Self-paced reading and sentence comprehension in Parkinson’s disease

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Abstract

Parkinson’s disease (PD) is associated with disturbances in sentence processing, particularly for noncanonical sentences. The present study aimed to analyse sentence processing in PD patients and healthy control participants, using a word-by-word self-paced reading task and an auditory comprehension task. Both tasks consisted of subject relative (SR) and object relative (OR) sentences, with comprehension accuracy measured for each sentence type. For the self-paced reading task, reading times (RTs) were also recorded for the non-critical and critical processing regions of each sentence. Analysis of RTs using mixed linear model statistics revealed a delayed sensitivity to the critical processing region of OR sentences in the PD group. In addition, only the PD group demonstrated significantly poorer comprehension of OR sentences compared to SR sentences during an auditory comprehension task. These results may be consistent with slower lexical retrieval in PD, and its influence on the processing of noncanonical sentences.

Keywords: Lexical retrieval; Parkinson’s disease; Self-paced reading; Sentence processing

1. Introduction

Parkinson’s disease (PD) is a progressive neurological condition associated with a loss of nerve cells in the substantia nigra. As a consequence, dopamine levels in the neostriatum also become depleted resulting in a variety of motoric deficits. Although PD is predominantly characterized by movement disorders, some patients with PD also present with poor...
comprehension of complex sentences. Previous research has attributed such difficulties to grammatical processing deficits (e.g. Lieberman et al., 1992; Natsopoulos et al., 1991, 1993), to possible limitations in the availability of executive resources (e.g. Geyer & Grossman, 1994; Grossman, Lee, Morris, Stern, & Hurtig, 2002; Kemmerer, 1999; McNamara, Krueger, O’Quin, Clark, & Durso, 1996) or to disturbances in selective attention (Lee, Grossman, Morris, Stern, & Hurtig, 2003).

Whilst investigations have probed PD patients’ comprehension of various sentence types, the reported sentence processing difficulties are particularly evident on noncanonical sentence constructions. Similarly, research has reliably demonstrated that even for healthy adults, sentences with a noncanonical structure (e.g. the girl that the boy pushed bought the food; object relative (OR) sentence) are more difficult to process than sentences with a simpler canonical structure (e.g. the girl that chased the boy bought the food; subject relative (SR) sentence) (Stromsworld, Caplan, Alpert, & Rausch, 1996). Processing difficulties for noncanonical sentences, however, are significantly more pronounced in many patients with PD (e.g. Grossman et al., 2000; Kemmerer, 1999; Natsopoulos et al., 1991), suggesting that their sentence processing deficit is not fully accounted for by the effects of age alone.

The increased difficulty with processing such noncanonical sentences may be attributed to the complexity of assigning thematic roles to the moved NP arguments. For example, in order to comprehend a sentence such as the girl that the boy pushed (t_i) bought the food, the first noun phrase (NP) the girl must be understood to be the object of the verb pushed, despite the fact that it occurs at the beginning of the sentence. A generally accepted theory is that the movement of the NP leaves a phonologically empty NP or placeholder at the position of the gap, which Chomsky (1981) refers to as a trace (indicated by the subscript (t_i) in the example). In regards to sentence processing, the theory postulates that this trace is assigned the thematic role, such that the moved object receives its role only indirectly by being coindexed to the trace. Thus, traces may be considered crucial for thematic role assignment in sentences with a noncanonical structure.

In order to efficiently process such noncanonical sentences and assign thematic roles appropriately, a sufficient availability of various cognitive resources will be required. For example, in order for the antecedent to be maintained until the gap is encountered, a sufficient availability of working memory resources will be required (Gibson, 1998). This notion has been well supported by research measuring event-related potentials during sentence processing in healthy adults, which has illustrated the additional demands placed on working memory during complex sentence processing (e.g. Fiebach, Schlesewsky, & Friederici, 2001, 2002; Haarmann, Cameron, & Ruchkin, 2003). Accordingly, since working memory deficits are evident even in the early stages of PD (Kensinger, Shearer, Locascio, Growdon, & Corkin, 2003; Patriot et al., 1996), working memory dysfunction may represent a plausible explanation for impaired comprehension of noncanonical sentences in PD. Indeed, the potential contribution of working memory dysfunction to noncanonical sentence processing deficits in PD has already been well recognised (Grossman, Carvell, Stern, Gollomp, & Hurtig, 1992; Grossman et al., 2000; Grossman, Lee et al., 2002; Kemmerer, 1999; McNamara et al., 1996).

Another resource deemed necessary for effective processing of noncanonical sentences is information processing speed. Specifically, during the online processing of such sentences in healthy adults, research has convincingly illustrated that the antecedent is rapidly reactivated at the position of the trace (Love & Swinney, 1996; Nicol & Swinney, 1989; Swinney, Onifer, Prather, & Hirshkowitz, 1979). This process is often termed trace reactivation and a slowed speed of information processing would be expected to interfere with this process. Consistent
with this theory, research into the aphasic population has effectively illustrated the influence that slowed information processing may have on the processing of noncanonical sentences. For instance, delayed lexical activation has been identified in Broca’s aphasia (Prather, Zurif, Stern, & Rosen, 1992) and the use of a cross-modal priming paradigm by Swinney, Zurif, Prather, and Love (1996) has illustrated an absence of trace reactivation for noncanonical sentences in Broca’s aphasics. Swinney et al. (1996) suggested that their results could be linked to delayed automatic lexical activation in Broca’s aphasia, which disrupts reactivation of the antecedent during online sentence processing.

Similarly, there is substantial evidence to support deficits to the speed of information processing in PD. In particular, delays in lexical activation have been identified in PD (Arnott, Chenery, Murdoch, & Silburn, 2001), and some researchers have illustrated that these delays are specific to those PD patients who present with poor comprehension of OR sentences (e.g. Grossman, Zurif et al., 2002). Recently, Lee et al. (2003) used an online word detection technique to investigate sentence processing in PD. During this task, patients were asked to press a button as quickly as possible when they heard a specific target word in a sentence. The researchers found that PD patients exhibited delayed sensitivity to a content word only when it followed a phonetic error in an OR sentence, which was consistent with the potential influence of altered lexical retrieval on the processing of complex sentences. Further endorsing such arguments are findings of reduced striatal recruitment in PD patients during the processing of complex sentences (e.g. Grossman et al., 2003), which could be linked to the fact that the striatum is one of the areas of the brain associated with information processing speed (Schubotz, Friederici, & von Cramon, 2000). Accordingly, while the contribution of working memory dysfunction to sentence processing deficits in PD is well recognised, there is also converging evidence to suggest that slowed lexical retrieval in PD may contribute to sentence processing difficulties. Additional research that has the potential to measure the influence of slowed lexical retrieval on sentence processing may further elucidate our understanding of the comprehension difficulties evident in PD.

At present, there are a number of methodologies available to analyse the processing of canonical and noncanonical sentences. Recently, Traxler, Morris and Seely (2002) measured participants’ eye movements to compare the processing of SR and OR sentences. The results revealed longer total eye gaze fixations at both the relative clause and the main verb for OR sentences, which were interpreted as an indication of greater processing difficulties associated with OR sentences. Similarly, the self-paced reading task is another paradigm that has been used to examine the processing of SR and OR sentences (e.g. King & Just, 1991; Stine-Morrow, Ryan, & Leonard, 2000).

Stine-Morrow et al. (2000) used the self-paced reading task to compare processing of SR and OR sentences within a group of younger and a group of older healthy adults. Specifically, the researchers analysed the reading times (RTs) to the ‘critical’ and ‘noncritical’ positions of each sentence, ‘critical’ being defined as the final word of the relative clause and the main verb of each sentence. For example, in the SR sentence the boy that pushed the girl bought the food, the words girl and bought would be classified as ‘critical’, as opposed to the words pushed and bought in the OR sentence the boy that the girl pushed bought the food. RT averages for the two ‘critical’ word positions revealed that only the younger readers were capable of differentially allocating processing time to the more difficult OR sentences, as evidenced by longer RTs at the ‘critical’ position for OR compared to SR sentences. Furthermore, the younger adults’ comprehension accuracy for OR sentences was significantly higher than that of the older adults. Consequently, Stine-Morrow et al. (2000) concluded that only the younger adults were able to
allocate the additional resources necessary to assign thematic roles appropriately for the OR sentences. In particular, the researchers suggested that only the younger adults might have had sufficient working memory resources to assign to sentence processing.

In light of this previous research using the self-paced reading paradigm, measures of both RT and comprehension accuracy may be sensitive to the additional demands imposed on cognitive resources during noncanonical sentence processing. Unfortunately, by averaging the RTs to the final word of the relative clause and the main verb for each sentence, the researchers were unable to compare the processing differences between SR and OR sentences separately for each ‘critical’ word position. Given that the final word of the relative clause corresponds to the location of the gap for OR sentences, it would be expected that the increased processing resources required for thematic role assignment would be particularly evident at this position, rather than at the main verb, and result in longer RTs when compared to SR sentences. Accordingly, if PD is characterized by slower lexical retrieval, then slower RTs will not be expected for OR sentences at the end of the relative clause, due to disturbances to thematic role assignment at the gap. Rather, the location of slower RTs in OR compared to SR sentences may be delayed, relative to healthy older adults, occurring only at positions following the end of the relative clause. For example, during processing of the sentence the boy that the girl pushed bought the food, slower RTs may occur at the verb bought or later. This result would indicate a disturbance to the thematic role assignment that should occur at the verb pushed, where the gap is located. As a consequence of this disturbance, poorer comprehension of OR compared to SR sentences in PD would also be expected.

Thus, the aims of the present study were based upon recent research into the influence of information processing speed on sentence processing in PD. Specifically, this research aimed to compare the processing and comprehension of SR and OR sentences in a PD group and a control group using a self-paced reading task and an auditory comprehension task. It is hypothesized that sentence processing and comprehension in PD will be influenced by alterations to information processing such as delayed lexical retrieval. Therefore, we predicted the following: (a) slower RTs for control participants at the end of the relative clause for OR compared to SR sentences, (b) slower RTs for OR compared to SR sentences only at the main verb or later for the PD group, and (c) that the PD group will demonstrate poorer comprehension of OR compared to SR sentences on both the self-paced reading task and the auditory comprehension task.

2. Methods

Participants. The two groups were comprised of 20 participants with idiopathic PD (diagnosis confirmed by Neurologist) and 23 non-neurologically impaired control participants. All participants were right handed, native speakers of English with no history of neurological surgery, drug or alcohol abuse, or dementia. Prior to the commencement of testing, the cognitive status of all participants was assessed using the Dementia Rating Scale 2 (DRS-2) (Jurica, Leitten, & Mattis, 2001). DRS-2 scores were significantly lower for the PD group ($t(41) = -5.99, p < .001$), however, all scores were above the recommended lower boundary for normal performance. The two groups did not differ with respect to sex distribution, age or education. Table 1 provides a summary of group demographics.

The PD group had a mean disease duration of 4.8 years (SD 3.04; range 1–12) and a mean age at onset of 59.55 years (SD 5.58; range 52–72). Hoehn and Yahr scores (Hoehn & Yahr, 1967) were used to classify the disease severity of the PD participants, with a mean score of 2.08 (SD 0.57; range 1–3). Predominant symptoms were tremor for 16 participants and
bradykinesia/rigidity for four participants. In addition, symptoms were predominantly left sided for six, right sided for five and bilateral for nine participants.

Eighteen of the patients in the PD group were receiving dopaminergic therapy in the form of levodopa (Madopar/Sinemet), seven patients were taking cabergoline (Cabaser) and one patient was not receiving any medication. For participants taking levodopa, average daily dosage was 606.94 mg (SD 360.33; range 100–1500), whilst for participants taking cabergoline, average daily dosage was 2.0 mg (SD 1.55; range 1.0–4.0). In addition to their levodopa supplementation, one of the PD patients was taking amantadine (Symmetrel), two were taking trihexyphenidyl (Artane) and one was taking pergolide (Permax). Fourteen of the PD patients also experienced a predictable ‘wearing off’ effect associated with their levodopa medication, such that motor symptoms typically increased approximately 3–4 h after dosage.

The experimental tasks were administered to all participants as a subcomponent of a larger battery of tests. PD participants were tested whilst optimally medicated, such that they were achieving maximum clinical benefit from their medication at the time of testing. Therefore, testing of the PD group was conducted approximately 45 min after dosage.

2.1. Self-paced reading task

Stimuli. The experiment was a $2 \times 2 \times 4$ (group $\times$ sentence type $\times$ sentence position) mixed factor design, with group (PD/control) as a between subjects factor, and sentence type (SR/OR) and sentence position (Intro/Word 1/Word 2/Object) as within subject factors. Experimental stimuli consisted of 24 sentences, half of which were SR sentences (e.g. *The girl that pushed the boy bought the food from the shop*). These 12 sentences were completely reversible, and equally plausible in both directions. The other half of the experimental sentences consisted of the same 12 sentences presented as an OR construction (e.g. *The girl that the boy pushed bought the food from the shop*). Consistent with the procedure implemented by King and Just (1991), closing phrases were added after the direct object of the main verb. These closing phrases ensured that ‘wrap up’ effects associated with processing the end of the sentence did not contaminate RTs on the direct object.

Two separate stimulus sets were constructed, such that each contained six SR sentences and six OR sentences. The second stimulus set, therefore, contained the same sentences as the first stimulus set, presented in their opposite form (i.e. SR or OR). Six filler sentences that were not SR or OR constructions, but which contained similar semantic content to the experimental sentences, were also included in each stimulus set. The order of presentation of sentences was initially randomized for each stimulus set, and then held constant for all participants.

A comprehension probe was also constructed for each sentence, to which participants had to reply ‘yes’ or ‘no’. Consistent with King and Just (1991), comprehension probes were developed
by combining one of the two verbs in the sentence with two of the three nouns. As such, four types of question probe would be possible for the example experimental sentence provided earlier; (a) Did the girl push the boy, (b) Did the boy push the girl, (c) Did the boy buy the food or (d) Did the girl buy the food. Equal numbers of each type of comprehension probe were utilized for both SR and OR sentences.

Participants received stimulus sets 1 and 2 in different testing sessions, separated by a minimum duration of 2 weeks, to reduce the likelihood that they would remember the sentence stimuli across testing sessions. All stimuli were presented using Superlab experimental software (Version 2.0) (Cedrus, 1996), which measured participants’ RTs via a Cedrus response pad (model RB-420) (accurate to within 1 ms) and collected all error and RT data automatically. Button 2 on the response pad was marked ‘Yes’ (in green) and button 3 on the response pad was marked ‘No’ (in red).

**Procedure.** All sentences were presented in the middle of the screen on a portable laptop computer using a word by word self-paced reading task. Participants were instructed to pace their way through each sentence by pressing the ‘yes’ button each time they wanted to read the next word in the sentence. Participants were also instructed to favour accuracy over speed when answering ‘yes’ or ‘no’ to each question probe. All participants performed practice trials, similar to those used in the experiment proper, at the beginning of each testing session to ensure that the task was understood.

Sentences were initially masked by a series of crosses, with each cross corresponding to a letter in the words of the sentence (e.g. XXX XXXX for ‘the girl’). When the ‘yes’ button was initially pressed, the first word of the sentence would be displayed. Each subsequent press of the ‘yes’ button would result in the display of the next word in the sentence, whilst the letters of the previous word would simultaneously become masked by crosses once more, ensuring that participants could not re-read earlier sentence material. All words were written in lower case letters of 30 point Arial Font. Once the last word of the sentence had been reached, pressing the ‘yes’ button would result in the presentation of the word ‘QUESTION’ in the center of the screen for 1000 ms, followed by the question probe. Following an answer (i.e. ‘yes’ or ‘no’) to the question probe, the next trial was initiated by the participant by pressing the ‘yes’ button.

### 2.2. Auditory comprehension test

**Stimuli.** Experimental stimuli consisted of 36 sentences. One third of these sentences were SR constructions (e.g. the boy that liked the girl bought an ice cream), and one third were OR constructions (e.g. the child that the mother kissed heard the noise). All sentences were plausible in both forward and reverse directions, to ensure that participants could not use the plausibility of thematic roles to guide their answers.

For each sentence, a question was designed that probed understanding of the thematic roles associated with each sentence. For the SR and OR sentences, four questions probed the subject of the first verb, four questions probed the object of the first verb and four questions probed the subject of the main verb. Therefore, for the sentence ‘the child that the mother kissed heard the noise’, the possible comprehension probes would be; (a) who was kissed, (b) who did the kissing or (c) who heard the noise.

Stimuli were divided into two stimulus sets, with equal numbers of each sentence type. The order of presentation of the sentences was randomized, and then held constant for each participant. Each stimulus set was administered during a separate testing session.

**Procedure.** Participants were instructed to listen to each sentence and answer the question that followed the sentence as accurately as possible. The researcher read each sentence
at a standard speaking rate, followed immediately by the question. Repetitions of the question were allowed, however no repetition of the sentences was given to participants. Participants’ answers were recorded verbatim at the time of testing. All participants were provided with practice sentences, prior to conducting the experiment proper.

3. Results

3.1. Self-paced reading task-RTs

All RTs less than 200 ms or greater than 3000 ms were considered outliers, and were subsequently removed prior to analysis. Similarly, all RTs for the closing phrases were also excluded from the analyses. Consistent with Stine-Morrow et al. (2000), RTs within non-critical positions were averaged. Thus, RTs for ‘The (NP1) that (verb1) the’ in SR sentences and RTs for ‘The (NP1) that the (NP2)’ in OR sentences were averaged to reflect processing of the initial part of the sentence, which was subsequently termed ‘intro’. The critical positions of the sentence were termed ‘word 1’ (NP2 for SRs and verb 1 for ORs) and ‘word 2’ (verb 2 for both SRs and ORs), respectively. Finally, the RTs for the NP following the word 2 position were averaged and termed ‘object’ for each sentence. For example, an SR sentence would be averaged in the following way, the girl that pushed the boy (Intro) bought (Word 1) the food (Object). Similarly, an OR sentence would be averaged as follows, the girl that the boy (Intro) pushed (Word 1) bought (Word 2) the food (Object). Table 2 illustrates the mean RTs for the PD and control groups, respectively, as a function of sentence and position.

Individual participant RTs were entered into a mixed linear model analysis with subject as a random factor (to control for baseline differences in RT across participants), group (PD, Control) as a between subjects factor, and testing session (First, Second), sentence (SR, OR) and position (Intro, Word 1, Word 2, Object) as within subject factors. The analysis revealed a significant main effect of session, sentence and position $[F(1,8370)=24.08, p<.001$, $F(1,8370)=14.76, p<.001$, respectively], and significant interaction effects of group $\times$ session, group $\times$ position, and sentence $\times$ position $[F(1,8370)=6.95, p=.008$, $F(3,8370)=7.42, p<.001$, and $F(3,8370)=3.56, p=.014$, respectively]. Importantly, testing session did not influence whether RTs differed as a function of sentence or position, as evidenced by the absence of session $\times$ position and session $\times$ sentence interaction effects. Further, overall RTs for the PD and control group were not significantly different, indicating that the button response times in the PD group were not influenced by motoric impairments.

Table 2

<table>
<thead>
<tr>
<th>Position</th>
<th>Parkinson’s disease sentence</th>
<th>Control sentence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SR</td>
<td>OR</td>
</tr>
<tr>
<td>Intro</td>
<td>869  (374)</td>
<td>894  (407)</td>
</tr>
<tr>
<td>Word 1</td>
<td>1061 (622)</td>
<td>1079 (583)</td>
</tr>
<tr>
<td>Word 2</td>
<td>956  (432)</td>
<td>1041 (497)</td>
</tr>
<tr>
<td>Object</td>
<td>857  (377)</td>
<td>887  (446)</td>
</tr>
</tbody>
</table>

SR, subject relative; OR, object relative; standard deviations in parentheses.
To investigate whether group differences in RT were evident across sentence type, group comparisons were conducted separately for SR and OR sentences using additional mixed linear model analyses, with subject as a random factor, group as a between subjects factor and position as a within subject factor. Analysis of the SR sentence data revealed a significant main effect of position \( F(3,4149) = 59.96, p < .01 \) and an interaction effect of group \( \times \) position, \( F(3,4149) = 3.07, p < .05 \). Inspection of the data in Table 2 suggests that the significant interaction effect is indicative of slower RTs for the PD group at the intro and word 1 positions. Analysis of the OR sentence data revealed similar results, with a significant main effect of position \( F(3,4196) = 95.19, p < .01 \) and a significant group \( \times \) position interaction effect \( F(3,4196) = 6.09, p < .01 \). Inspection of the data in Table 2 suggests that this result is related to the slower RTs for the PD group at the intro position.

Following these analyses, within group comparisons of RTs to SR compared with OR sentences were performed. This process aimed to detect differences in the processing of SR versus OR sentences at each position within each group. Thus, additional mixed linear model analyses were conducted, with subject as a random factor and sentence and position as within subject factors. Analysis of the control group’s data revealed a significant main effect of sentence \( F(1,4476) = 10.73, p = .001 \), position \( F(3,4476) = 121.51, p < .001 \) and sentence \( \times \) position \( F(3,4476) = 4.62, p = .003 \). In contrast, analysis of the PD group’s data revealed significant main effects of sentence \( F(1,3910) = 7.39, p = .007 \) and position \( F(3,3910) = 49.17, p < .001 \), however, no significant interaction effect was evident.

Whilst the main and interaction effects have been provided for descriptive purposes, the data provided therein do not explicitly test the a priori comparisons made specific when discussing the aims of this research. In particular, we aimed to identify any processing differences between SR and OR sentences within each group, as evidenced by differences in RTs at each sentence position. Further, analysis of the control and PD groups’ data was conducted, therefore, using separate planned pairwise comparisons between the SR and OR sentences at each position using mixed linear model analyses.

Analysis of the control group’s data revealed a significant effect of sentence at ‘word 1’ \( F(1,456) = 10.65, p = .001 \), however, no other significant effects were observed. Table 2 illustrates that this result is due to significantly slower RTs at the ‘word 1’ position for the OR sentences. In contrast, analysis of the PD group’s data revealed a significant effect of sentence at ‘word 2’ \( F(1,407) = 4.66, p = .031 \). Table 2 illustrates that this result is due to significantly slower RTs at the ‘word 2’ position for OR sentences. No other significant main effects of sentence were observed for the PD group.

The author’s do acknowledge, however, that ‘word 1’ is a verb in OR sentences, but a noun in SR sentences. Hence, while RTs were slower at the word 1 position in OR sentences for the control group, but not the PD group, the differing grammatical category of ‘word 1’ in the SR and OR sentences may have contributed to this finding. In order to investigate this possibility, RTs to verb 1 in the SR sentences, and NP2 in the OR sentences were compared. Since these words occurred within the intro section of each sentence, but were the same as those words compared at the ‘word 1’ position, the procedure allowed us to determine whether RT differences between these nouns/verbs were still present at a ‘non-critical’ syntactic position within the sentence. Average RT for the PD group was 903 ms (SD 351) at verb 1 and was 952 ms (SD 447) at NP 2, while the average RT for the control group was 874 ms (SD 391) at verb 1 and 890 ms (SD 471) at NP 2. The RTs were entered into a mixed linear model analysis with group as a between subjects factor and grammatical category (noun, verb) as a within subject factor. The analysis did not reveal a main effect of group \( (p = .648) \) or category.
(p = .169), or a group × category interaction effect (p = .325). These results suggest that grammatical category did not influence RTs in the present study.

3.2. Self-paced reading task—comprehension probes

The number of comprehension probes answered correctly by each participant for each sentence type were entered into a repeated measures MANOVA analysis, with group (PD, Control) as a between subjects factor and sentence (SR, OR) as a within subject factor. The mean accuracy of the PD group was 8.10 (SD 1.80) and 6.65 (SD 1.49) for SR and OR comprehension probes respectively. In contrast, the mean accuracy of the control group was 9.78 (SD 1.41) for SR and 8.04 (SD 2.27) for OR sentences. The MANOVA analysis revealed significant main effects of sentence [F(1,41) = 23.31, p < .001], and group [F(1,41) = 12.54, p < .001], however, no sentence × group interaction effect was evident. These results indicated that the PD group answered comprehension probes less accurately than the control group for both SR and OR sentences. More importantly, these results also illustrate that both groups responded less accurately to comprehension probes for OR compared to SR sentences.

3.3. Auditory comprehension test

The number of comprehension probes answered correctly by each participant for each sentence type were entered into a repeated measures MANOVA analysis, with group (PD, control) as a between subjects factor and sentence (SR, OR) as a within subject factor. The mean accuracy of the PD group was 10.40 (SD 1.43) and 8.00 (SD 2.13) for SR and OR comprehension probes, respectively. In contrast, the mean accuracy of the control group was 11.83 (SD 0.49) for SR and 11.26 (SD 1.21) for OR sentences. MANOVA analysis revealed significant main effects for sentence, [F(1,41) = 36.23, p < .001], and group, [F(1,41) = 44.07, p < .001], as well as an interaction effect of sentence × group, [F(1,41) = 13.87, p = .001]. This interaction effect indicates that only the PD group’s comprehension score was poorer for OR compared to SR sentences.

4. Discussion

The present study hypothesized that sentence processing and comprehension in PD, as measured by a self-paced reading task and an auditory comprehension task, would be influenced by alterations to information processing such as slowed lexical retrieval. The results of the present study supported this hypothesis. Within group comparisons on the self-paced reading task revealed slower RTs in OR compared to SR sentences at the main verb (word 2) for the PD group, as opposed to slower RTs at the final word of the relative clause (word 1) for the control group. Thus, the delayed sensitivity of the PD group to the critical processing region of OR sentences appear consistent with previous research that has identified slowed information processing in PD, as evidenced by a delayed time course of lexical activation (Arnott et al., 2001). Similarly, the poorer comprehension of OR compared to SR sentences for the PD group on the auditory comprehension task is consistent with previous findings of noncanonical sentence processing difficulties in PD (Grossman et al., 2000), and may also reflect the influence of slower lexical retrieval on sentence comprehension in these patients.
4.1. Self-paced reading task

According to the results of Stine-Morrow et al. (2000), slower RTs at the final word of the relative clause (i.e. word 1) and the main verb (i.e. word 2) in OR compared to SR sentences, may be indicative of the additional processing resources assigned to integrate thematic role information. As discussed earlier, however, the researchers averaged RTs at the word 1 and word 2 positions, rather than compare RTs for OR and SR sentences at each position separately. In contrast, RTs were compared separately at each position in the present study and, as illustrated in Table 2, revealed that the slower RTs for OR sentences occurred at the final word of the relative clause (i.e. word 1) for the control group, but occurred at the main verb (i.e. word 2) for the PD group.

As noted earlier, however, word 1 is a noun in SR sentences and a verb in OR sentences. Since nouns and verbs in English differ both phonologically and semantically, with number of syllables, duration in sentences, semantic complexity and conceptual range differing between the two types of words (Black & Chiat, 2003), it may be argued that the results evident at the word 1 position simply reflect the influence of a noun–verb dissociation on RT. This explanation of the results seems unlikely for a number of reasons. Firstly, if the grammatical category of the words accounted solely for the differences in RT, then differences in noun/verb RTs should also be evident at other positions of the sentence. This result was not the case, with the analyses revealing that RTs to verb 1 in SR sentences and NP 2 in OR sentences were not significantly different for either group. Given that these words are identical to the nouns/verbs appearing at the word 1 position of SR and OR sentences, the impact of grammatical category on RTs does not appear to provide an adequate account of the findings. Secondly, specific noun–verb dissociations have been observed in PD, with verb processing impairments evident on picture naming tasks (Bertella et al., 2002) and patients also performing more poorly on tests of verb compared to noun generation (Peran, et al., 2003). Based on these findings, longer RTs would certainly be expected for the PD group at the word 1 position of OR (verb) compared to SR (noun) sentences if grammatical category influenced RTs in the self-paced reading task. This result was not the case, again suggesting that RTs were not influenced by noun–verb processing differences. Thus, an alternative explanation of the findings in the present study is necessary.

The slower RTs for the control group at the end of the relative clause correspond to the position of the gap for OR sentences. These slower RTs are consistent with the increased processing resources required for thematic role assignment in OR sentences. More importantly, this result would be consistent with an intact speed of information processing in the control group. Specifically, if this cognitive resource was intact, then prompt reactivation of the necessary antecedent would take place at the gap position, facilitating thematic role assignment. Indeed, Giffard et al., (2003); Linnville (1995) have previously illustrated intact lexical activation in the healthy older population, as indicated by the presence of semantic priming effects, suggesting that this aspect of information processing in healthy older adults is intact. In contrast, however, the later position of the slower RTs for the PD group (i.e. word 2 as opposed to word 1) may be indicative of a slower speed of information processing in this group.

The slower RTs for the PD group in OR compared to SR sentences occurred only at the main verb of OR sentences (Table 2), which is located after the gap position. Thus, it may be reasonable to assume that when slower RTs do not occur until the main verb and subsequently, do not occur until after the gap position, that a disturbance to trace reactivation and/or thematic role assignment has occurred. Accordingly, a viable explanation for these results is a slower speed of lexical retrieval in PD. Specifically, if reactivation of the antecedent at the gap was delayed during sentence processing, then longer RTs would not be expected at the end of the relative clause. Instead, longer RTs would be
expected only once the delayed process of trace reactivation took place. Indeed, it has been suggested by Burkhardt, Pinango and Wong (2003) that once syntactic processes are underway all associated mechanisms will take place, including the establishment of long distance dependencies in noncanonical sentences. Based on this theory, delayed lexical retrieval in PD will not be expected to eliminate the process of trace reactivation, but rather cause the reactivation of the antecedent to occur at a later point in time. Consistent with this suggestion, both Burkhardt et al. (2003); Love, Swinney and Zurif (2001) have revealed that reactivation of the antecedent in Broca’s aphasics is not absent, but occurs some time after the gap position. Consequently, the longer RTs of the PD group at the main verb in the present study may be indicative of a similar delay to the reactivation of the antecedent, consistent with reports of delayed lexical activation in PD (Arnott et al., 2001; Grossman, Zurif et al., 2002), which could influence the processing of noncanonical sentences. Worthy of note is that we have previously charted the time course of lexical activation in the same group of control and PD participants who participated in the present study (Angwin, Chenery, Copland, Murdoch, & Silburn, 2004). The results revealed a delayed time course of lexical activation in the PD group, relative to the control group, lending further credence to our interpretations of the present study.

It has also recently been suggested that cognitive slowing and delays in lexical retrieval in PD may be determined by the magnitude of endogenous dopamine depletion for each patient (Grossman, Zurif et al., 2002), such that lexical retrieval may only be slowed for patients with more significant dopamine depletion. If this were the case, then only a subset of PD patients may be expected to present with delayed sensitivity to the critical processing regions of noncanonical sentences on a self-paced reading task. Accordingly, factors that contribute to the extent of dopamine depletion in PD such as disease duration, disease severity and amount of medication may influence the performance of PD patients on tests of sentence processing. Future research with a larger cohort of participants may delineate whether such disease related factors influence patterns of RTs in a self-paced reading task. Additional research using other measures of sentence processing may also assist in elucidating the precise nature of sentence processing deficits in patients with PD. In particular, the use of a cross-modal priming paradigm may assist in determining whether trace reactivation is absent in PD, or whether trace reactivation may in fact still occur, albeit in a protracted manner.

As identified earlier, the sufficient availability of working memory resources is also an integral component of complex sentence processing, particularly for successful thematic role assignment. Indeed, King and Just (1991) revealed longer RTs on the clause ending word (i.e. word 1) and the main verb (i.e. word 2) for OR sentences in healthy participants with lower working memory spans. Given that working memory deficits are evident even in the early stages of PD (Kensinger et al., 2003; Patriot et al., 1996), it appears reasonable to assume that working memory dysfunction would lead to a similar result in PD. The results of the present study were not consistent with this assumption, with statistical analyses revealing similar RTs for the control and PD group at the word 1 and word 2 position of OR sentences.

Nonetheless, it could still be argued that working memory dysfunction contributed to the delayed sensitivity of the PD group to the critical processing region of noncanonical sentences. Recent research, however, has raised doubts over whether working memory deficits influence processing times for noncanonical sentences. For instance, Waters and Caplan (2005) used a self-paced listening task to compare sentence processing in young versus elderly healthy adults. Despite the lower working memory capacity of the elderly participants, the results revealed that both groups exhibited longer processing times at the end of the relative clause (word 1) in OR compared to SR sentences. Further, it has also been suggested that while resources such as verbal
working memory may primarily mediate performance on offline measures of sentence comprehension, performance on online measures of sentence processing may be mediated primarily by factors such as processing speed (Dede, Caplan, Kemtes, & Waters, 2004). Thus, although it is possible that working memory dysfunction in PD influenced RTs, we propose that the slower RTs at the main verb for the PD group in the present study appear most consistent with the influence of delayed lexical retrieval, rather than working memory, on sentence processing.

Whilst our interpretation of the RTs remains consistent with slowed information processing in PD, the comprehension accuracy scores for the PD and control groups on the self-paced reading task are unexpected. Since a slowed speed of lexical retrieval would be expected to primarily interfere with thematic role assignment in noncanonical sentences, then poorer comprehension of OR compared to SR sentences would be expected for the PD group, but not the control group. In the present study, however, both groups responded to comprehension probes for OR sentences less accurately than SR sentences on the self-paced reading task. King and Kutas (1995) have suggested that when participants encounter substantial memory loads, they may reduce resource usage by storing items in memory for less time, thereby creating a speed–accuracy trade off. Thus, the poorer comprehension of OR compared to SR sentences evident for both groups on the self-paced reading task of the present study, may be consistent with this suggestion. Specifically, although control participants may have been able to initially comprehend the sentence material, the addition of the filler phrases at the end of the sentence combined with the inability to reread earlier sentence material may have placed a significant load on cognitive resources, reducing their ability to recall sentence content accurately once the comprehension probe was presented. In comparison, performance on standard auditory comprehension tasks may be less constrained by the demands of task performance.

4.2. Auditory comprehension task

Consistent with previous findings of noncanonical sentence processing difficulty in PD (Grossman et al., 2000; Kemmerer, 1999; Natsopoulos et al., 1991), analyses of the results for the auditory comprehension task indicated a significantly poorer comprehension of OR compared to SR sentences in the PD group. In contrast, a similar deficit in the processing of OR sentences was not evident in the control group. These results support our interpretation of the RTs in the self-paced reading task, suggesting that delayed lexical retrieval in PD disrupts thematic role assignment during the processing of syntactically complex sentences. It should be noted, however, that the results of previous research have also shown that difficulties on offline measures of complex sentence comprehension in PD are related to working memory dysfunction (Grossman et al., 1992; Grossman, Lee et al., 2002). Thus, it is proposed that changes to both working memory function and the speed of lexical retrieval contribute to the offline sentence comprehension difficulties typically evident in PD.

Another important result is that the comprehension of both SR and OR sentences was significantly lower for the PD group, relative to the control group. While delays in lexical retrieval have significant potential to affect the processing of noncanonical OR sentences, this influence would not be expected to extend to the processing of canonical SR sentences. Therefore, the influence of other cognitive resources such as attention and memory, which could impair recall of semantic content, could have contributed to the significantly poorer performance of the PD patients on all sentence types.
5. Conclusions

The results of the present study replicate previous findings of noncanonical sentence processing difficulties in PD. In addition, the results of the self-paced reading task appear to provide support for the influence of a slowed speed of information processing on these sentence processing difficulties. These conclusions should be interpreted tentatively, however, because although a different pattern of RTs was observed for the two groups, direct comparisons did not reveal robust differences in RT at each sentence position. Further, it should also be noted that since the analyses did not indicate a general slowing of all information processing in PD, the notion of slowing proposed for the PD group of the present study refers primarily to alterations in the speed of lexical retrieval. Additional research is certainly necessary in order to more precisely define the potential impact of slowed information processing on thematic role assignment in noncanonical sentences.

References