Effects of subthalamic deep brain stimulation on noun/verb generation and selection from competing alternatives in Parkinson’s disease

J E Castner, H J Chenery, P A Silburn, T J Coyne, F Sinclair, E R Smith, D A Copland

ABSTRACT

Background and aim: Impaired generation of verbs relative to nouns has been reported in Parkinson’s disease (PD) and has been associated with the frontal pathophysiology of PD. The aim of the present study was to measure noun/verb generation abilities in PD and to determine whether noun/verb generation is affected by stimulation of the subthalamic nucleus (STN).

Patients and methods: 8 participants who had been diagnosed with PD and had received surgery for deep brain stimulation (DBS) of the STN as well as 15 control participants completed a noun/verb generation task with four probe-response conditions—namely, noun–noun, verb–noun, verb–noun and verb–verb conditions. Patients with PD were assessed while receiving STN stimulation and without stimulation.

Results: During the off stimulation condition, patients with PD presented with a selective deficit in verb generation compared with control participants. However, when receiving STN stimulation, patients with PD produced significantly more errors than controls during the noun–noun and verb–verb conditions, supporting evidence from previous studies that STN stimulation modulates a frontotemporal network associated with word generation. Finally, errors during verb generation were significantly correlated with item selection constraint (ie, the degree to which a response competes with other response alternatives) in the on stimulation condition, but not the off stimulation condition.

Conclusion: Our results suggest that STN stimulation affects the ability to select from many competing lexical alternatives during verb generation.

Evidence for the differential processing of nouns and verbs in Parkinson’s disease (PD) has recently emerged. The presence of a selective impairment in verb production in patients with PD has stemmed from studies investigating double dissociations in aphasia, such that impairment in object naming has been associated with posterior lesions and impaired action naming has been associated with anterior lesions. Therefore, selective verb impairments in patients with PD have been attributed to frontal pathophysiology. Support for deficits in the processing of verbs relative to nouns has been detailed in relation to impairment in action fluency, verb generation and action naming.

In relation to verbal fluency, Signorini and Volpato found that action fluency was selectively impaired in patients with non-demented PD. The authors suggested that the verb generation deficit specific to verbal fluency is reflective of pathological basal ganglia–thalamic cortical circuitry disrupting executive functioning in PD. They also suggest that action fluency is particularly susceptible to impairment due to greater cognitive demands associated with action fluency relative to letter and semantic fluency. Possibly, action fluency could be considered more difficult due to the need for selection of words from more competing alternatives than semantic fluency. While Signorini and Volpato suggest that a verb processing deficit may be isolated to action fluency, Peran and colleagues have provided evidence that PD may be associated with a specific lexical deficit for verbs.

Peran and colleagues compared noun and verb processing in a word generation paradigm. Patients with PD and controls responded with nouns and verbs that were semantically related to probe nouns or verbs in four different conditions. These included; noun–noun, verb–noun, verb–verb and noun–verb probe–response conditions. Patients with PD had increased errors relative to controls in both verb generation conditions (ie, verb–verb and noun–verb). To determine the degree to which impaired performance on the verb generation conditions in patients with PD was due to the amount of competition for selection among competing alternatives, the mean error rate was compared with item selection constraint based on the responses provided by control participants. As the mean error scores for patients with PD were not correlated with item selection constraint, Peran et al suggested that the increased errors were a result of a selective deficit in the production of verbs, rather than difficulties in selection from competing alternatives. Further evidence for a specific verb deficit is presented by Bertella and colleagues, where the presence of noun/verb dissociation in PD participants was evident in an object and action naming task. Therefore, a verb deficit in PD may be considered to be due to impaired grammatical processing of verbs which is subserved by more frontal cortical regions in PD.

The frontal pathophysiology of PD is associated with disrupted basal ganglia–thalamic cortical circuits as a result of nigral dopaminergic degeneration. As the basal ganglia–thalamic cortical circuits consist of at least five functionally segregated motor and non-motor loops, the resultant disruption can affect both motor and cognitive processes. Recently, deep brain stimulation (DBS) of the subthalamic nucleus (STN) has become a common treatment for medically intractable PD,
and is overwhelmingly associated with improvements in PD motor symptoms. However, this treatment can be associated with cognitive impairment. While inconsistencies in the neuropsychological sequelae of DBS of the STN have been reported, deficits in verbal fluency remain the most commonly reported negative outcome.

Schoedler and colleagues explored the neural correlates of verbal fluency impairment subsequent to STN stimulation in a study utilising positron emission tomography. When patients with PD were receiving STN stimulation, impaired verbal fluency was associated with decreased regional cerebral blood flow in the left inferior frontal gyrus (IFG) and left inferior temporal gyrus. The authors concluded that STN stimulation affects a frontotemporal network associated with verbal fluency, indicating that STN stimulation modulates cortical networks that extend beyond the classic non-motor basal ganglia–thalamocortical circuits.

While abilities on verbal fluency tasks in PD participants as well as further changes as a result of stimulation of the STN have been extensively investigated, there have been no studies that have measured the influence of STN stimulation on noun and verb generation. The primary aim of the current study was to identify the extent to which modulation of basal ganglia–thalamocortical circuits via STN stimulation affects the generation of verbs and/or selection of responses among competing lexical–semantic alternatives in PD. The present study will adopt the noun/verb generation paradigm presented in Peran et al.’s study to compare noun and verb generation in a cohort of patients with PD who have received DBS of the STN under on and off stimulation conditions. It is predicted that patients with PD in the off stimulation condition will have a selective deficit in the generation of verbs, as described by Peran and colleagues.

As an additional variable under investigation, the present study will aim to measure the influence of probe stimuli that reflect differing semantic attributes versus grammatical roles. There is some contention as to whether noun–verb dissociations are due to the grammatical role or semantic attribute associated with noun and verb stimuli. For example, the majority of verbs used when representing noun/verb dissociations are action verbs (such as “running”), yet verbs that represent non-human actions (such as “blooming”) represent a more visual than action related semantic attribute. Similarly, nouns representing tools or implements convey meaning association with human action (eg, “fork”), which, according to the semantic attribute hypothesis, represent human action. The remaining 15 were living objects (eg, “cat”) are associated with stronger visual attributes than action related attributes. The present study will investigate the influence of probes representing visual semantic attributes (ie, non-human actions and living objects) and probes representing action semantic attributes (ie, human actions and tools/implements).

METHODS

Participants

Eight right-handed participants with PD who had received surgery for the implantation of permanent electrodes into the STN were included in the present study. DBS lead location within the STN was confirmed via postoperative MRI prior to inclusion in this study. These participants had received surgery at least 4 months prior to their participation and were reported to have stabilised stimulator parameters according to their neurologist. Details of the PD participants are presented in table 1. Patients with PD were assessed in both the on and off stimulation conditions. At least 6 weeks lapsed between PD assessment sessions, and the order of on and off stimulation session was counterbalanced. Fifteen right-handed non-neurologically impaired participants (five females) whose age (mean 63.53 (SD 6.71) years) and years of education (mean 12.8 (SD 5.41) years) were not significantly different from participants with PD (p>0.2) were recruited to act as controls.

Stimulus and design

Noun and verb generation was assessed with probe stimuli consisting of 50 nouns and 30 verbs. The noun and verb probe stimuli were matched for spoken lexical frequency (t(58) = −0.426, p>0.05) via norms provided on the Celex Lexical Database. Of the 30 noun probe stimuli, half of the stimuli were manipulable tools/implements (eg, fork), which, according to the semantic attribute hypothesis, represent human action. The remaining 15 were living objects (eg, rabbit) representing visual attributes with no human motor link. Similarly, half of the verb stimuli represented human actions (eg, juggling), and the remaining half had no human action link and consisted of non-human actions (eg, dripping). Probes representing human action (ie, tools/implements and human actions) were matched for spoken lexical frequency with probes representing non-human action/visual attribute (ie, living objects and non-human actions; t(58) = −0.547, p>0.05). The

Table 1 Participant information for those with Parkinson’s disease

<table>
<thead>
<tr>
<th>Patient No</th>
<th>Age (y)</th>
<th>Sex</th>
<th>Education (y)</th>
<th>Disease duration (y)</th>
<th>Severity (H&amp;Y)</th>
<th>UPDRS III on score</th>
<th>L-Dopa medication (mg/day)</th>
<th>Stimulator settings</th>
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<td></td>
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<td>15</td>
<td>3</td>
<td>10</td>
<td>1150</td>
<td>60/60</td>
</tr>
<tr>
<td>2</td>
<td>51</td>
<td>F</td>
<td>10</td>
<td>5</td>
<td>2.5</td>
<td>6</td>
<td>2 (mg cabergoline)</td>
<td>90/60</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>M</td>
<td>21</td>
<td>5</td>
<td>4</td>
<td>17</td>
<td>1750</td>
<td>90/60</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>M</td>
<td>15</td>
<td>12</td>
<td>3</td>
<td>19</td>
<td>1000</td>
<td>90/60</td>
</tr>
<tr>
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<td>41</td>
<td>M</td>
<td>18</td>
<td>9</td>
<td>2.5</td>
<td>11</td>
<td>400</td>
<td>90/60</td>
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<td>6</td>
<td>72</td>
<td>M</td>
<td>13</td>
<td>16</td>
<td>4</td>
<td>20</td>
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<td>17</td>
<td>3</td>
<td>17</td>
<td>1250</td>
<td>90/90</td>
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<td>65</td>
<td>F</td>
<td>7</td>
<td>15</td>
<td>2</td>
<td>11</td>
<td>100</td>
<td>60/60</td>
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</tbody>
</table>

UPDRS on score refers to on stimulation and on medication. H&Y, Hoehn and Yahr; L, left; R, right; UPDRS, Unified Parkinson’s Disease Rating Scale.
majority of word stimuli representing each semantic attribute and grammatical class were obtained from Lu et al.17

**Procedure**

Participants completed a noun and verb generation task under four blocked conditions resulting in four different probe–response pairings. Namely, for the first condition, noun probes were presented auditorily and participants were required to respond with a semantically related noun (ie, noun–noun condition). Secondly, verb probes were presented and participants were required to respond with a semantically related noun (ie, verb–noun condition). Two verb generation conditions were also included, where participants were presented with a noun probe and were required to respond with a semantically related verb (ie, noun–verb condition), and in the last condition they were presented with a verb and required to also respond with a verb (ie, verb–verb condition). The order of blocked conditions was counterbalanced so that participants either received the conditions in the following order, noun–noun, verb–noun, noun–verb, verb–verb, or the reverse of this order. One PD participant (participant No 5) did not complete the verb–verb condition during off stimulation because of assessment time constraints.

To be consistent with Peran and colleagues,7 control participants were allowed 4 s and participants with PD were given 6 s to respond to accommodate any motor speech impairment associated with PD. Responses were scored as errors if a semantically unrelated (ie, not semantically associated and/or semantically similar) or grammatically incorrect response was made. Any ambiguous noun/verb responses (eg, the response “thread” in relation to the probe “needles”) were scored as correct.

**RESULTS**

Analyses were conducted on the noun/verb generation error data. For participants with PD in both the on and off stimulation conditions, 21% of responses resulted in an error and 15% of responses by control participants resulted in an error. The proportion of error types for each participant group is presented in table 2, where it was revealed that the majority of errors were a result of no response or responses that exceeded the time limit. Interestingly, participants with PD had proportionately more grammatical errors than control participants.

Linear Mixed Model item analyses were conducted separately on the error data pertaining to the grammatical role hypothesis and semantic attribute hypothesis. For both analyses, individual subject variations and subject variation across sessions for participants with PD were treated as random factors.

### Table 2  Proportion (%) of error types for control participants and for participants with Parkinson’s disease

<table>
<thead>
<tr>
<th>Error type</th>
<th>Participant group</th>
<th>PD on stimulation</th>
<th>PD off stimulation</th>
<th>Control participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>No response/time error</td>
<td></td>
<td>59.8</td>
<td>50.8</td>
<td>61.5</td>
</tr>
<tr>
<td>Grammatical error</td>
<td></td>
<td>32.5</td>
<td>44.5</td>
<td>25.5</td>
</tr>
<tr>
<td>Semantic error</td>
<td></td>
<td>6.7</td>
<td>4.7</td>
<td>12.2</td>
</tr>
<tr>
<td>Grammatical and semantic error</td>
<td></td>
<td>1.0</td>
<td>0</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Grammatical role hypothesis**

To test the grammatical role hypothesis, probe grammar (noun versus verb) and response grammar (noun versus verb) were within subjects factors, and session (PD on and off stimulation and controls) acted as within and between subjects factors. The mean (SEM) per cent error for PD (on stimulation and off stimulation) and control participants is presented in fig 1. The mean per cent error for each PD participant has also been included in table 3 to show patterns of change in noun–verb generation as a function of STN stimulation.

The main effects for probe grammar ($F(1, 3656.495) = 38.310$, $p<0.001$) and response grammar ($F(1, 3656.495) = 22.723$, $p<0.001$) were highly significant, yet the effect for session did not reach significance. There was a significant interaction between probe and response grammar ($F(1, 3656.495) = 119.069$, $p<0.001$) and a three way interaction between probe grammar, response grammar and session ($F(2, 3655.907) = 3.986$, $p<0.05$).

Planned contrasts on the parameter estimates were performed on each probe–response pair (ie, noun–noun, verb–noun, noun–verb and verb–verb) and compared across sessions. PD participants in the on stimulation condition produced significantly more errors on the noun–noun condition compared with controls ($p<0.005$). There was no significant difference between the verb–noun error scores for participants with PD in the off and on stimulation conditions and control participants ($p>0.05$). In the noun–verb condition, PD participants in the off stimulation condition produced significantly more errors than controls ($p<0.05$). In the verb–verb condition, the difference between errors for the PD participants (on and off stimulation) and control participants was highly significant ($p<0.001$), suggesting that PD participants, regardless of STN stimulation condition, produced more errors in the verb–verb condition.

**Semantic attribute hypothesis**

To test the semantic attribute hypothesis, Linear Mixed Model analyses were conducted with probe semantic attribute (visual versus action) and response grammar (noun versus verb) as within subjects factors, and session (PD on and off stimulation, and controls) as within and between subjects factors. Mean (SEM) per cent error for the different probe response pairings for PD participants and controls is presented in fig 2.

The main effect for response grammar was highly significant ($F(1, 3655.699) = 19.695$, $p<0.001$) and was indicative of an average of 6% more errors when a verb response was required. There was no significant interaction between probe semantic attribute and session ($F(2, 3649.019) = 0.120$, $p>0.05$), nor an interaction between probe semantic attribute, response grammar and session ($F(2, 3649.019) = 0.843$, $p>0.05$) indicating that the semantic attribute of probes did not impact on response errors for PD participants (in the on and off stimulation conditions) and controls.

**Relationship between competing alternatives and mean error in PD participants**

In accordance with Peran and colleagues,7 non-parametric Spearman correlations were performed on mean per cent error and selection constraint for participants with PD in conditions in which impaired performance was evident (ie, noun–noun, noun–verb and verb–verb conditions). Selection constraint was calculated for each item under each probe–response condition from the correct responses of controls. Selection constraint
values were calculated according to the procedure outlined by Thompson-Schill and colleagues,20 where the ratio of the most common response was divided by the ratio of the second most common response. For example, in the noun–verb condition, when controls were provided with the probe “axe”, 87% of controls responded with “chopping” and the remaining 13% of participants responded with “cutting”. The selection constraint ratio was calculated by dividing the per cent occurrence of the first most common response (in this case 87%), by the per cent occurrence of the second response (13%) creating a ratio of 6.69 which reflects a high selection constraint. In contrast, when controls were presented with the probe “banana”, 17% of controls produced “peeling” and 17% of controls responded with “eating”, therefore resulting in a low selection constraint ratio of 1. Items with lower selection constraint reflect greater demand for selection among more competing alternatives compared with high selection constraint ratios.20

In the PD on stimulation condition, selection constraint was significantly correlated with mean error in the noun–verb condition \( (r_s = -0.471, p<0.01) \) and verb–verb condition \( (r_s = -0.504, p<0.01) \), reflecting an increase in errors for items with lower selection constraint and therefore selection from more competing alternatives. There was no correlation between mean error and selection constraint for the noun–noun condition \( (r_s = -0.170, p>0.05) \). In contrast, correlations between mean error and selection constraint for PD participants assessed without STN stimulation for the noun–noun, noun–verb and verb–verb conditions were not significant \( (p>0.05) \).

Figure 1  Noun–verb generation in patients with Parkinson’s disease (PD) and in control participants as a function of probe grammatical role. \( *p<0.05; \) \( **p<0.001 \).

**DISCUSSION**

The present study provides evidence for noun/verb dissociation with a relative deficit in verbs for people with PD, as reflected by a selective verb generation deficit in participants with PD when they were not receiving stimulation of the STN. The presence of a verb generation deficit in participants with PD without STN stimulation supports the relative verb generation deficit in patients with PD compared with controls in Peran et al’s study.5 Extending on the results presented by Peran and colleagues,5 this study provided evidence that STN stimulation differentially affects noun and verb generation in congruent grammatical conditions (ie, noun–noun and verb–verb conditions) and that verb generation is influenced by lexical selection from competing alternatives under the STN stimulation condition. Interestingly, patients with PD also displayed a greater proportion of grammatical errors than control participants, suggesting a grammatical basis for difficulties with word generation in PD.

The influence of grammatical role versus semantic attribute of probes on noun and verb generation was also investigated. As there was no interaction between session and probe semantic attribute or an interaction between probe session, semantic attribute and response grammar, the results of the present study indicate that the semantic attribute of probe stimuli had no influence on noun versus verb processing. In contrast, the interaction between session, probe grammatical role and target grammar implies that the presence of noun/verb dissociation in the present study was influenced by the grammatical role of the

**Table 3** Mean per cent error for individual participants with Parkinson’s disease (PD) in noun–verb generation as a function of STN stimulation

<table>
<thead>
<tr>
<th>Patient No</th>
<th>Noun–noun condition</th>
<th>Verb–noun condition</th>
<th>Noun–verb condition</th>
<th>Verb–verb condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On stimulation</td>
<td>Off stimulation</td>
<td>On stimulation</td>
<td>Off stimulation</td>
</tr>
<tr>
<td>1</td>
<td>13.33</td>
<td>43.33</td>
<td>6.67</td>
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<tr>
<td>8</td>
<td>6.67</td>
<td>16.67</td>
<td>16.67</td>
<td>16.67</td>
</tr>
</tbody>
</table>

PD, Parkinson’s disease.
probe stimuli. All further results will therefore be discussed in relation to the grammatical role hypothesis.

During the off stimulation condition, participants with PD had a selective impairment in the noun–verb and verb–verb conditions which was reflective of a deficit in the generation of verbs compared with controls. Furthermore, the mean number of errors during verb generation was not correlated with item selection constraint, suggesting that the verb generation deficit was not related to impairment in the selection of semantic knowledge among competing alternatives. The presence of a deficit in verb generation in PD participants in the off stimulation condition in the present study is consistent with the results from Peran et al’s study,20 where participants with PD were selectively impaired in the verb generation conditions and performed comparably to controls in noun generation conditions. The number of correct responses in these verb generation conditions in Peran et al’s study was also not correlated with selection constraint. These complementary results show that increased errors in conditions that require a verb response in patients with PD are reflective of a verb generation deficit rather than a lexical impairment in selection from competing alternatives.

In contrast, the number of errors in the noun–verb and verb–verb condition in participants with PD receiving stimulation of the STN was significantly correlated with selection constraint, suggesting that performance on both verb generation conditions was influenced by selection from competing alternatives. Specifically, greater selection demands are associated with poorer performance in verb generation. Interestingly, PD participants in the on stimulation condition had impaired performance relative to controls in the verb–verb condition, yet performance was comparable with controls in the noun–verb condition. STN stimulation therefore reduces the noun/verb differences observed in the off stimulation condition, yet has a negative influence on the ability to select responses among more competing alternatives under certain conditions.

The relationship between verb generation and selection from competing alternatives with STN stimulation is consistent with reports that verbal fluency is impaired with STN stimulation.13–15 Schroeder and colleagues16 linked left IFG activity with impaired verbal fluency when participants with PD were receiving stimulation of the STN. Furthermore, greater left IFG activity has been linked with verb generation under conditions of high versus low selection constraint in healthy controls17 and impaired verb generation under high demands for selection from competing alternatives has also been reported in participants with lesions within the left IFG, providing further support for a role of the left IFG in lexical selection from competing alternatives. De Gaspari and colleagues12 has suggested that the behavioural verbal fluency impairment in patients with PD receiving STN stimulation is due to impaired switching between items or clusters of items. Similarly, switching during verbal fluency has been associated with activation in the left IFG and with high selection demands.21 These convergent findings suggest that STN stimulation is related to verb generation under greater selection demands which is potentially linked with modulation of the left IFG. Ullman22 recently presented anatomical and functional evidence for direct links between the left IFG and basal ganglia–thalamocortical circuits. The results of the present study provide supporting evidence that STN stimulation may result in behavioural changes in verb generation which are consistent with left IFG involvement.

A somewhat unexpected result of the present study was impaired noun generation in the noun–noun condition when participants with PD were receiving STN stimulation, and performance on this condition was not associated with selection from competing alternatives. A potential explanation for this impairment could be related to an STN modulation of not only frontal networks, but also temporal networks involved in word generation. For example, during verbal fluency Schroeder and colleagues20 noted that STN stimulation was not only associated with decreased regional cerebral blood flow in the left IFG, but also the left inferior temporal gyrus. Furthermore, while action fluency is more reliant on frontal-striatal circuits, semantic fluency has been reported to be more dependent on temporal circuits.24 The present finding of impaired word generation in the noun–noun and verb–verb conditions under the STN stimulation condition may be consistent with STN stimulated modulation of frontotemporal networks. The additional variable of left versus right STN stimulation in participants with PD and the inclusion of a larger sample size in future research, would provide further evidence for the STN stimulated modulation of left frontotemporal networks. Alternatively, the deficit in noun–noun generation may be consistent with a generalised deficit in word generation associated with STN stimulation. This notion is supported by the numerous studies which have reported deficits in semantic fluency (ie, the generation of nouns) with STN stimulation in PD.12

In conclusion, the presence of a selective verb generation deficit in participants with PD in the off stimulation condition reflects a lexical deficit in verb generation associated with PD. During the STN stimulation condition, selective impairment in verb generation was no longer present, yet verb generation was associated with selection constraint, suggesting that STN stimulation affects selection from competing alternatives, potentially modulated by the left IFG. Finally, STN stimulation affected noun generation in the noun–noun condition, supporting the notion that STN stimulation affects a frontotemporal network associated with word generation or generalised word generation deficit associated with STN stimulation.

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REFERENCES

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