Decreased semantic competitive inhibition in Parkinson’s disease: Evidence from an investigation of word search performance

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Abstract
Aberrant semantic competitive inhibition has been reported in Parkinson’s disease (PD). Whether PD-related alterations cause an increase or a decrease in lateral inhibition, however, remains unclear. Accordingly, the present study aimed to examine semantic inhibition during lexical-semantic processing in non-demented people with PD. Twenty-two people with PD and 18 matched controls completed a computerized word search task in which both the relationship between the background items and the target (related or unrelated) and the search type (open e.g., any dog or closed e.g., collie) were manipulated. It was hypothesized that decreased semantic inhibition would be evidenced by abnormally short response times for open searches among words related to the target, while increased inhibition would lead to abnormally long response times. Analysis of the results revealed that control participants performed open searches faster for unrelated vs related word lists. In contrast, the PD group recorded similar response times regardless of background items. Hence, the present findings are consistent with the notion of decreased semantic competitive inhibition in PD and suggest that an impaired ability to inhibit unwanted information during lexical retrieval may underlie observed deficits on semantic tasks such as verbal fluency.

Keywords: Cognitive-linguistic interactions, expressive language, language processing, Parkinson’s disease.

Introduction
It is widely acknowledged that people with Parkinson’s disease (PD) exhibit lexical semantic processing deficits. These deficits are evidenced by impaired performance on tasks such as verbal fluency, word definition (Berg, Bjornram, Hartelius, Laakso, & Johnels, 2003), object identification (Righi, Viggiano, Paganini, Ramat, & Marini, 2007), and semantic priming (Angwin, Cherney, Copland, Murdoch, & Silburn, 2005; 2007; Arnott, Cherney, Murdoch, & Silburn, 2001; Grossman, Zurif, Lee, Prather, Kalmanson, Stern, et al., 2002). With respect to the precise nature of the processing deficits underlying these impairments, a number of researchers have examined the notion that PD disrupts inhibitory mechanisms operating within the semantic system (Bouquet, Bonnaud, & Gil, 2003; Copland, 2003; Gurd, 1996; Gurd & Oliveira, 1996; Henik, Singh, Beckley, & Rafal, 1993; Watters & Patel, 1999; 2002). To date, however, these investigations have yielded equivocal results. The present study employed a computerized version of the Neisser word-search task (Neisser & Beller, 1965) to further investigate inhibitory semantic processing in PD.

Gurd (1996) and Gurd and Oliveira (1996) employed novel variants of Neisser and Beller’s (1965) word search task to examine the impact of PD on lexical-semantic processing. Gurd (1996) employed single item word searches in which participants searched word lists for a particular target, e.g., lion, and multi-item word searches in which participants searched for a member of a target semantic set, e.g., any animal. The former were described as requiring simple stimulus examination and serial search processes while the latter evoked parallel search processes to examine semantic memory. A significant correlation between word search times and verbal fluency scores intrinsically linked verbal fluency deficits and slowed word search processes in PD.

Of particular interest to Gurd and Oliveira (1996), on the other hand, was the impact of competitive inhibition between semantic representations on word search performance (Stemberger, 1985). Again, participants were required to search through lists of words for targets that had either been named specifically, e.g., collie (simple/closed search), or
had been defined in terms of their category meaning, e.g., any dog (open search). In addition to manipulating the search type (closed vs open), the researchers varied the relationship of the word list distracter items to the target. For closed searches (e.g., collie), lists were composed of either unrelated items from various other semantic categories, related superordinate items (e.g., animals), or related basic items (e.g., dogs). For open searches (e.g., any dog), lists featured related superordinate items (e.g., animals) or unrelated items from either various other semantic categories or one unrelated category (e.g., fruit). Hence, each type of search was conducted amid three different word lists.

According to Stemberger’s (1985) interactive model of language production, the language system involves different levels (phonemic, lexical, semantic, syntactic), each being composed of units which are connected via links. These links enable units to alter the activity levels of other units by either excitation or inhibition. The links connecting units within a level tend to be inhibitory, whilst the links connecting the units of different levels tend to be excitatory. As shown in Figure 1, when a unit on one level becomes activated, e.g., a lexical representation, units on other levels (phonemes, semantic representations) that are associated with the activated representation also become activated. These units, in turn, excite other associated units. As a result, within the lexical level, many non-target representations become partially activated. In turn, these activated representations inhibit each other to compete for selection; the greater a representation’s activation level, the greater its power of inhibition. Hence, the target representation will be accessed by receiving the highest level of activation and imposing the greatest amount of inhibition on its competitors.

Consistent with Stemberger’s (1985) competition hypothesis, Gurd and Oliveira (1996) reasoned that competitive inhibition would be greater between related items than between unrelated items. Such a situation would result in control participants exhibiting slower reaction times for word searches conducted amid related items than for word searches amid unrelated items. More specifically, the researchers predicted that, for closed searches (e.g., collie), times for lists consisting of basic related items (e.g., dogs) would be slower than times for lists of superordinate items (e.g., animals), which in turn would be slower than unrelated items from various other categories. For open searches (e.g., any dog), on the other hand, participants would be slower when searching through related superordinate items (e.g., animals) than distracter items drawn from either a single unrelated category (e.g., fruit) or from various other unrelated categories. With respect to people with PD, Gurd and Oliveira anticipated results indicative of increased competitive inhibition processing within the semantic system.

Overall, the results of Gurd and Oliveira’s (1996) control participants were consistent with the competition hypothesis (Stemberger, 1985). Importantly, however, whilst group differences in response times appeared to be suggestive of PD-related difficulties in inhibitory processing, these difficulties supported the notion of decreased inhibition rather than, as predicted, increased inhibition. Specifically, the elderly control participants were twice as fast as participants with PD in the open search/unrelated distracters condition, but only 27% faster in the open search/related superordinate distracter condition. These group differences, however, failed to reach statistical significance. Regardless, the research suggested a link between semantic language deficits in PD and an inability to adequately inhibit competing semantic representations. In doing so, Gurd and Oliveira’s study led to significant advances in the investigation of PD-related semantic language deficits.

More recently, Copland (2003) investigated the nature (automatic/controlled) and time course of the processes underlying lexical ambiguity priming (e.g., bank: dominant meaning = money, subordinate meaning = river) in three subject groups, namely participants with non-thalamic subcortical lesions (NS), participants with PD, and matched controls. At the short inter-stimulus interval (ISI) of 200 ms, all participants showed priming for both the dominant and the subordinate meanings of the ambiguous words, suggesting intact automatic activation of all meanings. At the longer ISI of 1250 ms, however, control participants primed only the dominant meaning, whilst the participants with NS and PD continued to prime for all meanings. The author interpreted these findings as being indicative of an inability to properly engage lateral inhibitory mechanisms within the semantic system. As a result, people with NS and PD are unable to selectively engage semantic information on the basis of meaning frequency.
Also interested in the way in which people with PD process ambiguous words, Watters and Patel (2002) published a neural network simulation of semantic processing in PD which specifically examined competition and lateral inhibition for ambiguous words which differed according to their sense frequency (the degree to which the two meanings or senses of the ambiguous word differ with respect to frequency). Contrary to the findings of Gurd and Oliveira (1996) and Copland (2003), however, Watters and Patel’s results supported the notion that people with PD experience increased levels of lateral inhibition. Accordingly, the authors proposed that the poor performance exhibited by people with PD on open search tasks, as identified by Gurd and Oliveira (1996), was consistent with abnormally high levels of lateral inhibition for words whose meanings differed little with respect to frequency. Hence, Watters and Patel’s conclusions were in direct contrast to those of both Gurd and Oliveira and Copland.

Clearly, such apparently disparate results are worthy of further investigation. In particular, further research is needed to determine whether the findings of Gurd and Oliveira (1996) represent a replicable and statistically robust phenomenon. Given that, for Gurd and Oliveira’s participants with PD and elderly controls, group differences for raw mean search times per position ranged from only 40–90 milliseconds across the six experimental conditions, the accurate measurement of response times would appear to be a critical factor in any word search investigation. To this end, the present study sought to utilize an online version of Gurd and Oliveira’s word search task that would maximize the chances of highlighting group by condition effects dependent upon subtle reaction time differences.

The present study aimed to examine the impact of PD on semantic competitive-inhibition processing by employing a computerized version of Gurd and Oliveira’s (1996) word search task. As found by Gurd and others (Gurd, 1996; Gurd & Oliveira, 1996; Gurd, Elvevag, & Cortina-Borja, 1997), it was anticipated that open searches would be generally slower than simple searches across both subject groups. Further, in accordance with Stemberger’s (1985) interactive model of language processing, it was reasoned that inhibition would be greater for related background lists than for unrelated lists and for open vs closed searches. As such, consistent with the findings of Gurd and Oliveira (1996), the role of semantic competitive-inhibitory processing would be reflected during open searches (e.g., any dog) by longer response times for searches among superordinate category items (e.g., animals) vs unrelated items whether from the same (e.g., fruit) or different categories. With respect to closed searches (e.g., collie), search times would be longer for basic related than for superordinate lists, which, in turn, would be longer than for unrelated lists.

With respect to the performance of the participants with PD, it was hypothesized that decreased semantic inhibition as proposed by Gurd and Oliveira (1996) and Copland (2003) would be evidenced by abnormally small differences in response times, while increased lateral inhibition, as postulated by Watters and Patel (2002), would be supported by abnormally large differences in response times for:

1. open searches (e.g., any dog) amid related superordinate items (animals) vs unrelated items, either from different unrelated categories or from the one unrelated category (fruit); and
2. closed searches (e.g., collie) amid unrelated vs basic items (dogs) and between basic items and superordinate items (animals).

Methods

Participants

Twenty-two people with idiopathic PD and 18 healthy controls comprised the study’s two participant groups. All participants were right handed, native speakers of English with adequate normal or corrected to normal vision to complete the experimental tasks. Participants with a history of neurological disorder other than PD, neurological surgery, drug or alcohol abuse, or dementia were excluded from the study. Prior to admission to the study, the cognitive status of all participants was assessed using the Dementia Rating Scale (DRS, Mattis, 1988). All participants had DRS scores of 134 or greater, scores below 123 being considered indicative of impaired cognitive functioning. The two groups did not differ with respect to age, t(38) = −.10, p = .923, or education, t(38) = .72, p = .477 (two-tailed, equal variances assumed). DRS scores, however, were significantly lower for the PD group, t(31.92) = −2.66, p < .05 (two-tailed, equal variances not assumed). Table I illustrates the demographic characteristics for the two participant groups.

Prior to their recruitment in the study, all PD participants (a) had received a positive diagnosis of Parkinson’s disease and control groups.

Table I. Demographic data for the Parkinson’s disease and control groups.

<table>
<thead>
<tr>
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<th>PD</th>
<th>NC</th>
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<tr>
<td>n</td>
<td>22</td>
<td>18</td>
</tr>
<tr>
<td>Male:Female</td>
<td>12:10</td>
<td>10:8</td>
</tr>
<tr>
<td>Age (years)</td>
<td>66.55 (6.74)</td>
<td>66.78 (8.35)</td>
</tr>
<tr>
<td>Education (years)</td>
<td>12.32 (4.08)</td>
<td>11.50 (2.87)</td>
</tr>
<tr>
<td>Cognitive status*</td>
<td>138.64 (4.08)</td>
<td>141.28 (2.02)</td>
</tr>
</tbody>
</table>

Note: Data are expressed as mean (standard deviation). PD = Parkinson’s disease; NC = normal control; Cognitive status = Dementia Rating Scale raw score (DRS, Mattis, 1988).

*p < .05.
idiopathic PD from their neurologist and (b) if taking Parkinsonian medications, had been optimally medicated on an established treatment regime for at least 3 months. The PD group had a mean disease duration of 4.59 (SD = 3.66, range = 1–16) years and a mean age at onset of 62.00 (SD = 7.24, range = 45–75) years. According to the Hoehn and Yahr (1967) scale, which provides a classification of disease severity for people with PD, all PD participants were mildly impaired (Stage 1 or 2).

With respect to their medication regimes, two of the participants with PD were not medicated. Of the members of the PD group who were medicated, 10 people were taking levodopa in combination with either carbidopa (Sinemet) or benserazide (Madopar). In addition to their levodopa, four people were taking cabergoline (Cabaser), two people were taking trihexyphenydiyl (Artane), and two people were taking amantadine (Symmetrel). Finally, two people were not taking any levodopa preparations, one of these people was taking cabergoline only whilst the other was taking trihexyphenydiyl and cabergoline. For the group, the mean daily dosage of levodopa was 531.25 mg (SD = 332.22, range 150–1500), of cabergoline was 3.60 mg (SD = 2.07, range = 1–6), of trihexyphenydiyl was 4.67 mg (SD = 2.31, range = 2–6), and of amantadine was 150.00 mg (SD = 70.71, range = 100–200).

It was important that medicated participants with PD were tested whilst optimally medicated, such that they were achieving maximum clinical benefit from their medication at the time of testing. Hence, for these people, testing commenced ~45 minutes after dosage. In order to avoid testing during a person’s wearing-off phase, all medicated participants were requested to report to the researcher if they felt that their medication was wearing off, so that testing could be ceased. In addition, these participants with PD performed the Unified Parkinson’s Disease Rating Scale (Fahn, Elton, & Members of the UPDRS Development Committee, 1987) finger tap sub-test at 30 minute intervals throughout each testing session. This short test required participants to tap their index finger and thumb together as rapidly as possible for 5 seconds, each hand being assessed separately for speed, amplitude, and arrests of movement. A score between 0 (normal performance) and 4 (barely able to perform task) was then calculated. Since the effects of medication wearing-off are associated with reduced mobility, testing was ceased if a participant’s UPDRS score increased during any one testing session.

**Apparatus**

The experiments were computerised using Superlab experimental laboratory software (Version 2.0) (Cedrus, 1996) and were run on a portable computer with an active screen using the Microsoft Windows 98 interface. A Cedrus RB-420 response pad recorded subjects’ reaction times (rts) to within 1 millisecond of accuracy. Experimental word lists were created using Microsoft Word (New Times Roman bold 20 pt font), converted into bitmap files using Adobe Illustrator 10 and then imported into the Superlab experiments.

**Stimuli**

From the three superordinate level categories ANIMALS, VEHICLES, and FOODS, six basic categories were chosen: BIRDS, DOGS, BOATS, CARS, FRUITS, and VEGETABLES. Within each of these categories, six experimental conditions were created by manipulating the nature of the word search and the background/distractor items. Searches could be one of two types: open, in which participants were told to search for any member of a basic category, e.g., *any dog*, or closed, in which participants were told to search for a particular member of a basic category, e.g., *collie*. Background items, which varied in their relationship to the target, were members of either the target’s superordinate category (superordinate related), various other unrelated categories (various unrelated), the same unrelated category (single unrelated), or the target’s basic category (basic related). Hence, the six experimental conditions were:

1) closed/superordinate related: closed search (e.g., *collie*) among members of the target’s superordinate category (e.g., animals: *donkey, pig*);
2) closed/basic related: closed search (e.g., *collie*) among members of the same basic category level as the target (e.g., dogs: *poodle, corgi*);
3) closed/various unrelated: closed search (e.g., *collie*) among words drawn from various other unrelated categories (e.g., *candles, heel*);
4) open/superordinate related: open search (e.g., *any dog*) among members of the target’s superordinate category (e.g., animals: *donkeys, pigs*);
5) open/single unrelated: open search (e.g., *any dog*) among words drawn from one unrelated category (e.g., flower: *tulip, pansy*);
6) open/various unrelated: open search (e.g., *any dog*) among words drawn from various other unrelated categories (e.g., *candle, heel*).

Thirty-six lists (6 basic categories × 6 experimental conditions) of 20 words were created. The words comprising the lists were all concrete, imageable nouns (object names) of between three and 10 letters in length. Within each of the six basic category sets, word lists were matched with respect to written word frequency (Kucera & Francis, 1967) and length. The specific unrelated categories chosen for the open/unrelated single experimental condition were: birds/furniture, dogs/flowers, boats/clothing, cars/colours, fruit/gems, vegetables/trees. Where possible, words for all category lists (superordinate, basic, and
unrelated single) were taken from Australian norms (Casey & Heath, 1988).

Six targets were chosen from each of the six basic categories, birds, dogs, boats, cars, fruit, and vegetables, one for each condition. Target words ranged in length from five to nine letters and had a written frequency of between 0–27 occurrences per million (Kucera & Francis, 1967). Targets were matched for frequency and condition across each of the six experimental conditions. In a manner after Gurd and Oliveira (1996), each word list had five position groups: (a) 5–7, (b) 8–10, (c) 11–13, (d) 14–16, and (e) 17–19. The position group in which targets appeared was controlled such that (a) within both experimental condition (6) and basic category (6), targets appeared in each of the position groups once and (b) across the three experiments targets appeared in each position group at least seven times.

Procedure

The word search tasks were computerized and presented to participants via a portable computer, each search consisting of a series of four events. First, written search instructions were displayed. The instructions, which were either, “Press the button when you come to the name of any (category, e.g., dog)” or “Press the button when you come to (specific target, e.g., collie)”, remained visible for a period of 3000 milliseconds and were read aloud by the examiner. The second screen was blank except for an orienting black marker, positioned at the top centre of the screen. This mark stayed on screen for 1500 milliseconds and served to orient the participant to the position of the first word on the following word list. A vertical list of 20 words then appeared centred on the computer screen and remained visible until the participant depressed the response button. Finally, a blank screen provided an inter-trial interval of 3000 milliseconds. Targets never appeared in the first four positions or the last position in the word lists. Participant reaction times (Rts), or the time between the presentation of the word list and the depression of the response button, were automatically recorded. Errors (the identification of an incorrect word, the inability to locate the target, or scanning back up the page) were manually recorded by the examiner.

All participants completed a total of 36 word searches (6 basic categories × 6 conditions) in the same order. Participants were told that lists of 20 words would appear on the computer screen in front of them and that their task was to carefully read down each list of words to find a particular word. They were to read each word silently proceeding as quickly as possible but ensuring that they read each word, starting with the first and reading the whole word. When they found the target word, they were to click on the response button and immediately turn away from the screen. They would then be asked to say the name of the word and, in the case of simple searches where the instructions contained the name of the target they would be asked to indicate the target’s position in the word list by pointing to the screen immediately after pressing the response button. If they reached the end of the list and had not found the target, they were to immediately hit the response button and say “no”. At no time were they to search back up the list to try to locate the word. Prior to the commencement of testing, participants completed a practice set of six searches. They were free to repeat this practice set until they felt confident with the procedure.

Results

Reaction time (Rt) data for the three experiments were combined and cleaned by eliminating Rts for responses made in error. In addition, reaction times greater than 10 seconds were classified as extreme values reflecting responses lengthened due to extraneous variables such as disruptions. Extreme values were also eliminated from the data set. As one member of the control group recorded errors on one third of the word search trials, this person’s data were eliminated from further analyses. For the remaining participants, errors and extreme values accounted for .4% and 3.1% of control data, respectively, and 1.76% and 7.45% of PD data, respectively. The two groups did not differ with respect to the percentage of extreme, \( Z = -1.848, p > .05 \) (two-tailed), or erroneous responses, \( Z = -1.689, p > .05 \) (two-tailed). For each participant, means and standard deviations were then calculated by condition and any Rts greater than 2 standard deviations above or below the mean were replaced by the subject’s Tukey mean biweight estimator for that condition. In total, only three Rts needed to be replaced (two for the PD group and one for the NC group).

Next, in a manner after Gurd (1996), pure Rts were calculated by dividing each Rt by its target’s exact position in the word list. Measures of skewness and kurtosis revealed that pure Rts were not normally distributed. Accordingly, data were normalized by inversion (1/pure Rt) prior to analysis using a Linear Mixed Model with subject as a random variable, group (2) as a between-subjects variable, condition (6) as the within-subjects variable, and the order in which the experimental tasks were completed (36) as a covariate. Mean pure Rts are displayed as a function of group and condition in Table II.

All participants completed the 36 word search tasks in the same order. It was important, therefore, to ensure that this order of presentation had not biased results. The absence of a relationship between order and test results was confirmed when analysis revealed that p-values from the ANOVA table were not affected by including order as a covariate. In addition, when order was plotted against saved
residuals, observed and predicted values exhibited little difference, indicating that the influence of order on the groups’ performances was minimal.

Mixed model analysis revealed significant main effects for group, $F(1, 36.90) = 6.54$, $p < .050$, condition, $F(5, 1259.06) = 129.71$, $p < .001$, and a significant group by condition interaction, $F(5, 1259.06) = 2.94$, $p < .050$. In order to investigate the interaction effect further, the data for the two groups were analysed using custom hypothesis testing within separate linear mixed model procedures.

**Control participants**

A main effect for condition, $F(5, 568.02) = 54.38$, $p < .001$, was identified for the control group. Results of custom testing revealed that, overall, the group was slower for open searches than for closed searches, $t(568.04) = -14.18$, $p < .001$. With respect to closed searches, control participants searched faster among related superordinate distractors than among either related basic distractors, $t(568.00) = -3.71$, $p < .001$, or distractors from various other unrelated categories, $t(568.00) = 2.62$, $p < .010$. There was no difference, however, in the response times recorded for the basic related and various unrelated conditions.

For open searches, the control group recorded significantly slower response times when searching among related superordinate distractors than when searching among distractors from various unrelated categories, $t(568.04) = 1.97$, $p < .050$. Response times for searches conducted amid items from various unrelated categories and items from a single unrelated category, and for searches amid superordinate items and items from a single unrelated category, however, were statistically similar.

**Participants with PD**

Like their control counterparts, participants with PD recorded a significant main effect for condition, $F(5, 692.02) = 79.76$, $p < .001$, and were generally slower for open searches than for closed searches, $t(692.07) = -17.65$, $p < .001$. Closed searches were faster among superordinate items than among basic related items, $t(692.00) = -5.83$, $p < .001$ or items from other unrelated categories, $t(691.97) = 3.47$, $p < .010$. In addition, closed searches among items from other unrelated categories were faster than closed searches among basic related items, $t(692.00) = -2.35$, $p < .050$. With respect to open searches, however, the response times recorded by the PD group did not differ as a function of background.

From the preceding analyses, whilst the control group exhibited slower response times for open searches amid superordinate related items than for open searches amid various unrelated items, the response times recorded for the PD group were statistically similar for these two conditions. In order to determine whether, in accordance with the predictions made in the introduction, these group differences were statistically significant, the custom hypothesis test for the open/superordinate and open/other conditions were repeated with group as a between subjects factor. Results indicated that the group differences approached significance, $t(1260.08) = 1.76$, $p = .079$.

**Discussion**

Using a computerized version of the Neisser word search task (Neisser & Beller, 1965), the present research sought to validate Gurd and Oliveira’s (1996) study of competitive inhibition during lexical-semantic processing in PD. The on-line presentation of experimental tasks identified subtle PD-related abnormalities in performance. As predicted, regardless of list background, all participants performed closed searches (e.g., *collie*) faster than they performed open searches (e.g., *any dog*). In addition, whilst the two groups performed in a similar manner for closed searches, which required a search for a specified target e.g., *collie*, participants with PD exhibited abnormal performance for open word searches, in which they were required to search through a list of words for an unspecified member of a particular semantic category e.g., *any dog*. More specifically, the PD group’s pattern of performance for open searches provides tentative support for the notion of a disease-related decrease in semantic inhibition as previously proposed by Gurd and Oliveira (1996) and Copland (2003). The following discussion will focus first upon the present findings with respect to open word searches and altered lateral inhibition in PD. The groups’ performances for closed word searches as a function of search background will then be considered.

**Decreased semantic inhibition in PD**

By highlighting differences in the performances of people with PD and matched controls on open word
search tasks, the present research provides evidence suggesting decreased lateral inhibition in the semantic networks of people with PD. Based on Stemberger’s (1985) interactive model of language processing, it had been anticipated that, due to increased semantic inhibition between superordinate items (e.g., animals), control participants would take longer to conduct open word searches (e.g., *any dog*) amid superordinate items than among either items from one unrelated category or items from various other unrelated categories. Two competing hypotheses were made for the PD group. It was hypothesized that: (1) if, as proposed by Gurd and Oliveira (1996) and Copland (2003), people with PD experience decreased semantic inhibition, the PD group would record similar response times for open searches amid related superordinate items and open searches among unrelated items; and (2) if, as suggested by Watters and Patel (2002), lateral inhibition is increased in PD, the PD group would record an abnormally large difference in response times for searches involving related superordinate backgrounds vs unrelated backgrounds.

Accordingly, the finding that the open search response times recorded by participants with PD did not change as a function of background whilst the control group recorded slower response times in the superordinate condition than in the various unrelated condition supports the contention that competitive inhibition is decreased in PD. Considering the possible impact of such a PD-related decrease in lateral inhibition on lexical retrieval, it is suggested that the dampening of competitor words’ activation levels would proceed inefficiently. As a result, a target word would take longer to reach threshold activation. Accordingly, word search response times would be lengthened and fewer words would be retrieved during verbal fluency tasks.

Hence, the present results are consistent with suggestions that PD-related problems on tasks such as verbal fluency are the result of difficulties with lexical retrieval (Auriacombe, Grossman, Carvell, Gollomp, Stern, & Hurtig, 1993; Beatty, Monson, & Goodkin, 1989; Gurd, 1995; Gurd & Ward, 1989; Matison, Mayeux, Rosen, & Fahn, 1982; Randolph, Braun, Goldberg, & Chase, 1993; Raskin, Sliwinski, & Borod, 1992). The current findings are also in accordance with claims that, in particular, an impaired ability to inhibit unwanted information during lexical retrieval contributes to aberrant sentence completion during the Hayling test (Bouquet et al., 2003) and to priming deficits (Angwin, Copland, Chenery, Murdoch, & Silburn, 2006; Filoteo, Friedrich, Rilling, Davis, Stricker, & Prenovitz, 2003; Filoteo, Rilling, & Strayer, 2002; Mari-Beffa, Hayes, Machado, & Hindle, 2005) in PD. Finally, the present data are somewhat consistent with the role of the basal ganglia in inhibitory semantic processing, as proposed by Copland (2003). This proposal must be considered speculative, however, until confirmed by direct evidence regarding basal ganglia function.

With respect to why the present study’s word search results may be inconsistent with Watters and Patel’s (2002) modelling of increased lateral inhibition in PD, it is contended that the experimental task performed by Watters and Patel’s neural network was inherently different to the open word search tasks employed by both Gurd and Oliveira (1996) and the present study. For this reason, caution should be exercised in over-generalizing the findings. More specifically, using a computation model based on the Dual Route Cascaded (DRC; Coltheart, Curtis, Atkins, & Haller, 1993) model of reading, Watters and Patel (2002) employed stimuli comprised of polysemous words (words that have more than one sense). For example, the word *kind* has two senses: (1) a type or form and (2) showing a tender and considerate nature. Stimulus words were distinguished on the basis of their sense frequency delta (SFD) or the difference in frequency for a word’s two closest senses. Accordingly, stimuli had either a low SFD (e.g., *deed*) or a high SFD (e.g., *bluff*). With regard to the experimental task employed, Watters and Patel’s open search task required their network to correctly select the dominant sense of the polysemous words.

Given that the manipulation of lateral inhibition at the sense level rather than at the word level was a key contributor to the abnormal performance of Watters and Patel’s (2002) network, it is suggested that critical to the study’s findings were, first, the employment of polysemous word stimuli, and, second, a task involving searching for the most dominant sense of such words. After all, presumably words with only one sense as employed by both the present study and the study undertaken by Gurd and Oliveira (1996) would not be subject to similar levels of competition at the sense level as the polysemous words used by Watters and Patel. Accordingly, it is not surprising that the findings of word search studies are incongruent with the findings of Watters and Patel.

Based on the work of Gurd and Oliveira (1996), it had been anticipated that competitive inhibition between list items would be greater for superordinate word lists than lists composed of words from an unrelated category. Contrary to predictions, however, the control group recorded similar response times regardless of whether searches were conducted amid superordinate distractors or amid distractors from one unrelated category. Whilst such a finding is incongruent with our predictions and, hence, any explanation must be considered speculative, this finding can be accommodated by the competitive inhibition hypothesis.

As previously mentioned, open searches would necessitate the checking of each list item’s semantic features against the semantic features dictated by the search instructions (e.g., *any dog*—animate, barks...
etc.). In order for each list item’s semantic representation to become activated, semantically-related items would need to be inhibited. For example, during searches of unrelated lists such as items from the category of flowers, the activation of the concept rose would result in increased inhibition for other flowers. As each list item was processed, this inhibition would need to be overcome. Obviously, inhibition for lists featuring items unrelated to the target but drawn from the same category would be greater than the inhibition generated between unrelated items drawn from various categories (other) and less than the inhibition generated between items that are both related to the target and from the same category. Hence, open word search reaction times for unrelated backgrounds could conceivably be slowed sufficiently such that they are statistically similar to reaction times for both other backgrounds and superordinate backgrounds.

**Semantic inhibition and the closed word search task**

Whilst the findings of the present study with respect to open word search performance were consistent with the notion of altered semantic inhibition in PD, closed word searches support normal competitive inhibition during simple (serial) search processing in PD. It had been predicted that control participants would encounter greater lateral inhibition and, therefore, record longer response times when conducting closed searches (collie) through lists of related basic items than through lists of related superordinate items for which, in turn, response times would be longer than searches through lists of unrelated items from various other categories. The closed search results for both the control and the PD groups were generally consistent with these predictions. That is, both groups recorded slower response times for basic lists compared to superordinate lists.

Interestingly and contrary to predictions, both groups of participants conducted simple searches faster for superordinate lists than for unrelated word lists. This finding was somewhat unexpected but can be explained by the notion of facilitation and spreading activation (Gurd & Oliveira, 1996). The superordinate (ANIMAL) to which both the target collie and the superordinate list items (e.g., pig, goat) belong is continuously activated as the participant reads through the superordinate list. As a result, the meaning unit COLLIE and its lexical representation would also receive constant activation, thus facilitating lexical access.

It is important to note that the notion of decreased lateral inhibition in the semantic networks of people with PD has been advanced with several caveats in mind. Whilst the profiles of the PD and control groups differed as a function of experimental condition, when the performance of the two groups were directly compared only a tendency towards abnormality was identified for the participants with PD. Further, as the present research methodology included only six trials for each experimental condition, it is suggested that the employment of additional trials per experimental condition may have increased the sensitivity of the paradigm, thus providing more statistically reliable and consistent results. Accordingly, the current results must be considered preliminary awaiting further confirmation using an increased number of trials per condition.

**Conclusions**

In summary, the present study employed a computerized variant of the word search task to examine lexical-semantic processing deficits in PD. The results verify earlier descriptive data of PD-related deficits in open word search tasks obtained using a manual word search task and support the contention that semantic competitive inhibition is decreased in PD. Accordingly, these findings suggest that an impaired ability to inhibit unwanted information may contribute to such frequently reported clinical features of the disease as verbal fluency and naming deficits.

**References**


