Selective Attention Impairments in Alzheimer’s Disease: Evidence for Dissociable Components

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The mental activity labeled “attention” describes multiple cognitive phenomena and has been dissociated into numerous subcomponents such as selective, divided, and sustained attention. Selective attention is defined as the ability to screen out irrelevant information while attending to relevant, applicable information. Selective attention is also required to focus resources on a restricted number of sensory channels while ignoring or suppressing the processing of other information (Perry, Watson, & Hodges, 2000).

Numerous cognitive studies have examined the nature of selective attention in various groups (Baddeley, Baddeley, Bucks, & Wilcock, 2001; Cohen, Kaplan, Moser, Jenkins, & Wilkinson, 1999; Foster, 2001; Foster, Behrmann, & Stuss, 1999; Foster, Eskes, & Stuss, 1994; Parasuraman, Greenwood, & Alexander, 1995; Plude & Doussard-Roosevelt, 1989; Shum, McFarland, & Bain, 1990; Spikman, Deelman, & van Zomeren, 2000; Stuss, Binns, Murphy, & Alexander, 2002; Stuss et al., 1999). Considerable evidence has accumulated that selective attention can be dissociated into different subcomponents. The dissociation of selective attention has particular relevance for cognitive neuropsychologists who want to determine the nature of selective attention impairments in individuals with brain damage. One such example involves investigating the nature of attention impairments in subjects who have Alzheimer’s disease (AD; see reviews by Balota & Faust, 2002; Parasuraman & Haxby, 1993).

Perry and Hodges (1999) suggested that an examination of the nature of attentional impairments associated with AD is relevant for addressing three different issues—clinical symptoms of AD, anatomy of attentional systems, and theories of cognitive slowing. With regard to symptoms, they argued that the memory impairments associated with AD could be amplified by an accompanying inability to selectively attend to information, with concomitant disruption of the encoding process into short-term memory (STM; Perry & Hodges, 1999). The neuroanatomy of selective attention can be examined by relating selective attention impairments to the distribution of pathology in AD. Such investigations are needed to supplement the normative work, which suggests that attention operates neither as a single unitary function nor as a property of the whole brain (see Mesulam, 1990; Posner, 1980; Posner & Petersen, 1990).

Posner and Petersen’s (1990) characterization of two separate anatomic networks of attention—anterior and posterior—best exemplifies this argument. The anterior attention network involves the anterior cingulate and frontal lobe structures specialized for

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activities related to inhibiting automatic responses and overriding conflicts. The posterior attention network, localized in the parietal lobes, is specialized for performance on tasks related to visuospatial attention (i.e., locating objects in space). The pathology of AD is initially concentrated in structures in the medial temporal lobes, and later in the development of the disease, the degeneration involves heteromodal association cortices in the frontal and parietal lobes (Braak & Braak, 1991). Therefore, if one were to make a theoretical prediction about what cognitive impairment would be observed early in the development of AD on the basis of the neuroanatomical changes that are associated with the disease, then it would be that individuals with AD should manifest significant impairments in cognitive tasks requiring visuospatial attention involving the parietal cortex. These impairments should be followed in the later stages by impairments observed on measures of inhibition involving the frontal cortex. There is insufficient evidence from studies to date, however, to support this theoretical claim.

It appears that choosing the appropriate selective attention task also plays a crucial role in defining the extent of attentional impairments associated with AD. Spieler, Balota, and Faust (1996) proposed that selective attention is mediated during performance on the incongruent condition of the Stroop task, in which subjects are required to inhibit the automatic process of word reading in favor of naming the referent ink color of the word. Researchers (i.e., Collette, Van der Linden, & Salmon, 1999; Duke & Kaszniai, 2000; Fisher, Freed, & Corkin, 1990; Perry et al., 2000) have shown that AD subjects manifest significant impairments compared with healthy elderly individuals on the incongruent condition of the Stroop task. This indicates that AD subjects display impaired abilities to perform tasks of selective attention that require the inhibition of an automatic cognitive ability. Other tasks of inhibition have been used to measure selective attention impairments in AD subjects (Faust & Balota, 1997; Langley, Fuentes, Hochhalter, Brandt, & Overmier, 2001). However, these tasks often encompass cognitive abilities other than inhibition and can account, in part, for inconsistent results in the literature.

Similarly, there are other cognitive tasks that require selective attention. The visual search task (VST), developed by Treisman and Gelade (1980), was designed to assess visuospatial selective attention. In this task, the subject must detect the presence or absence of a target stimulus that is placed among an array of distractors. When there are two types of distractors in the array that share features with the target but are independent from each other, selective attention is required to detect the target in a serial manner. Some might suggest that inhibition could also be considered an aspect of this task (Foster, 2001). For example, subjects have a natural tendency to respond to partially correct targets and must constantly inhibit these incorrect motor responses. We would suggest, however, that the degree of inhibition required is related to the automaticity of the task; far greater inhibition is required to block overpracticed, automatic responses such as reading a word (as in the incongruent condition of the Stroop task).

AD subjects perform significantly slower than do healthy elderly control (HEC) subjects when they are required to detect a target that is dispersed among two types of distractors, as in the VST (Nebes & Brady, 1989; Parasuraman et al., 1995; Parasuraman, Greenwood, & Alexander, 2000; Parasuraman, Greenwood, Haxby, & Grady, 1992). In addition, the benefit of a cue does not improve the performance of AD subjects (Nebes & Brady, 1989), which indicates that individuals with AD are slower at disengaging their attention from one location to another (Parasuraman et al., 1992). These results are not surprising, given that visuospatial attention is associated with activity in the parietal lobes (Corbetta, Shulman, Miezen, & Petersen, 1995) and that in AD, the parietal lobes are affected by the formation of senile plaques and neurofibrillary tangles (Braak & Braak, 1991).

Finally, selective attention has also been considered a necessary component of decision making (Gordon & Carson, 1990; Greenwood & Parasuraman, 1991; Pate, Dyck, & Margolin, 1990). The specific cognitive processes related to decision making have been subjected to only limited studies to date; few functional imaging and lesion analyses have been performed that use decision-making tasks. However, results from reaction time (RT) studies suggest that intact selective attention is required to make efficient decisions, even during performance on a simple RT task (Pirozzolo, Christensen, Ogle, Hansch, & Thompson, 1981). For example, Gordon and Carson (1990) found that by varying the interstimulus interval, performance on a choice reaction time (CRT) task varied among both HEC and AD subjects, such that when there was a longer interstimulus interval, both groups responded to the target at a faster rate (Pate, Margolin, Friedrich, & Bentley, 1994).

Two relevant studies of attention have directly addressed the question of attentional deficits in AD. Perry and Hodges (1999) suggested that tasks involving inhibitory processes are sensitive to early cognitive changes in AD. In contrast, Baddeley et al. (2001) asserted that divided attention (measured with simple and choice RT tasks) is not impaired early on in AD. Furthermore, they found minimal changes in early AD in a different visual search task. However, on a divided attention task (a dual-task paradigm), they found marked abnormalities in early AD (Baddeley et al., 2001). Baddeley et al. addressed the issue of specificity to determine whether there are specific components of the attentional controller impaired in AD. In contrast, Perry and Hodges were interested in assessing which selective attention task was most sensitive in its ability to detect attentional impairments in AD subjects. With these issues in mind, our purpose in the current study was to compare the performance of a group of subjects with mild AD with that of a group of HEC subjects on three tasks of selective attention. The first goal was to determine which task of selective attention was most reliably impaired in AD. Furthermore, the current study also addressed the question of whether or not selective attention could be dissociated into different components.

We chose three tasks to examine putative components of selective attention: the Stroop task (considered to be predominantly a measure of inhibition), the VST (considered to be predominantly a measure of visuospatial attention), and the CRT and Cued Choice Reaction Time tasks (CCRT; considered to be predominantly measures of decision making). Despite the notion that there may be overlapping cognitive processes associated with all three, it is important to consider that at least for the more difficult (hard) conditions of each task, the cognitive processes involved act together as a measure of a unique component of selective attention. For example, the incongruent condition of the Stroop task requires the ability to selectively attend to the stimulus, remember the rule to name the ink color, inhibit a prepotent response for reading, and then switch attention to the next stimuli and repeat the process. The conjoined condition requires subjects to focus their attention on
one stimulus, remember the rule to search for the target, make a decision as to whether they are looking at the target, inhibit the motor response to push one of the response keys, switch attention to the next stimulus on the screen, and finally, activate the appropriate hand when the target has been detected or when a decision has been made that the target is absent. Finally, the CRT and CCRT tasks require subjects to selectively attend to the stimuli, remember the rule as to which button to push on the keyboard, make a decision, and inhibit one hand and activate the other hand to press the appropriate key.

We predicted that AD subjects would be significantly impaired on all tasks of selective attention. However, impairment would be most striking in the Stroop task, because this task is associated with inhibitory processes and less involvement of other factors, such as the ability to shift attention from one visual location to another or to make decisions. Because the Stroop task is most sensitive to inhibitory deficits and AD pathology affecting the frontal lobes, it is reasonable to hypothesize that in the AD group, performance on the Stroop task will be the most impaired of the three attentional tasks.

In their review of attention and AD, Perry and Hodges (1999) suggested that studies of attention impairments in subjects with AD should be designed to address the issue of generalized cognitive slowing. The theory of generalized cognitive slowing posits that constraints of slowed psychomotor speed occur as a function of normal aging. As such, it is unclear whether HEC subjects and, more specifically, AD subjects manifest specific cognitive impairments or whether their slowed performance on RT tasks is due to slowed psychomotor speed (Nebes & Brady, 1992; Nebes, Brady, & Reynolds, 1992; Salthouse, 2000). More precise studies are needed to clarify this issue. In studies with tasks of varying difficulty, it has been shown that an increase in task difficulty causes a proportionally greater effect on the performance of both HEC and AD subjects compared with healthy young individuals (Salthouse, 2000). As such, it can be suggested that the variance of RTs in HEC subjects contributes to significant group differences. Different methodological techniques should be used in the data analysis procedure to account for these factors (Baddeley et al., 2001; Foster et al., 1999; Spieler, Balota, & Faust, 1996).

To address the presence of extraneous factors such as generalized cognitive slowing, we followed the recommendations of Perry and Hodges and used proportional RT difference scores on attention tasks. The following calculation exemplifies the concept of proportional RT difference scores: (hard RT – easy RT)/easy RT. For the current study, this measurement will herein be referred to as proportional RT difference scores. This calculation was beneficial because comparisons could be made between all three tasks of attention that were independent of factors related to generalized cognitive slowing.

Method

Subjects

Twenty-three HEC subjects were recruited as volunteers from the community or from local general practitioners. (Older individuals who were considered mentally healthy were referred by their physicians and approached for inclusion in the project.) A neuropsychological battery, clinical assessment, and neurological examination were then carried out to determine whether the individuals met the criteria for being neurologically and cognitively healthy for their age (i.e., their performance on all cognitive domains was within 1 standard deviation of age-related mean values).

Thirty subjects with AD who met the National Institute of Neurological and Communications Disorders and Stroke and Alzheimer’s Disease and Related Disorders Association criteria for the diagnosis of probable AD and the Diagnostic and Statistical Manual of Mental Disorders (3rd ed., American Psychiatric Association, 1980) criteria for dementia were also studied (McKhann et al., 1984). Subjects were selected to participate in a number of cognitive tests as part of an ongoing clinical research study. All subjects were classified according to the Washington University Clinical Dementia Rating (CDR) scale and met the criteria for 1.0 on that scale (Hughes, Berg, Danziger, Coben, & Martin, 1982). There was no evidence on clinical evaluation of systemic or other neurological disease that was sufficient to interfere with cognitive function. Structural brain disease was excluded by computerized tomography or MRI and blood work was done, including complete blood cell count, routine chemistry, thyroid function, serum B12, folate, and VDRL (Syphilis screen). All subjects scored less than 4 on the Hachinski Ischemic Scale (Hachinski et al., 1975). The Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was carried out by the clinician as a global assessment tool. Table 1 displays the mean (±SD) age, education, and MMSE scores for both groups.

Procedure

Cognitive tasks of selective attention. Both groups of subjects completed three separate cognitive RT tasks of selective attention. Tests were administered at their homes in different sessions and were randomly ordered over 1 month of weekly visits. One HEC individual was excluded from the Stroop task analysis because of color blindness. Only 25 AD subjects completed all three tasks. Five AD subjects did not complete the VST. Each task consisted of two conditions, an easy and a hard condition. These tasks will be outlined in detail below.

Stroop task. The Stroop task (Stroop, 1935) consisted of two subtests. In the easy condition, subjects were instructed to name the color of 24 dots that were red, yellow, blue, or green. In the hard condition, subjects were required to name the ink color of 24 color referents. Words were presented in an ink color that was divergent from their verbal referents, such as the word green displayed in blue ink. The order of the color of the dots and words was randomized for every session, and each subject was shown the easy condition before the hard condition. The amount of time required to perform the task was measured in seconds.

VST. The VST (Treisman & Gelade, 1980) was performed on a Macintosh computer using PsychLab software (Bub & Gum, 1991). In the two conditions of this task, subjects were required to find a target that was embedded among an array of distractors. In the easy condition of the VST, subjects were shown an array that consisted of one target (a checker-filled circle, which was 0.75 × 0.75 cm in dimension) and 12 distractors (open circles, which were 0.75 × 0.75 cm in dimension) arranged quasi-randomly on the computer screen, which subtended an area of 12.0 × 18.0 cm.

Table 1

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Education (years)</th>
<th>MMSE (max = 30)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEC (n = 23; 10 men, 13 women)</td>
<td>73.0 (6.1)</td>
<td>13.1* (3.1)</td>
<td>28.8** (1.0)</td>
</tr>
<tr>
<td>AD (n = 30; 16 men, 14 women)</td>
<td>74.1 (8.3)</td>
<td>10.6 (3.5)</td>
<td>22.4 (3.1)</td>
</tr>
</tbody>
</table>

Note. MMSE = Mini-Mental State Examination; HEC = healthy elderly control; AD = Alzheimer’s disease. * p < .008. ** p < .001.
In the hard condition of the VST, subjects were also shown an array that consisted of one target (a checker-filled circle) and 12 distractors (six open circles and six checker-filled squares, which were $1.0 \times 1.0$ cm in dimension) arranged in a manner similar to the easy condition of the VST.

All subjects were instructed to work as quickly as possible while accounting for accuracy. Each subject completed eight blocks of 40 trials each, for a total of 320 trials. Four blocks were easy VST conditions, four were hard VST conditions, and each block was presented in a counterbalanced order. Target-absent and target-present trials were randomly dispersed throughout each block. For the purpose of this analysis, only the data from target-present trials are presented. The first five trials were dummy trials and were therefore discarded in the final analysis.

**Decision-making tasks.** Two computer RT tasks, consisting of an easy and a hard condition, were administered to all subjects to assess the nature of their decision-making abilities. These tasks were performed on a Macintosh computer using PsychLab software (Bub & Gum, 1991). The easy condition was the CCRT task. To prepare subjects for the upcoming stimulus, a prompt consisting of the word *Ready?* appeared on the screen. Then a question appeared on the screen that cued all subjects about the number that would appear in the next array (*Are you ready for the number 1?* or *Are you ready for the number 2?*). After 400 ms, a corresponding number followed the cue. Subjects were instructed to press one of two buttons on a keyboard depending on whether they saw the number 1 or the number 2. The hard condition of the decision-making tasks was the CRT task. The prompt for this task also consisted of the word *Ready?*, which was displayed before the target stimulus. After 400 ms, a number (1 or 2) appeared in the center of the computer screen. Subjects were told to press one of two corresponding buttons on the keyboard depending on whether they saw the number 1 or the number 2. All cues were valid (i.e., *Are you ready for the number 1?* was always followed by presentation of 1). All stimuli were written in Geneva font, point size 12.

The order in which the numbers appeared on the screen was randomized across sessions. For all subjects, the task order was the same, and the CCRT task was shown before the CRT task. Each task consisted of one block of 55 trials. The first 5 trials were dummy trials and were therefore discarded from the final analysis. Subjects were also given 10 practice trials for both tasks before the testing phase.

In addition to completing these two RT tasks, each subject also completed a general measure of simple reaction time (SRT). In this task, subjects were told that they would see the word *Ready*. After a 500-ms interval, a 0.75- × 0.75-cm black dot appeared in the middle of the screen. Subjects were told that as soon as they saw the dot, they were to press the space bar as quickly as possible. There were 55 trials, and the first 5 were discarded from the final analysis. Subjects were also given 10 practice trials before the testing phase.

### Statistical Analysis

A series of $2 \times 2$ analyses of variance (ANOVA) were performed to compare group differences between the mean RTs for all three tasks (Stroop, VST, and decision-making) for easy and hard conditions. A proportional RT difference score was calculated for each subject for each task with the formula *(hard RT – easy RT)/easy RT*. The mean group result for each task is shown in Table 2. A $3 \times 2$ ANOVA was conducted to compare group differences between the proportional RT difference scores for all three selective attention tasks. Follow-up on this interaction was done with a series of independent-samples $t$ tests that were conducted to examine group differences on each individual selective attention task. The 95% confidence intervals for proportional RT difference scores were also reported for each group individually.

To address intertask relationships, we performed correlations on the proportional RT differences as well as on the mean RT tasks for easy and hard RTs for each group separately. For all results, the value of $\alpha$ was set at .05.

### Results

#### Effects of Individual Tasks of Selective Attention and Task Difficulty Between Groups

**Stroop task.** A $2 \times 2$ ANOVA was conducted on the mean Stroop task RT performance. The between-subjects variable was group (HEC vs. AD), and the within-subjects variable was task difficulty (easy vs. hard). There was a main effect of group, $F(1, 50) = 18.55, p < .0001$, and task difficulty, $F(1, 50) = 67.23, p < .0001$. There was a significant Group × Task Difficulty interaction, $F(1, 50) = 11.14, p < .002$. This interaction was explored through the use of a simple effects test, which revealed that AD subjects were significantly slower than HEC subjects on both hard and easy conditions. The mean difference in RT between HEC and AD subjects for the hard condition was 1,400 ms, whereas the mean difference in RT between HEC and AD subjects for the easy condition was only 527 ms. Furthermore, the mean difference between hard and easy conditions for AD subjects was 1,510 ms, whereas the mean difference between hard and easy conditions for the HEC subjects was only 527 ms.

**VST.** A $2 \times 2$ ANOVA was conducted in which task difficulty (hard vs. easy) constituted the within-subjects variable and group (HEC vs. AD) constituted the between-subjects variable. There was a main effect of group, $F(1, 46) = 23.18, p < .0001$, and task difficulty, $F(1, 46) = 161.70, p < .0001$. There was also a significant Group × Task Difficulty interaction, $F(1, 46) = 25.62, p < .0001$. A simple effects test revealed that the AD group was significantly slower than the HEC group for both easy and hard conditions of the VST. The mean difference between AD and HEC subjects for the hard condition was 776 ms, whereas the mean difference between AD and HEC subjects for the easy condition was only 340 ms. Furthermore, the mean difference between hard and easy conditions for AD subjects was 760 ms, whereas the mean difference between hard and easy conditions for the HEC subjects was 369 ms.

**Decision-making tasks.** A $2 \times 2$ ANOVA was conducted on the decision-making tasks, in which the within-subjects factor was task difficulty (easy vs. hard) and the between-subjects factor was group (HEC vs. AD). There was a significant main effect of group, $F(1, 51) = 9.23, p < .004$, and task difficulty, $F(1, 51) = 7.31, p < .009$. There was no significant Task Difficulty × Group interaction, $F(1, 51) = 0.34, p = .56$.

In addition to this analysis, a $2 \times 2$ ANOVA for which the within-subjects factor was task difficulty (easy vs. hard) and the between-subjects factor was group (HEC vs. AD) was conducted as a post hoc analysis to contrast group performance when SRT was classified as the easy condition and CRT was classified as the hard condition. There was a significant main effect of group, $F(1, 51) = 11.1, p < .002$, as well as a significant main effect of task difficulty, $F(1, 51) = 10.12, p < .002$. However, there was no significant Task Difficulty × Group interaction, $F(1, 51) = 2.52, p = .12$.

### Group Proportional RT Differences for Selective Attention Tasks

A $3 \times 2$ ANOVA was carried out to compare the proportional RT difference scores on the three selective attention tasks. The within-subjects factor was task (Stroop vs. VST vs. decision mak-
ing), and the between-subjects factor was group (AD vs. HEC). There was a significant main effect of group, $F(1, 45) = 7.31, p < .01$, and a main effect of task, $F(1, 45) = 34.91, p < .0001$, as well as a significant Task × Group interaction, $F(2, 45) = 5.97, p < .004$. The mean (±SD) RT values for easy and hard selective attention tasks, and the mean (±SD) proportional differences for HEC and AD groups for all three selective attention tasks are reported in Table 2.

This Group × Task interaction was followed up with independent-samples $t$ tests that compared the proportional RT difference scores between AD and HEC groups for the three tasks. There was a significant group difference on the Stroop, $t(50) = 2.67, p < .05$, and on the VST, $t(46) = 3.42, p < .05$ tasks. However, there was no significant group difference when the proportional RT difference scores were compared for the decision-making tasks, $t(51) = .56, p = .58$. Figure 1 illustrates the proportional differences between groups for all three tasks of selective attention. Table 2 lists the 95% confidence intervals for both HEC and AD subjects for each separate task of attention.

### Intertask Correlations

The above results suggest that the three tasks are measuring dissociable components of attention. Therefore, a correlational analysis was performed between the proportional RT difference scores on all three selective attention tasks to evaluate the degree of correspondence between the tasks. Pearson correlation coefficients were computed on the proportional RT difference scores. There were no significant correlations between any of the three tasks of selective attention in either of the groups. Table 3 presents the correlation matrix for proportional RT difference scores for HEC and AD subjects.

A similar correlational analysis was carried out on the mean RT tasks to assess whether there were significant relationships between easy and hard RTs for all three selective attention tasks. Table 4 presents the correlation matrix between the mean RTs for all three tasks of selective attention for each individual group. There were significant relationships between the easy and hard conditions of the tasks of selective attention. There were also significant correlations between the mean RTs for the easy and hard conditions of the VST and the mean RTs for easy and hard decision-making tasks, which can potentially be attributed to the response mechanism used for the RT tasks.

As a caveat, the lack of correlations between the three attentional tasks might be due to low systematic variance within each variable that was used to measure selective attention. To address this issue, we computed reliability measures for the easy and hard components of the VST and the decision-making tasks. Each subject's RT values for each trial were divided into odd and even trials. Intersubject correlation analyses were computed, and a measure of Cronbach’s alpha was obtained for the easy and hard conditions of the RT tasks. The alpha reliability coefficients for the easy and hard VST were .98 and .96, respectively. The reliability coefficient for the easy condition of the decision-making task was .81, and for the hard condition, it was .88. A reliability measure for the Stroop task could not be obtained because only one RT value per subject was acquired. However, on the basis of the high reliability measures that were computed for the RT tasks, we can state that a lack of systematic variance between the variables did not account for our finding of null correlations between selective attention tasks.

### Discussion

AD subjects were tested on three different cognitive RT selective attention tasks to determine whether they were significantly

### Table 2

**Mean (± SD) RT for Easy, Hard, and Proportional RT Difference Scores**

<table>
<thead>
<tr>
<th>Group and measure</th>
<th>Stroop task</th>
<th>VST</th>
<th>Decision-making task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Easy</td>
<td>Hard</td>
<td>Proportional</td>
</tr>
<tr>
<td>HEC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$</td>
<td>679.9</td>
<td>1,316.3</td>
<td>0.88</td>
</tr>
<tr>
<td>$SD$</td>
<td>174.1</td>
<td>737.4</td>
<td>0.57</td>
</tr>
<tr>
<td>95% CI</td>
<td>0.63, 1.14</td>
<td></td>
<td>0.37, 0.57</td>
</tr>
<tr>
<td>AD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M$</td>
<td>1,260.9</td>
<td>2,716.7</td>
<td>1.47</td>
</tr>
<tr>
<td>$SD$</td>
<td>636.5</td>
<td>1,455.7</td>
<td>1.00</td>
</tr>
<tr>
<td>95% CI</td>
<td>1.12, 1.94</td>
<td></td>
<td>0.61, 0.88</td>
</tr>
</tbody>
</table>

**Note.** RT = reaction time; VST = visual search task; 95% CI = 95% confidence interval for proportional RT difference score; HEC = healthy elderly control; AD = Alzheimer's disease.
impaired on any of these tasks. We hypothesized that one component of selective attention would be more affected in AD subjects because of cognitive impairment associated with this disease. The current results indicate that visuospatial selective attention (as measured by VST performance) and inhibitory selective attention (as measured by Stroop task performance) were significantly impaired in AD subjects. In both of these tasks, AD subjects’ performance was affected far more by task difficulty than was that of HEC subjects. In the decision-making task, both AD and HEC subjects were slower on the CRT, but there was no evidence that this attentionally demanding task produced greater relative slowing in the AD group.

To assess whether there was a relationship between tasks of selective attention and whether components of selective attention could be dissociated, we performed a series of bivariate correlations on the proportional RT difference scores. There were no significant relationships demonstrated between the three selective attention tasks. Consequently, our results suggest that selective attention can be dissociated, which raises the possibility that there are components of attention that are differentially affected in subjects with AD. This effect may be due to the fact that brain regions related to these particular aspects of selective attention show different degrees of damage, depending on the stage of the disease.

Two other factors—sample size and the discrimination power of the task used—could conceivably account for the lack of correlations between our attentional tasks. Lack of significant correlations between the attentional tasks can theoretically be due to low reliability estimates for the tasks chosen, which in turn arise as a consequence of low discriminating power on the cognitive tasks. As evidence against this notion in the current study, we point to the high reliability measures that were obtained for the easy and hard conditions of the RT tasks. Although it was not possible in this study to compute a reliability coefficient for the Stroop task, previous studies that have examined test–retest reliability measures for this task have shown coefficient values of 0.84 (Dikmen, Heaton, Grant, & Temkin, 1999). These results provide further evidence for the possibility that selective attention consists of dissociable components, which are present in both HEC and AD subjects. Given the observed reliability coefficients, we can conclude that the finding of null correlations between the three tasks of selective attention was independent of factors that were associated with systematic variance within the individual variables.

Lack of correlation between tasks can also occur as a statistical artifact of using a sample size that is too small. In this study, 23 HEC subjects and 30 AD subjects were studied, a sample size that should be adequate to demonstrate correlations of moderate strength or greater. Although it is difficult to obtain large sample sizes of groups of individuals with AD, we must acknowledge the possibility that larger sets of subjects might demonstrate weak correlations between the tasks, and future studies should focus on this issue as a possibility for discrepant results. Finally, we also note that cognitive tasks are usually correlated with each other. This was apparent in the correlations between RT tasks, which were associated with general motor response mechanisms required for performance.

The significant group differences on the Stroop and VST tasks are not unexpected, given what we know of AD pathology. With regard to the VST, Perry and Hodges (1999) have indicated that it might be expected that AD subjects manifest significant impairments in tasks of selective attention related to parietal lobe functions, because this area of the brain is pathologically affected by the disease (Braak & Braak, 1991). Functional imaging studies (Corbetta, Miezen, Shulman, & Petersen, 1993; Corbetta, Shulman, Miezen, & Petersen, 1995; Desimone & Duncan, 1995; Nobre et al., 1997), as well as transcranial magnetic stimulation studies (Ashbridge, Cowey, & Wade, 1999; Ashbridge, Walsh, & Cowey, 1997; Walsh, Ellison, Ashbridge, & Cowey, 1999), have shown that the parietal lobes are recruited during tasks of visuospatial attention, as in the hard condition of the VST.

With regard to the relationship between Stroop task performance and anatomic pathology in AD subjects, recent studies have indicated that AD subjects display significant atrophy in frontal lobe structures such as the anterior cingulate (Callen, Black, Gao, Caldwell, & Szalai, 2001; Killiany et al., 2000; Salat, Kaye, & Janowsky, 1999, 2001). Given the known frontal lobe substrate for

<table>
<thead>
<tr>
<th>Variable and task</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>HEC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-0.25</td>
<td>-0.15</td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td></td>
<td></td>
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<tr>
<td>1</td>
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<td></td>
</tr>
<tr>
<td>2</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.07</td>
<td>0.20</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note. RT = reaction time; HEC = healthy elderly control; AD = Alzheimer’s disease.

1 = Stroop; 2 = decision making; 3 = visual search.

Table 3
Proportional RT Difference Scores Correlation Matrix

Table 4
Mean RT Correlations for Selective Attention Tasks for HEC and AD Subjects

<table>
<thead>
<tr>
<th>Group and task</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.30</td>
<td>0.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.06</td>
<td>-0.01</td>
<td>0.76*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.19</td>
<td>0.16</td>
<td>0.26</td>
<td>0.39*</td>
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</tr>
<tr>
<td>6</td>
<td>0.15</td>
<td>0.02</td>
<td>0.16</td>
<td>0.24</td>
<td>0.60*</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.11</td>
<td>0.18</td>
<td>0.81*</td>
<td>0.68*</td>
<td>0.43*</td>
<td>0.19</td>
</tr>
</tbody>
</table>

*Note. RT = reaction time; HEC = healthy elderly controls; AD = Alzheimer’s disease.

1 = Stroop, easy; 2 = Stroop, hard; 3 = Decision-making, easy; 4 = Decision-making, hard; 5 = visual search, easy; 6 = visual search, hard; 7 = simple reaction time.

*p < .05.
the Stroop task (Corbetta et al., 1993, 1995; Desimone & Duncan, 1995; Nobre et al., 1997), abnormal performance in AD subjects on this task in early stage AD is not an unexpected finding. With regard to the decision-making (RT) tasks, the neural substrate is less clear. Sensorimotor and frontal lobe regions are likely implicated. The fact that attention related to decision making was not impaired in our AD subjects underlines the dissociability of the task, but beyond that we can say little about why this task of attention was relatively preserved.

It is important to note that both the neural substrate of selective attention and the pathology of AD are complex phenomena. Cortical networks across multiple regions are involved in selective attention (Mesulam, 1981), and the precise localization of such networks is not yet clear. AD affects specific brain regions such as the temporal, frontal, and parietal lobes but is also characterized by depletion of cholinergic neurons in the frontal lobes (Muir, 1997). In addition, damaged corticocortical tracts that connect brain regions might also be affecting impaired performance in the AD subjects on inhibitory tasks (Parasuraman & Haxby, 1993). Thus, one cannot a priori be certain that any particular aspect of selective attention is preserved in AD. Given these factors, the finding of a relative impairment on two of the three tasks of selective attention studied, with relative sparing of attention on the third task, demonstrates that specificity in selective attention is demonstrable after brain damage.

In this study, we replicated the findings of Gordon and Carson (1990) that AD subjects do not benefit from the presence of a cue in decision-making tasks, specifically on the CCRT task, which constituted the easy form of decision making. We found that AD subjects were much slower in their responses than were HEC subjects. Consequently, the proportional slowing in RT in the HEC group was larger than that seen in the AD group, because the HEC group was much faster in their responses than were HEC subjects. Consequently, the proportional slowing in RT in the HEC group was larger than that seen in the AD group, because the HEC group was very fast when performing the CCRT. At first glance, this finding might seem to diminish our claim for specificity in selective attention impairments in AD, inasmuch as the pattern of results for CRT and CCRT might instead reflect a completely different cognitive domain—the inability to benefit from a cue. It is important to note, however, that substituting a different easy task such as SRT for the CCRT produced identical results. The lack of a statistical interaction, therefore, is not attributable to a separate impairment in using cues in the CCRT condition. Indeed, Baddeley et al. (2001) used SRT and CRT and achieved similar results to our own. We conclude that the selective attention component of decision-making tasks is relatively (not absolutely) spared in early AD.

Salthouse (2000) and Nebes, Brady, and Reynolds (1992) have stressed the explanatory role of cognitive slowing in explaining many results in healthy elders and in individuals with brain damage. Can cognitive slowing account for our results? Certainly, in Stroop and VST the AD subjects performed more slowly than did the HEC subjects. Therefore, cognitive-slowing theory predicts that on more demanding (that is, harder) versions of each task, AD subjects should be even more affected than control subjects. Baseline RTs in the easy condition of the three tasks in the AD subjects varied from 1,260.9 ms (Stroop task) to 1,065.7 ms (VST) to 941.7 ms (decision-making task). This difference of only 21% among the three easy conditions indicates roughly similar difficulty levels for individuals with AD. We suggest that the results on the hard condition of the three tasks cannot simply reflect overall task difficulty because (at least via RTs) the three tasks were of similar difficulty (see Table 2). Hence, our results cannot simply be explained in terms of cognitive slowing. Our pattern of results on the Stroop task suggests that the significant differences were caused by impaired inhibitory processes in the patient group, which were independent of factors such as generalized cognitive slowing. These results further replicate previous studies in which researchers tested AD subjects using the Stroop task but accounted for generalized cognitive slowing using other statistical procedures (Spieler et al., 1996).

In their review on attention, Perry and Hodges (1999) questioned which tasks of attention were sensitive to attention impairments in subjects with early-stage AD. In contrast, Baddeley et al. (2001) were interested in examining which tasks of attention were specific to AD subjects. The current study sought to measure the pattern of performance across a set of tasks tapping different aspects of selective attention, although these tasks were not exhaustive and additional attentional tasks can be conceived. Ideally, a longitudinal study that assesses RT performance on a long series of selective attention tasks in a group of subjects with a range of dementia severities would be useful to map out the decline of selective attention in AD. Further work will be necessary to support the claim that attention is impaired in AD subjects because of the regional pathology of the disease. Functional imaging studies in healthy individuals have shown that performance on tasks of attention are associated with specific brain regions (Bench et al., 1993; Corbetta et al., 1993, 1995; Pardo, Pardo, Janer, & Raichle, 1999). In the future, studies that relate performance on a specific task of selective attention with a brain region should be conducted in individuals with brain damage. Volumetric measures of atrophy acquired by manually segmenting MRI scans could also be used to relate performance on cognitive RT tasks of selective attention with levels of atrophy in the brain.

References


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