Verb and context processing in Parkinson’s disease

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Abstract

The aim of the present study was to investigate verb and context processing in 10 individuals with Parkinson’s disease (PD) and matched controls. A self-paced stop making sense judgment task was employed where participants read a sentence preceded by a context which made the thematic role of the verb plausible or implausible. Participants were required to indicate whether the sentence ceased to make sense at any point by responding yes/no at each word. PD participants were less accurate than the control participants at detecting sentence anomalies based on verb selection restrictions and previously encountered contextual elements. However, further research is required to determine the precise nature of the grammatical processing disturbance associated with PD.

Keywords: Parkinson’s disease; Verb processing; Context; Grammatical processing

1. Introduction

A growing body of research has indicated that sentence comprehension may be impaired in individuals with Parkinson’s Disease (PD) (Grossman, 1999; Grossman, Carvell, Stern, Gollomp, & Hurtig, 1992; Lieberman et al., 1992; Ullman et al., 1997). One of the earliest studies to investigate sentence processing in PD was conducted by Natsopoulou et al. (1991) who utilised a sentence-picture matching paradigm to investigate thematic role assignment within relative clause constructions. The PD participants performed significantly poorer than normal control participants, suggesting...
that the PD participants were interpreting the sentences based on a restricted variety of superficial structural rules (Natsopoulos et al., 1991).

Lieberman et al. (1992) employed a sentence-picture matching paradigm to investigate the comprehension of simple and complex sentences in participants with mild and moderate PD. Participants with moderate PD displayed higher error rates and longer response times than the mild PD participants, suggesting that syntactic comprehension in the PD participants was influenced by PD severity and sentence complexity. It was proposed that the comprehension difficulties reflected an impairment of syntactic rule application, rather than impaired attentional processes (Lieberman et al., 1992). Reduced attention span was discounted as a possible cause of the comprehension difficulties because short, syntactically complex sentences were associated with more errors and longer response times than longer, syntactically simple sentences. Furthermore, when sentence length was constant, error rates were higher for complex sentences than simple sentences (Lieberman et al., 1992). However, the sentences containing the complex syntactic structures may have required greater attentional resources than the simple sentences (Kemmerer, 1999). Thus, the discrepancy between the sentences may have reflected impaired language processing and/or impaired attentional processes rather than impaired language processing alone.

Congruent with Lieberman et al. (1992), Grossman et al. (1992) found a discrepancy between PD participants’ comprehension of simple and complex sentences during an offline sentence comprehension task. The researchers found that the PD participants displayed increasing sentence comprehension difficulties with increasing sentence complexity (Grossman et al., 1992). However, unlike Lieberman et al. (1992), Grossman et al. (1992) concluded that the effects of syntactic complexity were related to limited attentional resources, rather than impaired understanding of grammatical rules.

To further investigate the nature of the sentence processing impairment associated with PD, Grossman et al. (1992) examined the ability of PD participants to detect grammatical errors. Participants were required to answer questions about sentence stimuli, with 70% of the sentences containing errors. The errors included omissions of grammatical morphemes, alterations in the shape of grammatical morphemes, and modified word orders. The ability of the PD participants to detect the errors varied as a function of error type, showing that the PD group was less sensitive than the control group at detecting omitted grammatical morphemes. However, the groups did not differ in the ability to detect word order errors. It was suggested that the selective nature of the PD group’s ability to detect the errors reflected impaired attentional processes (Grossman et al., 1992). However, it was acknowledged that impaired attention may not have been the sole factor influencing sentence comprehension in the PD participants, suggesting that the impaired sentence comprehension reflected an interaction between grammatical complexity and limited attentional resources (Grossman et al., 1992). However, as the experiment involved a two-stage evaluation of each sentence, unnatural demands may have been placed on the participants’ attentional resources. Subsequent research has found that the comprehension accuracy of individuals with PD is sensitive to the introduction of a secondary task (Grossman et al., 2000).

The role of executive functions in impaired sentence comprehension in PD was further elucidated by Lee, Grossman, Morris, Stern, and Hurtig (2003) by means of a word
detection task. Word detection was selected in order to minimise the cognitive demands required by performance of the experimental task, thus allowing participants to devote a maximal amount cognitive processing to sentence comprehension. The PD participants were less sensitive to phonetic errors embedded within unbound grammatical morphemes in all sentence types and to errors in content words within object relative sentences. The authors attributed the impaired error detection rates to resource limitations in specific executive functions, notably attention and lexical retrieval associated with processing grammatically complex sentences (Lee et al., 2003).

In addition to findings of impaired sentence comprehension in PD, studies have found that verb learning may be impaired in PD. Grossman, Stern, Gollomp, Vernon, and Hurtig (1994) found that PD participants had greater difficulty than control participants when responding to probe questions about grammatical and semantic information associated with a newly acquired verb. An analysis of the PD participants’ individual performances indicated that a small number of the PD participants had difficulty recalling any information about the new verb. In contrast, a larger number of the PD participants had difficulties specific to sentence judgments about the usage of the new verb. It was suggested that the selective difficulties with sentence judgment may have reflected an impairment specific to grammatical processing (Grossman et al., 1994).

Additional research has found that individuals with PD may have difficulty integrating previously encountered discourse elements when answering questions about stories (Murray & Stout, 1999) and individual sentences (Grossman et al., 1992), and when resolving lexical ambiguities (Copland, Chenery, & Murdoch, 2001). Difficulty with the use of syntactic-thematic rules when mapping thematic roles onto constituents of grammatically complex sentences has also been associated with PD (Geyer & Grossman, 1994). Thus, research suggests that individuals with PD may have an impaired understanding of the relationships between the constituents of individual sentences and between neighbouring sentences.

In summary, previous studies have found that sentence processing is impaired in individuals with PD (Grossman et al., 1992; Lieberman et al., 1992; Natsopoulos et al., 1991). However, the underlying cause of the impairment is unclear. Limited attentional resources and an impaired understanding of grammatical rules have been suggested as possible origins of the impairment (Grossman et al., 1992; Lieberman et al., 1992). However, as most of the studies employed offline experimental methodologies, the results may have reflected processes other than language processing (Lee, Grossman, Morris, Stern, & Hurtig, 2000; Shapiro, Swinney, & Borsky, 1998). Thus, further research involving online experimental procedures is necessary to investigate the grammatical processing abilities of individuals with PD.

Current lexical storage theories propose that verb representations within the lexicon contain syntactic and semantic information. This information may include specifications about the type and number of arguments permitted by the verb (Boland, Tanenhaus, Garnsey, & Carlson, 1995; Friederici & Frisch, 2000; Shapiro et al., 1998). The stored information may place restrictions upon the other words in the sentence. Constraint-based models of sentence comprehension propose that when a listener perceives a verb in a sentence, all of the associated argument structures are temporarily activated in the listener’s lexicon (Boland et al., 1995; Shapiro et al., 1998). The incoming arguments
perceived after the verb are checked against the syntactic and semantic restrictive information stored with the verb (Boland et al., 1995; Friederici & Frisch, 2000). Online sentence processing tasks may provide information about which argument structures are activated for particular verbs and about the syntactic and semantic information represented with the verbs.

In addition to decisions about argument acceptability, research suggests that listeners concurrently assign thematic roles to the arguments. Current thematic role assignment theories propose that listeners automatically assign grammatical roles to as many sentence components as possible (Altmann, 1999). Thus, listeners build up an online representation of the sentence which includes syntactic and thematic information (Boland et al., 1995). Altmann (1999) suggested that during online sentence processing tasks, the object role in a sentence is assigned to a previously encountered discourse element when the listener encounters the main verb. Thus, it was proposed that discourse elements outside the target sentence influence thematic role assignment within the target sentence (Altmann, 1999). This proposal is particularly pertinent to the study of PD given that PD participants may have difficulties integrating previously encountered discourse elements (Copland et al., 2001; Grossman et al., 1992; Murray & Stout, 1999).

The purpose of the present study was to investigate grammatical processing, specifically verb and context processing, in individuals with PD using a self-paced online thematic role assignment task. In order to accomplish this, a modified version of a thematic role assignment study conducted by Altmann (1999) was employed. Even though the present study aimed to investigate grammatical processing, we acknowledge that the task tapping into thematic role assignment may have involved some semantic input in addition to grammatical processing. During Altmann’s study, participants were presented with sets of three sentences. In each set, the first two sentences appeared in their entirety and established a context, while the final sentence appeared word by word. The participants were required to indicate whether the final sentence ceased to make sense at any point (Altmann, 1999). Altmann manipulated both the preceding context (antecedent/no antecedent) and the main verb in the final sentence (selecting/nonselecting) (Note: Some of the sentences from Altmann’s study were modified to account for Australian English). The term antecedent referred to an entity in the context sentences which could have been assigned a thematic role by the main verb in the final sentence (Altmann, 1999). Experimental items in Altmann’s study involved either antecedent (e.g. ‘A car was driving downhill when it suddenly veered out of control. In its path were some pigeons and a row of posts. It injured/missed...’) or no antecedent conditions (e.g. ‘A car was driving downhill when it suddenly veered out of control. In its path were some dustbins and a row of posts. It injured/missed...’).

The term selecting referred to the main verb in the final sentence which placed restrictions upon potential discourse antecedents (Altmann, 1999). Experimental items in Altmann’s study involved either selecting (e.g. ‘It injured several posts that came close to being destroyed’) or nonselecting conditions (e.g. ‘It missed several posts that came close to being destroyed’). Altmann found that there were more ‘no’ responses for verbs that were preceded by a context that did not introduce a plausible antecedent than for the verbs that were preceded by a context that introduced a plausible antecedent. Consistent with
Altmann’s study, both context and the main verb in the final sentence were manipulated in the present study.

Given previous findings of impaired grammatical processing (Grossman et al., 1993, 2000), discourse comprehension problems (Copland et al., 2001; Murray & Stout, 1999), and reduced sensitivity to sentence anomalies in individuals with PD (Grossman et al., 1992, 2000), the following hypotheses were tested. Firstly, it was hypothesised that the PD participants would produce less accurate responses and longer response latencies than the control participants when deciding that a sentence had ceased to make sense. It was predicted that PD participants would produce fewer ‘no’ responses and longer response latencies than the control participants when viewing sentences that had violated verb selection restrictions. In addition, it was predicted that the control participants would produce more ‘no’ responses than the PD participants at early word positions for anomalous sentences. Secondly, it was hypothesised that the PD participants would use context less than the control participants when making sentence plausibility judgments.

2. Method

2.1. Participants

The PD group consisted of 10 individuals (5 males and 5 females) who had been diagnosed with idiopathic PD by a neurologist prior to inclusion in the study. The PD participants were right-handed native English speakers between the ages of 54 and 70 years old with a mean age of 62.80 years (SD = 4.13). The mean number of years of education for the PD participants was 11.00 (SD = 4.00, range = 6–19). All PD participants were able to read and possessed normal vision with or without corrective devices. Table 1 provides a description of the demographic and medical characteristics of the PD group.

Table 1
Summary of Parkinson’s disease participant characteristics

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Education (years)</th>
<th>Time post-diagnosis (years)</th>
<th>Medication</th>
<th>Hoehn and Yahr stage</th>
<th>MDRSa</th>
<th>NARTb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>M</td>
<td>12</td>
<td>4</td>
<td>Madopar, cabergoline</td>
<td>2</td>
<td>136</td>
<td>111</td>
</tr>
<tr>
<td>2</td>
<td>54</td>
<td>F</td>
<td>10</td>
<td>2</td>
<td>Madopar, cabergoline</td>
<td>1</td>
<td>142</td>
<td>114</td>
</tr>
<tr>
<td>3</td>
<td>66</td>
<td>F</td>
<td>10</td>
<td>5</td>
<td>Madopar, avapro</td>
<td>2</td>
<td>140</td>
<td>111</td>
</tr>
<tr>
<td>4</td>
<td>64</td>
<td>M</td>
<td>16</td>
<td>6</td>
<td>Madopar, oroxine, cabergoline</td>
<td>3</td>
<td>140</td>
<td>116</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>F</td>
<td>19</td>
<td>4</td>
<td>Artane, cabergoline</td>
<td>n/a</td>
<td>140</td>
<td>n/a</td>
</tr>
<tr>
<td>6</td>
<td>61</td>
<td>F</td>
<td>12</td>
<td>6</td>
<td>Madopar</td>
<td>2</td>
<td>136</td>
<td>111</td>
</tr>
<tr>
<td>7</td>
<td>61</td>
<td>M</td>
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<tr>
<td>8</td>
<td>64</td>
<td>M</td>
<td>8</td>
<td>8</td>
<td>Madopar, cabergoline</td>
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<td>119</td>
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<tr>
<td>9</td>
<td>70</td>
<td>M</td>
<td>10</td>
<td>1</td>
<td>Sinnemet</td>
<td>2</td>
<td>138</td>
<td>111</td>
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<tr>
<td>10</td>
<td>63</td>
<td>F</td>
<td>7</td>
<td>5</td>
<td>Sinnement, cabergoline</td>
<td>1</td>
<td>139</td>
<td>107</td>
</tr>
</tbody>
</table>

a MDRS, Mattis Dementia Rating Scale.
b NART, National Adult Reading Test.
The PD participants obtained scores above 135 on the Dementia Rating Scale-2 (DRS-2), which suggested the absence of dementia (Jurica, Leitten, & Mattis, 2001). The PD participants obtained estimated intelligence quotients of at least 107 on the National Adult Reading Test (NART) (Nelson, 1982) (see Table 1).

At the time of testing, nine of the ten PD participants had a Hoehn and Yahr (1967) disease severity rating between I and III ($M = 1.89$, $SD = 0.74$). A Hoehn and Yahr (1967) score was not available for one PD participant (see Table 1). The mean time post-onset for the PD group was 4.50 years ($SD = 2.01$). The movement disorders of the PD participants were not sufficiently severe to significantly interfere with the voluntary pressing of a response button. Individuals with PD were excluded from the study if they had any psychiatric disorders, other neurological or degenerative conditions, or other motor disorders.

The control group consisted of 10 healthy, nonneurologically impaired individuals (6 males and 4 females) from the general Brisbane community. The control group was matched to the PD group for age ($M = 60.80$, $SD = 3.40$, range = 54–72 years; $t(18) = 0.59$, $p > 0.05$) and years of education ($M = 13.7$, $SD = 4.60$, range = 7–22 years; $t(18) = -1.40$, $p > 0.05$). The control participants were right-handed native English speakers with normal vision (with or without corrective devices). Control participants were excluded from the study if they had psychiatric disorders, neurological or degenerative conditions, or motor disorders.

2.2. Stimuli

Consistent with the study conducted by Altmann (1999), the experiment involved a factorial repeated measures design with a Latin square, which enabled the different variables and their interactions to be investigated using a small number of participants. Each participant viewed 64 test items comprising of 32 critical and 32 filler sentences (See Altmann, 1999 for a list of critical sentences). The filler sentences were introduced to avoid expectancy effects (Altmann, 1999). Each test item (both critical and filler sentences) consisted of three sentences. The first two sentences in each item established a context, while the final sentence required the participant to make grammatical acceptability decisions. The final sentence in each item consisted of a critical or filler sentence. The final sentence followed the structure: subject (word position one), verb (word position two), determiner (word position three), object (word position four), and subordinate clause (remaining word positions). For example, participants may have seen: A car was driving downhill when it suddenly veered out of control. In its path were some pigeons and a row of posts. It injured several posts that came close to being destroyed.

There were two variations of each main verb for each critical sentence (selecting and nonselecting) and two variations of each context for the introductory sentences (antecedent and no antecedent). For example, in the above test item, the word pigeons was viewed under the antecedent condition (e.g. In its path were some pigeons and a row of posts), while the word dustbins was viewed under the no antecedent condition (e.g. In its path were some dustbins and a row of posts). For verbs, the word injured was viewed under selecting conditions (e.g. It injured several posts that came close to being destroyed), while the word missed was viewed under nonselecting conditions.
(e.g. *It missed several posts that came close to being destroyed*). Participants viewed either an antecedent or no antecedent, and a selecting verb or a nonselecting verb for each test item. No participant viewed both the antecedent and no antecedent conditions, or the selecting and nonselecting verbs for any test item. Four sets of sentence stimuli were constructed by manipulating the combinations of verbs and contexts. Each combination (containing either a selecting or nonselecting verb, and a context antecedent or no antecedent) was allocated to one of the four stimuli sets. No critical sentence variation appeared in more than one stimulus set. However, the same 32 filler sentences were included in each stimulus set. To control for expectancy effects, the order of item presentation was randomised within each stimulus set.

2.3. Procedure

The present study was conducted using an online grammatical processing paradigm. As previously discussed, the paradigm enabled grammatical processing to be observed while the processes were occurring (Shapiro et al., 1998). Participants viewed one of the stimulus sets individually on a laptop computer using Superlab experimental software (Cedrus, 1996) in their own homes during single testing sessions. Participants responded to the sentence stimuli by pressing a button on a Cedrus RB-600 response box. The participants’ responses and response latencies for target sentences were automatically recorded in milliseconds by Superlab.

Participants were informed that they would view some stories, each consisting of three sentences. The first two sentences in each item would appear in their entirety as a single string of words when participants pressed the ‘yes’ button. The third sentence would then appear as a string of asterisks across the screen, with each asterisk representing a single letter. Words would subsequently appear one by one as the participant pressed the response button. Each button press would reveal a new word and hide the previous word. Words were presented in 30 point black arial baltic font against a white background. Participants were instructed to press the ‘yes’ response button if a sentence continued to make sense. However, if participants believed that a sentence stopped making sense at any point, they were required to press the ‘no’ button as quickly as possible for the remainder of the sentence. A total of 64 test items were presented to each participant. The participants were given a rest after 32 test items. Ten sentences were presented as practice trials at the beginning of the experiment in the same format as the test items.

The PD participants completed the experiment during their ‘on’ medication period (i.e. the time during which medication to control PD symptoms is most effective). This was approximately 45 min after each participant’s mid-morning or mid-afternoon dosage. To ensure that the PD participants did not enter their ‘off’ medication period (i.e. the time during which medication to control PD symptoms is least effective) during testing, a brief fine motor finger tapping task (Fahn & Elton, 1987) was administered at intervals throughout the session. In addition, participants were required to indicate if they felt that the effect of their medication was wearing off during the session.
3. Results

Prior to statistical analysis, the data were examined for outliers (responses greater than two standard deviations above or below the mean and responses greater than 1500 ms), which were subsequently removed. Statistical analyses were conducted on the dependent variables of judgment accuracy (yes, no) and latency of ‘yes’ responses (time in milliseconds). As per Altmann (1999) statistical analyses were conducted on only the first five word positions due to the small number of ‘yes’ responses beyond the fifth word position. For each dependent variable (judgment accuracy and latency) we analysed differences and similarities between the PD and control participants overall, and then at each word position. An analysis of the participants’ responses at each word position enabled us to determine at which point participants integrated contextual information and knowledge about verb arguments to decide that a sentence was anomalous.

3.1. Judgment accuracy of yes/no responses

The dependent variable judgment accuracy was used to investigate whether participants integrated contextual information and knowledge about verb arguments when making decisions about sentence acceptability. Judgment accuracy referred to whether participants had accurately decided that a sentence had ceased to make sense (correct answer), or whether they had inaccurately decided that an anomalous sentence was legally acceptable (false positive) or that a legally acceptable sentence was anomalous (false negative). Statistical analyses for judgment accuracy were conducted using the cumulative percentage of ‘no’ responses at each word position. Cumulative percentages were used instead of cumulative numbers in order to minimise dependence effects between the cumulative number of ‘no’ responses at one word and the cumulative number of ‘no’ responses at the proceeding word (Altmann, 1999). The cumulative percentage of ‘no’ responses was calculated by converting the number of ‘no’ responses in each trial to a percentage of the potential responses still available at that point for the trial (see Table 2).

An arc sine transformation for binomial proportions was used to reduce skewness in the data. The transformation increases the variance of the data by spreading out proportions

<table>
<thead>
<tr>
<th>Group</th>
<th>Target</th>
<th>Context</th>
<th>Word position</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Selecting Antecedent</td>
<td>0.0 (0.0)</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td></td>
<td>No antecedent</td>
<td>0.0 (0.0)</td>
<td>1.3 (2.6)</td>
</tr>
<tr>
<td>Nonselecting</td>
<td>Antecedent</td>
<td>0.0 (0.0)</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td></td>
<td>No antecedent</td>
<td>0.8 (1.7)</td>
<td>1.3 (2.6)</td>
</tr>
<tr>
<td>PD</td>
<td>Selecting Antecedent</td>
<td>0.3 (0.8)</td>
<td>0.7 (1.4)</td>
</tr>
<tr>
<td></td>
<td>No antecedent</td>
<td>0.6 (1.8)</td>
<td>1.4 (2.5)</td>
</tr>
<tr>
<td>Nonselecting</td>
<td>Antecedent</td>
<td>1.0 (3.2)</td>
<td>1.3 (4.0)</td>
</tr>
<tr>
<td></td>
<td>No antecedent</td>
<td>1.0 (2.4)</td>
<td>1.9 (3.0)</td>
</tr>
</tbody>
</table>

Standard deviations are provided in brackets.
near zero or one (Snedecor & Cochran, 1989). The binomial theory specifies that if $a$ successes out of $n$ are obtained, then the proportion $\hat{p} = a/n$ has the variance $p(1-p)/n$. The arc sine transformation involves the replacement of $\hat{p}$ with an angle with sine $^{-1}$ of $\sqrt{\hat{p}}$ (Snedecor & Cochran, 1989). As the sample size was less than 50, proportions with a value of zero were converted to $1/(4n)$, while proportions with a value of one were converted to $(n-1)/4n$ prior to the transformation. The conversions were conducted to improve the equality of variance in the angles following the transformation (Snedecor & Cochran, 1989).

Prior to analysis of the percentage of ‘no’ responses according to word position, the percentage of sentences containing ‘no’ responses was analysed. Overall, participants produced more ‘no’ responses under selecting conditions compared to nonselecting conditions ($F(1, 18) = 118.57$, $p < 0.001$). There was no significant difference in the overall percentage of ‘no’ responses between the control or PD groups under selecting (84.4% for the control group, 82.3% for the PD group) or nonselecting conditions (14.5% for the control group, 24.6% for the PD group). A $2 \times 2 \times 2$ repeated measures ANOVA with group (control, PD) as a between participants factor, and with verb (selecting, nonselecting) and context (antecedent, no antecedent) as within participants factors indicated that there were no significant interactions between the variables (all $p > 0.10$). Given the differences expected at specific word positions, the factors of verb, context, and group were then analysed at each word position.

**Word position one (the pronoun).** At word position one, there was a significant main effect for verb ($F(1, 603) = 4.13$, $p < 0.05$), which was reflected through a greater number of ‘no’ responses for nonselecting verbs than selecting verbs for both groups (see Table 2).

**Word position two (the verb).** At word position two, there were no significant main effects or interactions between group, context and verb (all $p > 0.05$) (see Table 2).

**Word position three (the determiner).** At word position three, there was a main effect for context ($F(1, 603) = 5.24$, $p = 0.022$), which indicated that there were significantly more ‘no’ responses under the no antecedent condition than antecedent condition (see Table 2).

**Word position four (the postverbal noun).** At word position four, there was a strong main effect for verb ($F(1, 602) = 473.04$, $p < 0.001$), and strong interactions between group and verb ($F(1, 602) = 12.34$, $p < 0.001$), which suggested that the PD participants were reacting differently to the stimulus words compared to the control participants. By the fourth word position, the control participants had judged that 39.3% of the selecting and 3.5% of the nonselecting sentences had ceased to make sense (see Table 2 for a breakdown into specific conditions). In contrast, by this point in the sentence, the PD participants had judged that 29.8% of the selecting and 3.9% of the nonselecting sentences had ceased to make sense. Within the control group, there was a marginal effect for context ($F(1, 306) = 3.65$, $p = 0.057$), with the control participants judging that 22.9% of antecedent and 19.9% of the no antecedent sentences had ceased to make sense. In contrast, there were no significant main effects or interactions with context for the PD group (all $p > 0.10$). By word position four, the PD participants had judged that 15.8% of the antecedent and 17.9% of the no antecedent sentences had ceased to make sense (see Table 2 for a breakdown into specific conditions).

**Word position five.** At word position five, there was a strong main effect for verb ($F(1, 603) = 748.90$, $p < 0.001$) and a strong interaction between group and verb
which reflected the high number of ‘no’ responses produced by the control group under selecting conditions compared to the PD group (see Table 2).

3.2. Latency

In order to provide an indication of the speed at which participants integrated contextual information and knowledge about verb arguments, we recorded the latency times of ‘yes’ responses (i.e. responses in which participants indicated that the sentence continued to make sense). The latency data for both participant groups was transformed using a log transformation to reduce skewness (Tabachnick & Fidell, 2001). A 2×2×2 linear mixed model with group (control, PD) as a between participants factor, and with verb (selecting, nonselecting) and context (antecedent, no antecedent) as within participants factors indicated that there was a strong main effect for context \(F(1, 2348)=7.40, \ p<0.05\), and strong interactions between group and context \(F(4, 2348)=6.13, \ p<0.05\) and between group and verb \(F(1, 2350)=6.66, \ p<0.05\). A 2×2×2 linear mixed model with group (control, PD) as a between participants factor, and with verb (selecting, nonselecting) and context (antecedent, no antecedent) as within participants factors was subsequently carried out at each word position. Table 3 provides a summary of the mean latency times for each group according to word position.

**Word position one (the pronoun).** At word position one, there was a significant main effect for group \(F(1, 588)=7.50, \ p<0.05\), with the control group responding faster to the stimulus words than the PD group. There were no significant main effects or interactions for context or verb (all \(p>0.10\)).

**Word position two (the verb).** At word position two, there was a significant main effect for group \(F(1, 566)=6.49, \ p<0.05\), with the control group responding faster to the stimulus words than the PD group. There were no significant main effects or interactions for context or verb (all \(p>0.10\)).

**Word position three (the determiner).** At word position three, there was a significant main effect for group \(F(1, 572)=11.65, \ p<0.05\), with the control group responding faster to the stimulus words than the PD group. There were no significant main effects or interactions for context or verb (all \(p>0.10\)).

**Word position four (the postverbal noun).** At word position four, there were no significant main effects or interactions between group, context, or verb (all \(p>0.10\)).

**Word position five.** At word position five, there was a significant main effect for context \(F(1, 286)=7.84, \ p<0.05\). In addition, there were strong interactions between group and verb \(F(1, 291)=9.54, \ p<0.05\) and between context and verb \(F(1, 286)=3.90, \ p<0.05\). Within the control group, participants responded significantly faster under nonselecting conditions compared to selecting conditions \(F(1, 159)=5.00, \ p<0.05\). In contrast, there was no significant difference in response times for the PD subjects under selecting or nonselecting conditions (\(p>0.10\)) (see Table 3).
Table 3
Mean latency times for the first five word positions (ms)

<table>
<thead>
<tr>
<th>Group</th>
<th>Target</th>
<th>Context</th>
<th>Word position</th>
<th></th>
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<tr>
<td>Control</td>
<td>Selecting</td>
<td>Antecedent</td>
<td>528.1 (119.1)</td>
<td>656.3 (202.6)</td>
<td>577.0 (149.1)</td>
<td>729.9 (273.0)</td>
<td>786.3 (260.3)</td>
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<tr>
<td></td>
<td></td>
<td>No antecedent</td>
<td>537.0 (137.1)</td>
<td>689.5 (224.1)</td>
<td>595.8 (168.5)</td>
<td>828.9 (289.2)</td>
<td>712.2 (320.2)</td>
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<td></td>
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<td>Antecedent</td>
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<td>620.3 (167.4)</td>
<td>588.9 (172.3)</td>
<td>786.2 (259.8)</td>
<td>621.6 (162.0)</td>
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<td>No antecedent</td>
<td>540.8 (126.3)</td>
<td>619.1 (135.5)</td>
<td>576.2 (170.7)</td>
<td>739.8 (245.7)</td>
<td>611.3 (173.4)</td>
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<td>690.3 (230.3)</td>
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<tr>
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<td>698.1 (266.0)</td>
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<td>699.0 (278.4)</td>
<td>803.5 (281.6)</td>
<td>679.6 (213.5)</td>
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</table>

Standard deviations are provided in brackets.
4. Discussion

The aim of the present study was to investigate verb and context processing in individuals with PD compared to normal controls by using a self-paced online thematic role assignment task. It was expected that the PD participants would exhibit impaired sentence processing characterised by a reduced sensitivity to verb selection and context anomalies, and slower response times. The results indicated that the PD participants were (a) less accurate than control participants at detecting verb selection anomalies, and (b) less sensitive to context than the control participants, which was consistent with previous findings of sentence processing difficulties in PD (Grossman et al., 1992; Lieberman et al., 1992; Natsopoulou et al., 1991). The results will be discussed firstly in terms of the control participants compared to the findings of previous studies and then in terms of the PD participants.

4.1. The effect of verb type on control participants

Consistent with the results of the study by Altmann (1999), control participants in the present study produced more ‘no’ responses and longer overall latencies for sentences containing selecting verbs than for sentences containing nonselecting verbs (see Tables 2 and 3). Altmann suggested that the difference in responses for the two types of verbs reflected a ‘processing cost’ associated with attempting to locate referents that satisfied the selectional restrictions specified by a selecting verb. Similarly, Boland et al. (1995) reported that sentences which required increased cognitive processing were associated with more ‘no’ responses and longer response latencies during online thematic role assignment tasks. In addition, Shapiro et al. (1998) found that sentences containing syntactic violations were processed significantly slower than sentences without anomalies during online word monitoring tasks. Thus, the difference between selecting and nonselecting verbs for the control group in the present study supported the results of previous research.

4.2. The effect of context on control participants

Altmann (1999) found that context alone did not substantially influence participants’ responses during online thematic role assignment tasks. During the present study, the control group displayed some overall context effects for response time and marginal word position specific context effects for accuracy of ‘no’ judgments (see Tables 2 and 3). The difference in responses between the antecedent and no antecedent conditions in the present study suggested that the control participants relied partially on previously encountered discourse entities when deciding that a sentence had ceased to make sense. The difference between the findings of the present study compared to Altmann’s study may have reflected age-related differences in cognitive processing and allocation of cognitive resources (Brebion, 2001, 2003).
4.3. The combined influence of verb and context on control participants according to word position

Consistent with Altmann (1999), by the fourth word position, control participants in the present study were more likely to decide that a sentence stopped making sense if it was under the selecting antecedent condition. Altmann suggested that when participants encountered the main verb in a target sentence, the selectional restrictions specified by the verb were used to predict the ensuing postverbal expression and to determine the presence of any discourse antecedents which could be co-referential with the verb. It was suggested that when the antecedents failed to satisfy the selectional restrictions specified by the verb, participants responded that the sentence did not make sense (Altmann, 1999). Thus, consistent with the present study, when participants reached word position four (i.e. participants had encountered both the main verb and postverbal noun) there were more ‘no’ responses for sentences containing a selecting verb preceded by an antecedent that was incompatible with the verb than for sentences containing a nonselecting verb and no antecedent (Altmann, 1999).

Congruous with Altmann (1999), control participants in the present study produced few ‘no’ responses until the fourth word position. As previously discussed, this may have reflected predictions by participants about the upcoming postverbal expression based upon their knowledge of verb arguments when they encountered the main verb in the sentence (Altmann, 1999). Thus, it was unlikely that participants would indicate that sentences had ceased to make sense until after they had encountered the main verb. In addition, the high number of ‘no’ responses after the fourth word position may have reflected a mismatch between the actual postverbal expression and the postverbal expression expected by the participants, as predicted by the selectional restrictions specified by the verb and any discourse antecedents (Altmann, 1999). Furthermore, Boland et al. (1995) reported that participants produced more ‘no’ responses and longer response latencies during online grammatical processing tasks at sentence regions that necessitated the use of increased cognitive processing due to grammatical incongruities.

4.4. Sentence judgment by PD participants

During the present study, the PD participants produced fewer ‘no’ responses overall than the control participants, however the difference was not significant. Word position analyses indicated that there was a significant difference in the number of ‘no’ responses produced by participants in the two groups at word positions four and five, with the control participants producing significantly more ‘no’ responses than the PD participants (see Table 2). The difference between the two groups suggested that the PD participants were less accurate than the control participants at detecting sentence anomalies, and was consistent with the results of a sentence comprehension study conducted by Grossman et al. (1993). Grossman et al. (1993) found that PD participants were less accurate than control participants at detecting sentence anomalies in the form of altered phonological shapes and omitted morphemes during offline sentence comprehension tasks. However, Lee et al. (2000) reported that PD participants were as sensitive as control participants to grammatical agreement violations during online sentence comprehension tasks, but less
sensitive than control participants during offline comprehension tasks. Furthermore, the researchers suggested that the grammatical comprehension problems displayed by PD participants during offline grammatical comprehension tasks reflected impaired executive functions, rather than grammatical comprehension problems (Lee et al., 2000).

The differences between the results of the present online study and the results obtained by Lee et al. (2000) may have reflected the different cognitive requirements of the online experimental tasks. The present study was an online stop making sense task, while the study by Lee at al. was an online target word detection task. As the present study required participants to continually make metalinguistic judgments about the plausibility of each word within the target sentences, cognitive processes other than language processing may have been involved (Shapiro et al., 1998), influencing differences in response accuracy between the PD and control participants in the present study.

4.5. Response times for PD participants

The results of previous studies suggest that PD participants have slower response times than control participants when processing sentences (Grossman et al., 2000; Lieberman et al., 1992). However, in the present study, there was a variable difference in response latency between the PD and control participants. The PD participants produced significantly longer response times at word positions one, two, and three. There was no significant difference between the groups at word position four, while at word position five the PD participants responded faster than the control subjects under selecting conditions (see Table 3). Thus, on a superficial level, the variability of the results of the present study appeared to contradict the findings of previous research.

One explanation for the variability in latency times during the present study was that the PD participants were less sensitive to sentence anomalies than the control participants. As previously discussed, several offline sentence comprehension studies have reported that PD participants are less sensitive than control participants when detecting sentence anomalies (Grossman et al., 1992). Therefore, at word position five under selecting conditions, the control participants may have responded slower than the PD participants due to the extra processing time required by the control participants to process the anomalies. The PD participants may have been unaware of the anomaly at this point and therefore, may not have required the extra processing time. In addition, words at position five typically consisted of unbound grammatical morphemes, such as that. Studies have found that individuals with PD are less aware of unbound grammatical morphemes than normal controls (Grossman et al., 1992; Lee et al., 2003). Lee et al. (2003) have attributed the insensitivity towards unbound grammatical morphemes to more global deficits in executive function associated with PD.

4.6. Effects of verb and context on ‘no’ judgments by PD participants

Congruous with the control group, PD participants in the present study produced more ‘no’ responses for sentences containing selecting verbs compared to sentences containing nonselecting verbs. However, the PD participants produced fewer ‘no’ responses under selecting conditions than the control group, although the difference was significant only at
word positions four and five (see Table 2). The lower number of ‘no’ responses under selecting conditions suggested that the PD participants were less sensitive to the selectional restrictions imposed by the verb upon the upcoming verb arguments than the control participants (Altmann, 1999; Boland et al., 1995).

Unlike the control participants, there was no significant difference in response times for the PD participants under selecting or nonselecting conditions, however, the difference between selecting and nonselecting conditions for the control group only reached significance at word position five (see Table 3). Previous research involving online grammatical processing tasks has found that participants often produce longer response latencies at sentence regions that require increased cognitive processing due to the presence of grammatical incongruities (Boland et al., 1995). Thus, the similarity in response times for the PD group between selecting and nonselecting conditions at word position five suggested that the PD participants in the present study may have been processing the sentences on a more superficial level than the control participants. The PD participants may have been less able to process relationships between verbs and potential arguments when judging sentence plausibility compared to the control participants, which was consistent with previous findings of impaired thematic role mapping in individuals with PD (Geyer & Grossman, 1994).

With respect to context, unlike the control participants who showed a marginal effect for context, there was no difference between the number of ‘no’ judgments under the antecedent and no antecedent conditions for the PD participants overall or at any specific word position, suggesting that the PD participants were less able to distinguish between information that had been encountered previously and new information (see Table 2). In other words, the PD participants were less efficient than the control participants at utilizing previously encountered discourse elements. The discrepancy between the PD and control groups in the present study supported the results of Grossman et al. (1992) where PD participants displayed an impaired ability to answer questions about previously encountered discourse elements relative to control participants. In addition, Copland et al. (2001) found that PD participants had difficulties integrating previously encountered discourse information in order to resolve lexical ambiguities. Thus, the reduced sensitivity to context displayed by PD participants during the present study may have been reflective of more global discourse comprehension difficulties.

An additional contributing factor to the similarity in responses between the antecedent and no antecedent conditions by PD participants may have been impaired working memory. Individuals with PD have been found to display impaired working memory abilities relative to healthy controls (Kemmerer, 1999; Lee et al., 2003). As the present study required participants to make metalinguistic judgments about sentence plausibility during a self-paced reading task, the PD participants may not have had the memory resources available to link sentence elements in the target sentence to antecedents encountered in an earlier sentence in the same test item. Thus, the reduced awareness of context antecedents displayed by PD participants during the present study may have reflected a fusion of global discourse comprehension difficulties and impaired working memory.

Consistent with the control participants, the PD participants produced the greatest number of ‘no’ responses under the selecting antecedent condition at word positions
four and five. The difference between sentences containing selecting and nonselecting verbs suggested that the PD participants were sensitive to the selectional restrictions specified by the verb, which was consistent with the results of the study by Lee et al. (2000). Lee et al. suggested that PD participants were as sensitive as control participants to violations in grammatical agreement during online sentence comprehension tasks. However, in the present study, the similarity in the percentage of ‘no’ responses produced by the PD participants under antecedent and no antecedent conditions when the sentences contained a selecting verb compared to the control participants at word position four suggested that the PD participants were less accurate when distinguishing between previously encountered discourse elements and new discourse elements than the control participants.

4.7. Bradyphrenia and the PD participants

General slowing of movement has been identified as a characteristic of PD (Grossman, 1999). However, there is controversy as to whether general cognitive slowing or bradyphrenia, is a characteristic feature of PD that accounts for language performance (Skeel et al., 2001; Spicer, Brown, & Gorell, 1994). Some studies have reported a generalised cognitive slowing in PD participants, while other studies have reported that cognitive slowing in PD participants manifests only during tasks requiring complex cognitive processes (Spicer et al., 1994). For the present study, it was expected that general cognitive slowing would manifest as longer response times for the PD participants at all word positions. However, the results of the present study indicated that the difference in response times between the PD and control participants was variable (see Table 3), suggesting that the differences between the PD and control participants in the present study could not be accounted for by generalised slowing or bradyphrenia in the PD participants.

5. Conclusions

Despite the limitations of the present study in terms of subject numbers, there was evidence to suggest that grammatical processing abilities differ between individuals with PD and normal controls. In terms of similarities, both the control and PD participants were more likely to decide that a sentence did not make sense if it contained a selecting rather than a nonselecting verb. For both groups, the majority of ‘no’ responses occurred after the postverbal noun. However, the PD participants were less accurate than the control participants at detecting verb selection anomalies and at using previously encountered discourse antecedents when deciding that a sentence had ceased to make sense. Although this study provides an insight into sentence processing in PD as it unfolds, the nature of the task (i.e. metalinguistic judgment) makes it susceptible to other cognitive deficits present in PD, suggesting the need to further investigate the interaction between cognitive deficits and online sentence processing.
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References


