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Evidence for impaired sentence comprehension in early Alzheimer's disease

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Abstract

We investigated sentence comprehension in 46 patients with probable minimal (very mild), mild, or moderate dementia of the Alzheimer type (DAT), comparing their performance on the Test for the Reception of Grammar (TROG), with that of 20 age- and education-matched controls. Performance on the TROG was generally related to dementia severity, independent of lexicosemantic and working memory (digit span) impairments, but related to at least 1 measure of attention. Some patients in the minimal group showed sentence comprehension deficits while others in the moderate group did not, indicating that DAT may impair sentence comprehension at the very earliest stages of disease, but that its effects are heterogeneous. Patients were most impaired on sentences with 2 propositions and noncanonical word order, suggesting difficulties with both interpretative and postinterpretative stages of sentence processing. Further investigation is needed into the relationship between attentional processes, interpretative and postinterpretative stages of syntactic processing in DAT. (*JINS*, 1999, *5*, 393–404.)

Keywords: Syntax, Alzheimer's disease, Language, Dementia

INTRODUCTION

Investigations into the language impairments that may arise in the context of dementia of the Alzheimer type (DAT) have typically focused on the lexical and semantic components of language (Gainotti, 1993; Greene & Hodges, 1995; Hart, 1988; Huff et al., 1987). Such impairments frequently occur early in the disease (Bayles et al., 1993), are present across a majority of patients (Hodges & Patterson, 1995), and have been used by some authors for staging the progression of the disease (Bayles, 1982; Kaszniak et al., 1986; Kertesz et al., 1986; Locascio et al., 1995). By contrast, the phonological and syntactic aspects of language in DAT have received less attention, presumably because these abilities are generally considered to be preserved until the late stages of the disease (Bayles & Boone, 1982; Hier et al., 1985; Kertesz et al., 1986; Miller, 1989). More recently, however, it has been suggested that this assumption may be incorrect, or at least overinclusive, and that both phonological (Biassou et al., 1995; Croot, 1997; Croot et al., 1996; Kennedy et al., 1995), and syntactic processes (Bates et al., 1995; Greene et al., 1996), may, in fact, be compromised in some cases of DAT, even at the early stages. The focus of language investigation in DAT is therefore broadening, to investigate the extent of such deficits, and the mechanisms behind them. In particular, empirical studies of the syntactic breakdown in DAT have begun to inform models of normal syntactic processing (Rochon et al., 1994; Waters et al., 1995), as well as to improve clinical understanding of the disease. The issue of whether syntactic impairments can be found in DAT is clearly important for diagnosis, and has implications for understanding the distribution of the neuropathological changes in the disease.

Several analyses of the syntactic constructions present in the speech of DAT patients have shown little difference from those in the speech of elderly controls (Blanken et al., 1987; Illes, 1989; Kempler et al., 1987), but spontaneous production tasks are relatively unconstrained, and a more stringent test of patients' syntactic processing is whether they still perform within normal limits when required to comprehend sentences containing complex syntactic constructions. Earlier investigations of sentence comprehension in DAT, however, frequently confounded general task and response demands with the syntactic processing required in the experimental tasks (see Rochon et al., 1994 for review). For example, one study which concluded that elderly adults with DAT were unable to parse complex syntax used a sentence-comprehension task requiring real-world (semantic) knowl-

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edge as well as syntactic processing abilities (Emery, 1985). Another (Tomoeda et al., 1990), showed that DAT patients were no more impaired than controls in responding to commands in the Revised Token Test (De Renzi, 1979), but this test confounds syntactic complexity with sentence length. In further studies, the DAT patients' single word comprehension, praxic, and visuospatial deficits may also have confounded the investigation of their syntactic processing (Ernst et al., 1970; Sherman et al., 1988).

A few studies have used sentence–picture matching tasks to probe DAT patients' sentence comprehension, manipulating syntactic complexity while preserving simple response demands (Grossman et al., 1995, 1996b; Rochon et al., 1994; Small et al., 1997; Waters et al., 1995). In these studies, unselected DAT patients did show sentence comprehension deficits relative to elderly controls, but there was no consensus about the source of the deficits. For example, Small and colleagues (Small et al., 1997) proposed that impaired working memory (indicated by low digit span among other measures) compromised the patients' ability to interpret complex syntactic constructions, whereas other authors have shown no relationship between digit span and sentence comprehension in DAT (Grossman et al., 1995; Waters et al., 1995). These authors (Grossman et al., 1995; Rochon et al., 1994; Waters et al., 1995) attributed the comprehension deficits in DAT to the second of two processing stages putatively involved in sentence comprehension.

At the first of these stages, *sentence interpretation*, the propositional meaning of a sentence is extracted on the basis of syntactic form; at the second stage, *postinterpretative processing*, the propositional meaning of the sentence is matched to the appropriate picture. Sentence interpretation is thought to be influenced by factors such as the number of thematic roles assigned around each verb and the canonicity of word order in a sentence (subject–verb–object is the canonical order in English), whereas postinterpretative processing is influenced by the number of propositions in a sentence. In two sentence–picture matching studies by Waters and colleagues (Rochon et al., 1994; Waters et al., 1995), neither the number of thematic roles nor canonicity of word order in the sentences affected DAT patients' comprehension, but the patients were significantly impaired on sentence types containing two propositions, rather than one. By contrast, Small and colleagues (Small et al., 1997) reported that although a group of DAT patients made more errors on two-proposition sentences than on one-proposition sentences, the significant differences only arose from sentences with noncanonical subject–object order. None of these studies therefore argued for a specific deficit in the computation of syntactic relationships *per se* (the first stage of sentence comprehension) in DAT.

Despite the more typical observation that syntactic ability deteriorates only at the later stages of DAT (Bayles, 1982; Bayles and Boone, 1982; Hier et al., 1985), two studies have reported impaired sentence comprehension performance that did not correlate significantly with overall dementia severity as measured by the Mini-Mental State Examination (MMSE; Grossman et al., 1995; Waters et al., 1995). According to the categorization based on MMSE scores in the present investigation (see below), the patients in these two studies were mildly to moderately demented. This lack of correlation probably indicates that sentence comprehension abilities may sometimes be selectively impaired in DAT, independent of the other cognitive processes assessed by the MMSE. Converging evidence for this comes from a small number of single case studies in which patients later shown to have pathologically confirmed Alzheimer's Disease (AD) *presented* with clinically evident syntactic impairments (Croot, 1997; Green et al., 1990; Greene et al., 1996; Karbe et al., 1993).

Research into the effect of DAT on syntactic processing has thus progressed beyond the assumption that this linguistic domain is simply spared throughout most of the disease, yet several issues remain controversial. The first is the extent to which sentence processing may be impaired in patients with very early disease, and a related issue is the degree of correlation between sentence comprehension and dementia severity. A third issue concerns the relationship between deficits of the working memory system involved in span tasks and sentence comprehension in DAT. A final question is whether the computation of syntactic relationships *per se* is impaired in DAT, or whether observed comprehension deficits arise mainly at the level of postinterpretative processes. To address these four issues, our study explored the performance of a comparatively large group of DAT patients on the Test for the Reception of Grammar (TROG; Bishop, 1989), a four-choice sentence–picture matching task that includes a somewhat different range of syntactic and morphosyntactic structures from those assessed in previous studies. Patients were classified into *minimal*, *mild*, or *moderate* subgroups according to dementia severity as measured by the MMSE.

We hypothesized (1) that because the DAT patients in our study were drawn from a wider range of dementia severity than the patients in previous studies, there would be a relationship between dementia severity as measured by MMSE score and sentence comprehension performance on the TROG; (2) that if the sentence comprehension deficits in DAT are related to immediate memory impairments, the patients' TROG scores would correlate positively and significantly with measures of working memory and attentional abilities; and (3) that if the patients' deficits were specifically in postinterpretative processing, they would not be affected by noncanonical subject–object word order, but would be more severely impaired on the two-proposition sentences than the one-proposition sentences.

METHODS

Research Participants

Forty-six patients diagnosed with probable DAT and 20 age- and education-matched controls took part in the study. Written, informed consent was obtained from all participants and/or from caregivers where appropriate. The patients had presented to a memory disorder clinic at Addenbrooke's Hospital. The series was unselected (Giles et al., 1996; Greene & Hodges, 1996; Hodges & Patterson, 1995; Hodges et al., 1996; Patterson et al., 1994) in the sense that it represents all of the patients seen over a 2-year period who were willing to participate in a longitudinal study of language and other aspects of cognition in DAT, except that patients who presented with progressive aphasia (Mesulam & Weintraub, 1992) as their primary deficit were excluded from the study. Diagnoses of probable Alzheimer's disease were made according to the National Institute of Neurological and Communicative Disorders and Stroke, and the Alzheimer's Disease and Related Disorders Association inclusion and exclusion criteria (McKhann et al., 1984). Dementia was therefore established by clinical examination, decline in two or more areas of cognition (including memory) as documented by neuropsychological testing (see below), no disturbance of consciousness, and an absence of systemic disorders, other brain diseases, and psychiatric disorders that might account for the dementia. Controls were obtained from the MRC Cognition and Brain Sciences Unit participant panel. None of the patients or controls had clinically apparent hearing impairments that might have affected their performance on the TROG. All testing was performed by one of two trained female research assistants.

Background demographic information about the patients and controls, and their scores on two standard clinical tests of cognitive function, the MMSE (Folstein et al., 1975) and the Dementia Rating Scale (DRS; Mattis, 1992), are given in Table 1. Following a classification system previously used to enable the investigation of cognitive function at different stages of DAT (Giles et al., 1996; Greene & Hodges, 1996; Hodges & Patterson, 1995; Hodges et al., 1996; Patterson et al., 1994), the patients were classified as having *minimal*, *mild*, or *moderate* dementia according to whether their MMSE scores fell in the range 24 to 30, 18 to 23, or 2 to 17 respectively. The cutoff of 24 was used because this is typically regarded as the lower limit of normality; the cutoff of 18 was chosen as the median value for those cases scoring below 24. Although the designation "minimal" may be considered controversial in view of these patients' "normal" performance on the MMSE, it is now acknowledged that the MMSE is insensitive in the earliest stages of DAT, especially in younger patients with high background intellectual ability (Welsh et al., 1991, 1992). The grade of minimal corresponds to what some investigators have termed very mild. All of the moderate patients were living at home without respite care and scored no more than Grade 2 on the Clinical Dementia Rating Scale. Of the 14 patients in this group only 4 scored below 10 on the MMSE. On follow-up, 12 of 17 patients classified with minimal DAT in an earlier study reported by our group had progressed to the mild category (Hodges & Patterson, 1995). Six patients in the study (1 minimal, 2 mild and 4 moderate) have since died and had pathologically confirmed Alzheimer's disease.

Neuropsychological Assessment

All patients were further assessed on a range of standard neuropsychological measures including the Rey Complex Figure Copy (Rey, 1941), Benton's Judgment of Line Orientation Test (Benton et al., 1983), an unusual views matching test (Humphreys & Riddoch, 1984), the Recognition Memory Test (Warrington, 1984), digit span subtests from

Table 1. Basic demographic data for DAT patients and elderly controls

Group	Control	DAT subgroup			DAT total
		Minimal	Mild	Moderate	
N	20	16	16	14	46
male:female	4:16	5:11	3:13	6:8	14:32
Age					
M	68.7	72.4	66.8	65.1	68.2
(*SD*)	(7.5)	(7.1)	(8.4)	(8.8)	(8.5)
Years of education					
M	11.1	11.1	11.6	10.6	11.1
(*SD*)	(2.3)	(3.0)	(3.6)	(2.4)	(3.0)
General Rating Scales					
MMSE (out of 30)					
M	29.3	25.5	21.1	9.86	19.2
(*SD*)	(1.0)	(1.9)	(1.7)	(5.2)	7.3
range	27–30	24–30	18–23	2–16	2–30
DRS (out of 144)					
M	140.7	123.6	112.6	74.9	104.9
(*SD*)	(2.5)	(8.8)	(9.6)	(22.0)	(24.9)

MMSE = Mini-Mental State Examination (Folstein et al., 1975). DRS = Dementia Rating Scale (Mattis, 1992).

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Table 2. Summary of scores on general neuropsychological testing for DAT patients and controls

	Control		DAT subgroup						DAT total	
			Minimal		Mild		Moderate			
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
Visuospatial and perceptual tests										
Object Match										
(Humphreys & Riddoch, 1984) (40)*	37.9	(1.6)	35.6	(2.8)	35.1	(3.9)	28.6	(4.9)	33.3	(4.9)
Line Orientation (Benton et al., 1983) (30)	28.4	(2.2)	25.8	(5.0)	20.9	(5.1)	5.2	(8.5)	18.1	(10.5)
Rey Figure Copy (Rey, 1941) (36)	34.8	(1.6)	28.5	(8.6)	22.4	(9.0)	7.9	(8.1)	20.1	(12.0)
Memory tests										
Rey Figure Recall (36)	15.9	(8.0)	2.8	(4.3)	1.0	(1.7)	0.3	(1.1)	1.5	(3.0)
Recognition Memory Test (Warrington, 1984)										
Words (50)*	47.8	(2.1)	34.6	(5.8)	29.5	(4.9)	25.0	(2.3)	30.3	(6.1)
Faces (50)*	44.1	(3.9)	35.9	(6.3)	35.1	(8.6)	25.1	(2.8)	32.6	(7.9)
Digit Span Forward (Wechsler, 1987)	6.8	(1.1)	6.6	(1.2)	5.8	(1.1)	4.2	(1.1)	5.6	(1.6)
Digit Span Backward (Wechsler, 1987)	5.0	(1.2)	4.8	(1.1)	3.3	(0.8)	2.2	(1.1)	3.5	(1.4)
Language and semantic tests										
Category Fluency, Living										
(Hodges & Patterson, 1995; four categories)	60.7	(11.7)	34.2	(10.8)	27.3	(12.4)	9.0	(8.7)	24.1	(14.9)
Category Fluency, Manmade										
(Hodges & Patterson, 1995; four categories)	56.3	(8.6)	34.4	(13.2)	29.4	(11.2)	9.4	(7.9)	25.0	(15.3)
Letter Fluency (FAS)	45.6	(10.4)	32.5	(12.2)	26.1	(14.4)	7.5	(7.6)	22.7	(15.7)
Naming (Hodges & Patterson, 1995) (48)	44.0	(2.3)	38.6	(4.6)	37.8	(6.8)	27.1	(9.5)	34.8	(8.7)
Word–Picture Matching										
(Hodges & Patterson, 1995) (48)	47.7	(0.6)	46.4	(1.7)	45.5	(4.0)	39.7	(5.3)	44.0	(4.8)
Pyramids and Palmtrees										
(Howard & Patterson, 1992) (52)*	51.6	(0.7)	47.8	(4.4)	45.8	(4.7)	34.8	(7.8)	43.9	(7.5)

Note. Numbers in parentheses after test names indicate maximum possible score.
*Chance level of performance = .5.

the Wechsler Memory Scale (Wechsler, 1987), the FAS test of Verbal Fluency, and the Pyramids and Palm Trees Test (Howard & Patterson, 1992). In addition, patients were administered the Hodges and Patterson Semantic Battery (Hodges & Patterson, 1995), which consists of a number of subtests all containing the same 48 core items (24 living and 24 man-made). Knowledge of these items is probed using different input and output modalities (e.g., category fluency, picture naming, naming to description, word–picture matching). The patients' performance relative to controls across these tests is given in Table 2.

Test for the Reception of Grammar (TROG; Bishop, 1989)

The TROG is a four-choice sentence-picture matching task containing 80 items, divided into 20 blocks of four items each, with each block testing a different lexical, morphosyntactic or syntactic construction. A block is scored as passed only if all four items within it are answered correctly; otherwise it is failed. Later blocks are generally more difficult than earlier blocks. Only simple, high-familiarity words are used in the stimuli, and a pretest ensures that participants know the meaning of the 32 nouns, 8 verbs, and 8 adjectives that occur in the test. The characteristics of items in each block are summarized in Table 3.

The first five blocks contain word–, phrase– or sentence–picture matching items assessing lexical comprehension only. The remaining 15 blocks, which require syntactic interpretation and postinterpretative processing in order to select the correct picture, were therefore of primary interest in the study. These 15 blocks may be further classified into two groups according to the type of distractor pictures they contain. In the first seven of these blocks, two of the three foils depict different lexical items than those mentioned in the target sentence; the third foil depicts an incorrect syntactic interpretation of the sentence (see, e.g., Figure 1). In the final eight blocks, all three foils depict incorrect syntactic interpretations of the target sentence. In this paper, these two types of blocks are referred to as lexical and syntactic distractor (L&S) blocks, and syntax only (S-only) blocks, respectively.

Participants were tested individually on the task. Target items were read aloud by an experimenter and repeated at the participant's request; participants were asked to point to the picture that matched the spoken stimulus. Dependent variables were the number of items correct, the number of blocks correct, the rate of errors to syntactic and lexical foils in the L&S blocks, and the rate of errors on the S-only blocks.

Table 3. Characteristics of items in the Test for the Reception of Grammar (TROG; Bishop, 1989)

Block	Syntactic construction and example	Distractors	Words	Propositions*
A, B, C	Noun/verb/adjective (e.g., *shoe*)	Lexical	1	n/a
D	Phrase/sentence (e.g., *the big cup*)	Lexical	3–4	n/a
F	Sentence with two nouns (e.g., *the boy is jumping over the box*)	Lexical	6–7	1
E	Negative (e.g., *the boy is not running*)	Lexical and syntactic	5	1
G	Singular/plural personal pronoun (e.g., *they are sitting on the table*)	Lexical and syntactic	5–6	1
H	Reversible active (e.g., *the girl is pushing the horse*)	Lexical and syntactic	6	1
I	Masculine/feminine pronoun (e.g., *she is sitting on the chair*)	Lexical and syntactic	5–6	1
J	Singular/plural noun inflection (e.g., *the cats look at the ball*)	Lexical and syntactic	5–6	1
K	Comparative/absolute (e.g., *the knife is longer than the pencil*)	Lexical and syntactic	7	1
L	Reversible passive (e.g., *the girl is chased by the horse*)	Lexical and syntactic	7	1
M	In and on (e.g., *the cup is in the box*)	Syntactic	6	1
N	Postmodified subject (e.g., *the pencil on the shoe is blue*)	Syntactic	7	1
O	*X* but not *Y* (e.g., *the box but not the chair is red*)	Syntactic	7–8	1
P	Above and below (e.g., *the star is above the circle*)	Syntactic	6	1
Q	Not only *X* but also *Y* (e.g., *not only the bird but also the flower is blue*)	Syntactic	9–10	1
R	Relative clause (e.g., *the girl chases the dog that is big*)	Syntactic	8–9	2
S	Neither–nor (e.g., *neither the dog nor the ball is brown*)	Syntactic	7–8	1
T	Embedded sentence (e.g., *the book the pencil is on is red*)	Syntactic	7–8	2

*Following the method used by Rochon and colleagues (Rochon et al., 1994) the number of propositions in a sentence is considered to be indicated by the number of finite verbs.

Measures of Working Memory and Attention

Forward and backward digit span were measured using the subtests from the Wechsler Memory Scale–Revised (Wechsler, 1987). Letter fluency (number of words beginning with the letters 'F', 'A', and 'S' in 1 min each) and the DRS scores for Initiation/Perseveration and Attention were used as measures of the executive components of working memory as both tests are known to be sensitive to the executive dys-

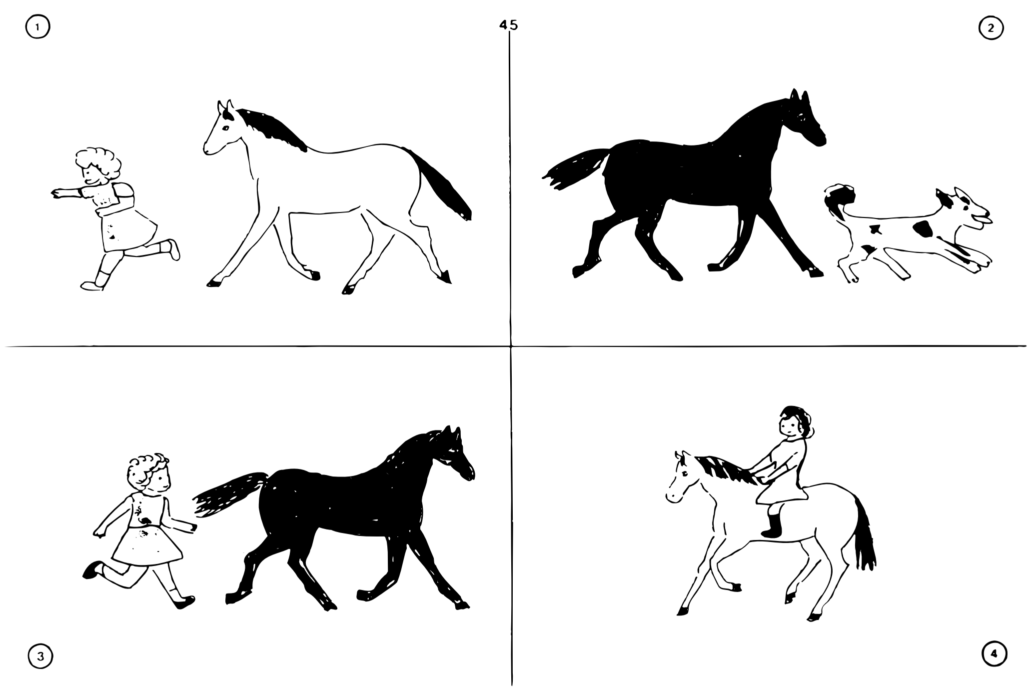

Fig. 1. Example of target and distractor pictures from the Test for the Reception of Grammar (TROG; Bishop, 1989) for the sentence, "The girl is chased by the horse" (Item 45, Block K, Reversible Passive). Picture 1 is correct; Pictures 2 and 4 are lexical foils, Picture 3 is a syntactic foil.

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function seen in patients with frontal and frontostriatal pathology (Rossor & Hodges, 1994). The DRS Memory subtest was also included as this contains items with attentional and/or delayed verbal recall demands.

Statistical Analyses

Because there was little variability between control participants in the number of blocks and items correct, but increasing variability in both measures with increasing dementia severity, all analyses of mean differences between controls and DAT subgroups assumed unequal variance. F ratios for all analyses of variance (ANOVAs) were estimated (F'') using the Welsh procedure (Howell, 1992); t tests and planned *post-hoc* contrasts also assumed unequal variance. Contrasts were performed using a Bonferroni correction for multiple comparisons such that the overall significance value (α) was .05. Simple chi-squared analyses were used for comparisons of different error types across groups, and Pearson product–moment correlations were used to assess relationships between patients' TROG performance and other measures.

RESULTS

Relationship Between TROG Performance and Dementia Severity

Box-and-whisker plots illustrating the three DAT subgroups' performance compared with that of the controls, for number of blocks and items correct, are shown in Figures 2a and 2b respectively. The DAT patients as a group were significantly impaired relative to controls on both blocks and items [blocks: $t(48.7) = 7.1$, $p < .001$; items: $t(46.4) = 5.6$, $p < .001$]. A one-way ANOVA (controls *vs*. minimal *vs*. mild *vs*. moderate DAT) also revealed significant effects [blocks: $F''(3,25.9) = 49.5$, $p < .001$; items: $F''(3,26.0) = 34.4$, $p < .001$]. Pairwise contrasts ($\alpha = 0.05/6 = .0083$) revealed a different pattern for blocks and items. For blocks correct, controls scored significantly better than minimal DAT patients [$t(16.3) = 2.7$, $p = .008$, marginally significant], and significantly better than the mild DAT group [$t(17.7) = 3.8$, $p < .001$], and mild DAT patients scored significantly better than the moderate group [$t(19.2) = 9.9$, $p < .001$]. The overall pattern was therefore controls $>$ minimal $=$ mild $>$ moderate. For number of items correct, the minimal group were *not* significantly impaired relative to controls [$t(16.8) = 3.2$, $p = .013$], but otherwise the same pattern (controls $>$ mild $>$ moderate, minimal $=$ mild) was seen for items as for blocks [controls *vs*. mild DAT: $t(18.3) = 5.3$, $p < .001$; minimal *vs*. mild DAT: $t(27.8) = 2.1$, $p = .15$; mild *vs*. moderate DAT: $t(17.7) = 3.8$, $p < .001$].

Because there was considerable overlap between the controls and the two less-impaired DAT subgroups, we examined further the proportion of impaired patients within each DAT group. On the measure of blocks correct, control group results ranged from 17 to 20; 31.3% of minimal patients, 68.8% of mild patients and 92.9% of moderate patients passed fewer than 17 blocks. In terms of the number of items correct, controls scored 75 to 80 correct, and 18.8% of minimal, 50% of mild and 81.3% of moderate patients attained scores below this range. Thus, while an increasing number of DAT patients showed sentence comprehension deficits with increasing DAT severity, in none of the subgroups were all patients impaired relative to controls. It is noteworthy

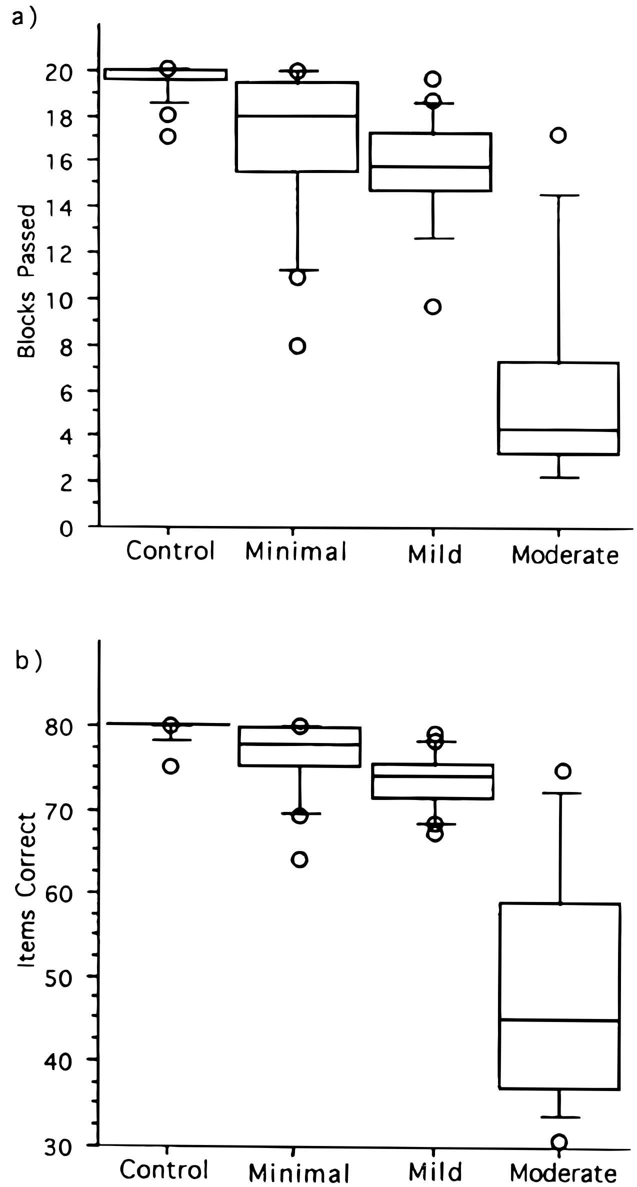

Fig. 2. Box-and-whisker plots showing performance of controls and DAT subgroups on the Test for the Reception of Grammar (TROG; Bishop, 1989): (a) Blocks and (b) Items. The bottom and top edges of the boxes represent the 25th and 75th percentiles, respectively; the line dividing the box indicates the median score. The ends of the lower and upper whiskers indicate the 10th and 90th percentiles respectively; circles represent individual scores lying outside these percentile ranges.

that between approximately 19 and 31% of patients with MMSE scores greater than 24 fell outside the normal range on the TROG.

Performance on Blocks With Syntactic and Lexical Distractors

As noted earlier, the TROG contains some items with lexical foils only, some with lexical and syntactic foils, and some with syntactic foils only. To determine whether dementia severity affected comprehension of sentence structure over and above lexical comprehension, the rates of errors to lexical *versus* syntactic foils were calculated for the seven blocks where both types of foil were available (Table 4). In each of these items, there were two lexical foils to one syntactic foil. We therefore used chi-squared analyses to test the null hypothesis that patients would select a lexical foil at least twice as often as a syntactic foil if their difficulties were not specific to the comprehension of the syntactic constructions in the sentences. Whether analyzed for the overall DAT group or for the subgroups, the null hypothesis was rejected [all DAT: $\chi^2(1) = 90.0$, $p < .001$; minimal: $\chi^2(1) = 21.5$, $p < .001$; mild: $\chi^2(1) = 32.0$, $p < .001$; moderate: $\chi^2(1) = 44.4$, $p < .001$]. That is, syntactic misinterpretations accounted for a significantly larger proportion of errors than would be expected by chance.

Relationship Between Syntactic Errors and Dementia Severity

The number of syntactic foils selected in both the L&S blocks and the S-only blocks increased as a function of dementia severity ($\alpha = .05/6 = .0083$). For the L&S blocks, the overall pattern was controls > minimal = mild > moderate (controls *vs*. minimal: binomial $p < .001$; minimal *vs*. mild: $\chi^2(1) = 0.44$, $p = .51$; mild *vs*. moderate: $\chi^2(1) = 58.4$, $p < .001$]. Almost the same pattern arose in the S-only blocks, namely: controls > minimal > mild > moderate (control *vs*. minimal: $\chi^2(1) = 23.3$, $p < .001$; minimal *vs*. mild: $\chi^2(1) = 5.84$, $p = .004$; mild *vs*. moderate: $\chi^2(1) = 439.8$, $p < .001$].

Table 4. Percentages of errors to lexical *versus* syntactic foils made by controls and patients in the three DAT subgroups, on blocks with lexical and syntactic foils

Group	*N*	Type of foil: Syntactic	Type of foil: Lexical	Total errors
Controls	20	1	0	1
Minimal	16	17	3	20
Mild	16	21	2	23
Moderate	14	88	60	148
All DAT patients	46	126	65	191

Effect of Sentence Length

In the L&S blocks, which contained sentences of five, six, or seven words, there were no differences in the rate of incorrect selection of the syntactic foil across the three lengths for all DAT patients [$\chi^2(2) = 2.4$, $p = .3$], the minimal and mild subgroups, whose errors were pooled to provide sufficiently large numbers for analysis [$\chi^2(2) = 2.1$, $p = .36$], and the moderate subgroup [$\chi^2(2) = 2.3$, $p = .32$]. For the S-only blocks, a correlation analysis between the number of words per sentence (6–10 words) and the number of errors made per sentence revealed no significant correlations for all DAT patients combined ($r = .04$, $p = .79$), nor for any of the DAT subgroups (minimal: $r = .03$, $p = .91$; mild: $r = .04$, $p = .88$; moderate: $r = .17$, $p = .56$). The absence of relationship between number of words per item and rate of errors was also evident from the fact that sentences in Block T, which elicited the highest rate of errors from the DAT group (49% errors), were seven to eight words long, while sentences in Block Q, which elicited the lowest error rate of the S-only blocks (13% errors), were the longest (9–10 words in length).

Relationship to Working Memory and Attentional Abilities

TROG performance of the DAT patients as a whole group, as measured by both blocks and items correct, was significantly correlated with all measures of working memory and attention (Table 5). Because most patients with moderate dementia show deficits across a broad range of neuropsychological tests, however, relationships between individual cognitive abilities are obscured by the larger effect of dementia severity. We therefore also considered the relationship between working memory–attention and TROG performance for just the minimal and mild patients combined, on the grounds that scores across these subgroups of patients should show neither floor nor ceiling effects, and so provide a more reliable measure of the interrelationship between cognitive functions. As Table 5 also shows, in the combined minimal–mild DAT group, the correlation between TROG performance (both for blocks and items) and the attentional subtest of the DRS was marginally significant after correction for multiple comparisons ($\alpha = .05/5 = .01$), but none of the other correlations reached statistical significance. The general lack of a strong relationship between measures of working memory–attention and patients' scores on the TROG is also illustrated by the fact that a substantial percentage of patients remained within the control ranges on tests of working memory and/or attention but nevertheless performed below the control range on the TROG (Table 6).

Effect of Number of Propositions and Canonicity of Subject–Object Order

Because six of the S-only blocks contained one proposition (M, N, O, P, Q, S), and two contained two propositions

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Table 5. Correlations between DAT patients' performance on the TROG and measures of immediate memory

	Blocks		Items	
Group	*r*	*p*	*r*	*p*
All DAT patients ($N = 46$)				
Digits Forward	.67	<.001**	.72	<.001**
Digits Backward	.64	<.001**	.68	<.001**
Letter Fluency (FAS)	.69	<.001**	.70	<.001**
DRS Initiation/Perseveration	.77	<.001**	.82	<.001**
DRS Attention	.77	<.001**	.85	<.001**
DRS Memory	.66	<.001**	.67	<.001**
Minimal and mild patients ($N = 32$)				
Digits Forward	.15	.41	.19	.30
Digits Backward	.19	.30	.23	.21
Letter Fluency (FAS)	.32	.07	.35	.05
DRS Initiation/Perseveration	.20	.27	.24	.19
DRS Attention	.48	.01*	.43	.01*
DRS Memory	.19	.30	.21	.26

Note. DRS = Dementia Rating Scale (Mattis, 1992).
* = marginally significant at $\alpha = .05/5 = .01$.
** = significant at $\alpha = .01$.

(R, T), we were able to investigate the effect of number of propositions on the patients' error rates. Following the method used by Rochon and colleagues (Rochon et al., 1994) the number of propositions in a sentence was considered to be indicated by the number of finite verbs. Two items in Block N (Numbers 53 and 55) were omitted from this analysis because they contained a verb participle in addition to a finite verb (e.g., *the boy chasing the horse is fat)*. It was debatable that these contained only one proposition, although each contained only one finite verb; there was also no precedent in the work of Rochon and colleagues for categorizing this type of sentence. The analysis showed a significant effect of number of propositions on error rate when the DAT patients were considered as a single group, as well as within each subgroup ($p < .002$ for all comparisons).

Sentences in the two-proposition blocks (R and T) also differ on the canonicity of subject–object order; thus the error rates were also examined separately for these two blocks. Figure 3 shows that only the sentences in Block T (*embedded sentences)* elicited significantly more errors than those in the one-proposition blocks [all DAT: $\chi^2(1) = 205.8$, $p < .001$; minimal: $\chi^2(1) = 19.4$, $p < .001$; mild: $\chi^2(1) = 96.9$, $p < .001$; moderate: $\chi^2(1) = 15.2$, $p < .001$]. Patients were only marginally poorer on the sentences in Block R (*relative clause)* than on the one-proposition blocks [all DAT: $\chi^2(1) = 3.8$, $p = .05$; minimal: $\chi^2(1) = 0.23$, $p = .63$; mild: $\chi^2(1) = 4.8$, $p = .03$; moderate: $\chi^2(1) = 2.0$, $p = .16$]. Patients' performance was significantly poorer on Block T compared with Block R [all DAT: $\chi^2(1) = 74.9$, $p < .001$; minimal: $\chi^2(1) = 5.49$, $p = .02$; mild: $\chi^2(1) = 20.41$, $p < .001$; moderate: $\chi^2(1) = 4.38$, $p = .04$].

Table 6. Percentage of DAT patients below control range on the TROG but within control range on working memory–attention tests

	Percentage below control range on TROG	
Test*	Blocks	Items
Digits Forward	52.2	41.3
Digits Backward	19.6	15.2
Letter Fluency (FAS)	6.5	4.4
DRS Initiation/Perseveration	13.0	6.5
DRS Attention	30.4	26.1
DRS Memory	0	0

Note. DRS = Dementia Rating Scale (Mattis, 1992).
*Working memory–attention test on which performance was normal.

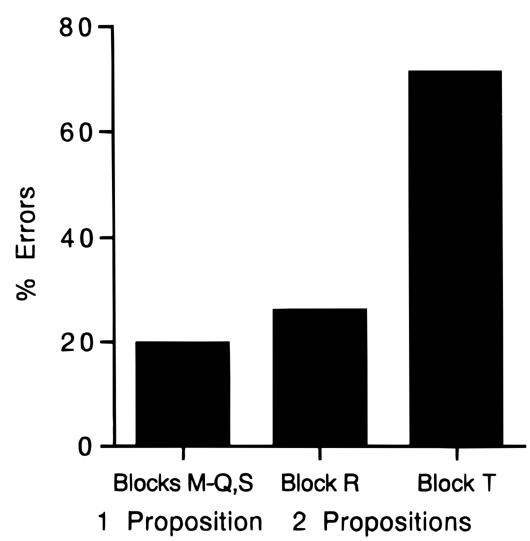

Fig. 3. Percentage of errors made by all DAT patients to blocks containing one *versus* two propositions.

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A comparison of syntactic error rates in Blocks H (*reversible active)* and L (*reversible passive)* showed no effect of canonicity in the one-proposition sentences [all DAT: $\chi^2(1) = 0.000$, $p > .9$] but as the minimal and mild patients were at ceiling on both blocks, these sentence types may have been too easy to reveal canonicity effects. The control group made a maximum of 2 errors per block (2.5% error) on Blocks M to R, and 7 errors (8.8%) on Block T.

DISCUSSION

In common with several other recent studies (Grossman et al., 1995; Rochon et al., 1994; Small et al., 1997; Waters et al., 1995), we have shown that, independent of lexical comprehension deficits, sentence comprehension is impaired in DAT. We tested a relatively large cohort of DAT patients on the TROG sentence–picture matching test, and have extended previous findings in showing that sentence comprehension deficits may arise in the earliest (minimal) stage of DAT—a stage not even recognized as DAT under some definitions. In probing factors potentially related to level of sentence comprehension, we found no relationship to sentence length, and when the moderately demented patients were excluded from the analysis, we found no correlation between performance on the TROG and working memory (as measured by digit span), although there was a significant correlation with one of the attentional measures. The DAT patients were more impaired on two-proposition sentences with noncanonical word order than on two-proposition sentences with canonical word order.

Across the cohort of DAT patients we studied, there was a relationship between dementia severity (minimal, mild, or moderate) and performance on the TROG. Thus, at the minimal stage, approximately 20 to 30% of patients showed deficits, while at the moderate stage almost all patients were impaired. At no stage of the disease, however, were *all* patients impaired relative to controls. The number of failed blocks constituted a more sensitive indicator of deficit than the number of incorrect items at each stage of disease severity.

The heterogeneous effects of DAT on sentence processing in different individuals is similar to the heterogeneous effects of this disease on other cognitive processes such as semantic processing, reading, and constructional abilities (Hodges & Patterson, 1995; Hodges et al., 1996; Mackenzie-Ross et al., 1996; Patterson et al., 1994). In some cases, sentence comprehension may be so severely impaired as to be one of the *presenting* features in a progressive aphasic syndrome where the pathology is later shown to be that of Alzheimer's disease (Green et al., 1990; Karbe et al., 1993). Although the present study specifically excluded cases presenting with progressive aphasia, our research group has seen three cases of this type with pathologically confirmed Alzheimer's disease (Croot, 1997; Greene et al., 1996). Such cases, and the findings of this study, do not therefore support claims that DAT only affects syntactic processing at the latest stages of the disease (Bayles, 1982; Bayles & Boone, 1982; Hier et al., 1985; Kertesz et al., 1986; Miller, 1989). Instead, and contrary to some reports (Grossman et al., 1996a; Waters et al., 1995), our results demonstrate that there is a relationship between MMSE score and sentence comprehension deficits across a large group of DAT patients, but that there is also considerable within-group heterogeneity at each stage of severity.

Our study did not support claims that sentence comprehension deficits in DAT are secondary to working memory impairments as measured by digit span tasks (Small et al., 1997). Although there were correlations between TROG scores and a range of working memory–attentional measures across the whole DAT group in our study, when we removed the moderate patients' scores from the analyses because of floor effects on some measures (e.g., letter fluency, backward digit span; see Table 2), almost all the significant correlations disappeared for the remaining patients (minimal and mild combined). Further, many patients were impaired relative to controls on the TROG while showing no impairment on forward digit span (Table 6).

The relationship between sentence comprehension and the attentional subscale of the DRS, however, did remain marginally significant for the combined minimal and mild patients. This relationship thus demands further investigation, first, to determine whether a more reliable correlation would emerge using a larger participant group or more items. Second, using a wider range of attentional measures it is necessary to clarify at least two questions: (1) which specific type(s) of attentional resources might be involved in sentence comprehension, and (2) how do these relate to the sentence interpretation *versus* postinterpretative stages of sentence comprehension?

We found mixed support for the hypothesis of Waters and colleagues (Rochon et al., 1994; Waters et al., 1995) that it is the second (postinterpretative) stage of sentence comprehension that is most impaired in DAT. Patients were more impaired on two-proposition sentences than one-proposition sentences, indicative of postinterpretative processing difficulties; however they were only marginally poorer on those two-proposition sentences with canonical subject–object order (Block R), but markedly impaired on noncanonical two-proposition sentences (Block T). This was true for the DAT group as a whole, and within each subgroup. Canonicity (associated with the sentence interpretation stage of comprehension) did not effect performance on one-proposition sentences (Blocks H *vs*. L), but the ceiling effect for the minimal and mild groups limits interpretation of this finding.

In previous studies manipulating canonicity and number of propositions, Small et al. (1997) reported that patients were only impaired on two-proposition sentences with noncanonical order, whereas Waters and colleagues (Rochon et al., 1994; Waters et al., 1995) found number of propositions significant while canonicity had no effect. Although one explanation offered for these inconsistent findings has been differential task demands (Waters and colleagues used one picture foil, while Small and colleagues used three), Waters et al. (1995) reported that when the number of foils was

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increased to three in their task, there was still no effect of canonicity or number of thematic roles. As the TROG contains three picture foils, our task and results were more consistent with those of Small and colleagues, and suggest that *both* stages of sentence comprehension may be impaired in DAT. Deficits at the first stage may become more evident when task demands are increased (e.g., with more foils), or it may be that DAT has heterogeneous effects across different subcomponents of sentence comprehension in different individuals.

Our finding of sentence comprehension deficits in up to one-third of the minimal patients in this study suggests that the pathological process in some patients with DAT may spread to left-hemisphere perisylvian language areas associated with syntactic processing (Just et al., 1996; Rothi et al., 1982) earlier than is typically presumed. It has been proposed on the basis of neuropathological studies (Braak & Braak, 1991; Damasio et al., 1990) that the neurofibrillary tangles characteristic of Alzheimer's disease typically appear first in the transentorrhinal region, then spread to the limbic structures and only afterwards appear in the cortical association areas. However, the few patients with pathologically confirmed Alzheimer's disease who have presented with nonfluent progressive aphasia have shown a concentration of pathology in superior perisylvian areas of the left hemisphere (Croot, 1997), in 1 case, even sparing the medial temporal structures (Greene et al., 1996). Further, a group of 10 patients who presented with clinically apparent phonological and syntactic deficits in the context of more widespread cognitive deficits typical of DAT (Croot, 1997), including below-normal TROG scores showed brain abnormalities in both structural (MRI) and functional (SPECT) imaging that were also focused around the perisylvian regions typically associated with syntactic deficits in patients with vascular etiology (Goodglass & Kaplan, 1983; Kertesz, 1979). The present study thus indicates that it is not only patients with Alzheimer's disease who *present* with syntactic processing deficits who may have neuropathology extending into cortical regions associated with syntactic processing at early stages of the disease.

Alzheimer's disease is clearly a heterogeneous entity, both in terms of the distribution of the pathological process and the neuropsychological profiles that emerge as a consequence. Specific deficits in sentence comprehension have previously been reported in rare cases of subsequently confirmed Alzheimer's disease where the patient presented with a progressive aphasic syndrome. The current study demonstrates that deficits in sentence comprehension may also occur in a substantial proportion of unselected cases, even at very early stages of the disease, but that not all patients with moderate dementia may show such deficits. These probable DAT patients had impaired comprehension of a wide range of syntactic structures, including some less complex than those reported in previous sentence–picture matching investigations of this type (Rochon et al., 1994; Small et al., 1997; Waters et al., 1995). Further, measures thought to reflect both the sentence interpretation and postinterpretative stages of sentence comprehension were impaired in the group of patients investigated. Additional research is necessary to clarify the specific processes involved in sentence comprehension, how these interact with measures of attentional capacity, and the manner in which the broad range of cognitive abilities deteriorate with advancing DAT. From a practical point of view, impairment in syntactic processing is clearly compatible with a diagnosis of even early DAT.

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