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Failure to Control Prepotent Pathways in Early Stage Dementia of the Alzheimer's Type: Evidence From Dichotic Listening

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The authors examined the right ear advantage in a dichotic listening task in healthy aging and very mild and mild stages of Alzheimer's disease. Subjects were simultaneously presented 3 pairs of digits to the left and right ears (e.g., left ear: 4, 3, 1; right ear: 9, 2, 5) for immediate ordered recall. Four lists of triads were presented, varying in presentation rate between digit pairs within a triad (0.5, 1.0, 1.5, 2.0 s). Results indicated that the very mild and mild Alzheimer's groups showed a larger right ear advantage in free recall compared with the healthy controls, indicating a tendency to respond to the prepotent left hemisphere pathway for language processing. Also, the right ear advantage and proportion of switches made during recall were correlated with psychometric measures of frontal lobe function in the mild Alzheimer's group but not in the very mild or healthy control groups.

Keywords: Alzheimer's disease, attention, dichotic listening

Dementia of the Alzheimer's type (DAT) is characterized by a generalized breakdown in cognitive performance. In particular, in addition to the memory breakdowns, there are deficits in performance in tasks that demand attentional processing, and these deficits occur even in the early stages of the disease (Balota & Faust, 2001; Parasuraman & Haxby, 1993; Perry & Hodges, 1999). Perry and Hodges (1999) have suggested that attention is the first nonmemory aspect of cognition that declines in DAT prior to any deficits in language or visuospatial abilities, and this declining attentional capacity may underlie the difficulty with daily activities often seen in the early stages of the disease.

In this light, it is critical to fractionate the components of attention to better understand the precise nature of this attentional deficit. The available literature indicates that various subcomponents of attention may be differentially affected in DAT. For example, there is some evidence that sustained and focused attention appear to be relatively preserved in early stage DAT (e.g., Baddeley, Baddeley, Bucks, & Wilcock, 2001; Nebes & Brady, 1993). However, deficits in selective attention in DAT have been reported across several tasks, such as Stroop interference (Spieler, Balota, & Faust, 1996), visual–spatial attention (Greenwood, Parasuraman, & Alexander, 1997; Greenwood, Parasuraman, & Haxby, 1993), visual search (Nebes & Brady, 1989), and negative priming and flanker paradigms (Faust, Balota, & Duchek, 1995; Sullivan, Faust, & Balota, 1995). Deficits in divided attention have also been reported in dual-task paradigms, with greater costs in dual-task performance relative to single-task performance in DAT compared with healthy aging (e.g., Baddeley et al., 2001; Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986).

Balota and Faust (2001) have proposed a generalized breakdown in attentional control in early stage DAT. Specifically, DAT individuals have difficulty controlling attention to select the appropriate pathway when confronted with competing information. For example, in the Stroop study by Spieler, Balota, and Faust (1996), individuals with DAT showed a breakdown in the ability to inhibit the word code when naming colors in a Stroop task compared with healthy older adults (also see Balota & Duchek, 1991; Faust, Balota, Duchek, Gernsbacher, & Smith, 1997). Thus, there appears to be a deficit in early stage DAT in the ability to control attention in order to select an appropriate processing pathway and/or control or inhibit the prepotent pathway (e.g., naming the word rather than the color in the Stroop task). It has been argued that such attentional breakdowns may be related to the memory deficits observed in early stage DAT (Balota & Faust, 2001; Becker, 1988; Perry & Hodges, 1999) and that attentional selection may be subserved by frontal control systems (Balota & Faust, 2001; Dempster, 1992; Shallice, 1982; Stuss & Benson, 1986). Finally, it has been suggested that the neuropathology seen in the frontal lobes in early DAT (e.g., J. C. Morris et al., 1996) may be related to such deficits in attentional control (Balota & Faust, 2001).

The classic dichotic listening task affords a unique experimental paradigm to address the ability to select a nondominant processing pathway and control a prepotent processing pathway (e.g., Broadbent, 1952; Cherry, 1953; Treisman, 1960). Specifically, a right ear advantage in free recall is commonly reported in dichotic listening tasks (e.g., Carter & Wilson, 2001; Strouse, Wilson, & Brush, 2000a) and has been explained by the superiority of the left hemisphere in processing language. If DAT individuals have difficulty controlling the prepotent processing pathway, then they should have more difficulty controlling the left hemisphere dominance for language when presented with competing information to both auditory channels. Thus, DAT individuals might actually

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show a pattern of an exaggerated right ear advantage in recall performance and a decreased ability to switch attention and report from the left ear.

Mohr, Cox, Williams, Chase, and Fedio (1990) directly examined the ability to selectively allocate attention to one channel and switch attention in a cued dichotic listening paradigm in DAT. In an ordered recall condition, subjects were given a precue indicating which channel (left vs. right) to report first. The results indicated that overall accuracy was lower in DAT relative to older controls. More interesting, in the ordered recall condition, DAT individuals were unable to selectively direct attention to the precued ear and instead showed consistent right ear preferences in recall regardless of the precue. Although deficits in dichotic listening performance in early stage DAT also have been reported in other studies (e.g., Gates et al., 1995; Grady et al., 1989; Grimes, Grady, Foster, Sunderland, & Patronas, 1985), these studies did not directly address the right ear advantage and attentional control changes.

On the basis of the Mohr et al. (1990) study, it appears that the ability to selectively allocate attention in a dichotic listening task may be impaired in DAT. DAT subjects were unable to use a precue to direct attention to the appropriate channel and instead performance was driven by the stronger tendency to report from the right ear. Of course, one alternative possibility is that the DAT subjects simply did not process the precue in the Mohr et al. study to the same extent as the control individuals, and thus the right ear advantage was not necessarily indicative of an inability to selectively allocate attention. The present study will expand on the Mohr et al. findings by directly testing whether DAT individuals can control the tendency to report from the prepotent pathway (i.e., right ear) when instructed to recall the order of presentation of the items during recall and hence switch attention between the ears. This study also will examine the time course for switching attention by varying the presentation rate of the dichotic message. It is possible that the right ear advantage in DAT may be attenuated when the dichotic message is presented at a slower rate and subjects have more time to switch attention between the ears.

In support of this latter contention, Broadbent (1954) found that the ability to switch attention between the ears improved as presentation rate slowed down. In the Broadbent (1954) study, young adults were presented three pairs of dichotic digits and were asked to report the digits in the order in which they were presented, thus forcing a strategy of switching attention between channels. The presentation rate between pairs of digits within a triad varied from among 0.5, 1.0, 1.5, and 2.0 s across trials. The results indicated that subjects' ability to report across the ears (i.e., percentage correct order recall) increased at the longer 1.5- and 2.0-s presentation rates. Broadbent (1954) concluded that a time interval of 1–2 s was necessary to shift attention back and forth between channels.

The primary purpose of the present study was to investigate the ability to control a prepotent pathway, as reflected by left hemisphere linguistic processing, with a secondary purpose to examine the ability to switch attention across ears as a function of healthy aging and dementia severity. Although previous studies have shown deficits in DAT in the dichotic listening task, the influence of the prepotent right ear advantage has not been directly investigated. Moreover, we are particularly interested in whether we can isolate an impairment in the ability to control the prepotent pathway from overall levels of performance in this task.

In the present study, healthy older adults, individuals with very mild DAT, and individuals with mild DAT participated in a dichotic listening task, similar to the classic Broadbent (1954) study, wherein the presentation rate of the dichotic message was varied. We expected a larger right ear advantage in early stage DAT due to the inability to switch attention between channels, and we expected performance to be primarily driven by the prepotent linguistic channel. The inclusion of two groups that vary in terms of dementia severity (i.e., very mild vs. mild DAT) allowed us to examine the progression of this attentional breakdown across groups at varying levels of the disease process. If individuals in the earliest stages of the disease exhibit an overreliance on the prepotent linguistic pathway, this could potentially serve as an early marker for cognitive impairment. Finally, the relationship between attentional selection and frontal control systems in the early stages of DAT was explored by correlating various psychometric and dichotic listening measures.

Method

Subjects

A total of 94 subjects (55 men, 39 women) were recruited from the Washington University Alzheimer's Disease Research Center for this study. All subjects were originally screened for depression, hypertension, reversible dementias, and other disorders that could potentially produce cognitive impairment. All subjects were reevaluated every 6 months for changes in cognitive status and medical comorbidities that may affect cognition. Thus, subjects were considered to be free of medical comorbidities that could affect cognition at the time of testing. The inclusionary and exclusionary criteria for DAT are consistent with the National Institute of Neurological and Communicative Diseases and Stroke–Alzheimer's Disease and Related Disorders Association criteria (McKhann et al., 1984). The severity of dementia was staged according to the Washington University Clinical Dementia Rating (CDR) Scale (Berg, 1988; Hughes, Berg, Danziger, Coben, & Martin, 1982; J. C. Morris, 1993). According to this scale, scores of 0, 0.5, 1, 2, and 3 represent no dementia, very mild dementia, mild dementia, moderate dementia, and severe dementia, respectively. The CDR is based on a 90-min interview with both the subject and a collateral source. This interview assesses the subjects' cognitive abilities in the areas of memory, orientation, judgment and problem solving, community affairs, home and hobbies, and personal care. Both the reliability of the CDR and the validation of the diagnosis (based on autopsy) by the research team have been excellent (93% diagnostic accuracy) and well documented (e.g., Berg et al., 1998).

Of the 94 subjects, 44 were healthy older controls (CDR = 0; 26 men, 18 women; mean age = 74.50 years, *SD* = 7.94, range = 61–91; mean education = 15.00 years, *SD* = 3.06), 28 were diagnosed with very mild DAT (CDR = 0.5; 16 men, 12 women; mean age = 74.00 years, *SD* = 7.67, range = 61–88; mean education = 14.10 years, *SD* = 3.01), and 22 were diagnosed with mild DAT (CDR = 1; 13 men, 9 women; mean age = 71.20 years, *SD* = 8.84, range = 58–95; mean education = 14.00 years, *SD* = 3.42). There were no significant differences among the groups in age or education (all $ps > .14$). Overall, 96.4% of the total sample was right-hand dominant (97.7% for CDR 0, 95.8% for CDR 0.5, 94.1% for CDR 1).

Psychometric Testing

Each subject from the Washington University Alzheimer's Disease Research Center was administered a 2-hr comprehensive psychometric battery that assessed various aspects of memory, intelligence, and language. Memory was assessed with the Wechsler Memory Scale (Wechsler

& Stone, 1973) and scored accordingly: Logical Memory (immediate, with no delayed recall; recall of Scoring Units 0–23), Forward and Backward Digit Span (number of correct digits, 0–8 or 0–7, respectively), Paired Associate Learning Recall (sum of correctly recalled pairs over three trials, 0–18 easy pairs, 0–12 hard pairs), Mental Control (scored 0–9). The Word Fluency Test (Thurstone & Thurstone, 1949) was administered in which subjects had to name as many words as possible that started with the letter *S* or *P* in a 60-s period. General intelligence was assessed with the Information (scoring range = 0–29), Block Design (scoring range = 0–48), and Digit Symbol (scoring range = 0–90) subtests of the Wechsler Adult Intelligence Scale and scored according to the manual (Wechsler, 1955). Visual perceptual-motor performance was assessed with the Benton Visual Retention Test and the Benton Copy Test (number correct, number errors; Benton, 1963) and Part A of the Trail Making Test (number of seconds to complete; Armitage, 1946). Finally, the Boston Naming Test (Goodglass & Kaplan, 1983) was administered as a test of semantic–lexical retrieval (number correct out of 60). Psychometric tests are scored such that greater scores indicate better performance with the exception of Trail Making (Part A) and Benton Copy errors, for which higher scores indicate slower and hence poorer performance. Psychometric testing always occurred within a 2-month window of the dichotic listening task.

Materials and Procedures

All stimulus materials were constructed using SoundEdit on a Macintosh computer and then recorded and presented on an Optimus SCT-7500 stereo cassette deck and Realistic Nova 40 stereo headphones.

One practice list and four test lists were constructed for this study. Each list contained eight dichotic messages. Each dichotic message consisted of three digit pairs (e.g., left ear: 4, 3, 1; right ear: 9, 2, 5). The triads of digits were created using the numbers 1–9 (excluding the two-syllable Number 7) without repeating the same digit within a triad. Each list of eight triads was blocked according to the presentation rate among digit pairs within a triad (0.5, 1.0, 1.5, and 2.0 s). For example, in List 1 the digit pairs within each triad were presented at 0.5-s intervals. In List 2, the digit pairs within each triad were presented at 1.0-s intervals and so forth The ordering of presentation for the four test lists was counterbalanced across subjects in each group. The presentation rate for the practice list was 1.0 s between digit pairs.

All subjects were tested in a quiet room with the headphones and volume on the stereo amplifier adjusted according to the subject's preferences. After each triad, subjects were instructed to recall the digits in the order in which they were presented. Additional practice was given if necessary to ensure the subjects understood the task, and the instructions were repeated before each of the four test lists. Following each triad, the experimenter recorded the subject's responses.

Results

Percentage Correct Free Recall

To examine the right ear advantage, we scored the data for (a) percentage correct free recall by ear regardless of input order and (b) percentage correct first item output by ear. Percentage correct free recall was calculated as the number of digits recalled out of three for the right ear and the left ear, respectively. Percentage correct first item output was calculated by determining the number of trials on which the first correctly recalled item came from the right ear versus the left ear. Both of these measures address whether there is a right ear advantage in recall.

Figure 1 displays the percentage correct free recall as a function of group, presentation rate, and ear (left vs. right). The results of a 3 (group) × 4 (presentation rate) × 2 (ear) analysis of variance

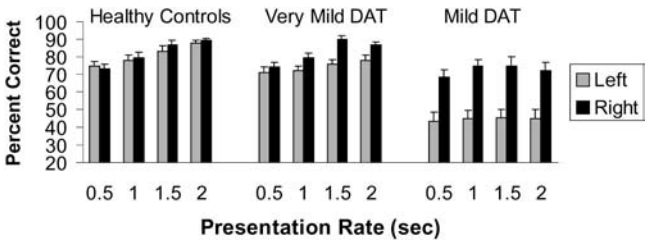


Figure 1. Free recall as a function of group, presentation rate, and ear. Error bars represent standard errors. DAT = dementia of the Alzheimer's type.

(ANOVA) on the percentage correct free recall yielded a significant main effect for group, $F(2, 91) = 38.34$, $MSE = 860.10$, $\eta^2 = .46$, $p < .0001$; presentation rate, $F(3, 273) = 19.43$, $MSE = 160.50$, $\eta^2 = .18$, $p < .0001$; and ear, $F(1, 91) = 34.32$, $MSE = 811.50$, $\eta^2 = .27$, $p < .0001$. There was also a significant Group × Presentation Rate interaction, $F(6, 273) = 3.13$, $MSE = 160.50$, $\eta^2 = .06$, $p = .005$, indicating that the mild DAT group did not show an increase in free recall across presentation rates, $F(3, 63) = 2.27$, $MSE = 73.53$, $\eta^2 = .10$, $p = .09$, as did the healthy control, $F(3, 129) = 14.94$, $MSE = 250.00$, $\eta^2 = .26$, $p < .001$, and very mild DAT groups, $F(3, 81) = 16.87$, $MSE = 85.55$, $\eta^2 = .39$, $p < .001$. A significant Presentation Rate × Ear interaction indicated a slightly larger right ear advantage across presentation rates, $F(3, 273) = 3.38$, $MSE = 101.40$, $\eta^2 = .04$, $p = .019$. Finally, there was a highly reliable Group × Ear interaction, $F(2, 91) = 12.96$, $MSE = 811.50$, $\eta^2 = .22$, $p < .0001$. Post hoc analyses comparing the healthy control and very mild DAT groups yielded a significant Group × Ear interaction, $F(1, 70) = 4.99$, $MSE = 357.20$, $\eta^2 = .07$, $p < .003$, indicating a right ear advantage in the very mild group ($\eta^2 = .25$, $p < .006$), but the right ear advantage was not reliable for the healthy control group ($\eta^2 = .01$, $p = .45$). Although both the very mild ($\eta^2 = .25$, $p < .006$) and mild ($\eta^2 = .42$, $p = .001$) DAT groups produced a highly reliable right ear advantage, the mild DAT group produced a larger right ear advantage than the very mild DAT group, as reflected by a reliable Group × Ear interaction, $F(1, 48) = 7.32$, $MSE = 1{,}278.60$, $\eta^2 = .13$, $p < .01$. Thus, there was a larger right ear advantage in the mild DAT group compared with the healthy control and very mild DAT groups. Finally, the overall Group × Presentation Rate × Ear interaction did not approach significance, $F(6, 273) = 0.39$, $MSE = 101.40$, $\eta^2 = .008$, $p = .89$.

Of course, one might be concerned that the Group × Ear interaction is due to the near-ceiling, free-recall performance of the healthy control and to some extent the very mild DAT groups. It is possible that the right ear advantage seen in the mild DAT group may simply reflect this group's overall lower free-recall performance. To address this concern, we conducted a 3 (group) × 4 (presentation rate) × 2 (ear) analysis of covariance, with overall recall performance as a covariate. The results of this analysis yielded a significant main effect of presentation rate, $F(3, 270) = 13.03$, $MSE = 143.10$, $\eta^2 = .13$, $p < .001$, and ear, $F(1, 90) = 7.75$, $MSE = 787.40$, $\eta^2 = .08$, $p = .007$. Again as indicated in the previous ANOVA, there was a significant two-way interaction between group and presentation rate, $F(6, 270) = 7.36$, $MSE = 143.10$, $\eta^2 = .14$, $p < .001$, but not presentation rate and ear, $F(3, 270) = 0.81$, $MSE = 101.30$, $\eta^2 = .009$, $p = .48$. Most

important, there was a significant Group × Ear interaction, $F(2, 90) = 3.31$, $MSE = 787.40$, $\eta^2 = .07$, $p = .04$, indicating a larger right ear advantage in the mild DAT group compared with the healthy control and very mild DAT groups after using overall recall performance as a covariate.

To further examine the reliability of the Group × Ear interaction, we performed a median split on each group to equate free-recall performance across groups. Figure 2 displays the percentage correct recall as a function of group, high–low performers, and ear (collapsed across presentation rates for ease of presentation). To equate overall performance across groups, we performed a separate 3 (group) × 4 (presentation rate) × 2 (ear) ANOVA comparing the low healthy control, low very mild DAT, and high mild DAT groups (mean recall = 74.4%, 71.2%, and 68.0%, respectively), $F(2, 43) = 2.01$, $MSE = 632.30$, $\eta^2 = .09$, $p < .15$. The results of this analysis yielded a significant main effect of presentation rate, $F(3, 129) = 6.90$, $MSE = 269.90$, $\eta^2 = .14$, $p = .0002$, and ear, $F(1, 43) = 21.70$, $MSE = 650.10$, $\eta^2 = .34$, $p < .0001$. As indicated in the previous ANOVAs, there were significant two-way interactions between group and presentation rate, $F(6, 129) = 2.23$, $MSE = 269.90$, $\eta^2 = .09$, $p < .05$, and Presentation Rate × Ear, $F(3, 129) = 2.99$, $MSE = 116.20$, $\eta^2 = .07$, $p = .03$. In addition, there was a marginally significant Group × Ear interaction, $F(2, 43) = 2.87$, $MSE = 650.10$, $\eta^2 = .12$, $p = .067$, indicating a larger right ear advantage in the mild DAT group compared with the healthy control and very mild DAT groups even when performance has been equated, as displayed in Figure 2.

Further right ear advantage analyses were conducted by examining the percentage of time the first item output came from the right ear. Because this analysis is based on only one item being recalled, it is relatively impervious to overall group differences in recall, because virtually all subjects recalled at least one item on all trials. These data are displayed in Figure 3. The results of a 3 (group) × 4 (presentation rate) ANOVA yielded two significant main effects. There was a significant main effect for group, $F(2, 89) = 4.47$, $MSE = 1{,}042.30$, $\eta^2 = .09$, $p = .014$. Post hoc analyses revealed a significant difference between healthy control and mild DAT groups, $F(1, 62) = 8.11$, $MSE = 1{,}142.90$, $\eta^2 = .12$, $p < .006$, but no difference between healthy control versus very mild DAT ($\eta^2 = .03$, $p < .13$) or very mild DAT versus mild DAT ($\eta^2 = .04$, $p < .16$) groups. There also was a significant main effect of presentation rate, $F(3, 267) = 4.80$, $MSE = 258.79$, $\eta^2 = .05$, $p < .003$. Post hoc analyses indicated lower first item recall from the right ear at the 1.0-s presentation rate, compared with all other presentation rates ($\eta^2 > .10$, all ps $< .002$). Although it is unclear what produced this lower recall performance at the 1.0-s rate, the important point is that this effect was constant across groups. The Group × Presentation Rate interaction did not approach significance ($F < 1.00$, $\eta^2 = .01$).

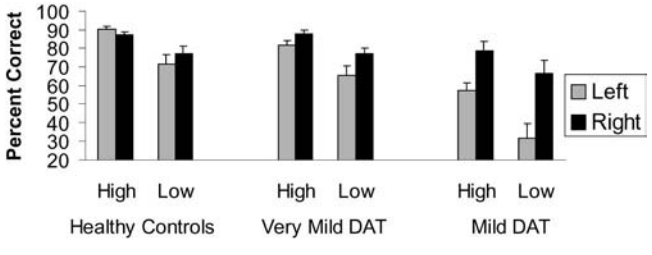


Figure 2. Free recall as a function of group, high–low performers, and ear. Error bars represent standard errors. DAT = dementia of the Alzheimer's type.

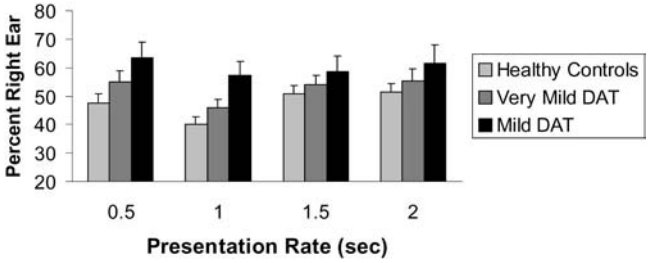


Figure 3. First item output. Error bars represent standard errors. DAT = dementia of the Alzheimer's type.

Proportion of Switches in Output

To further examine the reliance on the prepotent processing pathway (i.e., the right ear) during dichotic listening, we analyzed the proportion of ear switches during recall. Subjects were instructed to report the digits in the order in which they were presented (i.e., alternate between the ears). The proportion of switches was computed by totaling the number of times digits were correctly recalled across ears divided by the total number of digits correctly recalled (i.e., number of switches / total number recalled). Thus, this measure controls for group differences in overall recall performance.

Figure 4 displays the proportion of switches across ears during recall relative to the total correct recall as a function of group and presentation rate. The results of a 3 (group) × 4 (presentation rate) ANOVA yielded a significant main effect of group, $F(2, 89) = 38.36$, $MSE = 421.27$, $\eta^2 = .46$, $p < .0001$. Post hoc analyses indicated there were fewer switches made in the mild DAT group (.34) compared with the healthy control (.57) and very mild DAT (.55) groups, $F(1, 62) = 56.47$, $MSE = 524.90$, $\eta^2 = .48$, $p < .0001$, and $F(1, 48) = 33.67$, $MSE = 629.30$, $\eta^2 = .41$, $p < .0001$, respectively. Because this measure takes into account overall correct recall, this effect does not simply reflect group differences in overall performance. There was no difference in the proportion of switches between the healthy control and very mild DAT groups, $F(1, 68) = 1.38$, $MSE = 180.00$, $\eta^2 = .02$, $p < .25$. Second, as discovered by Broadbent (1954), there was an increase in the proportion of switches with increasing (i.e., slower) presen-

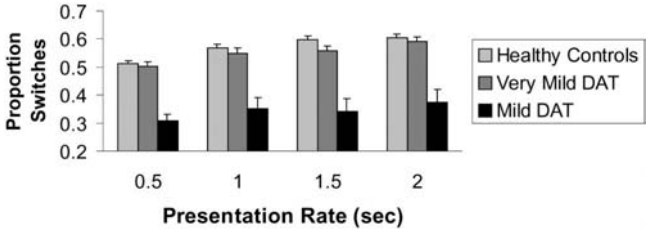


Figure 4. Proportion of switches as a function of group and presentation rate. Error bars represent standard errors. DAT = dementia of the Alzheimer's type.

Table 1
Psychometric Means and Standard Deviations as a Function of Group

	Healthy control		Very mild DAT		Mild DAT	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Logical Memory	10.03	3.18	7.30	3.49	2.83	2.59*^
Digits Forward	6.81	1.09	6.54	1.14	5.70	1.35
Digits Backward	5.29	1.40	4.64	1.16	3.76	1.04^
WMS—Paired Associate Learning Recall easy	17.19	1.33	15.11	2.88	13.20	2.59*
WMS—Paired Associate Learning Recall hard	6.69	3.47	3.00	3.84	0.80	1.67*
WMS Mental Control	7.90	1.88	7.11	1.85	4.95	2.18^
Word Fluency Test (Letter *S* or *P*)	34.57	12.10	28.54	11.30	15.71	11.60^
WAIS Information	22.31	3.87	17.75	5.09	10.81	5.83*^
WAIS Block Design	33.86	9.37	27.75	8.84	15.86	12.3*^
WAIS Digit Symbol	49.62	11.30	40.82	11.90	21.74	10.3*^
Benton Recall[a]	6.64	1.68	5.21	1.71	2.89	1.85*^
Benton Copy Test	9.74	0.54	9.68	0.61	9.21	1.44
Benton Delay Errors C[a]	5.60	3.67	8.43	3.77	15.58	4.89*^
Benton Copy Errors D[b]	0.26	0.54	0.32	0.61	0.95	1.87
Trail Making Test (Part A)	42.40	14.30	43.18	13.00	87.76	42.90^
Boston Naming Test	55.21	4.55	49.89	10.80	41.71	9.03*^

Note. DAT = dementia of the Alzheimer's type; WMS = Wechsler Memory Scale; WAIS = Wechsler Adult Intelligence Scale.
[a] Measure from the Benton Visual Retention Test. [b] Measure from the Benton Copy Test.
* $p < .01$ for the comparison between healthy controls versus very mild DAT. ^ $p < .01$ for the comparison between very mild DAT versus mild DAT.

tation rates, $F(3, 267) = 18.26$, $MSE = 54.93$, $\eta^2 = .17$, $p < .0001$. There was no significant interaction between group and presentation rate, $F(6, 267) = 0.72$, $MSE = 54.93$, $\eta^2 = .02$, $p = .63$. Thus, all subject groups made more switches with slower presentation rates, but the overall proportion of switches was consistently lower in the mild DAT individuals, thereby reflecting an inability to switch between channels.

Psychometric Performance and Correlations Among Right Ear Advantage, Switches, and Psychometric Data

The means and standard deviations for the psychometric measures for each of the groups are presented in Table 1. A series of one-way ANOVAs, with group as a between-subjects factor, indicated that performance on all of the psychometric measures, except Benton Copy errors, was significantly different among groups (all ps $< .05$). Post hoc comparisons between the healthy control versus very mild DAT groups and the very mild DAT versus mild DAT groups generally indicated decreasing psychometric performance with increasing dementia severity (see Table 1).

To examine the relationship between the right ear advantage and general psychometric performance, we correlated a single composite measure of the right ear advantage (i.e., percentage correct right ear / percentage correct left ear) and the proportion of switches (i.e., the number of ear switches made during recall output / total correct recall) with all of the psychometric measures for each group. First, it should be noted that there is a highly reliable correlation between the right ear advantage and the number of switches for the very mild DAT ($r = -.57$, $p = .001$) and mild DAT ($r = -.67$, $p = .001$) groups, indicating that the DAT subjects showed a larger right ear advantage when they made fewer switches between the ears. This correlation was not statistically significant for the healthy controls ($r = -.15$, $p = .34$) but was in the same direction.

To examine the relationship between psychometric performance and attentional mechanisms, we correlated the measures of the right ear advantage and the proportion of switches with composite psychometric scores that were created as a function of differences in possible underlying neural systems (i.e., medial–temporal, parietal, and frontal). On the basis of previous literature (e.g., Chase et al., 1984; Glisky, Polster, & Routhieaux, 1995; Lezak, 1995; Milner, 1972; Mishkin, 1978) and the factor analysis work of Kanne, Balota, Storandt, McKeel, and Morris (1998), we defined medial–temporal measures as Wechsler Adult Intelligence Scale information, Boston Naming Test, Logical Memory, and Paired Associate Learning Recall. Parietal measures were defined as Benton Copy, Trail Making (Part A), Block Design, and Digit Symbol (e.g., Chase et al., 1984; Kanne et al., 1998; Lezak, 1995). Frontal measures were defined as Digits Forward, Word Fluency, and Mental Control[1] (e.g., Glisky et al., 1995; Kanne et al., 1998; Parks et al., 1988). Kanne et al. (1998) found that not only did these tests load on the appropriate factor structure, but these factors were also related to neuropathology in the targeted areas at autopsy.

[1] Clearly, there are recent measures that may be more appropriate to assess frontal functioning, however, these measures (i.e., Digits Forward, Word Fluency, Mental Control) were available on the present sample and have been reported to be sensitive to frontal involvement in DAT (Kanne et al., 1998).

For each subject, a z score was computed for each psychometric test based on the healthy control subject's group mean.[2] Then three overall z scores (medial–temporal, parietal, frontal) were created for each subject that were based on the average of the four medial–temporal measures, the four parietal measures, and the three frontal measures, respectively. The correlations between the right ear advantage and the proportion of switches and the medial–temporal, parietal, and frontal scores are presented in Table 2 as a function of group. For the healthy control group, only the correlation between the right ear advantage and the medial–temporal score approached statistical significance ($p = .055$). None of the correlations reached statistical significance for the very mild DAT group. Most interesting, the right ear advantage was marginally correlated ($p = .087$), and the proportion of switches was reliably correlated with the frontal measure ($p < .01$) but not the parietal or medial temporal measures for the mild DAT group.

Discussion

The purpose of the present study was to examine the right ear advantage in early stage DAT as a measure of attentional control. A clear right ear advantage in free-recall performance was found in early stage DAT. In fact, this right ear advantage was quite dramatic in the mild DAT group. Moreover, the large right ear advantage in mild DAT did not appear to be due to the overall lower free-recall performance in this group because the advantage remained when overall recall was used as a covariate and in the matched subjects analysis. Further analyses also supported this finding. That is, the first item output in free recall was more likely to come from the right ear in mild DAT compared with the healthy control and very mild DAT groups, and also there was evidence of a decrease in switching across ears in the mild DAT group.

The larger right ear advantage in early stage DAT is consistent with Claus and Mohr (1996) and the Mohr et al. (1990) study, which reported an inability of DAT subjects to strategically allocate attention to the left ear on precue, resulting in a strong right ear preference in recall. The present results extended this observation by showing that this pattern is not limited to a cueing manipulation. Furthermore, the present study afforded an analysis of the right ear advantage as a function of dementia severity in early stage DAT. In contrast, the Mohr et al. study reported that their subjects were at the mild to severe stage of DAT. Thus, the present study extends the use of the dichotic listening task to discriminate early stages of dementia. Moreover, the present results clearly indicate that the right ear advantage increased with dementia severity. That is, the very mild DAT group showed a larger right ear advantage than the healthy controls, even though the proportion of switches did not differ between these two groups. Also, switching ability was correlated with the right ear advantage in the very mild DAT group but not in the healthy controls. Thus, although very mild DAT individuals could switch attention between channels like the healthy controls, they still showed a tendency toward a larger right ear advantage. Similarly, the mild DAT group showed a larger right ear advantage than the very mild DAT group. Thus, the reliance on the prepotent linguistic channel increased with dementia severity.

It is also interesting to note that the healthy older adults did not show a reliable right ear advantage in free recall in the present study, even though there has been evidence of a right ear advantage in dichotic listening in healthy older adults (Alden, Harrison, Snyder, & Everhart, 1997; Carter & Wilson, 2001; Strouse, Wilson, & Brush, 2000b). The lack of a right ear advantage in the present older adults is likely due to the emphasis in this study to report the digits in the order in which they were presented. Healthy older adults were able to switch attention between the ears and thus report from both ears. This is evidenced by the finding that only 47.5% of the time the first item output in free recall was from the right ear for the healthy controls, compared with 60.3% for the mild DAT group.

Along these same lines, there is evidence that the right ear advantage seems to be modulated by the complexity of the dichotic listening task. Specifically, there is some literature that suggests that the right ear advantage increases as task complexity increases. That is, Mondor (1991) found that when subjects are confronted with competing information and attention needs to be selectively allocated, the left hemisphere processing is more likely to drive performance. It is possible that the present paradigm did not sufficiently push healthy older adults to produce the right ear advantage.

We would argue that the large right ear advantage in mild DAT reflects a greater reliance on the prepotent pathway for language processing (i.e., the left hemisphere) when confronted with competing information (i.e., from the left and right ear simultaneously). This notion is further supported by two other findings. First, when one compares the proportion of switches made during recall across the groups (which controls for overall recall performance), it is clear that the mild DAT group is making fewer switches between the ears compared with the very mild DAT and healthy control groups (.34, .55, and .57, respectively). The pro-

Table 2
Correlations Between Medial-Temporal, Parietal, and Frontal Psychometric Measures and Proportion of Switches and Right Ear Advantage

Measure	Medial-temporal	Parietal	Frontal
	Healthy control		
Right ear advantage	−.30	−.09	−.09
Proportion of switches	.09	.18	.18
	Very mild DAT		
Right ear advantage	.10	−.08	−.13
Proportion of switches	.10	−.01	.17
	Mild DAT		
Right ear advantage	−.18	.01	−.38^
Proportion of switches	.23	.13	.57*

Note. DAT = dementia of the Alzheimer's type.
^ $p = .087$. * $p < .01$.

[2] The overall pattern of the correlations between the right ear advantage and the proportion of switches and the medial–temporal, parietal, and frontal scores presented in Table 2 did not change when the z scores were also calculated on the basis of each group's respective means, as opposed to the healthy control group's means.

portion of switches made by these latter two groups is remarkably similar. It also should be noted that there is an increase in the proportion of switches during recall across presentation rates (i.e., more switches with slower presentation rates) across all groups, precisely as Broadbent (1954) found in his original study. However, the mild DAT group still exhibited a large right ear advantage at the slowest presentation rates. Thus, the left hemisphere is clearly driving output during recall in these individuals.

Second, there was a strong correlation between the right ear advantage and the proportion of switches in both DAT groups. A decreasing ability to switch attention between the ears was related to an increased reliance on reporting from the language-dominant right ear in early stage DAT. This was not the case in the healthy control group. As previously mentioned, we have reported findings from other cognitive tasks in which DAT subjects are unable to control attention to select a specific pathway when confronted with competing prepotent information compared with healthy controls, such as Stroop performance (e.g., Spieler et al., 1996). We have also extended this perspective to reading (e.g., Balota & Ferraro, 1993, 1996; Duchek, Balota, & Thessing, 1998) and memory (e.g., Balota et al., 1999) performance. Of course, control of prepotent pathways is intimately involved in working memory (see Engle, Kane, & Tuholski. 1999). Along these lines, Conway, Cowan, and Bunting (2001) reported that low-span subjects were more likely to report hearing their own name in an unattended irrelevant message during a shadowing task, indicating that low-span subjects have difficulty inhibiting prepotent information. Thus, the results of the present study are likely to converge on the working memory deficits in DAT (R. G. Morris, 1994). In this light, one might question whether working memory capacity plays a role in the present results. It is possible that the reduced capacity of the DAT subjects induces subjects to attend to the prepotent channel (right ear) to maximize their recall performance. In an attempt to address this issue, we examined the correlation between the right ear advantage and Digits Forward and Digits Backward performance, as measures of working memory capacity, for both the DAT groups. The results indicated that although these correlations were in the predicted direction, none of the correlations were reliable (all ps $> .144$). Thus, it appears that a reduced working memory capacity, at least as reflected by these measures, cannot fully account for the larger right ear advantage in mild DAT.

Other alternative interpretations for the larger right ear advantage in mild DAT need to be addressed. For example, it is possible that the presentation rate may have been too fast for the mild DAT subjects to process the digits in each ear or manipulate items in working memory before recall and thus they were forced to rely on the prepotent channel due to general cognitive slowing. To address this concern, we reanalyzed the free-recall data (i.e., percentage correct free recall by ear), with digit symbol performance as a covariate. Digit symbol performance was chosen as a measure of general processing speed on which the mild DAT subjects showed deficient performance relative to the very mild DAT and healthy control groups. If the Group $\times$ Ear interaction in free-recall performance is simply due to cognitive slowing, then one might expect the interaction to disappear when a measure of cognitive slowing (digit symbol) is taken into account. The results of this analysis indicated that the Group $\times$ Ear interaction remained highly reliable after covarying out digit symbol performance, $F(2, 86) = 8.56$, $MSE = 667.57$, $\eta^2 = .14$, $p < .001$. Thus, overall general cognitive slowing (at least as measured by digit symbol performance) cannot fully account for the larger right ear advantage in mild DAT. Of course, one might more directly address this issue by examining longer presentation rates than those used in the present study.

It is also possible that the DAT individuals may have had difficulty maintaining the instructions to switch between the ears over the course of the experimental task and thus simply relied on the prepotent right channel for recall. This seems unlikely for two reasons: (a) subjects were reminded of the instructions to switch prior to the presentation of each list, and (b) the mild DAT group was able to switch on some trials (proportion switches = .34), and they did recall digits from both ears (72.5% right ear recall and 44.5% left ear recall across presentation rates).

Finally, one limitation of this study was that there was no measure of hearing sensitivity available for these subjects. One might argue that the results were due to differential left–right ear hearing loss. Of course, there would have to be differential left–right hearing loss as a function of group to account for the larger right ear advantage found in the mild DAT group. We think that this is unlikely because studies indicate that early stage DAT is not associated with greater hearing loss than healthy aging using both behavioral and psychophysiological measures (e.g., otoacoustic emissions) of hearing sensitivity (Gates et al., 1995; Sommers, 1998).

Also, the right ear advantage ($p = .087$) and the proportion of switches during recall were reliably correlated with a composite score from frontal measures in the mild DAT group but not parietal and medial–temporal measures. These attentional measures were not correlated with frontal psychometric measures in either the very mild DAT or healthy control group. This finding is suggestive that deficits in attentional control in early stage DAT may reflect a breakdown, at least in part, in frontal lobe functioning.

In sum, the present study is consistent with previous reports of impaired dichotic listening performance in DAT (e.g., Claus & Mohr, 1996; Mohr et al., 1990). A large right ear advantage in free recall is evident in mild DAT, providing further support that attentional processing, like other cognitive processes, is affected early in the disease process, and deficient attentional control may force responding based on familiar, prepotent information pathways. One can speculate about the importance of attentional control in everyday tasks, such as driving. Indeed, early studies by Kahneman and colleagues indicated that dichotic listening performance was a good predictor of accident rates in commercial bus drivers (Kahneman, Ben-Ishai, & Lotan, 1973; Mihal & Barret, 1976). More recent studies of driving performance in DAT suggest that aspects of attentional selection and control are better predictors of safe driving than general cognitive status and neuropsychological test performance (Duchek, Hunt, Ball, Buckles, & Morris, 1998).

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