Attentional resource and processing speed limitations during sentence processing in Parkinson’s disease

Christine Lee, Murray Grossman,* Jennifer Morris, Matthew B. Stern, and Howard I. Hurtig

Department of Neurology, Hospital of the University of Pennsylvania, 3 Gates Center, 3400 Spruce Street, Philadelphia, PA 19104-4283, USA
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Abstract

Several studies have suggested that patients with Parkinson’s disease (PD) have sentence comprehension difficulty in part because of their limited executive resources. However, these assessments confound the executive resources contributing to sentence comprehension with the resources needed for task performance. In the present study, we used a word detection technique that minimizes task demands in order to evaluate attentional and processing speed resources during the comprehension of simple sentences without subordinate clauses and sentences containing subject-relative and object-relative center-embedded subordinate clauses. We found that PD patients have poor sensitivity to phonetic errors embedded in unbound grammatical morphemes, regardless of the clausal structure of the sentence, suggesting difficulty attending to grammatical morphemes. We also found that PD patients are significantly slowed in their sensitivity to phonetic errors in content words embedded in object-relative center-embedded sentences. Slowed sensitivity to content words in object-relative sentences was correlated with timed executive measures of planning. On a traditional measure of comprehension, these PD patients were impaired for sentences containing object-relative center-embedded clauses compared to sentences with subject-relative center-embedded clauses, and comprehension of object-relative sentences was correlated with executive measures. Our findings are consistent with the claim that limited executive resources for strategic attention and processing speed contribute to the sentence comprehension difficulties of PD patients.

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1. Introduction

Parkinson’s disease (PD) is an akinetic-rigid disorder with clinical features of tremor, rigidity, gait instability, and bradykinesia. This is due to the depletion of monoaminergic neurotransmitters—in particular, reduced dopamine projections to the basal ganglia and a frontal-striatal-thalamic loop. About 20% of PD patients have a dementia, but another 60% demonstrate cognitive impairments without a dementia. This includes difficulty with executive functions such as planning, selective attention, working memory, inhibitory control, and information processing speed (Brown & Marsden, 1988; Brown & Marsden, 1991; Maddox, Filoteo, Delis, & Salmon, 1996; Sharpe, 1992; Taylor, Saint-Cyr, & Lang, 1986). Many of these patients also exhibit sentence comprehension difficulty. The basis for this deficit, however, is unclear. Some investigators have attributed PD patients’ impaired sentence comprehension to a grammatical processing deficit (Cohen, Bouchard, Scherzer, & Whitaker, 1994; Lieberman et al., 1992; Natsopoulos et al., 1991; Ullman et al., 1997). Others have argued that a limitation in executive resources contributes importantly to the sentence comprehension deficit in PD (Geyer & Grossman, 1994; Grossman, Carvell, Stern, Gollomp, & Hurtig, 1992; Grossman, Lee, Morris, Stern, & Hurtig, in press; Waters & Caplan, 1997). The results of these studies have been difficult to interpret because the resource demands thought to contribute to sentence comprehension have been confounded by the demands associated with task performance. In the present study, we used a technique with limited resource demands to investigate the role of

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*Corresponding author. Fax: 1-215-349-8464.
E-mail address: mgrossma@mail.med.upenn.edu (M. Grossman).

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attention and processing speed in non-demented PD patients’ sentence comprehension difficulty.

Sentences containing complex clauses with a non-canonical word order—such as a sentence with an object-relative center-embedded subordinate clause like “The boy that the girl hugged is friendly”—are more difficult to understand than sentences containing a subject-relative center-embedded clause like “The boy that hugged the girl is friendly” (Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996; Ford, 1983; Frazier & Rayner, 1982). Direct probes of sentence comprehension in PD have demonstrated an exaggeration of this effect, namely, that PD patients have disproportionately greater difficulty understanding sentences with a grammatically complex clausal structure than sentences with a simpler clausal structure (Grossman et al., 1992; Lieberman, Friedman, & Feldman, 1990; Natsopoulos et al., 1991). Evidence of this sort has been interpreted to support the claim that PD patients have difficulty processing grammatical aspects of sentences. For example, one study correlated sentence-picture matching difficulty with the impaired categorical production of speech sounds in PD (Lieberman et al., 1992). This kind of speech deficit has been observed in Broca’s aphasics who are thought to have a grammatical processing impairment (Blumstein, 1995), supporting the investigators’ inference that the comprehension deficit in PD is also due to a grammatical impairment. Indeed, difficulty with the rules underlying syntactically licensed long-distance dependencies in sentences may be a specific instance of a broader deficit in procedural learning and rule-based processing associated with disorders of the basal ganglia (Ullman et al., 1997). Support for this hypothesis has come from the observation that PD patients have selective difficulty producing regular past tense forms of verbs despite preserved production of irregular past tense forms, and this difficulty was correlated with the severity of the patients’ motor disorder.

An alternative approach has related the deficit understanding sentences in PD to the executive resource demands associated with comprehension processes such as gap-filling (Swinney & Fodor, 1989). Syntactic operations such as gap-filling allow the listener to determine that “the boy” in “The boy that the girl hugged is friendly” is the object of “hugged” even though it is encountered non-canonically at the beginning of the sentence rather than following the verb (Chomsky, 1981). Several executive resources appear to contribute to this gap-filling process. One obvious resource is concerned with working memory, or the ability to retain the moved constituent mentally until it must be retrieved at the gap (Gibson, 1998; Zurif, Swinney, Prather, Wingfield, & Brownell, 1995). Another crucial resource during the comprehension of center-embedded clauses is concerned with information processing speed. The absence of a phonetic marker at the gap leaves the gap-filling process vulnerable to degradation unless lexical retrieval at the gap proceeds instantaneously. Comprehension impairment in agrammatic patients has been associated with slowed lexical retrieval at the gap (Swinney, Zurif, Prather, & Love, 1996; Zurif, Swinney, Prather, Solomon, & Bushell, 1993). A third resource mediates shifting attention to grammatical morphemes during the course of comprehension since they are relatively difficult to detect. Grammatical morphemes like “that” are unstressed in oral presentation, yet these words explicitly mark the clausal structure of a sentence containing a center-embedded clause. Without “that,” a sentence may become ambiguous and difficult to parse (as in the center-embedded garden-path sentence “The horse raced past the barn fell”) (Bever, 1970). Finally, planning may be implicated in non-canonical sentences to co-ordinate the multiple mental activities necessary for their comprehension.

The role of these executive resources has been investigated during sentence comprehension in PD. For example, one study has associated slowed lexical retrieval in PD with difficulty understanding sentences containing object-relative center-embedded clauses (Grossman et al., 2002). PD patients were studied with a lexical priming procedure using a list presentation technique where the interstimulus interval between continuously presented words was 500, 1100, or 1500 ms. We found that the subgroup of PD patients with impaired comprehension of sentences containing object-relative center-embedded clauses differs from healthy control subjects and non-impaired PD patients since the impaired subgroup primed only at the prolonged 1500 ms interstimulus interval. This resembled the slowed lexical retrieval during gap-filling seen in stroke patients with Broca’s aphasia who have more obvious grammatical comprehension difficulty (Swinney et al., 1996; Zurif et al., 1993). Another study demonstrated degradation of sentence comprehension during concurrent performance of a secondary task in PD (Grossman, Kalmanson, Bernhardt, Stern, & Hurtig, 2000). We have also reported that PD patients are impaired in their ability to detect the presence and nature of phonetic errors in the grammatical morphemes of center-embedded sentences (Grossman et al., 1992). In this study, moreover,

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1 From this perspective, non-canonical sentence structures involve constituent movement, and movement of this sort leaves a “trace”—an abstract, phonetically unrealized placeholder—in the vacated position or “gap.” Traces are held to be crucial for the assignment of thematic roles in a sentence, such roles being assigned to hierarchically structured sentence positions regardless of the identity of the assignee. If a thematic position contains a trace, then the trace is assigned the appropriate thematic role and the moved constituent gets its role only indirectly, by being coindexed to the trace (indicated by the subscript “i”). In the example above, “the boy” becomes the “huggee” by being linked to a trace after the verb, as in “[The boy], that the girl hugged i is friendly.”
sentence comprehension accuracy correlated with difficulty on executive measures involving attention and working memory.

Unfortunately, these previous studies were faulted since the executive resources needed for gap-filling were confounded with the resources needed for task performance. A recent study attempted to address this confound by using a “word detection” technique that minimizes executive resources associated with task performance (Grossman et al., in press). This approach avoids directly probing the feature of interest. Instead, subjects are asked to perform a word detection task that has fewer resource demands than are required during explicit performance of a traditional sentence comprehension measure. Inferences about the grammatical or executive features of the sentence are based on the location of the target word relative to a grammatical agreement and the latency to respond during the word detection task (Tyler, 1985). When the target word immediately follows a grammatical agreement violation—that is, when the target word occurs in the time window during which the grammatical agreement is activated—there is a brief but reliable delay in responding to the target word in comparison to detection immediately following a correct grammatical agreement. By comparison, when the target word occurs several syllables after a grammatical agreement violation—that is, once the activation for the grammatical agreement has returned to baseline—there is no delay in target word detection. Control subjects and PD patients demonstrated equivalent sensitivity to grammatical agreement violations with this technique. The PD patients participating in this study, however, were significantly impaired with a traditional technique that directly probes their sentence comprehension with a simple question. There was no difference on the word detection measure between the subgroup of PD patients with difficulty understanding sentences containing object-relative clauses and PD patients with relatively preserved comprehension, although the relatively impaired subgroup of PD patients were significantly impaired in their performance on a timed measure of executive planning. These observations were most consistent with the hypothesis that limited executive resources contribute to the sentence comprehension deficit in PD.

The present study re-investigated the role of attention and information processing speed during sentence comprehension in PD (Grossman et al., 1992). We minimized a major confound of our previous study by using the word detection technique that minimizes task-related resource demands. Unlike our previous study, moreover, this word detection task included errors in content words as well as in unbound grammatical morphemes. In the present assessment with reduced task demands, we again expected to find reduced sensitivity to grammatical morphemes in sentences. A shortcoming of our recent investigation using the word detection technique (Grossman et al., in press) was that the sentence structures used in the word detection task differed from the stimuli used so often in traditional studies directly probing sentence comprehension. To address this limitation, all sentence stimuli in the present word detection study included subject-relative and object-relative clauses. Based on our previous correlative study of information processing speed during lexical priming and grammatically complex sentences in PD (Grossman et al., 2002) and the work demonstrating the role of slowed lexical retrieval during gap-filling in Broca’s aphasia (Swinney et al., 1996; Zurif et al., 1993), we expected to find slowed access to content words in PD, particularly for sentences containing object-relative center-embedded clauses.

2. Methods

We assessed 19 right-handed, native English-speakers who were diagnosed with mild, idiopathic PD. These patients were recruited from the Parkinson’s Disease and Movement Disorders Center at Pennsylvania Hospital and the University of Pennsylvania. PD patients were screened for the presence of dementia, and participation was restricted to non-demented patients [Mini-Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975) score mean (±SD) = 28.67 (±1.33)]. We excluded patients with other causes of neurologic disease such as stroke, Alzheimer’s disease, or hydrocephalus, psychiatric disorders such as primary depression or psychosis, infectious diseases that may have resulted in progressive intellectual decline, and/or other medical illnesses or metabolic conditions that may have resulted in an encephalopathy. None of the subjects were taking sedating medications at the time of testing, and there was no history of neuroleptic drug use. Demographic and clinical features of the PD patients are summarized in Table 1. For the word detection procedure, the PD patients were compared to 15 healthy, elderly, right-handed, native English-speakers matched for age [mean (±SD) age = 70.80 (±12.76) years; t(32) = 0.96; ns] and education [mean (±SD) education = 15.67 (±3.15) years; t(32) = 1.60; ns]. For the traditional, sentence probe procedure, the PD patients were compared to 16 healthy, elderly controls matched for age [mean (±SD) age = 70.81 (±10.75) years; t(33) = 1.07; ns] and education [mean (±SD) education = 14.94 (±2.57) years; t(33) = 0.91; ns].

2.1. Materials

2.1.1. Word detection procedure

Each trial was initiated with a brief auditory warning signal followed 500 ms later by the aural presentation of
a target word. Then a brief auditory warning signal was heard 500 ms prior to the aural presentation of a sentence. Subjects were instructed to press a button as soon as the target word was heard in the sentence. This button press stopped the computer’s clock that had been initiated at the beginning of the target word in the sentence. Without informing the subjects, half of the sentences contained a phonetic error prior to the target word (the substitution of a single incorrect speech sound that yielded a pronounceable nonword). Half of these sentences included a violation of an unbound grammatical morpheme, and half contained a violation of a content word. To examine grammatical phrase structure, one-third of both the correct and incorrect sentences featured a subject-relative center-embedded subordinate clause, one-third an object-relative center-embedded subordinate clause, and one-third did not have a subordinate clause (we refer to these as “simple”).

In each type of sentence, half of the errors under study immediately preceded the target word, and the remaining errors were separated from the target word by four syllables. This condition allowed us to establish whether sensitivity to the phonetic error occurred only in the temporal window during which the lexical representation has been activated (i.e., in the immediate temporal vicinity of the word) or following a delay (i.e., when the word is no longer activated). In half of each type of item, moreover, the violation-target word combination was distributed in the first half of the sentence, and the remainder occurred in the second half of the sentence (although the target word was never the last word in a sentence). This was in order to minimize the expectation of a violation occurring in a particular part of a sentence.

A total of 288 sentences were presented in all, divided into six equal blocks of stimuli. Each block contained randomly ordered stimuli that included violations as well as an equal number of control items of each type without a violation. To encourage subjects to listen to the entire sentence and not merely perform a vigilance test for a single word, subjects’ knowledge of the content of 10% of the sentences in each block was probed randomly. A training procedure was used to introduce subjects to the word detection paradigm, to familiarize subjects with the response modality, and to make them aware that they would be probed for their knowledge of sentences during the course of stimulus sentence presentation.

The stimuli were digitized by MacRecorder 16 software v1.0, stimulus presentation was controlled by PsychoScope v1.1b9 software and a Macintosh 1400C or G3 laptop computer was used to administer the stimuli and record responses. Latencies to respond to the target words were analyzed once each subject’s responses had been screened with a two-standard deviation filter based on that subject’s mean response latencies. There was no significant difference between the average number of items screened out for Parkinson’s patients [mean (±SD) = 6.14% (±2.35%)] and for the elderly control group [mean (±SD) = 5.15% (±1.47%)] [t(28) = 1.27; ns].

2.1.2. Direct probes of sentence comprehension

This traditional measure of sentence comprehension required subjects to answer a simple probe question about a semantically unconstrained sentence. These sentences were particularly difficult since they contained two transitive verbs, three nouns, and a grammatical structure that has a subordinate clause. The tester, in a natural voice and cadence, read each sentence twice, then asked a probe question. The subject’s responses were manually recorded. Twenty-four randomly ordered sentences containing center-embedded subordinate clauses were presented. Half of the target sentences contained a subject-relative clause (e.g., “The car that crushed the van towed the truck”) and half contained an object-relative clause (e.g., “The zebra that the elephant scared hunted the fox”). These were embedded in an
equal number of sentences with terminal subordinate clauses. Half of the probes for each type of item were in the active voice (e.g., “What did the hunting?”) and half were in the passive voice (e.g., “What was pursued?”). Half of each type of question probed the subordinate clause and half probed the matrix sentence. For the purpose of equating this direct method of sentence comprehension with the word detection technique, we averaged across active-voice and passive-voice probes and we averaged across subordinate clause and matrix sentence probes for target sentences containing a subject-relative center-embedded clause and for sentences containing an object-relative center-embedded clause.

2.1.3. Executive resource measures

We also administered independent measures of executive resources to the PD patients and elderly controls. These measures included:

Category naming fluency (Mickanin, Grossman, Onishi, Auria Combe, & Clark, 1994): a measure of mental planning and organization requiring subjects to name as many different words as possible beginning with the letters F, A, and S in 60 s; we report the total number of unique words produced on average over 60 s.

Stroop test (Stroop, 1935): a measure of inhibitory control that requires subjects to name the color of the font in which a color name is printed, where the font color does not correspond to the printed color name; we report the time that each subject required to complete this 80-item task.

Trail-making test, part B (Reitan, 1958): a measure of planning and inhibitory control that requires subjects to trace a line between an ascending series of alternating numbers and letters that are randomly arrayed on a page; we report the time required to complete the task.

Digit span (Wechsler, 1987): a measure of auditory-verbal short-term memory (forward digit span) and working memory (reverse digit span); we report the maximum number of digits repeated correctly in the order of presentation and in an order reversing the order of presentation.

3. Results

3.1. Word detection procedure

An analysis of variance (ANOVA) was used to evaluate the latencies to respond to a target word in a sentence with a group (2—control subjects, PD patients) × phonetic coherence (2—correct, violation) × target–error distance (2—near, distant) × word category (2—content, grammatical) × grammatical clause structure (3—simple, subject-relative, object-relative) design. We observed a significant main effect for phonetic coherence \( F(1,32) = 107.91; p < .01 \) and a significant interaction effect for phonetic coherence × target–error distance \( F(1,32) = 47.25; p < .01 \), but there was no interaction effect for phonetic coherence × target–error distance × group \( F(1,32) = 3.28, \text{ ns} \). To ensure that delayed response times following a phonetic error were not due to slowed movement in general, we calculated a difference score reflecting the difference in latency to respond to a target word following a phonetic error compared to a target word following a correct phonetic shape. Both PD patients [mean (±SD) difference score = 38.41 (±45.8) ms; \( t(18) = 3.68, p < .005 \)] and healthy control subjects [mean (±SD) difference score = 65.90 (±41.9) ms; \( t(14) = 6.09, p < .001 \)] demonstrated a larger response latency for target words in the immediate vicinity of the phonetic error compared to target words following the phonetic error by four syllables. These observations indicate that PD patients are as sensitive as control subjects to phonetic errors in sentences.

There was also a significant interaction effect for phonetic coherence × target–error distance × grammatical structure \( F(1,32) = 34.62; p < .001 \), and for phonetic coherence × target–error distance × grammatical structure × word category \( F(1,32) = 13.41; p < .001 \). These findings are summarized in Fig. 1. We investigated group differences in these interaction effects because of predicted distinctions in performance patterns depending on the clausal structure and word class in which the phonetic error was embedded. Consider first the subjects’ performance with phonetic errors embedded in an unbound grammatical morpheme. Elderly controls exhibited a longer response latency for target words immediately following a phonetic error than for targets following an error by four syllables for simple

![Image](image_url)
sentences \(t(14) = 5.00; p < .001\) and subject-relative sentences \(t(14) = 3.72; p < .005\). For object-relative sentences, elderly controls demonstrated no difference in their response latency to target words immediately following a phonetic error in comparison to targets following a phonetic error by four syllables \(t(14) = 0.58; \text{ns}\). In PD patients, by comparison, there were never significant differences in response latency for target words immediately following a phonetic error in a grammatical morpheme compared to target words following an error in a grammatical morpheme by four syllables [simple: \(t(18) = 1.18; \text{ns}\), subject-relative: \(t(18) = 0.96; \text{ns}\), and object-relative: \(t(18) = 0.16; \text{ns}\)]. These data suggest that PD patients are relatively insensitive to phonetic errors in grammatical morphemes, regardless of the clausal structure of the sentences.

Consider next the sentences with phonetic errors in content words. Performance profiles in PD patients and control subjects were identical for simple and subject-relative sentences. Both healthy elderly control subjects \(t(14) = 9.11; p < .001\) and PD patients \(t(18) = 9.60; p < .001\) had a longer response latency for target words immediately following a phonetic error in a content word than for targets following an error by four syllables when embedded in grammatically simple sentences. For content words in subject-relative sentence structures, neither elderly controls \(t(14) = 0.09; \text{ns}\) nor PD patients \(t(18) = 0.21; \text{ns}\) demonstrated a longer latency to respond to a target word in the immediate vicinity of a phonetic error as compared to a target word following an error by four syllables. For content words in object-relative sentences, control subjects \(t(14) = 0.58; \text{ns}\) did not have a longer latency to respond to target words in the immediate vicinity of a phonetic error compared to target words following an error by four syllables, paralleling their performance with grammatical morphemes. However, PD patients differed from control subjects, and from their own responses with grammatical morphemes, because of their delayed sensitivity to an error in a content word in object-relative sentences. Thus, PD patients had a significant difference in response latency only in object-relative sentences when the target followed the content word by four syllables \(t(18) = 2.77; p < .05\).

3.2. Traditional sentence comprehension procedure

We used a comparably structured set of sentences with center-embedded clauses to examine sentence comprehension in PD patients using a traditional method. As summarized in Fig. 2, PD patients were significantly less accurate in answering probes about sentences containing an object-relative center-embedded subordinate clause than sentences containing a subject-relative center-embedded subordinate clause \(t(18) = 3.46; p < .005\), a difference that was not evident in control subjects.

3.3. Correlations of sentence comprehension with executive measures

We correlated measures of executive resources with a measure of sensitivity to phonetic errors in order to test whether executive resources are correlated with PD patients’ comprehension performance as measured by the word detection procedure. We calculated an overall difference score that subtracted PD patients’ difference score for target words following the locus of the phonetic change by four syllables from the difference score for target words immediately following the locus of the phonetic change \([\text{error} – \text{correct}]_{\text{four-syllables}} – [\text{error} – \text{correct}]_{\text{immediate}}\). The results are summarized in Table 2. We found a significant correlation between delayed sensitivity to a content word in an object-relative context and the time to complete the Trails test \(r(17) = -.47; p < .05\) as well as Category naming fluency (FAS) \(r(17) = .54; p < .05\). There were no correlations between executive measures and the overall difference score for a grammatical morpheme in sentences with an object-relative center-embedded clause. Nor did we find a correlation between executive measures and the overall difference scores for a content word or a grammatical morpheme in a sentence containing a subject-relative subordinate clause. This emphasizes the selective, resource-dependent nature of slowed content word retrieval during processing of grammatically complex sentences in PD.

Correlation analyses also were performed in PD patients between performance on executive measures and accuracy during direct probes of sentences that contain an object-relative center-embedded clause. As shown in Table 2, we observed a correlation between this traditional measure of sentence comprehension and Digit-Span backward \(r(17) = .51; p < .05\) and Category naming fluency (FAS) \(r(17) = .48; p < .05\). There were
no correlations between executive measures and accuracy understanding sentences that contain a subject-relative center-embedded clause. We should also mention that we did not find a correlation between the traditional comprehension measure for sentences with an object-relative center-embedded clause and the overall difference score on the word detection procedure for a content word located in a sentence with an object-relative center-embedded clause \([r(17) = –.09; \text{ ns}].\)

4. Discussion

Several earlier studies have suggested that PD patients’ impaired sentence comprehension is due in part to a limitation in the executive resources that contribute to linguistic processes such as gap-filling. For example, PD patients are more impaired than control subjects at attending to the presence and nature of a phonetic error in the grammatical morphemes signaling the clausal structure of a sentence (Grossman et al., 1992). We have also observed that PD patients’ sentence comprehension is more sensitive to concurrent performance of a secondary task than control subjects (Grossman et al., 2000), and that PD patients with difficulty understanding sentences featuring an object-relative center-embedded clause have slowed lexical retrieval (Grossman et al., 2002). The results of these and other studies have been difficult to interpret, however, since the resources contributing to sentence comprehension were confounded by the resources required for task performance. We attempted to reduce the impact of this problem in the present study by using a word detection technique that minimizes task demands: subjects were asked to detect the occurrence of a target word in a sentence, rather than answer a probe question about a sentence. A previous study using this technique demonstrated that PD patients, while impaired on a traditional sentence comprehension task, are as sensitive as control subjects to a grammatical agreement violation in a sentence (Grossman et al., in press). The results of the present study provide additional detail that can help us understand the nature of the sentence comprehension deficit in PD.

4.1. Word detection procedure

There are two observations of note in the present study. First, we found that PD patients are insensitive to phonetic errors embedded in unbound grammatical morphemes. Unlike control subjects, they were consistently less sensitive to the occurrence of a phonetic error in a grammatical morpheme, even when located in a grammatically simple sentence. This agrees with our previous observation of PD patients’ difficulty detecting phonetic errors in grammatical morphemes (Grossman et al., 1992). These words play a crucial role in sentence comprehension since they mark important structural features of a sentence such as clausal structure. For example, the word “that” typically indicates that a subordinate clause follows, as in “The horse that raced past the barn fell.” The sentence remains grammatically correct even if “that” is omitted (“The horse raced past the barn fell”). However, many individuals judge this latter sentence unacceptable because of the ambiguity that ensues, and the comprehension of this kind of sentence requires significantly more processing time without “that” (Bever, 1970; Ferreira & Henderson, 1991; Frazier & Clifton, 1998). PD patients’ apparently limited sensitivity to these words thus could have a negative impact on their sentence comprehension relative to control subjects’ comprehension.

We previously hypothesized that the phonetically unstressed nature of grammatical morphemes such as “that” contributes to their limited detection by PD patients (Grossman et al., 1992). One alternative account for this deficit is that a specialized lexical retrieval mechanism for grammatical morphemes (Garrett, 1996; Levelt, 1992) is impaired in PD. Evidence against this claim comes in part from the observation that a very small proportion of PD patients are impaired in their expression of quantifiers (Grossman, Carvell, & Peltzer, 1994), and that PD patients are not necessarily agrammatic in their performance on sentence comprehension.

<table>
<thead>
<tr>
<th>Mean (±SD) PD performance</th>
<th>Traditional sentence comprehension</th>
<th>Word detection: overall difference score reflecting sensitivity to phonetic errors</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Subject-relative</td>
<td>Object-relative</td>
</tr>
<tr>
<td>Digits forward</td>
<td>8.53 (±1.6)</td>
<td>0.01</td>
</tr>
<tr>
<td>Digits reverse</td>
<td>5.79 (±2.3)</td>
<td>0.29</td>
</tr>
<tr>
<td>Trails (s)</td>
<td>167.53 (±69.9)</td>
<td>0.03</td>
</tr>
<tr>
<td>Stroop (s)</td>
<td>107.23 (±20.6)</td>
<td>–0.08</td>
</tr>
<tr>
<td>FAS (words/min)</td>
<td>14.95 (±5.6)</td>
<td>0.20</td>
</tr>
</tbody>
</table>
tasks (Grossman, 1999). It is also important to emphasize that PD patients are not universally insensitive to a phonetic error in a word. For example, PD patients were as accurate as control subjects at detecting a phonetic error when located in a content word embedded in a grammatically simple sentence. These observations help distinguish the present findings from the broad body of work demonstrating an executive resource and attentional limitation in non-linguistic studies of PD (Brown & Marsden, 1988; Brown & Marsden, 1991; Maddox et al., 1996; Sharpe, 1992; Taylor et al., 1986). In particular, the selective nature of the attentional impairment in PD is consistent with the claim that the executive resources contributing to sentence comprehension in PD are in part material-specific in nature.

Our second finding of note is that PD patients are slowed in their sensitivity to a content word located in an object-relative center-embedded sentence. Thus, while PD patients did not differ from control subjects in their detection of a phonetic error in a content word embedded in a sentence that is grammatically simple or contains a subject-relative clause, PD patients differed from control subjects in that they appeared to be sensitive to a content word in an object-relative clause only when the target word was delayed by four syllables after the error. This observation is consistent with the finding that PD patients’ difficulty understanding sentences containing an object-relative center-embedded clause is related in part to their slowed lexical retrieval on a list priming procedure (Grossman et al., 2002). We may not have observed this slowing for a grammatical morpheme in an object-relative sentence because of PD patients’ general insensitivity to these unstressed words.

There has been considerable controversy surrounding the claim that PD patients have bradyphrenia, that is, cognitive slowing that parallels their bradykinesia or motor slowing (Rogers, 1986). Some studies have found cognitive slowing on various measures such as memory scanning (Ransmayr et al., 1990; Russ & Seger, 1995; Wilson, Kaszniaik, Klawans, & Garron, 1980) and other time-sensitive measures of cognitive functioning (Flowers, Robertson, & Sheridan, 1995; Jordan, Sagar, & Cooper, 1992; Revonsuo, Portin, Koivikko, Rinne, & Rinne, 1993), but others have failed to confirm this finding (Howard, Binks, Moore, & Playfer, 1994; Rafal, Posner, Walker, & Friedrich, 1984; Smith, Goldman, Janer, Baty, & Morris, 1998). Regardless of the outcome of this debate, it is evident in the present study that slowed lexical retrieval is not a general property of PD patients’ performance, and slowing appears to be selective for the retrieval of a particular class of words in a specific sentence context.

Additional evidence consistent with the resource-dependent nature of cognitive slowing in PD patients’ sentence processing comes from the correlation pattern we observed between their performance on the word detection procedure and their performance on the battery of executive measures. We found that delayed sensitivity to a content word in an object-relative center-embedded sentence is correlated with the time to complete the Trails procedure and with Category naming fluency. These executive tasks are thought to be measures of planning. This result implies that the speed of lexical retrieval for a content word in a grammatically complex sentence is related to part mental planning. It is noteworthy that other measures of executive functioning do not correlate with sentence processing for a content word in the word detection procedure, and that delayed sensitivity to a grammatical morpheme in an object-relative sentence is not correlated with performance on executive measures. This pattern of selective correlations, and the absence of a correlation between executive measures and grammatical morpheme sensitivity in particular, is consistent with the view that these two classes of words are dependent in part on different processes: attention to grammatical morphemes, but rate-dependent lexical retrieval of content words in grammatically complex sentences.

It is noteworthy that control subjects did not demonstrate sensitivity to a phonetic error in a content word or a grammatical morpheme in a sentence with an object-relative center-embedded clause. Since control subjects showed insensitivity to grammatical morphemes in a grammatically complex sentence, it is difficult to interpret the basis for PD patients’ insensitivity to grammatical morphemes in this context. PD patients’ insensitivity to a grammatical morpheme in an object-relative sentence context may be another reflection of an apparently pervasive insensitivity to grammatical morphemes in all sentence contexts, but we cannot definitively rule out the possibility that they have normal behavior for grammatically complex sentences. Control subjects’ relative insensitivity to a content word in an object-relative sentence does differ from PD patients’ performance, since PD patients exhibited a delay in the retrieval of a content word in a grammatically complex sentence. We can only speculate about the basis for control subjects’ general insensitivity to a phonetic error in a content word located in an object-relative sentence, since our experiment was not designed to assess this issue. One possible account is that the significant executive resources ordinarily required to understand a grammatically complex sentence may obscure subtle slowing associated with the detection of a phonetic error in this kind of sentence.

4.2. Traditional sentence comprehension procedure

We also monitored sentence comprehension in the PD patients with a traditional measure of sentence processing. We found that PD patients are more impaired in their comprehension of object-relative
sentences than subject-relative sentences, a difference that was not seen in healthy control subjects. In the context of PD patients’ attentional and processing speed limitations during the word detection procedure, the comprehension difficulty on this traditional measure in PD may be due in part to the same factors. We attempted to select a traditional sentence evaluation procedure that probes sentences approximating those used in the word detection procedure. In this way, we would bolster our attempt to make meaningful comparisons across traditional and word detection tasks using similar sentences. While we did not find a significant correlation between these two manners for assessing sentence processing, there were some differences between the two tasks that may have contributed to this failure. For example, these sentences contained two verbs and three noun phrases compared to the sentences in the word detection task that featured only one substantive verb and two noun phrases. Also, in the traditional measure, we averaged over probes of the matrix sentence and the subordinate clause, and over active voice probes and passive voice probes in the traditional sentence measure.

We also found a correlation between our traditional measure of sentence comprehension for object-relative sentences and executive measures of reverse digit span and category naming fluency. We observed this correlation pattern in previous studies of sentence comprehension in PD (Grossman et al., 1992). These object-relative sentences require additional working memory compared to sentences with subject-relative clauses because of the greater distance between the antecedent noun and the trace (Gibson, 1998). While there was no correlation with forward digit span, this short-term memory factor may contribute to PD patients’ difficulty understanding these sentences. It will be important to manipulate this distance feature systematically in future studies of sentence processing in PD. While we found these correlations between executive measures and traditional assessments of sentence comprehension, the results have been difficult to interpret because of the resource demand associated with task performance. The present study used a word detection measure to assess sentence comprehension in order to minimize task performance demands. The finding of correlations between executive measures and the less resource demanding assessment of sentence comprehension is consistent with the claim that executive resources contribute fundamentally to sentence comprehension.

Several caveats should be kept in mind when considering our results. We studied only mildly impaired, non-demented PD patients, and our findings cannot be generalized to more severely impaired patients with PD. We focused on a particular type of sentence structure, and studies of sentence processing must be extended to other types of sentences. With these caveats in mind, we conclude that sentence comprehension difficulty in PD is due in part to a limitation in specific executive resources such as attention to unstressed grammatical morphemes, and slowed retrieval of content words during processing of grammatically complex sentences.

References


