patients) as the between-subjects variable and semantic priming effects (benefits and costs) and spatial cuing condition (cued and uncued) as the within-subjects variables. Only semantic priming effects were significant,  $F(1, 35) = 5.61, p < .05$ , indicating that benefits were greater than costs. However, an analysis of homogeneity of variance indicated that, even with the RT transformation, the group comparisons did not meet the assumption of homogeneity of variance for the analysis of variance,  $F_{\max}(3, 13) = 4.71, p < .05$ . Therefore, as in Experiment 1, we examined semantic priming effects separately within each group (Milberg et al., 1995).

Semantic benefits and costs were examined within each group using 2 x 2 repeated measures ANOVAs, with semantic priming effects (benefits and costs) and spatial cuing location (cued and uncued) as the within-subjects variables. For younger adults, semantic benefits were larger in magnitude than semantic costs,  $F(1, 13) = 4.73, p < .05$ . The Semantic Priming Effect x Spatial Location interaction approached significance,  $F(1, 13) = 3.65, p = .077$ .



**Figure 4.** Semantic benefits and semantic costs as represented by percentage change scores at the spatially-cued and uncued locations in Experiment 2.



**Figure 5.** Spatial inhibition of return (IOR) scores as represented by percentage change scores in each semantic priming condition (valid, invalid, and neutral) in Experiment 2. Spatial IOR scores were calculated as  $(\text{Cued RT} - \text{Uncued RT}) / \text{Uncued RT} * 100$ .

Analyses with untransformed RTs indicated that for targets presented at spatially-cued locations, the effect of semantic priming condition,  $F(2, 26) = 17.54$ ,  $p < .0001$ , was characterized by both semantic benefits (valid RT < neutral RT) and semantic costs (invalid RT > neutral RT), as assessed by LSD  $t$  tests. In contrast, for targets presented at spatially-uncued locations, the effect of semantic priming condition,  $F(2, 26) = 11.60$ ,  $p < .001$ , was characterized by semantic benefits but not semantic costs.

For older adults, the results of the  $2 \times 2$  ANOVA indicated that significant semantic priming effects were characterized by larger benefits than costs,  $F(1, 13) = 5.99$ ,  $p < .05$ . Analyses with untransformed RTs indicated that the effects of semantic priming condition at both the spatially-cued location,  $F(2, 26) = 8.18$ ,  $p < .01$ , and the spatially-uncued location,  $F(2, 26) = 4.25$ ,  $p < .05$ , were characterized by semantic benefits (valid RT < neutral RT) but not semantic costs, as indicated by LSD  $t$  tests.

**Table 3.** Mean RTs (ms) and Errors (%) as a Function of Semantic Priming Condition and Spatial Cuing Condition in Experiment 2.

	<u>Semantic priming condition</u>		
	<b>VALID</b>	<b>NEUTRAL</b>	<b>INVALID</b>
	<b>Cued location</b>		
Younger adults ( <i>n</i> = 14)			
<i>M</i> RT	636	663	689
( <i>SD</i> )	(77)	(60)	(78)
<i>M</i> errors	3.1	2.0	5.4
( <i>SD</i> )	(3.0)	(2.6)	(7.3)
Older adults ( <i>n</i> = 14)			
<i>M</i> RT	831	875	874
( <i>SD</i> )	(89)	(127)	(110)
<i>M</i> errors	1.6	1.1	1.8
( <i>SD</i> )	(2.3)	(1.6)	(3.8)
AD patients ( <i>n</i> = 10)			
<i>M</i> RT	1099	1143	1151
( <i>SD</i> )	(322)	(255)	(396)
<i>M</i> errors	8.3	4.7	11.3
( <i>SD</i> )	(6.7)	(6.3)	(14.1)
	<u>Semantic priming condition</u>		
	<b>VALID</b>	<b>NEUTRAL</b>	<b>INVALID</b>
	<b>Uncued location</b>		
Younger adults ( <i>n</i> = 14)			
<i>M</i> RT	541	585	588
( <i>SD</i> )	(89)	(67)	(69)
<i>M</i> errors	3.1	1.8	4.5
( <i>SD</i> )	(2.7)	(2.4)	(7.9)
Older adults ( <i>n</i> = 14)			
<i>M</i> RT	723	758	761
( <i>SD</i> )	(102)	(105)	(126)
<i>M</i> errors	0.9	1.3	4.9
( <i>SD</i> )	(1.1)	(2.0)	(6.1)
AD patients ( <i>n</i> = 10)			
<i>M</i> RT	1037	1074	1056
( <i>SD</i> )	(332)	(293)	(388)
<i>M</i> errors	7.9	5.3	9.4
( <i>SD</i> )	(5.8)	(5.5)	(7.9)

**Note.** RT = reaction time

For AD patients, the 2 x 2 ANOVA revealed that semantic benefits did not differ in magnitude from semantic costs,  $F(1, 9) = 0.78, p > .40$ . Spatial location effects were also unreliable,  $F(1, 9) = 0.28, p > .60$ , and there was no Semantic Priming Effect x Spatial Location interaction,  $F(1, 9) = 0.03, p > .80$ . Analysis with untransformed RTs demonstrated that the effects of semantic priming condition were not significant at either the spatially-cued location,  $F(2, 18) = 0.47, p > .60$ , or the spatially-uncued location,  $F(2, 18) = 0.36, p > .70$ . In other words, there were no significant differences between RTs in the semantically-valid, neutral, and invalid conditions (no costs or benefits) for AD patients.

**Spatial IOR effects.** To examine spatial IOR effects, percentage change scores representing IOR effects were submitted to a 3 x 3 mixed ANOVA with group (younger adults, older adults, and AD patients) as the between-subjects variable and semantic priming condition (valid, neutral, and invalid) as the within-subjects variable. For this analysis, the assumption of homogeneity of variance was not rejected,  $F_{\max}(3, 13) = 1.29, p > .05$ . There was a marginal effect of group,  $F(2, 35) = 2.61, p = .087$ ; LSD *t* tests indicated that both younger adults and older adults had significantly greater IOR scores than AD patients,  $ps < .05$ , but younger adults and older adults had IOR scores similar in magnitude. The main effect of semantic priming condition was not reliable,  $F(2, 70) = 0.78, p > .40$ , indicating that the magnitude of spatial IOR scores did not differ reliably across the three semantic priming conditions. There was no Group x Semantic Priming Condition interaction,  $F(4, 70) = 0.66, p > .60$ .

**Errors.** Errors were submitted to a Group (younger adults, older adults, and AD patients) x Semantic Priming Condition (valid, neutral, and invalid) x Location (cued and uncued) mixed ANOVA. There were main effects of group,  $F(2, 35) = 9.16, p < .001$ , and semantic priming condition,  $F(2, 70) = 9.76, p < .001$ . AD patients committed significantly more errors than did either older adults or younger adults, and errors were significantly greater in the invalid condition than in the valid or neutral conditions, as indicated by LSD *t* tests. None of the interactions were significant.

## DISCUSSION

Patterns of semantic priming in Experiment 2 largely replicated those of Experiment 1. Both semantic benefits (facilitated categorization with valid primes) and semantic costs (slowed categorization with invalid primes) were evident in the RT performance of younger adults, at least at the spatially-cued location, whereas benefits without costs characterized the performance of older adults at both spatial locations. Although benefits in the performance of AD patients were of similar magnitude as those of the other two groups, they

were not statistically reliable, nor were costs, at either spatial location. The pattern of semantic priming effects associated with aging and AD supported the conclusions of Experiment 1: The use of controlled attention-dependent expectancies is less likely to occur in older adults and AD patients. Examination of the error data revealed higher error rates for AD patients than for the other two groups, and these errors were primarily associated with invalid primes.

Although the neutral condition is essential for distinguishing semantic costs from semantic benefits, we recognize the difficulties in interpreting semantic priming effects that can arise from possible non-neutral characteristics of the neutral condition. The neutral condition in the present experiments was neutral in the sense that it did not convey semantic information, but as observed by other researchers (Balota et al., 1992; De Groot et al., 1982; Jonides & Mack, 1984), Xs can produce interference effects of their own (but see Neely, 1977). In the present experiments, Xs may have elicited additional processing because they were the only non-words among the stimuli. If so, this non-semantic slowing would lead to underestimation of semantic costs and overestimation of semantic benefits. Furthermore, if older adults and AD patients experienced greater interference effects than younger adults, this would compromise the ability to use neutral primes to assess age- and AD-related changes in cost scores.

Studies have circumvented the non-neutrality issue by directly comparing valid and invalid conditions (e.g., Albert & Milberg, 1989; Nebes, Brady, & Huff, 1989). As a post hoc analysis, we recalculated the semantic priming effects in Experiments 1 and 2 using the formula  $(\text{Invalid RT} - \text{Valid RT}) / \text{Valid RT} \times 100$ . In Experiment 1, semantic priming effects as measured without reference to the neutral condition were reflected in the performance of all three groups (10.6%, 9.3%, and 6.4% for younger adults, older adults, and AD patients, respectively),  $t_s > 2.5$ ,  $p_s < .02$ , and the magnitude of the priming effects did not differ significantly between groups,  $F(2, 37) = 0.81$ ,  $p > .40$ . In Experiment 2, we found semantic priming effects that did not differ significantly in magnitude in the performance of younger adults and older adults (8.3% and 4.7%, respectively),  $t_s(13) > 3$ ,  $p_s < .05$ . Priming effects in the performance of AD patients (2.6%) were not significant,  $t(9) < 1$ ,  $p > .40$ . Thus, disregarding the neutral condition, there was no evidence of age-related changes in semantic priming effects, but there was evidence of AD-related reductions in priming effects in Experiment 2.

Turning to matters of spatial attention, reliable patterns of spatial IOR (slower responses to targets presented at previously attended locations) were observed in the performance of all three groups. However, IOR effects were reduced in magnitude for AD patients. This finding is consistent with the hypothesis that IOR patterns in AD patients are impaired on discrimination tasks (Langley et al., 2001) but are intact on detection tasks (Danckert et al., 1998; Faust & Balota, 1997; Langley et al., 2001). A parallel pattern is found with disengagement of spatial attention: AD patients exhibit difficulties with disengagement on discrimination tasks (Oken et al., 1994; Parasuraman et al., 1992) but not on detection tasks (Faust & Balota, 1997; Parasuraman et al.,



1992; Wright et al., 1994). Taken together, the evidence suggests that task demands influence the functioning of spatial attention in AD patients. A slightly different explanation for the AD-related reductions in IOR effects is that combining the spatial IOR task with the semantic priming task led to competition for limited attentional resources. When both semantic and spatial aspects of attention were taxed, inhibitory mechanisms of spatial attention were overly challenged in AD patients.

A point of interest regarding Experiment 2 concerns interactions between semantic priming and spatial IOR. When all three groups were included in the analysis, we found no statistical interaction between semantic priming and spatial IOR, which might lead us to conclude that the attentional processes involved in these effects were independent of one another (see Fuentes et al., 1999a; and Posner, Inhoff, Friedrich, & Cohen, 1987, for a different view). However, as Fuentes et al. (1999a) pointed out, if the attentional mechanisms involved in spatial orientation and semantic processing interact with one other, one should expect such an interaction only in those participants in which normal functioning of the aforementioned mechanisms could be exhibited (which, in the present study, would be the younger adults). Evidence that the processes involved in semantic priming and spatial IOR in younger adults interacted in the present study was a marginal Semantic Priming Effect x Spatial Location interaction. Younger adults' response times reflected semantic costs in spatially-cued locations but not in uncued locations. In other words, the processes involved in biasing attention to explore new (uncued) spatial locations fostered shifting attention to semantically-invalid targets, and therefore semantic costs were reduced compared to when semantically-invalid targets were presented to already explored (cued) locations. Additionally, examining the spatial IOR effect more closely in younger adults, we noted that it was greater in magnitude when target words were preceded by prime words (semantically-valid or invalid) than when targets words were preceded by prime non-words (Xs), although the difference was only marginally significant,  $t(13) = 2.06$ ,  $p = .078$ . When attention to semantic information was involved (semantically-valid and invalid trials), orienting attention to the inhibited (cued) spatial location took longer (larger IOR effects) than when attention to semantic information was not involved (neutral trials). These results suggest that, at least in younger adults, the mechanisms that control attention to semantic information and to spatial locations interact.

## GENERAL DISCUSSION

People frequently, and sometimes simultaneously, attend to semantic and spatial cues in the environment. The results of the present experiments suggest that both older adults and AD patients experience changes in attention-dependent semantic processing, in terms of a reduced likelihood of forming controlled expectancies for semantic information. In Experiments 1 and 2, younger adults' performance reflected both semantic benefits and semantic costs of attending to prime words that predicted the categorical membership of subsequently-presented words. In contrast, the performance of

older adults and AD patients reflected only semantic benefits, not semantic costs. This pattern suggests that automatic activation processes of semantic priming were operative with aging and AD, but older adults and AD patients did not form attention-dependent semantic expectancies for regularly-paired words.

As discussed earlier, the finding of no semantic costs in the performance of older adults contrasts with previous studies that have found little impact of aging on the ability to form attention-dependent expectancies (Burke et al., 1987; Chiarello et al., 1985). However, there is some evidence that older adults do not perform priming tasks in a manner consistent with expectancy formation (Balota et al., 1992; Milberg et al., 1995). The discrepancy in findings may be related to the semantic processing requirements of the priming tasks, or it may be related to the nature of the neutral conditions. As suggested by the secondary analysis that found age constancies in priming effects that were measured without reference to the neutral condition, the neutral condition in the present study may have underestimated cost effects in older adults. An interesting alternative hypothesis is that older adults *could* form expectancies for related targets, but deliberately chose a strategy in which they ignored the predictability information contained in the primes. Older participants may have decided that responses based on expectancies would potentially increase errors on invalid trials, therefore they sacrificed speed for accuracy by forming responses based upon the appearance of the target rather than in anticipation of the target. To summarize, although there was clear evidence *for* expectancy development in younger adults, the evidence *against* expectancy development in older adults was less clear. The present results could be alternatively interpreted as evidence that (a) older adults were less able to form controlled expectancies; (b) older adults were able, but chose not to, form controlled expectancies in order to maintain high accuracy; or (c) older adults formed controlled expectancies, which were obscured by the chosen neutral condition. Only further research will distinguish between these possibilities. However, it is important to note that there was no evidence *for* controlled expectancy formation in older adults, as there was for younger adults.

Although the above alternative interpretations also apply to AD patients' semantic priming performance, the conclusion that controlled attention-dependent expectancy formation is impaired in AD patients is in agreement with findings from other studies (Albert & Milberg, 1989; Chenery et al., 1994; Hartman, 1991). It should be noted, however, that a separate set of studies have used manipulations to encourage controlled attention-dependent processing (long SOAs, pairwise priming, and a high relatedness proportion) and have actually found increases rather than decreases in semantic priming effects in AD patients (see review by Ober & Shenaut, 1995). It is difficult to resolve the discrepancy between the two sets of findings because many of the studies in which *hyperpriming* has been found did not include a neutral condition, so it is unclear whether the increased semantic priming effects were due to increased benefits or increased costs. Increased benefits would suggest changes in automatic priming processes, whereas increased costs would

suggest changes more specific to controlled expectancy processes. Although the Ober and Shenaut review concludes, as we do, that controlled attention-dependent expectancy processes change with AD, it does so based on an opposite pattern of findings.

Surprisingly, a subgroup of AD patients in Experiment 1 appeared to have formed controlled attention-dependent expectancies. This being the case, they still exhibited deficits of semantic attention. Although their performance was slowed in the invalid condition, consistent with the formation of expectancies that hindered performance when the prime was invalid, their performance also became less accurate. The errors were consistent with an inability to disengage attention from the expectancy in order to attend to the presented target, similar to spatial disengagement difficulties displayed on spatial attention tasks (Oken et al., 1994; Parasuraman et al., 1992).

A spatial mechanism in visual search, IOR, prevents attention from returning to locations that have already been explored. This component of spatial attention appears to be preserved with healthy aging but impaired with AD, at least on more complex discrimination tasks. Taken together, the present results indicate that semantic and spatial aspects of attention appear to undergo different patterns of change with normal aging and with AD.

One popular framework of attention advanced by Posner and colleagues (Posner, 1992; Posner et al., 1987; Posner & Petersen, 1990; Posner & Raichle, 1994), derived from neurophysiological and brain imaging evidence, suggests that the *executive network* (also called the *anterior attention network*) oversees control functions associated with selection of objects based on physical and semantic features, whereas the *orienting network* (also called the *posterior attention network*) is associated with selection of objects based on location. The executive and the orienting networks seem to be part of a common attentional system (Fuentes et al., 1999a; Posner et al., 1987). Posner et al. (1987) proposed that under certain circumstances the executive network overrides activity of the orienting network. On the other hand, Fuentes et al. (1999a) demonstrated that the orienting network interferes with actions of the executive network. Importantly, in the present study, we observed interactions between the two attentional networks going in both directions. Experiment 2 demonstrated that, at least in younger adults, semantic costs decreased when targets were presented at uncued spatial locations compared to cued locations. This points to an influence of the orienting network on the executive network. In addition, spatial IOR effects were greater for semantically-valid and invalid targets than for neutral targets. This points to an influence of the executive network on the orienting network. Fuentes et al. (1999a) accounted for the complex interactions between the two attentional networks in terms of task priorities. When the executive task was more demanding on attentional resources than the spatial task, it took precedence. Conversely, when the orienting task was more demanding on attention resources, it took precedence. Finally, as observed in the present study, when attentional demands were similar in the two tasks, the two attentional networks mutually influenced one another.

In summary, these experiments produced evidence consistent with (a) age- and AD-related changes in the use of controlled attention-dependent expectancies during semantic priming performance, and (b) AD-related impairments of inhibition on a spatial cuing task. This pattern of results suggests that older adults direct attention to semantic information differently than younger adults, although they inhibit attention to spatial locations in the same manner as younger adults. AD patients appear to experience difficulty with both semantic and spatial attentional processing. Patients with AD either failed to fully utilize the information provided by semantic cues, or failed to efficiently disengage from the semantic information when it proved to be invalid. Furthermore, AD patients were less likely than younger or older adults to use spatial cue information to direct their attention away from spatial locations. These findings, together with evidence that aspects of semantic and spatial attention interact in younger adults, are congruous with an anatomical framework that proposes that different but closely interconnected brain areas mediate attention to semantic and spatial information.

## RESUMEN

**Atención a la información espacial y semántica en el envejecimiento y la enfermedad de Alzheimer.** Los efectos atencionales para la información espacial y semántica se estudiaron en 2 experimentos en sujetos jóvenes, personas mayores y pacientes con la enfermedad de Alzheimer (EA). En el primer experimento utilizamos una tarea de 'priming' semántico para estudiar cómo la edad y la EA pueden afectar a la atención dirigida a la información semántica. En el segundo experimento modificamos la tarea para que adicionalmente nos permitiera medir la inhibición de retorno (IR). La combinación de las tareas espacial y semántica nos permitió medir (a) cómo se ve afectada la atención dirigida a señales espaciales así como a la información semántica en las personas mayores y pacientes con EA, y (b) las interacciones entre las redes involucradas en la atención a la información espacial y semántica. Los resultados de ambos experimentos mostraron diferencias entre los grupos en la tarea semántica, sugiriendo que tanto las personas mayores como los pacientes con EA tuvieron dificultades para generar expectativas dependientes de la atención para los estímulos relacionados semánticamente. Los tres grupos de sujetos mostraron efectos de IR en el Experimento 2, aunque de menor tamaño en el grupo de pacientes con EA. Los sujetos jóvenes mostraron interacciones entre los efectos semánticos y espaciales. Estos resultados nos permiten concluir que (a) la selectividad vía estímulos semánticos y señales espaciales refleja mecanismos atencionales diferentes, y (b) los aspectos semánticos y espaciales de la atención están mediatizados por redes neurales diferentes pero estrechamente interconectadas.

**Palabras clave:** Redes neuronales atencionales, deterioros de la atención, envejecimiento, enfermedad de Alzheimer.

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