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Effects of working memory capacity on inference generation during story comprehension in adults with Parkinson's disease

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Abstract

A group of non-demented adults with Parkinson's disease (PD) were studied to investigate how PD affects pragmatic-language processing, and, specifically, to test the hypothesis that the ability to draw inferences from discourse in PD is critically tied to the underlying working memory (WM) capacity of individual patients [Monetta, L., & Pell, M. D. (2007). Effects of verbal working memory deficits on metaphor comprehension in patients with Parkinson's disease. *Brain and Language*, *101*, 80–89]. Thirteen PD patients and a matched group of 16 healthy control (HC) participants performed the Discourse Comprehension Test [Brookshire, R. H., & Nicholas, L. E. (1993). *Discourse comprehension test*. Tucson, AZ: Communication Skill Builders], a standardized test which evaluates the ability to generate inferences based on explicit or implied information relating to main ideas or details presented in short stories. Initial analyses revealed that the PD group as a whole was significantly less accurate than the HC group when comprehension questions pertained to implied as opposed to explicit information in the stories, consistent with previous findings [Murray, L. L., & Stout, J. C. (1999). Discourse comprehension in Huntington's and Parkinson's diseases. *American Journal of Speech–Language Pathology*, *8*, 137–148]. However, subsequent analyses showed that only a subgroup of PD patients with WM deficits, and not PD patients with WM capacity within the control group range, were significantly impaired for drawing inferences (especially *predictive* inferences about implied details in the stories) when compared to the control group. These results build on a growing body of literature, which demonstrates that compromise of frontal–striatal

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systems and subsequent reductions in processing/WM capacity in PD are a major source of pragmatic-language deficits in many PD patients.

Keywords: Language processing; Discourse comprehension; Pragmatics; Resource allocation; Frontal–striatal disorders; Parkinson's disease

1. Introduction

Parkinson's disease (PD) is a chronic neurodegenerative illness linked to decreased dopamine production in the basal ganglia and is recognized primarily by its motor symptoms. However, from early stages of the disease and in the absence of dementia, many PD patients display cognitive impairments that include difficulties with planning, selective attention, and working memory (WM) (Brown & Marsden, 1991; Cooper, Sagar, & Sullivan, 1993; Lewis et al., 2003; Owen et al., 1993, 1992; Taylor, St-Cyr, & Lang, 1986). Many of these limitations in ''executive'' control and associated resources can be traced to progressive changes in the frontal lobes and connecting pathways (the frontal–striatal–thalamic system), which functionally decline over the course of PD. Of key interest here, WM deficits are present in many PD patients and have been linked to altered dopaminergic innervations to the dorsolateral prefrontal cortex (DLPFC) and progressive interruptions in the frontal–striatal pathways (Gilbert, Belleville, Bherer, & Chouinard, 2005; Lewis et al., 2003; Monetta & Pell, 2007).

WM, which can be subdivided into verbal and visuospatial components, refers to a dynamic cognitive system required to maintain information ''on-line'' and to manipulate it (Baddeley, 1986; Just & Carpenter, 1992; Petrides, 1995). Neuroimaging studies highlight an important link between different prefrontal sites and processes for manipulating information in WM (DLPFC) and processes for information encoding and retrieval (ventral prefrontal regions; for reviews see D'Esposito et al., 1995; Owen, 2000; Petrides, 1995). In addition, dopaminergic projections to the DLPFC (Williams & Goldman-Rakic, 1995) and possibly also to the caudate nucleus (Collins, Wilkinson, Everitt, Robbins, & Roberts, 2000) seem to play an important modulating role in the function of the WM network. Given that many of the functional brain regions implicated by WM systems overlap considerably with those which systematically decline in PD, some researchers have investigated a possible link between changes in individual WM capacity in PD and specific language processing abilities (Breitenstein, Van Lancker, Daum, & Waters, 2001; Grossman et al., 2003; Hochstadt, Nakano, Lieberman, & Friedman, 2006; Monetta & Pell, 2007).

In fact, there is growing evidence that PD is associated with selective difficulties in processing language and that some of these deficits may be explained by limitations in WM or other measures of individual processing resource capacity. Many PD patients fail to perform normally when language processing is ''complex'' or depends on high resource capacity, such as when the patients are required to interpret the intended or pragmatically appropriate meaning of metaphorical language, paralinguistic behaviors, or discourse as defined by its social context (see Berg, Bjornram, Hartelius, Laakso, & Johnels, 2003; McNamara & Durso, 2003; Natsopoulos et al., 1993, 1997; Natsopoulos, Katsarou et al., 1991; Natsopoulos, Mentenopoulos et al., 1991). In one study, Natsopoulos et al. (1997)

presented five tasks of deductive reasoning (e.g., syllogisms) and three tasks of inductive reasoning (e.g., metaphors) to individuals with PD and healthy control (HC) participants. They found that verbal reasoning abilities were significantly impaired in the PD relative to the control group, especially in PD patients with more advanced (i.e., bilateral) motor signs. Similarly, Berg et al. (2003) identified a range of ''high-level'' language difficulties in a group of PD patients, which affected the ability to generate inferences, to recreate sentences, and to comprehend metaphors and lexically ambiguous words. However, neither of these studies looked for a specific link between measures of pragmatic-language processing and the individual processing capacity of their patients.

McNamara and Durso (2003) examined the conversational and social skills of a group of PD patients with respect to verbal behaviors (e.g., speech acts, message specificity), nonverbal behaviors (e.g., facial expressions, gestures), and paralinguistic behaviors (e.g., fluency, prosody) and then compared these measures to the patients' performance on traditional ''frontal lobe'' tasks (e.g., Tower of London, Stroop task). Their results confirmed that many pragmatic communication skills are frequently impaired in PD patients, and that these communication deficits are significantly related to impairments on frontal lobe tasks for the PD group under study. Based on these observations, Monetta and Pell (2007) tested a group of PD patients using a detailed task of understanding metaphorical language (timed property verification; Gernsbacher, Keysar, Robertson, & Werner, 2001). This study examined the relationship between metaphor comprehension measures and the WM capacity of individual PD patients as estimated by an adapted listening span task (Tompkins, Bloise, Timko, & Baumgaertner, 1994). Results showed that PD participants with unimpaired verbal WM processed metaphors such as, ''*That baby's cheeks are roses*'', in a manner similar to HC participants, whereas PD patients with impaired WM were notably slower and less accurate in their responses to these metaphorical expressions.

These findings argue that there is an important interaction between verbal WM capacity and the ability to comprehend metaphorical language in PD, and perhaps other pragmatic abilities, which are known to be dependent on intact WM/fronto-striatal systems which deteriorate in PD. More generally, these data fit with theories which state that many language processing deficits produced by brain damage can be explained by the individual resource capacity of individual patients (e.g., Caplan, Waters, DeDe, Michaud, & Reddy, 2007; McNeil, Odell, & Tseng, 1991; Monetta & Joanette, 2003). However, the literature on this topic remains sparse and there are few empirical data that exemplify which social-pragmatic processes of language depend critically on intact WM functions in PD.

1.1. Relationship between inference generation and WM capacity

Based on the small literature to date, another pragmatic ability that appears to be affected in PD patients is the ability to draw linguistic inferences (Berg et al., 2003). An *inference* can be defined as any piece of information that is not explicitly stated in a text; that is, an inference is any conclusion that a participant draws about what is ''not said'' based on what is actually ''said''. Drawing inferences is a necessary process in order to fully understand a narrative text or story; for example, when the events in a story are not explicitly related to each other, readers must generate an inference to link them together to form a coherent internal representation of the story. Presumably, this internal representation combines explicit information from the text and general world knowledge already held by the reader (McKoon & Ratcliff, 1992; Potts, Keenan, & Golding, 1988). The construction–integration model of reading text comprehension (Kintsch, 1988) is consistent with this description of inferencing and could also be applied to auditory text comprehension. According to the construction–integration model, an initial process in which the reader (or listener) generates many possible inferences is followed by a second process of integrating only those inferences that have a high degree of connection with the text. Thus, successful generation of an inference will result in a story representation that involves both the explicit specific propositions contained in the text and those implicit propositions that were inferred by the individual to connect information in the text.

In the psycholinguistic literature, it has been proposed that different types of inferences (e.g., coherence, predictive) can be drawn during discourse processing and that certain types of inferences are known to be critically dependent on the availability of individual processing resources during language comprehension. *Coherence* inferences (sometimes called backward, bridging, or minimal inferences) are routinely necessary to resolve an apparent coherence break in a text. Research indicates that coherence inferences are generated in an automatic manner with relatively minimal demands on individual processing resource capacity (Beeman, Bowden, & Gernsbacher, 2000; McKoon & Ratcliff, 1992; Potts et al., 1988). In contrast, *predictive* inferences (also known as forward or elaborative inferences), which are not always necessary to comprehend a text, are often drawn to predict upcoming consequences of story events or to elaborate the story. For example, after hearing "*The plane waited at the end of the runway*" many listeners would draw a predictive inference that the plane will take off. There is evidence that when compared to coherence inferences, predictive inferences demand more processing resources during language comprehension and are not drawn by all individuals in all situations (McKoon & Ratcliff, 1992). The likelihood that individual characteristics such as WM capacity influence the ability to generate predictive inferences from discourse has been specifically demonstrated by several studies (Lehman-Blake & Tompkins, 2001; St. George, Mannes, & Hoffman, 1997; see Lehman-Blake & Tompkins, 2001, for a review).

In one study, St. George et al. (1997) compared how healthy individuals with different WM capacity generated (required) coherence inferences versus (optional) predictive inferences by analyzing evoked brain potentials to stimuli in each condition. Results showed that participants with high WM capacity generated both coherence (required) and predictive (optional) inferences, whereas participants with low WM capacity only generated basic coherence inferences. The authors argued that for participants with low WM, these resources were taxed to the point that other processes that required WM, such as syntactic analysis and integration, were rendered ineffective during the task (St. George et al., 1997). The claim that there is an important relationship between inferencing abilities and WM capacity during normal language processing is supported by other research which has compared these abilities in healthy individuals with high versus low WM (Linderholm, 2002; Virtue, Haberman, Clancy, & Beeman, 2006).

1.2. Effects of PD on inference generation

In light of the data on normal inference processing, and research which has examined related pragmatic skills in the context of PD (McNamara & Durso, 2003; Monetta & Pell, 2007), there are reasons to suspect that changes in the WM capacity of PD patients could negatively impact inference generation abilities during discourse processing, especially predictive inferences which are highly resource demanding. To test this hypothesis, we adopted the Discourse Comprehension Test (DCT; Brookshire & Nicholas, 1993) as a standardized measure of how participants process explicit versus implied information during story comprehension; this task has been used effectively in the past with brain-damaged patients with cortical lesions as well as with PD patients (Ferstl, Walther, Guthke, & von Cramon, 2005; Murray & Stout, 1999; Nicholas & Brookshire, 1986, 1995). The DCT requires participants to answer a series of questions pertaining to different types of information presented in stories; some of these questions test how well the participant can process explicit main ideas or details mentioned in the stories, whereas other questions require the participant to process implied details (i.e., to generate a predictive inference) about the story which is assumed to be more resource demanding.

In an investigation of nine PD patients who performed the DCT, Murray and Stout (1999) found that PD patients were more accurate on questions probing main ideas than details, and, in addition, the patients were more accurate on questions probing stated (explicit) information than those which required inferences (implied information). When compared to HC participants, the PD patients were impaired as a group in interpreting both detailed and implied information from discourse. Although the authors commented on likely associations between their PD participants' discourse comprehension skills and general cognitive abilities, no significant correlations between these two sets of measures were actually found; this outcome may be due to the small size of their PD group and insufficient statistical power. In the present study, we adopted a similar approach to test inferencing abilities in a larger PD group and looked more carefully at how PD patients with normal versus impaired WM responded to questions about explicit and implied information in the DCT in reference to an HC group.

Since the DCT places significant off-line demands on WM in order to answer questions about each story, we expected the PD group to perform less accurately than the control group overall when responding to implicit and detailed information as demonstrated previously by Murray and Stout (1999). However, because PD patients tend to vary in the extent to which WM functions (and presumably the fronto-striatal pathways) are compromised in the mild–moderate stages of the disease (see Vera-Cuesta, Vera-Acosta, Alvarez-Gonzalez, Fernandez-Maderos, & Casabona-Ferandez, 2006), we predicted that subdividing the PD group according to whether individual patients had intact versus impaired WM would reveal a significant relationship between individual WM capacity and the ability to draw inferences. This relationship was expected to be most evident for recalling implied details about the stories which would require a relatively demanding, predictive inference in most cases. Through this approach, our findings should help clarify the role of WM in PD as a major and potentially primary source of these patients' difficulties on many tasks of pragmatic-language processing such as the ability to draw inferences.

2. Methods

2.1. Participants

Participants entered into the study were 14 native English speakers diagnosed with idiopathic PD (mean age: 65.9, range: 52–82) and 16 HC participants (mean age: 66.9, range: 49–80) matched for age, sex, and education. One PD participant was unable to complete the task and was subsequently excluded, leaving a total of 13 participants in the

PD group. All participants displayed normal or corrected-to-normal vision as determined by self-report, and acceptable hearing thresholds at the important frequencies for speech intelligibility (minimum of 30 dB HL at 500, 1000, and 2000 Hz), as confirmed by pure tone audiometric screening.

Diagnosis of idiopathic PD was confirmed by a neurologist on the basis of accepted motor criteria (Calne, Snow, & Lee, 1992). Motor disability of individuals within the PD group was in the mild to moderate severity range according to the Hoehn and Yahr (1967) staging criteria. All patients were optimally medicated during testing as follows: levodopa–carbidopa ($n = 6$), dopamine agonists/Mirapex ($n = 4$), MAO-B inhibitor/Selegiline ($n = 3$), COMT inhibitor ($n = 2$), amantadine ($n = 5$), and Permax ($n = 3$). Two PD patients were receiving an antidepressant. Patients with other serious medical conditions (e.g., stroke) or a history of substance or alcohol abuse were systematically excluded. All individuals were screened for dementia using the Mattis Dementia Rating Scale (DRS; Mattis, 1988) and there were no significant differences among the groups on this measure, $F(2, 26) = 0.43$, $p = 0.66$. The presence and severity of depression in all PD and HC participants was estimated using the short form of the Hamilton Depression Inventory (Reynolds and Kobak, 1995) and again the groups did not differ significantly on this measure [$F(2, 26) = 0.53$, $p = 0.59$].

2.2. Neuropsychological tests

Each PD and HC participant completed a battery of standardized neuropsychological tests which included measures estimating frontal lobe and executive resource functions (e.g., the ability to switch from one strategy to another, to mentally plan and solve problems, or to inhibit irrelevant information). Participants first completed a Verbal WM Span Test (Tompkins et al., 1994) which served as the basis for later splitting patients into subgroups of individuals with "impaired" versus "unimpaired" WM. This listening span task is an adaptation of Daneman and Carpenter (1980) where participants are required to listen to increasingly longer sequences of sentences and to recall the final word of all the sentences at the end of each sequence (Tompkins et al., 1994).

The other tests administered were Color Trail-Making Test (D'Elia, Satz, Uchiyama, & White, 1996), Tower of London (Culbertson & Zillmer, 2001), Warrington Recognition Memory Test for faces and words (Warrington, 1984), Benton Phoneme Discrimination and Face Recognition Subtests (Benton, Hamsher, Varney, & Spreen, 1983), Forward Digit Span Test, and a Verbal Fluency test. The attention subtest of the Mattis Dementia Rating Scale (Mattis, 1988) was also examined separately to provide further insight into basic attentional functioning. A series of one-way ANOVAs (reported in Table 2) indicated that the two PD subgroups (with impaired or unimpaired WM) and the HC group performed in a comparable manner on all cognitive and "frontal lobe" measures with the exception of the verbal WM task [$F(2, 26) = 15.00$, $p < 0.0001$] and the Benton Face Recognition task [$F(2, 26) = 10.98$, $p < 0.001$]. Tables 1 and 2 summarize the major demographic, clinical, and neuropsychological features of the three groups.

2.3. Discourse comprehension test

All participants performed the DCT (Brookshire & Nicholas, 1993) after completing the battery of neuropsychological tests. PD patients were tested in their homes when their

Table 1
Major demographic and clinical features of participants with Parkinson's disease (PD) and healthy control participants (HC)

	Group					
	PDI ($n = 6$)		PDU ($n = 7$)		HC ($n = 16$)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	71.0	7.3	61.6	9.0	66.9	9.4
Education (years)	15.0	3.2	14.3	2.9	15.3	2.8
Disease duration (years)[a]	7.5	3.2	6.4	2.0	–	–
Hoehn and Yahr stage	2.8	0.8	2.0	0.8	–	–
Mattis Dementia Rating (/144)	137.7	1.6	139.6	3.7	139.1	4.5
Hamilton Depression Inventory (/33)[b]	4.7	3.3	5.4	4.0	3.5	4.5

[a]Following diagnosis of PD.
[b]Increased scores indicate greater impairment.

Table 2
Neuropsychological performance measures obtained for the healthy control (HC) group compared to PD patients with unimpaired (PDU) or impaired (PDI) working memory

Neuropsychological tests	Group						ANOVA
	PDI ($n = 6$)		PDU ($n = 7$)		HC ($n = 16$)		
	Mean	SD	Mean	SD	Mean	SD	
DRS, Mattis Attention Subtest (/37)	36.3	0.8	36.6	0.8	36.1	1.4	NS
Working memory recall (/42)	23.0	1.3	31.9	3.6	35.0	5.5	$p<0.0001$[a]
Digit Span (/9)	6.8	0.8	7.0	1.2	7.2	1.6	NS
Verbal Fluency: Animals	14.0	2.1	15.7	4.6	19.1	9.4	NS
Benton Face Recognition (/54)	40.0	7.2	43.6	2.1	48.3	2.6	$p<0.001$[b]
Benton Phoneme Discrimination (/30)	27.2	2.1	27.3	2.2	27.6	1.5	NS
Color Trail-Making Test	104.0	30	94.0	43.9	91.8	24.2	NS
Warrington Memory: Faces	39.5	3.8	40.9	4.4	41.3	5.6	NS
Warrington Memory: Words	45.7	4.3	48.7	2.1	48.2	2.0	NS
Tower of London (initiation time, sec)	117.3	24.3	119.7	25.0	121.4	18.4	NS

NS: non-significant.
[a]All three groups differed significantly (HC > PDU > PDI) following Tukey's post hoc comparisons.
[b]HC > PDI only.

symptoms were least severe (in most cases 45 min to 1 h after receiving their medications), whereas HC participants were tested in a quiet laboratory at McGill University. Participants listened to short stories and then answered yes/no questions which probed their understanding of different aspects of the text, allowing their accuracy to be analyzed. Stimuli for the DCT were five pre-recorded 5-min stories, followed by eight yes/no questions per story (see Table 3 for an example of one of the stories).

The questions were designed to assess comprehension of information that varied in terms of both salience and directness: two questions probed stated main ideas, two probed

Table 3
Example of one story presented in the Discourse Comprehension Test (Brookshire & Nicholas, 1993)

George arrived at a baseball park just as the sun went down. When he got to his seat, he put on an old baseball glove and began to practice catching imaginary foul balls. He told everyone sitting nearby that he had been a famous high school baseball star
In the fifth inning, the batter hit a foul ball straight at George. George stood up and made a grab for the ball, but he fell over the railing onto the grass
When George got back to his seat, a man tapped him on the shoulder. George turned around and the man handed him the ball and a business card. George asked him if he was a baseball scout
Nope, said the man, I am with the circus. One of our clowns retired last week. Would you be interested in taking his place?

implied main ideas, two probed stated details, and two probed implied details. For example, after listening to the story about the man who goes to a baseball game, participants were asked the following questions: "Did George go to a baseball game?" (main idea stated); "Did George try to impress the people around him?" (main idea implied); "Was it an evening game?" (detail implied); "Was George's baseball glove new?" (detail stated). With respect to salience, questions about main ideas tested comprehension of key information that was either repeated or elaborated throughout the story, whereas questions about details tested comprehension of ancillary information that was referred to only once or not embellished. With respect to directness, questions about stated information referred to details that were explicitly stated in the story, whereas questions about implied information tested comprehension of details that had to be inferred from other material in the story.

Participants were encouraged to listen carefully to each story, which was presented auditorily through headphones from a laptop computer. At the end of each story, participants answered a series of yes/no comprehension questions and the responses were recorded by the examiner and entered manually into the computer. Participants were paid a nominal fee for their participation and to cover travel-related expenses whenever relevant. All data included in this study were obtained in compliance with the ethical regulations of McGill University. The accuracy of responses to different features of the text (salience, directness) was submitted to statistical analysis.

3. Results

3.1. HC versus PD participants

In the first analysis, the performance of all PD patients was compared with that of the HC participants similar to the analysis conducted by Murray and Stout (1999). This analysis was conducted to see if there were overall differences due to group membership without taking into account the effects of WM capacity. Separate mixed ANOVAs were conducted to examine the effect of directness (i.e., questions regarding stated versus implied information) and salience (i.e., questions regarding main ideas versus details). Post hoc analyses using the Tukey HSD method ($p<0.05$) were conducted to compare responses to different question types within each group.

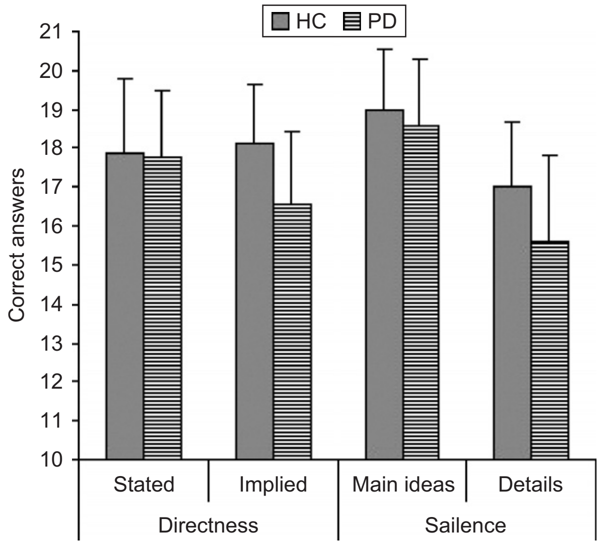

Fig. 1. Performance on the Discourse Comprehension Test (mean correct responses + standard deviation) for the healthy control (HC) participants and adults with Parkinson's disease (PD).

3.1.1. *Directness*

A 2×2 mixed ANOVA (Directness: stated versus implied information × Group: HC, PD) yielded no significant main effects for Group or Directness. However, the interaction of Directness × Group was significant [$F(1, 27) = 4.65$, $p < 0.01$]. Post hoc analyses revealed that there was a significant difference between the comprehension of stated versus implied information only for the PD group (see Fig. 1). These results indicate that answering questions about implied information was relatively more difficult for the PD than the HC participants.

3.1.2. *Salience*

A 2×2 ANOVA (Salience: main ideas versus details × Group: HC, PD) yielded a significant main effect of Salience [$F(1, 27) = 48.42$, $p < 0.0001$]. In general, questions about main ideas were answered significantly more accurately than questions about details by all participants. No main or interaction effects involving Group were significant (see Fig. 1).

3.2. *HC versus PD patients with impaired or unimpaired WM*

Our main analysis tested the effect of WM impairments within our PD group on the ability to draw inferences and to answer questions about story details. To address this question, the PD group was divided into two subgroups: PD patients with impaired WM (PDI) and PD patients with unimpaired WM (PDU). Following previous methods (Monetta & Pell, 2007; Tompkins et al., 1994), the two PD subgroups were constructed with reference to the distribution of verbal WM scores of participants in the HC group (WM range: 27–42, mean: 35). This division resulted in a subgroup of seven PD patients with unimpaired WM (PDU) who each demonstrated WM scores within the HC group range (WM range: 27–38, mean: 32). A second subgroup of six PD patients displayed impaired WM (PDI) with WM scores below the HC group range (WM range: 21–25, mean: 23). As our a priori goal was to test for specific group differences which revolve around WM capacity, planned comparisons between the HC group and each of the PD groups were carried out in addition to the ANOVAs reported below.

3.2.1. Directness

An initial 2×3 ANOVA compared the HC, PDU, and PDI groups on their ability to comprehend implied and stated information while listening to a story. Results revealed a marginally significant main effect of Group [$F(1, 26) = 3.80$, $p = 0.07$], where the PDI group was less accurate in answering all question types than the HC group. In addition, a marginally significant main effect of Directness was found [$F(1, 26) = 3.11$, $p = 0.09$]. As illustrated in Fig. 2, the PDI patients were selectively less accurate (78%) in their responses to questions about implied (inferred) information than the HC group (90%) and the PDU (87%) group. For the processing of implied information, planned comparisons revealed a significant difference between the HC and PDI groups [$F(1, 26) = 8.67$, $p < 0.01$], whereas there was no significant difference in this ability between the HC and PDU groups [$F(1, 26) = 0.77$, $p = 0.38$]. While accuracy to questions about implied information differed noticeably for the PDI and PDU groups (78% versus 87%), this difference was not significant [$F(1, 26) = 2.6$, $p = 0.11$].

3.2.2. Salience

A 2×3 ANOVA compared the HC, PDU, and PDI groups in their ability to comprehend information about main ideas and details while listening to a story. Results uncovered a

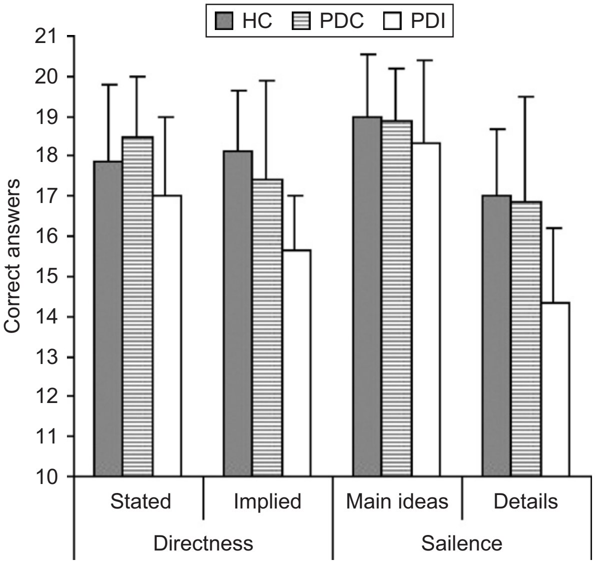

Fig. 2. Performance on the Discourse Comprehension Test (mean correct responses + standard deviation) for healthy control participants (HC) and PD patients with unimpaired (PDU) versus impaired (PDI) working memory.

Table 4
Relationship between neuropsychological measures and performance on the Discourse Comprehension Test (Pearson correlations) for the patients with Parkinson's disease ($n = 13$)

Neuropsychological tests	DCT score			
	Main ideas stated	Main ideas implied	Details stated	Details implied
Mattis Dementia Rating Scale	0.06	0.34	0.49	0.47
DRS, Mattis Attention Subtest	0.38	0.19	0.12	0.21
Hamilton Depression Inventory	0.33	0.13	−0.23	0.21
Working memory recall	0.43	0.20	0.57*	0.66*
Digit Span	0.49	0.30	0.25	0.29
Verbal Fluency task: animals	0.28	0.61*	0.56*	0.42
Benton Face Recognition	−0.11	−0.25	0.25	0.47
Benton Phoneme Discrimination	0.13	0.00	0.12	0.21
Color Trail-Making Test	0.09	−0.06	−0.35	−0.45
Warrington Memory: Faces	0.20	−0.02	0.40	0.55
Warrington Memory: Words	−0.25	−0.36	−0.12	0.38
Tower of London (initiation time)	−0.13	−0.29	−0.05	0.27

*$p < 0.05$.

significant main effect of Salience [$F(1, 26) = 53.24$, $p < 0.0001$] indicating that questions about main ideas were more accurately answered than questions about details. A marginally significant main effect of Group was also found [$F(1, 26) = 2.6$, $p = 0.09$] which showed that the PDI group tended to be less accurate than the HC group. The Salience × Group interaction was also a strong trend in the data [$F(2, 26) = 2.9$, $p = 0.07$]. Qualitative inspection of these patterns showed that the PDI group was less accurate than the HC group only when answering questions about detailed information. Planned comparisons performed on the data for processing detailed information revealed a significant difference between the HC and PDI groups [$F(1, 26) = 8.05$, $p < 0.01$], but no significant difference between the HC and PDU groups [$F(1, 26) = 0.02$, $p = 0.80$] or the PDI and PDU groups [$F(1, 26) = 4.2$ $p = 0.22$].

3.3. Correlations between neuropsychological variables and performance on the DCT

To examine the relationship between a wider range of neuropsychological measures and the performance of the PD patients on the DCT, Pearson correlations were computed between neuropsychological test scores and scores in each condition of the DCT as shown in Table 4. A moderate correlation was observed between verbal WM (words recalled in the listening span task) and the ability to draw inferences (implied and detailed information) [$r = 0.66$, $p < 0.05$]. A second correlation was observed between the WM measure and the ability to answer questions related to stated details in the story [$r = 0.57$, $p < 0.05$]. Finally, there was a correlation between the patients' verbal fluency and their ability to answer questions about implied main ideas [$r = 0.61$, $p < 0.05$] and stated details in the story [$r = 0.56$, $p < 0.05$]. No other correlations were observed for any of the remaining cognitive or "frontal lobe" measures.

4. Discussion

This study examined whether non-demented adults with idiopathic PD can effectively draw inferences from discourse and whether these abilities differ in individuals with "impaired" versus "unimpaired" WM. In general, our results confirm that WM capacity was significantly associated with the ability to generate inferences by individuals in the PD group under study, supplying additional evidence that PD impacts negatively on pragmatic-language processing (Berg et al., 2003; McNamara & Durso, 2003). However, our new data clarify that deficits for drawing inferences from discourse are not a uniform feature of PD, but rather depend in large part on the status of WM resources in individual patients (Monetta & Pell, 2007). These findings allow comments on the nature of pragmatic-language deficits in patients with PD and how deficits in inference generation and other "complex" forms of language processing may be traced to functional deterioration within frontal–striatal pathways which progressively limit the availability of WM resources in many PD patients.

4.1. Effects of PD on inference generation

The DCT provides a useful, standardized measure of how listeners with and without brain damage derive meaning about main ideas, story details, and explicit versus implicit information conveyed by discourse (Brookshire & Nicholas, 1993). Previous research shows that the ability to draw certain types of inferences, especially those which predict future events from a text, requires a greater WM capacity than the ability to process meanings which are explicitly stated (McKoon & Ratcliff, 1992; St. George et al., 1997). As expected, we found that a group of healthy adults responded more accurately to questions pertaining to main ideas than to story details, although the HC group did not show significant differences in the ability to process information which was explicitly stated versus implied (i.e., which would have generated an inference). Similarly, our data show that the PD group as a whole performed more poorly on questions probing story details than main ideas overall, although the PD patients also responded less accurately to questions which referred to *implied* relative to explicit information contained in the stories. The comprehension pattern demonstrated by our PD group as a whole, which emphasizes that patients had greatest difficulty processing meaning from details and implied information in discourse, replicates an identical pattern reported by Murray and Stout (1999) in the only other investigation which administered the DCT to PD patients.

At first glance, these findings appear to substantiate claims that the ability to draw inferences is a general feature of non-demented PD (Berg et al., 2003; Murray & Stout, 1999). However, given that PD leads to a progressive decline in WM capacity (e.g., Gabrieli, Singh, Stebbings, & Goetz, 1996), our main hypothesis tested whether PD patients with relatively "normal" WM (i.e., WM performance within the HC group range) would closely resemble HC participants in the ability to draw inferences from discourse, whereas PD patients with impaired WM would be selectively impaired in processing implied information when compared to the HC group. Planned comparisons between each PD subgroup and the HC group revealed no evidence that patients with unimpaired WM (PDU) differed significantly from HCs in the ability to respond to either details or implied information in the DCT. In contrast, PD patients with impaired WM (PDI) made notably more errors than both the PDU and HC groups when questions referred to details or implied story details (which would have required a predictive inference to be made) and our analyses demonstrated that only the PDI group was significantly less accurate in responding to implied information than the HC group. Finally, we observed a significant correlation between individual WM scores and the ability to respond to questions about implied information in the DCT when the PD group was analyzed as a whole. These outcomes suggest that the ability to draw inferences from discourse is related in an important manner to the WM capacity of PD patients, as was similarly argued in a related investigation of metaphorical-language comprehension in PD patients with impaired versus unimpaired WM (Monetta & Pell, 2007).

The possibility that the observed patterns on the DCT can be explained by other clinical or neuropsychological variables of our PD patients cannot be excluded but seems unlikely for this patient sample. When PD subgroups were constructed according to differences in WM capacity, there were few remaining differences between the PDU and PDI groups on several common measures of executive functioning which are meant to estimate mental organization and planning (Tower of London, Trails Test) and scores on these tests did not correlate with performance on the DCT for the PD group as a whole. Also, the PDU and PDI groups were highly comparable on measures of general cognitive status (Dementia Rating scale) and depression which can sometimes interfere with performance on language tasks. While one must interpret these data cautiously due to the small number of patients in each PD subgroup (PDU = 7, PDI = 6), it is reasonable to argue from our analyses that limitation in individual WM capacity was the major determinant of pragmatic abilities within the current PD group (Monetta & Pell, 2007). Of course, this claim does not preclude the possibility that other cognitive restrictions which we did not evaluate, such as slowed information processing or reductions in strategic attention, also contribute in some way to difficulties with inferencing in PD (Grossman et al., 2002; Lee, Grossman, Morris, Stern, & Hurtig, 2003). The impact of these factors, which likely refer to different but overlapping facets of individual processing capacity, will need to be differentiated by future studies.

Although our data show that only PD patients with impaired versus unimpaired WM performed with significantly less accuracy than HCs when questions required an inference, it bears noting that our two PD subgroups did not differ in a statistically significant manner for this measure (although the difference was marked as suggested by Fig. 2). This finding is not altogether surprising given that our PDU group, while displaying WM scores within the HC group distribution, was nonetheless significantly impaired relative to the HC group on the WM measure (and responded somewhat less accurately to questions about implied information as shown in Fig. 2). Since reductions in WM capacity in PD occur incrementally as the disease has progressive effects on the frontal–striatal pathways, one can speculate that the subtle reductions in WM of the PDU group studied here were beginning to influence their ability to draw inferences and to process details in the DCT, and, perhaps, to perform other resource-demanding tasks that rely on WM. Although this possibility remains speculative at present, the notion that neurogenerative illness should lead to *graded* differences in the ability to draw inferences, or to engage in other processes which rely on a depleting source of mental resources such as WM which are affected by the disease, is logical and may be exemplified by these data.

Independent of what type of information is being processed, the DCT is presumed to be relatively resource demanding due to significant "off-line" task requirements which inherently tax WM (i.e., listeners must retain a considerable amount of information until the end of the story and until the relevant question is asked by the examiner). For this reason, drawing inferences about details (i.e., generating a predictive inference) may have been especially difficult for PD patients with declining WM resources because this information does not pertain to the main theme of the story and it may often come from a single sentence in the text. Thus, it is likely that the length of the stories taxed the PD patients' WM resources in such a way that only the most difficult information to recall, that referring to implied details, could not be effectively retained. Within the present framework, it is possible that the same patients would demonstrate an improved capacity to derive inferences if they were to answer questions about implied details immediately after the necessary information was presented in the text, although this manipulation has not been tested to date. In a similar manner, administering tasks which require inferences to be generated in an *on-line* fashion during language processing might reveal different findings from those reported here if these tasks serve to mitigate demands on WM within the limitations of individual PD patients. The adoption of on-line paradigms in future studies is a promising direction to study the relationship between WM and inferencing abilities in PD with greater precision.

4.2. Contributions of frontal–striatal circuitry to WM and inference generation

A number of theories propose that following brain damage, linguistic deficits can vary in severity or fluctuate according to some measure of the processing capacity of individual patients (Caplan et al., 2007; Kolk, 1998; McNeil et al., 1991). In line with this research, a major implication of the present results is that inference deficits are related in a *secondary* manner to a disruption of WM functions in patients with PD. This observation is not trivial since WM deficits are a prominent cognitive sign of PD and are often detectable even in the early stages of the disease (Gilbert et al., 2005; Lewis et al., 2003; Lewis, Slabosz, Robbins, Barker, & Owen, 2005; Monetta & Pell, 2007; Owen, Iddon, Hodges, Summers, & Robbins, 1997; Pell & Leonard, 2003). As noted earlier, many of the operations which support WM performance have been linked to frontal–striatal systems (Cummings, 1993; Gabrieli et al., 1996; Goldman-Rakic, 1995) and it has been specifically argued that compromise within the frontal–striatal pathways is responsible for deficits in both WM and inference generation abilities in PD. Notably, Copland, Chenery, and Murdoch (2001) found that PD patients were impaired in generating predictive inferences when listening to short two-sentence passages (e.g., *The woman awoke to a sound from downstairs. She reached in her purse but found only a file*) and subsequently making a visual lexical decision about words that were related to a predictive inference which could be drawn from the passage (e.g., *burglar*). The PD patients, when compared to healthy participants, showed no priming for inference-related target words at a 1000 ms ISI; the authors attributed these deficits to underlying problems within frontal–striatal-dependent WM systems (Copland et al., 2001). These data argue that intact frontal–striatal systems upon which WM resources are dependent are critical to generate certain types of inferences as is implied by our data.

The likelihood that frontal–striatal systems maintain WM resources necessary for inference generation is further supported by the results of neuropsychological and neuroimaging studies (Ferstl & von Cramon, 2001; Ferstl, Guthke, & von Cramon, 2002; Mason & Just, 2004). Ferstl et al. (2002) reported that patients with left and bilateral frontal lesions (and not those with right frontal and left temporal lesions) had considerable difficulty drawing inferences in a task where they had to judge whether pairs of sentences were pragmatically related (i.e., whether the second sentence was a coherent continuation of the first sentence). Also in a recent fMRI study, Mason and Just (2004) showed that distinct regions of the brain are differentially involved in various stages of processing inferences (i.e., at the generation versus integration stages). More specifically, bilateral DLPFC seems to be involved whenever the generation of an inference is necessary whereas right hemisphere areas seem to play an active role in integrating the inferences into the internal representation of a story. Although the present data do not speak directly to these findings, they are consistent with the idea that frontal areas are implicated in inference generation, perhaps because these processes rely heavily on intact executive and WM resources.

If one looks at the broader literature on how the neuropathology of PD affects communication processes, it is therefore possible that some of the communication deficits exhibited by PD patients, such as difficulties in sequencing and syntactic integration, can be traced directly to dopaminergic changes within the basal ganglia (Friederici, Kotz, Werheid, Hein, & von Cramon, 2003; Pell & Leonard, 2003). In contrast, many pragmatic deficits or difficulties with complex sentence processing exhibited by PD patients are likely due to underlying changes in frontal–striatal/WM systems which are progressively impacted by the disease (Grossman et al., 2002; Hochstadt et al., 2006; Monetta & Pell, 2007), possibly at a somewhat later stage. Without doubt, future studies are needed to evaluate the various implications of frontal–striatal damage on high-level language abilities, such as understanding sarcasm, jokes, irony, or indirect requests. Presumably, these abilities are also dependent on intact systems for WM and are likely to be susceptible to frontal–striatal dysfunction as PD advances.

Finally, one of the contributions of this research is to show that pragmatic deficits in PD are often dependent on the resource/WM capacity of individual patients and not uniformly present in the disease. This finding has important implications for clinical evaluation purposes because it could influence the way in which pragmatic abilities are assessed and treated in individuals with PD. First and foremost, more standardized tests need to be developed to evaluate PD patients' pragmatic abilities in relation to WM capacity as a part of the patients' routine assessment. For the purposes of treatment, WM could be targeted to improve pragmatic communication skills; if patients are able to develop compensatory strategies to elaborate story details or to hold more information in WM, they may improve their ability to draw coherence and elaborative links across various elements of the story facilitating their overall comprehension. For example, story comprehension could be improved by rehearsing familiar stories with the patients, such that minimal information about story events is first provided and then this information becomes elaborated upon in subsequent recounting of the stories. If constructive steps are taken to remediate the pragmatic communication deficits of PD patients, it may be possible to mitigate the negative effects of these changes on how individuals with PD are often perceived in social contexts (Pell, Cheang, & Leonard, 2006; Pitcairn, Clemie, Gray, & Pentland, 1990).

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