Available online at www.sciencedirect.com
ScienceDirect
Brain and Language 101 (2007) 80–89
Brain and Language
www.elsevier.com/locate/b&l

Effects of verbal working memory deficits on metaphor comprehension in patients with Parkinson's disease

Laura Monetta *, Marc D. Pell

School of Communication Sciences and Disorders, McGill University, 1266 avenue des Pins ouest, Montreal, Que., Canada H3G 1A8

Accepted 15 June 2006
Available online 27 July 2006

Abstract

This research studied one aspect of pragmatic language processing, the ability to understand metaphorical language, to determine whether patients with Parkinson disease (PD) are impaired for these abilities, and whether cognitive resource limitations/fronto-striatal dysfunction contributes to these deficits. Seventeen PD participants and healthy controls (HC) completed a series of neuropsychological tests and performed a metaphor comprehension task following the methods of Gernsbacher and colleagues [Gernsbacher, M. A., Keysar, B., Robertson, R. R. W., & Werner, N. K. (2001). The role of suppression and enhancement in understanding metaphors. *Journal of Memory and Language, 45*, 433–450.] When participants in the PD group were identified as "impaired" or "unimpaired" relative to the control group on a measure of verbal working memory span, we found that only PD participants with impaired working memory were simultaneously impaired in the processing of metaphorical language. Based on our findings we argue that certain "complex" forms of language processing such as metaphor interpretation are highly dependent on intact fronto-striatal systems for working memory which are frequently, although not always, compromised during the early course of PD.

Keywords: Language processing; Parkinson's disease; Pragmatics; Cognitive resources; Fronto-striatal dysfunction; Basal ganglia

1. Introduction

Parkinson disease (PD) is a chronic, progressive nervous disease linked to decreased dopamine production in the basal ganglia, particularly in the *substantia nigra*. In the early stages of the disease, many PD patients display cognitive impairments in the absence of dementia, including difficulty with executive functions such as working memory (WM), planning, and selective attention (Brown & Marsden, 1991; Lewis et al., 2003; Taylor, St-Cyr, & Lang, 1986). Frequently, PD patients who present cognitive impairments exhibit concurrent language difficulties (see Berg, Bjornram, Hartelius, Laakso, & Johnels, 2003; Lewis, Lapointe, Murdoch, & Chenery, 1998). In some cases, these observations have led researchers to study PD patients, as a neuropsychological model for determining how the basal ganglia contribute to language processing and social cognition (Friederici, Kotz, Werheid, Hein, & Cramon, 2003; Grossman et al., 2003; Kotz, Frisch, Cramon, & Friederici, 2003; Pell & Leonard, 2003; Tettamanti et al., 2005; Ullman et al., 1997). However, it is likely that many of the language processing deficits observed in PD patients are linked to basic limitations in executive resources such as WM, due to the compromise of fronto-striatal pathways in PD (see Grossman et al., 2003 for a general review on this topic).

Certain language abilities are likely more dependent on an intact cognitive resource capacity, especially the "pragmatic" functions of language (McDonald & Pearce, 1998; Monetta & Champagne, 2004; Stemmer, Giroux, & Joanette, 1994). Pragmatics is at the interface of linguistic and non-linguistic cognitive systems (Perkins, 1998), where the capacity to communicate does not only rest on an intact language system but also on the knowledge of a specific

* Corresponding author. Fax: +1 514 398 8123.
E-mail address: Laura.monetta@mail.mcgill.ca (L. Monetta).

0093-934X/$ - see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandl.2006.06.007

communicative exchange context and high-level capacities (Martin & McDonald, 2003). For example, pragmatic language functions include the ability to generate appropriate inferences from linguistic material, to interpret metaphors and non-literal language, and to interpret language in the context of paralinguistic, non-verbal, and situational cues which inform intended meanings. To date, pragmatic communication abilities have been evaluated mostly in adults with focal right or left brain damage (Joanette, Goulet, & Hannequin, 1990; Myers, 2001), traumatic brain injury patients (McDonald, 1993), and schizophrenic patients (Titone, Holzman, & Levy, 2002). However, a small number of studies have recently explored these abilities in the context of PD by administering a general battery of tests presumably sensitive to pragmatic language functions (Berg et al., 2003; McNamara & Durso, 2003; Natsopoulos et al., 1997).

Natsopoulos and colleagues (1997) compared individuals with PD with healthy control (HC) participants on five deductive reasoning tasks (e.g., interpreting syllogisms) and three inductive reasoning tasks (e.g., interpreting metaphors). They found that relative to healthy controls, both types of reasoning abilities were significantly impaired in the PD patient group, especially in patients with bilateral motor signs. More recently, McNamara and Durso (2003) evaluated PD patients using a formal pragmatic communication skills protocol (Prutting & Kirchner, 1987). This battery examined features of verbal behavior (e.g., speech acts, message specificity, cohesion), non-verbal behavior (e.g., facial expressions, eye gaze, gestures), paralinguistic behavior (e.g., fluency, prosody, vocal quality), and the participants' conversational and social skills. In addition, traditional tests of frontal lobe functioning were administered (e.g., Tower of London, Stroop color-word test). Their results again demonstrated that pragmatic communication skills were impaired in the PD group and that these deficits were predicted by impairments on frontal lobe tasks. Finally, using a distinct battery of tests, Berg et al. (2003) reported that PD patients exhibit "high-level" language difficulties which affect the ability to generate inferences, recreate sentences, and comprehend ambiguities and metaphors in language.

It is noteworthy that, although none of these initial investigations evaluated specific pragmatic skills in extensive detail, difficulties in the comprehension of *metaphorical language* in PD were highlighted by more than one study. Metaphor comprehension is one dimension of pragmatic processing that has been presumed in the literature to be highly resource demanding (see Monetta, Ouellet-Plamondon, & Joanette, 2006). As previous studies have shown that PD participants were particularly impaired in comprehending metaphors within a general battery of pragmatic language tasks (Berg et al., 2003; Natsopoulos et al., 1997), a detailed study of this pragmatic dimension could help to better determine whether an important relationship exists between metaphor processing abilities and the individual resource capacity of the patients tested.

Different assumptions have been made about the normal processes that contribute to metaphor comprehension. According to the theory of Gernsbacher (see Gernsbacher, Keysar, Robertson, & Werner, 2001), understanding the meaning of a metaphor such as, "*That tiny mosquito was a vampire*" involves both the suppression of irrelevant information activated by the stimulus (e.g., *Vampires wear black*) and the enhancement of relevant information which pertains directly to the metaphorical interpretation (e.g., *Vampires suck blood*) (see Kintsch, 2000; for alternative perspectives on this process). These researchers have tested the enhancement and suppression of relevant and irrelevant information during metaphor comprehension using the timed property-verification task (Gernsbacher et al., 2001). In this procedure, participants read a series of sentences one at a time and must decide following each sentence whether or not it makes sense. "Prime" sentences which promote metaphorical processing (e.g., "*That tiny mosquito was a vampire"*) are followed by a "target" sentence that is either relevant (e.g., *Vampires suck blood*) or irrelevant (e.g., *Vampires wear black*) to the metaphorical interpretation presumably generated by the prime. The accuracy and latency of responses are then compared across key conditions to infer whether metaphorical meanings are being activated during sentence verification as a function of the prime-target relationship.

The results of studies involving young healthy individuals (Gernsbacher et al., 2001), and those which have compared young and older adults without brain damage (Newsome & Glucksberg, 2002), indicate that listeners tend to enhance metaphor-relevant information and to filter metaphor-irrelevant information (irrespective of age), based on results obtained from the timed property-verification task. These data imply that the suppression mechanism is especially crucial for eliminating potentially confusing (irrelevant) information during metaphor processing in healthy listeners. Given the emerging evidence that high-level pragmatic abilities such as metaphor comprehension are adversely affected by the neurodegenerative course of PD (Berg et al., 2003; Natsopoulos et al., 1997), we adopted the timed property-verification task to evaluate metaphor comprehension functions in a well-defined sample of adults with PD using the same set of materials that have been used successfully on healthy, elderly subjects (see Newsome & Glucksberg, 2002).

Our goals were to: verify whether PD patients exhibit abnormalities in the comprehension of metaphorical language based on a comprehensive assessment of these abilities; explore whether metaphor impairments reflect specific deficits of suppression or enhancement of metaphor-related information (Gernsbacher et al., 2001); and determine whether an important relationship exists between metaphor processing abilities and the individual resource capacity of the patients tested (with a particular focus on WM, which is a critical measure of cognitive/executive resources). We anticipated that metaphor comprehension would be problematic for PD patients as a group (Berg et al., 2003; Natsopoulos et al., 1997) but that performance would be highly influenced by the availability of cognitive resources (Monetta & Champagne, 2004; Stemmer, 1994) such as WM in individual PD patients. As suppression and enhancement of metaphorical information are assumed to draw significantly on working memory (see Tompkins, Lehman-Blake, Baumgaertner, & Fassbinder, 2001, 2000), one might expect these effects to be disturbed in some manner in the PD group with impaired WM, whereas the patients without WM impairments would show greater similarities to participants in the aged-matched control group.

2. Method

2.1. Participants

Seventeen native English speakers diagnosed with idiopathic Parkinson's disease (PD) and without dementia participated in the study. Diagnosis of idiopathic PD was confirmed by a residing neurologist on the basis of accepted motor criteria (e.g., Calne, Snow, & Lee, 1992). Patients ranged in age from 52 to 83 years old (average: 66.4). Motor disability of individuals within the PD group was in the mild to moderate severity range according to Hoehn and Yahr's staging criteria (Hoehn and Yahr, 1967). Most of the PD participants (14/17) showed unilateral motor signs at the time of testing, on the left ($n = 10$) or the right ($n = 4$) side; while only three PD participants displayed bilateral signs. All the patients were optimally medicated during testing as follows: Levodopa-carbidopa ($n = 15$), Dopamine agonists/Mirapex ($n = 5$), MAO-B inhibitor/Selegiline ($n = 3$), COMT inhibitor ($n = 3$), amantadine ($n = 6$) and Permax ($n = 4$). Three PD patients were receiving an antidepressant. Patients with other serious medical conditions (e.g., stroke) or history of substance abuse were excluded.

All PD patients were matched for sex, age, and educational status with 17 healthy aging control (HC) participants. Healthy volunteers were recruited from the local community and did not vary significantly in age ($t(32) = -0.27$, $p = .78$) or education ($t(32) = -0.75$, $p = .45$) from members of the PD group. Individuals in both groups exhibited a negative history of neurological and psychiatric disease and were screened for evidence of intact intellectual status on the Mattis Dementia Rating Scale (Mattis, 1988). A t-test confirmed that there were no differences between groups in general mental status [$t(32) = 1.48$, $p = .16$]. Presence and severity of depression in all PD and HC participants were estimated with the short-form of the Hamilton Depression Inventory (Reynolds & Kobak, 1995). Diagnosis of PD was associated with elevated depression scores [HDI-SF: $t(32) = -2.1$, $p < .05$]; although only one PD and HC participant satisfied criteria for severe (21.5) and moderate (16.5) depression, respectively. All participants displayed normal to corrected-to-normal vision as determined by self-report. Except for one PD individual who presented with auditory problems and had a hearing aid, all other participants had 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.

All PD and HC participants were screened using standardized neuropsychological tests and independent measures of "frontal lobe" executive resource capacity and functioning (e.g., the ability to switch from one strategy to another, to mentally plan and solve problems, or to inhibit irrelevant information). The tests administered were: Forward Digit Span; Verbal Working Memory Span (Tompkins, Bloise, Timko, & Baumgaertner, 1994); Color trail-making test (D'Elia, Satz, Uchiyama, & White, 1996); Verbal Fluency test; Tower of London (Culbertson & Zillmer, 2001); Warrington Recognition Memory test for faces and words (Warrington, 1984); and the Benton Phoneme Discrimination and Face Recognition Subtests (Benton, Hamsher, Varney, & Spreen, 1983).

The attention subtest of the Mattis Dementia Rating scale (Mattis, 1988) was also examined separately to obtain further information on basic attentional functioning. The major clinical features of each participant group and key demographic variables are summarized in Table 1. A series of t-tests revealed that both participant groups performed comparably in: measures of attention [Dementia Rating scale attention subscore, $t(32) = -0.61$, $p = .54$]; simple auditory memory [forward digit span, $t(32) = -0.35$, $p = .72$]; ability to discriminate speech sounds [Benton phoneme discrimination, $t(32) = 1.4$, $p = .16$;]; and verbal fluency [animal naming, $t(32) = 1.9$, $p = .06$]. However, verbal auditory WM capacity was significantly reduced in the PD group [$t(32) = 4.00$, $p < .001$]; as was the ability to switch from one strategy to another [Color trail-making test, [$t(32) = -2.56$, $p < .05$]; to initialize a strategy [Tower of London, initiation time: $t(32) = 2.97$, $p < .05$]; and to discriminate and memorize faces [Benton face discrimination task: $t(32) = 3.47$, $p < .05$; Warrington memory recognition faces: $t(32) = 2.08$, $p < .05$].

2.2. Tasks/Materials

All participants completed the battery of neuropsychological tests and then performed a metaphor comprehension

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

Variables	Groups				
	PD		HC		*t*-test
	M	*SD*	*M*	*SD*	PD ≠ HC
Age (years)	66.4	11.6	67.4	9.8	NS
Education (years)	14.3	3	15.3	2.7	NS
Disease duration (years)	7	2.3	—	—	—
Hoehn and Yahr rating score	2	0.8	—	—	—
Mattis dementia rating scale[a]	136.5	5.8	139.3	4.3	NS
Hamilton depression inventory[b]	6.6	5.4	2.9	4.3	$p < 0.05$

Each group was composed of 17 participants (nine female and eight male).
[a] Mattis DRS total score maximum: 144.
[b] Hamilton Depression inventory (short-form maximum = 33, increased scores indicate greater impairment).

task (timed property-verification task). For this task, participants read a series of sentences, which appeared one at a time on a computer screen, and decided whether each sentence made sense or not. The stimuli used in the experiment were identical to those presented by Gernsbacher et al. (2001). The list of sentences included 96 pairs of sentences which were related or unrelated. Half of the sentences made sense, such as "His watch is an antique" (YES response), and half of the sentence did not make sense, such as "Antiques are elected to office" (NO response). Combining these two kinds of sentences generated sentence pairs that allowed for four different response conditions: YES–YES, YES–NO, NO–YES and NO–NO. Sentences entered into the YES–YES condition constituted the experimental trials.

All "prime" sentences in each sentence pair were phrased in the form, "X is a Y". For the experimental trials, half of the prime sentences were *metaphorical* (such as "That baby's cheeks are roses"), and half were *literal* (such as "Those pretty flowers are roses"). For the experimental prime sentences, Gernsbacher et al. (2001) constructed first the metaphorical prime sentences and then their literal prime sentence counterparts by selecting a member of the basic-level category. None of the metaphors used in this study were reversible, signifying that the topic and the vehicle of the metaphor could not be interchanged and retain the same meaning as the original metaphor. This feature of the metaphor prime sentences precludes the possibility that priming, if observed, could be attributable to properties provided by the metaphor vehicle (see Newsome & Glucksberg, 2002; for more information on this topic). Each prime sentence, metaphor and literal, was followed by a target sentence. Target sentences were statements, such as: "Roses are often red". There were two kinds of target sentences: metaphor-relevant (MR), where the target referred to a property that was relevant to the metaphorical interpretation (e.g., "*That baby's cheeks are roses*"/"*Roses are often red*"); and metaphor-irrelevant (MI), where the target referred to a property that was not relevant to the metaphor (e.g., "*That baby's cheeks are roses*"/"*Roses have thorns*").

Sentences entered into the YES–YES condition (25% of all stimuli) constituted the experimental trials of the present study and responses to "prime" and "target" sentences within these pairs were always analyzed. The combination of different primes and targets within YES–YES trials resulted in four distinct types of experimental trials: metaphor prime/metaphor-relevant target; metaphor prime/metaphor-irrelevant target; literal prime/metaphor-relevant target; and literal prime/metaphor-irrelevant target. (See Table 2 for examples of experimental stimuli.) Overall, 24 sentences per participant were averaged for errors and RT for each target type, and 48 sentences per participant were averaged for errors and RT for each prime type. Using a quasi-Latin square procedure these trials were distributed into four different lists, randomly intermixed with an equal number of non-experimental trials (i.e., those eliciting NO–NO, YES–NO, and NO–YES responses). Trials generating a NO–NO response were composed of 24 pairs of anomalous sentences (e.g., "*Her sink in the bathroom is a bulb*"/"*Bulbs are only found in bath tubs*"). Among the 24 YES–NO trials, half were composed of a metaphor prime sentence followed by an anomalous sentence (e.g., "*That four hour opera was a sedative*"/*Sedatives need to be moved frequently*"); while the other half were composed by a literal prime sentence followed by an anomalous sentence (e.g., "*His new pen was a magic marker*"/"*Magic markers are food for rabbits*"). Finally the 24 NO–YES trials were anomalous primes followed by a property statement (e.g., "*The basement door is a sermon*"/"*Sermons are heard at church*".)

Table 2
An example of prime and target sentences used to construct the experimental trials (YES–YES judgment)

	Metaphor	Literal
Prime Sentence	That tiny mosquito was a vampire.	That Romanian count was a vampire.
Target Metaphor-relevant	Vampires suck blood.	Vampires suck blood.
Prime Sentence	That tiny mosquito was a vampire.	That Romanian count was a vampire.
Target Metaphor-irrelevant	Vampires wear black.	Vampires wear black.

2.3. Procedure

Neuropsychological testing of each participant was completed during two one-hour sessions, which preceded a third 30-minute session for administering the metaphor comprehension task. PD patients were tested at their home at a time of a day at which motor symptoms were typically least severe, while HC participants were tested in a quiet laboratory environment at McGill University. For the metaphor comprehension task, stimuli were presented from a portable computer with wide screen monitor and a millisecond timer controlled by SuperLab software (Cedrus Corporation, USA). Participants were seated in a comfortable chair approximately 60 cm from the computer screen. The four stimulus lists were distributed into four blocks, which were counterbalanced for presentation order between participants. All sentences were presented left justified and vertically centered on the screen so that the beginning of each sentence always appeared in the same location. Each sentence remained on the screen for 5500 ms or until the participant pressed a key, followed by a blank screen of 450 ms between sentences.

Participants were instructed to read each sentence silently and to decide whether or not it made sense as quickly as possible. Participants responded using their dominant hand by pressing the YES or NO button on a Cedrus 730 response box. Both accuracy and speed of the response were recorded. Prior to testing, participants read instructions on the computer screen that explained the task and they were informed that some of the sentences would be metaphorical. An explanation and some examples of metaphorical sentences were given. To familiarize participants with the procedure, testing always began with a training block of ten sentences. After each practice item, participants received written feedback on the computer screen about their accuracy ("correct" or "incorrect"), and speed when a response was not recorded within 5 s ("No answer"). Participants were paid a nominal fee to compensate for travel-related expenses and the inconvenience of testing.

3. Results

The accuracy and response times (RT) for judging prime and target sentences were analyzed separately. Only verification times for which participants responded correctly to both the prime sentence and the target were analyzed. Outliers, defined as two standard deviations above or below each participant's mean for each independent condition, were deleted (8% of total data points). Data from one HC participant who performed poorly throughout the experiment (<65% correct for all sentence pair types) were eliminated from all analyses on the basis that this participant did not correctly understand the task. To verify that there were no items that produced more errors or longer RT in a predominant way, an item analysis was run and showed no difference between all the sentences used in the task.

3.1. Analyses of prime sentences

A general analysis first compared the number of errors and the mean RT when judging metaphor prime sentences e.g., "*That tiny mosquito was a vampire*" versus literal primes sentences e.g., "*That Romanian count was a vampire*". A 2 × 2 ANOVA involving group (PD, HC) and prime type (metaphor, literal) indicated that for both participant groups, judgments about metaphorical sentences generated more errors ($F_{(1.31)} = 77.64$; $p < .01$), and were slower ($F_{(1.31)} = 3.92$; $p < .05$) than judgments about literal sentences (main effects of prime type). For both dependent measures, there was a group main effect indicating that the PD group made more errors ($F_{(1.31)} = 4.89$; $p < .05$) and was slower ($F_{(1.31)} = 18.2$ $p < .001$) than the HC group in responding to both prime types. There was no interaction of group by prime type for either analysis. The data for prime sentences are summarized in Table 3.

3.2. Analyses of target sentences

A second set of analyses considered the errors and RTs to target utterances which followed a relevant or irrelevant prime sentence. In general, it was noted that both participant groups responded very accurately to the target sentences (less than 5% errors) irrespective of the prime type. Three different analyses were run to evaluate the judgment of targets as a function of prime type sentence.

Table 3
Mean errors and response times for metaphorical and literal prime sentences for the healthy control (HC) and Parkinson disease (PD) groups of participants

	Group							
	Number of errors (%)				Reaction time (ms)			
	HC		PD		HC		PD	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Prime type								
Metaphor	15.0	9.9	19.7	8.8	1870	499	2537	544
Literal	3.5	2.3	7.7	4.1	1809	481	2447	492
Target type								
MR-metaphor[a]	0.1	0.3	0.9	1.1	1065	268	1322	307
MR-literal	0.1	0.2	0.7	1.1	1099	295	1290	220
MI-metaphor[a]	0.7	0.7	0.8	0.8	1256	268	1632	323
MI-literal	0.2	0.5	0.8	1.5	1176	271	1467	260

[a] Metaphor-relevant (MR) and metaphor-irrelevant (MI) target types were associated with literal and metaphorical sentences.

First, two separate ANOVAs examined the error and latency patterns corresponding to metaphor-relevant (MR) targets (e.g., "*Vampires suck blood*") versus metaphor-irrelevant (MI) targets (e.g., "*Vampires wear black*"), following a metaphorical prime ("*That tiny mosquito was a vampire*"). Each measure was entered into a 2 × 2 design involving group (PD, HC) with repeated measures on target type (MR, MI). The ANOVA on errors yielded no group or target type main effects but a significant interaction between group and target type was observed, $F_{(1.31)} = 6.19$; $p < .05$. Post-hoc comparisons using the Tukey HSD test ($p < .05$) showed that the HC group made more errors judging metaphor-irrelevant than metaphor-relevant targets following a metaphorical prime sentence; whereas accuracy for the PD group did not vary as a function of target type. The corresponding ANOVA on RT revealed a target type main effect, $F_{(1.31)} = 54.3$; $p < .001$ and a group main effect, $F_{(1.31)} = 9.67$; $p < .005$, revealing that the PD patients were generally slower to judge target sentences than the HC group. There was no interaction of group and target type.

A second analysis evaluated the average errors and verification times when judging sentences that were always metaphorical relevant (MR), e.g., "*Vampires suck blood*" after participants read a metaphorical prime sentence ("*That tiny mosquito was a vampire*"!) versus a literal prime sentence (e.g., "*That Romanian count was a vampire*"). This analysis was conducted to test whether participants were able to enhance metaphor-relevant information in the task as evaluated by Gernsbacher et al. (2001). Each 2 × 2 ANOVA produced a group main effect showing that PD patients made more errors $F_{(1.31)} = 7.5$; $p < .05$, and were slower, $F_{(1.31)} = 8.57$; $p < .01$ than the HC participants overall. There were no differences in error or latency rates to judge metaphor-relevant targets after reading a literal compared to a metaphorical prime, implying the absence of the "*enhance accessibility effect*" described by Gernsbacher et al. (2001). The interaction of group and target type as a function of prime sentence was not significant for errors or RTs.

Table 4
Neuropsychological performance measures obtained for the healthy control (HC) group compared to Parkinson disease patients with unimpaired (PD-U) or impaired (PD-I) working memory

Tests of executive resources	Groups						
	HC		PD-U		PD-I		PD-U ≠ PD-I
	M	*SD*	*M*	*SD*	*M*	*SD*	*t*-test
DRS, Mattis attention subtest/37	36	1.37	36.5	0.8	36.1	0.9	NS[b]
Working memory recalled/42	35.2	5.5	31.6	1.8	22.8	1.2	$p < 0.001$
Digit span/9	6.8	1.8	7.3	0.4	6.6	1	NS
Verbal fluency task (animals)	21.2	10	15.3	4.7	14	1.7	NS
Benton face recognition/54	47.9[a]	4.7	42.5[a]	3.9	40.7	6.7	NS
Benton phoneme discrimination/30	28.3	1.3	27.3	2.2	26.5	1.9	NS
Color trail-making test	105	45.3	105.5	23.7	142.1	53	NS
Warrington recognition memory faces	47.8	2.4	47.3	3.8	42.11	7.1	NS
Warrington recognition memory words	41.5	5.5	40.8	4.7	40.11	4.8	NS
London tower (Initiation time)	124	18.6	107	17	114	24	NS
Hamilton depression inventory	2.9	4.3	7.4	5.1	5.7	4.2	NS

[a] The only significant difference between HC and PD-U was in the Benton face recognition [*t*-test (Bonferroni adjusted probability $p < 0.05$)].
[b] NS (non-significant).

A third analysis focused on the error and latency patterns recorded for metaphor-irrelevant (MI) targets as a function of the prime type sentence to establish if participants were able to suppress irrelevant information in the task (Gernsbacher et al., 2001). Separate 2 × 2 (Group × Target type) ANOVAs compared whether metaphor-irrelevant statements, ("*Vampires wear black*") were judged differently after participants read a metaphorical prime sentence ("*That tiny mosquito was a vampire*"), versus a literal prime sentence ("*That Romanian count was a vampire*"). For errors, the ANOVA yielded no main or interactive effects. For verification times, there was a group main effect, $F_{(1.31)} = 14.048$; $p < .001$ which again showed that PD participants were generally slower than HC participants. In addition, a main effect of target type, $F_{(1.31)} = 16.91$; $p < .001$ was explained by the fact that responses to metaphor-irrelevant targets were slower when they followed a metaphor prime than a literal prime, reflecting the *suppression effect*. However, qualitative inspection of the group trends on a marginally significant interaction in the data indicated that this *suppression effect* appeared only for the PD group of participants.

3.3. Influence of working memory on metaphor comprehension

To evaluate the possible relationship between our metaphor comprehension measures and the individual cognitive resource (working memory) capacity of our PD patients, a final set of analyses was performed by sub-dividing individuals in the PD group according to their performance on the verbal working memory span task (Tompkins et al., 1994). PD participants with a WM span comparable to that of the HC participant group (range: 27–42) were entered into the PD "unimpaired" WM group (PD-U); whereas those with WM scores outside the expected normal range (less than 27) were entered into the PD "impaired" WM group (PD-I). This division resulted in a PD-U group of eight patients (score range: 29–34; average: 31.6), and a PD-I group of nine patients (score range: 21–25; average: 22.8). Although the two PD subgroups were significantly different in verbal working memory span [$t = (15) = -8.7$, $p < .001$], a series of *t*-tests showed that the two PD groups were comparable in education level [$t = (15) = -0.4$, $p = .68$], disease stage [$t = (15) = 1.3$, $p = .32$] and disease duration, [$t = (15) = 1.2$, $p = .22$], although not in age [$t = (15) = 2{,}19$, $p < .05$]. The PD-I group was older (range: 62–82; average: 71) than the PD-U group (range: 48–79, average: 61). A series of *t*-tests indicated that the two PD subgroups performed in a comparable manner on all cognitive and "frontal lobe" measures gathered with the exception of WM, as demonstrated in Table 4. A correlation analysis between dopamine administration level with WM and answers to primes and targets was also run. Results show a significant positive correlation ($p = -053$) between WM and the level of dopamine administration.

Due to the fact that our PD subgroups differed significantly in age, the age of all participants was entered as a covariate in all ANOVAs which tested the effects of working memory performance on metaphor comprehension measures. As before, accuracy and RT were analyzed for prime and target sentences to compare the performance of the two PD subgroups with the HC group. A 3 × 2 ANOVA involving different prime types (metaphorical, literal) for the three participant groups (HC, PD-U and PD-I) reaffirmed that metaphorical sentences generated more errors ($F_{(1.30)} = 74.31$; $p < .001$), and took longer to judge ($F_{(1.30)} = 4.78$; $p < .05$) than literal sentences (main effects for prime type). Critically, a significant group main effect ($F_{(2.30)} = 7.6$; $p < .005$; $F_{(2.30)} = 10.628$; $p < .001$) was explained by the fact that only PD-I (and not PD-U patients) were slower and made more errors than the HC group (see Fig. 1). There was no interaction of group and prime type.

The analysis of errors and RT to target sentences as a function of prime sentence attributes was also repeated according to the new grouping variable. The 2 × 3 (target

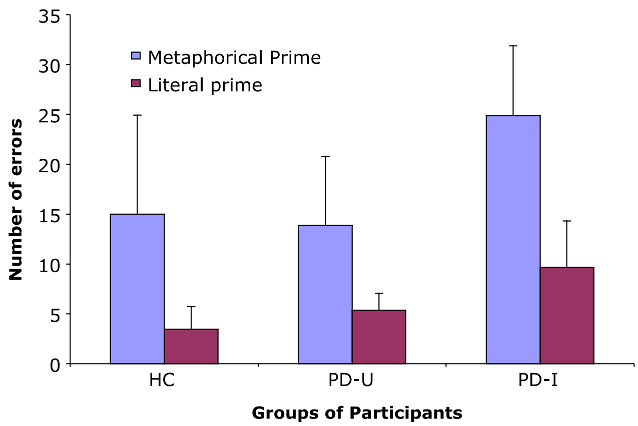

Fig. 1. Mean error rate for literal and metaphorical prime sentences for healthy control participants (HC) and Parkinson Disease patients with unimpaired (PD-U) or impaired (PD-I) working memory.

type × group) ANOVA, which examined the accessibility of metaphor-relevant and irrelevant targets after reading a metaphor prime, showed a main group effect for RT, $F_{(2.31)} = 5.38$; $p < .05$. Tukey comparisons ($p < .05$) indicated that the PD-I group was significantly slower than the HC group in both conditions, whereas the PD-U group did not differ from either the HC or the PD-I group. Predictably, responses to MR targets were generally faster than to MI targets, $F_{(1.30)} = 56.6$; $p < .001$. The ANOVA on errors yielded no significant main effects but did produce a significant interaction of group and target type, $F_{(2.30)} = 3.19$; $p < .05$. It was found that only the HC participants exhibited greater accuracy for metaphor-relevant versus irrelevant target sentences following a metaphorical prime, as illustrated in Fig. 2.

A 2(MR-target type) × 3 (group) ANOVA on MR targets was next conducted to test whether participants show an "*enhance accessibility*" effect following metaphorical versus literal primes. For error rates, there was a group main effect, $F_{(2.30)} = 6.28$; $p < .01$ demonstrating that only the PD-I group made more errors in this context than the HC group. No additional effects were significant for this analysis. For latencies, no main or interactive effects were found suggesting an absence of the "*enhance accessibility*" effect for all groups (see Fig. 2).

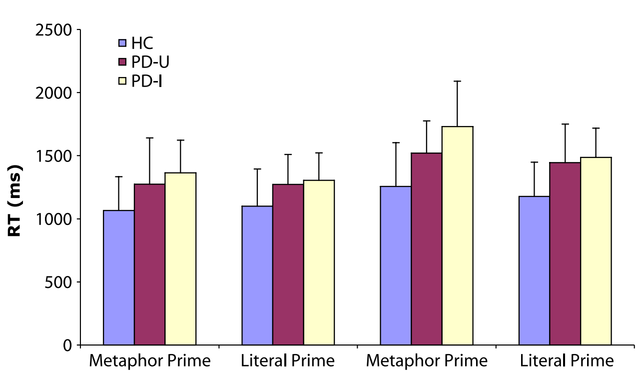

Fig. 2. Mean response time of for healthy control participants (HC) and Parkinson Disease patients with unimpaired (PD-U) or impaired (PD-I) working memory to metaphor-relevant (MR) and metaphor irrelevant (MI) targets after metaphorical or literal prime ! sentences.

Finally, to re-analyze the processing of metaphor-irrelevant targets ("suppression effect"), a 2 × 3 ANOVA was conducted. For errors, no significant effects emerged for this analysis. For RT, the analysis produced significant main effects for group [$F_{(2.30)} = 5.98$; $p < .01$], target type [$F_{(2.30)} = 20.09$; $p < .001$], and the interaction of group × target type [$F_{(2.30)} = 4.2$; $p < .05$]. Post-hoc inspection of the interaction revealed that only the responses of the PD-I group differed in speed when processing metaphor-irrelevant targets as a function of prime sentences, showing a *suppression effect* only for the PD-I group (see Fig. 2).

4. Discussion

This research studied how PD patients with and without cognitive resource deficits process metaphorical meanings in language. In particular, we looked at whether metaphor comprehension deficits in PD patients are strongly tied to individual resource capacity which is likely needed to support the concurrent storage and processing of metaphorical information during language processing. In general, we noted that PD participants were less efficient in processing metaphors, committing more errors and responding more slowly in all conditions. Interestingly, extended analysis of our data revealed that only a subgroup of PD patients with reduced WM abilities differed significantly from the HC participants in both the speed and accuracy of their decisions in the metaphor conditions. Thus, our data provide a meaningful argument that the impact of PD on metaphor comprehension varies as a function of WM abilities and that language functions implicated by this, and perhaps related tasks seem to be susceptible to critical reductions in WM in many adults with PD (see Grossman et al., 2003; for similar conclusions).

4.1. Influence of working memory on metaphor comprehension in PD

Many researchers agree that WM can be defined as a dynamic cognitive system required for the concurrent storage and processing of information (Baddeley, 1986; Just & Carpenter, 1992; Petrides, 1995). Previous studies of WM deficits in patients with PD have shown that these executive resource functions are frequently attenuated in the disease, even in the early stages (Gabrieli, Singh, Stebbings, & Goetz, 1996; Taylor et al., 1986). This study demonstrates that PD patients with reduced WM capacity but who displayed "normal" cognitive abilities in many other areas of testing were uniquely impaired in the comprehension of metaphors, whereas PD participants at a similar disease stage but without WM difficulties performed largely like the HC participants. Brief comparison of the findings uncovered no apparent relationship between metaphor comprehension abilities and other PD characteristics (e.g., side of motor signs, and stage of the disease), although the influence of these factors should be monitored further in future research.

Previous studies have noted that PD patients perform like healthy control participants on various tasks when only relatively few items are involved, but in more demanding task conditions their deficits begin to emerge (Gabrieli et al., 1996; Owen, James, Leigh, Marsden, & Quinn, 1992). It would appear that processing metaphorical language—a relatively "demanding" language processing task that requires the manipulation of potentially relevant and irrelevant information within WM in order to interpret the non-literal meaning of these sentences—is within the cognitive capacity of many PD patients, except those who present with detectable restrictions in their verbal WM store. These results lend further support to the assumption put forward by Gabrieli et al. (1996) that many cognitive difficulties in PD patients are in some degree predicted by limitations in individual WM capacity, extending this notion as a possible explanation of certain pragmatic language deficits witnessed in PD. On a related note, deficits in sentence comprehension have also been attributed to a limitation in executive resources, perhaps affecting strategic attention and processing speed during these tasks (Grossman et al., 2003).

Recently, Lewis and colleagues differentiated the verbal WM functions of two groups of PD patients who differed according to their performance on the tower of London test (Lewis et al., 2003). Their results suggested that verbal WM deficits are only observed in PD if the task requires the manipulation of information within WM, but not if the task requires only the maintenance and retrieval of that information, suggesting that it is the fronto-striatal circuitry that is primarily affected in PD. Similarly, Gilbert and colleagues examined the nature of verbal WM in PD patients using a classical verbal span test, WM tasks and psychomotor speed tasks (Gilbert, Belleville, Bherer, & Chouinard, 2005). Their results again suggested that PD patients are selectively impaired on those WM tasks which centre on the manipulation of information in memory.

Based on neuroimaging studies, the neurobiological basis of WM procedures is known to involve the prefrontal cortex (D'Esposito et al., 1995; Salmon et al., 1996). More specifically, the manipulation of information within WM is thought to implicate mid-dorsolateral prefrontal regions, whereas processes for encoding and retrieval involve more ventral prefrontal regions (see Petrides, 1995 for a general review on this topic). In patients with idiopathic PD, dopamine depletion within the nigro-striatal dopamine system is known to yield progressive dopamine depletion and corresponding functional disturbance within the frontal cortex itself, by means of connecting nigro-striatal-thalamo-cortical circuits (Alexander, DeLong, & Strick, 1986). According to Alexander et al. (1986), five distinct pathways connect the frontal cortex to the basal ganglia. Owen and collaborators have shown that the disruption of pathways serving the prefrontal cortex results in a WM deficit (Owen, Doyon, Dagher, Sadikot, & Evans, 1998). In conclusion, all the evidence mentioned above suggests that the frontal-striatal loop and projections from the dorsolateral PF cortex are affected in PD and this is the same anatomical region involved in WM process.

4.2. On the suppression and enhancement of metaphor-related information in PD

In an exploratory manner, the present study also examined whether metaphor deficits in PD affect distinct procedures for suppressing metaphor-irrelevant information and enhancing metaphor-relevant meanings (Gernsbacher et al., 2001). In contrast to previous findings reported by these researchers, the current results did not reveal an important effect of either enhancement or suppression on the performance of either the HC or PD participants, (based on previously-established methods for determining these effects). As explained by Gernsbacher and colleagues (2001), an enhancement effect is due to an increase in the activation of memory nodes for information needed during the metaphor comprehension process, and should be revealed by the facilitation of decisions about a metaphor-relevant target following a metaphor prime sentence (versus a literal prime sentence). However, this comparison yielded no significant differences either within or among the three groups in this study. Possibly, the smaller number of participants in our experiment compared with the Gernsbacher et al. (2001) study could explain these differences across studies. Given the prominent demands of WM for this particular task, it is perhaps unsurprising that the PD-I group was slower and made more errors than the HC group when processing metaphor-related targets, whereas the PD-U group performed just like controls. This issue could be addressed in the future by investigating metaphor comprehension in PD using a distinct task design or in multiple conditions which vary the task demands on WM processes in a systematic manner.

Of even greater interest than enhancement, all theories about the metaphor comprehension process argue that filtering irrelevant (literal) information is a central requirement (Newsome & Glucksberg, 2002). This filtering process may involve reduced activation of memory nodes for concepts or information which is not directly relevant to the comprehension of metaphorical meanings. According to Gernsbacher et al. (2001), metaphor-irrelevant properties become less accessible so they are suppressed to enable metaphor understanding. Here, we found that there was no difference in responses to metaphor-irrelevant targets following a metaphorical versus a literal prime sentence except for the PD-I group, implying that only the PD group with impaired WM showed a suppression effect. Since we found no evidence of a suppression effect for our HC group, one can speculate that the results for the PD-I group in our study do not reflect the suppression process, but rather, a more general delay process. While in need of further testing, support for the idea of a delay process in our PD-I patients comes from Grossman et al. (2002), who found that impaired comprehension of complex syntax correlated with a measure of processing speed for planning and inhibition in patients with Parkinson's disease.

4.3. Fronto-striatal contributions to language processing

The cognitive and language deficits present in non-demented adults in the early stages of PD are sometimes studied to infer the role of the basal ganglia in different aspects of cognition (e.g., Brown & Marsden, 1998; Taylor et al., 1986; Ullman et al., 1997). Although idiopathic PD cannot be treated as a "pure" model of basal ganglia functioning and related behavioral findings must be interpreted with caution, the accumulating descriptions of language as well as cognitive deficits in PD patients have generated various theories about the direct involvement of sub-cortical structures in certain aspects of language processing (Crosson, 1985; Wallesch & Papagno, 1988). For example, some have speculated that the basal ganglia supply a mechanism for certain forms of implicit learning during language acquisition (Ullman et al., 1997) and the contribution of the striatum to the decoding of speech prosody and other sequential representations in the vocal channel has been advanced (Pell & Leonard, 2003).

In the case of pragmatic language phenomena, such as the ability to process metaphors and to generate linguistic inferences (Monetta, Grindrod, & Pell, in review), our current data suggest that reductions in fronto-striatal systems which support WM and other determinants of "executive resource capacity", seem to be responsible for these types of deficits in many patients with PD. When viewed in the broader literature, this explanation renders it likely that many adults with PD exhibit both primary and secondary impairments which affect different aspects of their communication and language, due to the evolving neuropathological consequences of the disease with progressive fronto-striatal involvement. Future studies are clearly needed to evaluate the contributions of the fronto-striatal circuitry in other high-level language abilities, such as the ability to process linguistic and social inferences which similarly depend on intact systems for WM and fronto-striatal "executive" functions.

Acknowledgments

This research was supported by CIHR-IA postdoctoral fellowship to the first author (L.M.) and a CIHR operating grant and New Investigator award to the second author (M.D.P.). The assistance of Joshua Simmonds, Shiri Freiwald, Lisa Spinney and Nicole Price in data collection and manuscript preparation is gratefully acknowledged.

References

Alexander, G. E., DeLong, M. R., & Strick, P. L. (1986). Parallel organization of functionality segregated circuits linking basal ganglia and cortex. *Annual Review of Neuroscience, 9*, 357–381.

Baddeley, A. D. (1986). *Working memory*. Oxford, England: Oxford University Press.

Benton, A. L., Hamsher, K. D., Varney, N. R., & Spreen, O. (1983). *Contributions to neuropsychological assessment: A clinical manual.* Oxford: Oxford University Press.

Berg, E., Bjornram, C., Hartelius, L., Laakso, K., & Johnels, B. (2003). High-level language difficulties in Parkinson's disease. *Clinical Linguistics and Phoniatric, 17*(1), 63–80.

Brown, P., & Marsden, C. D. (1998). What do the basal ganglia do? (review). *Lancet, 351*, 1801–1804.

Brown, R. G., & Marsden, C. D. (1991). Dual task performance and processing resources in normal subjects and patients with Parkinson's disease. *Brain, 114*, 215–231.

Calne, D. B., Snow, B. J., & Lee, C. (1992). Criteria for diagnosing Parkinson's disease. *Annals of Neurology, 32*, 125–127.

Crosson, B. (1985). Subcortical functions in language: A working model. *Brain & Language, 25*(2), 257–292.

Culbertson, W. C., & Zillmer, E. A. (2001). *The tower of London DX (TOL DX) Manual.* North Tonawanda, NY: Multi-Health Systems.

D'Elia, L. F., Satz, P., Uchiyama, C. L., & White, T. (1996). *Color trails test: Professional manual.* Odessa, FL: Psychological Assessment Resources.

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 378*(6554), 279–281.

Friederici, A. D., Kotz, S. A., Werheid, K., Hein, G., & Cramon, D. Y. v. (2003). Syntactic comprehension in Parkinson's disease: Investigating early automatic and late integrational processes using event-related brain potentials. *Neuropsychology, 17*(1), 133–142.

Gabrieli, J. D., Singh, J., Stebbings, G. T., & Goetz, C. G. (1996). Reduced working memory span in Parkinson's disease: Evidence for the role of a frontostriatial system in working and strategic memory. *Neuropsychology, 10*, 322–332.

Gernsbacher, M. A., Keysar, B., Robertson, R. R. W., & Werner, N. K. (2001). The role of suppression and enhancement in understanding metaphors. *Journal of Memory and Language, 45*, 433–450.

Gilbert, B., Belleville, S., Bherer, L., & Chouinard, S. (2005). Study of verbal working memory in patients with Parkinson's disease. *Neuropsychology, 19*, 106–114.

Grossman, M., Cooke, A., DeVita, C., Alsop, D., Detre, J., Chen, W., et al. (2002). Age-related changes in working memory during sentence comprehension: An fMRI study. *Neuroimage, 15*(2), 302–317.

Grossman, M., Cooke, A., DeVita, C., Lee, C., Alsop, D., Detre, J., et al. (2003). Grammatical and resource components of sentence processing in Parkinson's disease: An fMRI study. *Neurology, 60*(5), 775–781.

Hoehn, M. M., & Yahr, M. D. (1967). Parkinsonism: Onset, progression and mortality. *Neurology, 17*, 427–442.

Joanette, Y., Goulet, P., & Hannequin, D. (Eds.). (1990). *Right hemisphere and verbal communication.* New York: Springer Verlag.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*, 122–149.

Kintsch, W. (2000). Metaphor comprehension: A computational theory. *Psychonomics Bulletin Review, 7*(2), 257–266.

Kotz, S. A., Frisch, S., Cramon, D. Y. v., & Friederici, A. D. (2003). Syntactic language processing: ERP lesion data on the role of the basal ganglia. *Journal of International Neuropsychology, 9*(7), 1053–1060.

Lewis, S. J., Cools, R., Robbins, T. W., Dove, A., Barker, R. A., & Owen, A. M. (2003). Using executive heterogeneity to explore the nature of working memory deficits in Parkinson's disease. *Neuropsychologia, 41*(6), 645–654.

Lewis, F. M., Lapointe, L. L., Murdoch, B. E., & Chenery, H. J. (1998). Language impairment in Parkinson's disease. *Aphasiology, 12*, 193–206.

Martin, I., & McDonald, S. (2003). Weak coherance, no theory of mind, or executive dysfunction? Solving the puzzle of pragmatic language disorders. *Brain & Language, 85*(3), 451–466.

Mattis, S. (1988). *Dementia rating scale professional manual*. Odessa, FL: Psychological Assessment Resources.

McDonald, S. (1993). Pragmatic language skills after closed head injury: ability to meet t! he informational needs of the listener. *Brain & language, 44*(1), 28–46.

McDonald, S., & Pearce, S. (1998). Requests that overcome listener reluctance: Impairment associated with executive dysfunction in brain injury. *Brain and Language, 61*(1), 88–104.

McNamara, P., & Durso, R. (2003). Pragmatic communication skills in patients with Parkinson's disease. *Brain & Language, 84*(3), 414–423.

Monetta, L., & Champagne, M. (2004). Processus cognitifs sous-jacents déterminant les troubles de la communication verbale chez les cérébrolésés droits. *Rééducation Orthophonique, 219*, 27–41.

Monetta, L., Grindrod, C.M., & Pell, M.D. (in review) Inference generation and working memory capacity in adults with Parkinson's disease.

Monetta, L., Ouellet-Plamondon, C., & Joanette, Y. (2006). Simulating the pattern of right-hemisphere-damaged patients for the processing of the alternative metaphorical meaning of words: Evidence in favor of a cognitive resources hypothesis. *Brain & Language, 96*(2), 171–177.

Myers, P. S. (2001). Toward a definition of rh syndrome. *Aphasiology, 15*, 913–918.

Natsopoulos, D., Katsarou, Z., Alevriadou, A., Grouios, G., Bostantzopoulou, S., & Mentenopoulos, G. (1997). Deductive and inductive reasoning in Parkinson's disease patients and normal controls: Review and experimental evidence. *Cortex, 33*(3), 463–481.

Newsome, M. R., & Glucksberg, S. (2002). Older adults filter irrelevant information during metaphor comprehension. *Experimental! Aging and Research, 28*(3), 253–267.

Owen, A. M., Doyon, J., Dagher, A., Sadikot, A., & Evans, A. C. (1998). Abnormal basal-ganglia outflow in Parkinson's disease identified with PET: Implications for higher cortical functions. *Brain, 121*, 946–965.

Owen, A. M., James, M., Leigh, P. N., Marsden, B. A. S. C. D., & Quinn, N. P. (1992). Fronto-striatal cognitive deficits at different stages of Parkinson's disease. *Brain, 115*, 1727–1751.

Pell, M. D., & Leonard, C. L. (2003). Processing emotional tone from speech in Parkinson's disease: a role for the basal ganglia. *Cognitive, Affective, & Behavioral Neuroscience, 3*(4), 275–288.

Perkins, M. R. (1998). Is pragmatics epiphenomenal? Evidence from communication disorders. *Journal of Pragmatics, 29*, 291–311.

Petrides, M. (1995). Functional organization of the human frontal cortex for mnemonic processing. *Annals of the New York Academy of Sciences, 769*, 85–96.

Prutting, C. A., & Kirchner, D. M. (1987). A clinical appraisal of the pragmatic aspects of language. *Journal of Speech and Hearing Disorders, 52*(2), 105–109.

Reynolds, W. M., & Kobak, K. A. (1995). *Hamilton depression inventory: A self-report version of the Hamilton Depression Rating Scale*. Odessa, FL: Psychological Assessment Resources.

Salmon, E., Van der Linden, M., Collette, F., Delfiore, G., Maquet, P., Degueldre, C., et al. (1996). Regional brain activity during working memory tasks. *Brain, 119*, 1617–1625.

Stemmer, B. (1994). A pragmatic approach to neurolinguistics: Requests (re) considered. *Brain & Language, 46*(4), 565–591.

Stemmer, B., Giroux, F., & Joanette, Y. (1994). Production and evaluation of requests by right hemisphere brain-damaged individuals. *Brain and Language, 473*(1), 1–31.

Taylor, A. E., St-Cyr, J. A., & Lang, A. E. (1986). Frontal lobe dysfunction in Parkinson's disease: The cortical focus of neostriatal outflow. *Brain, 109*, 845–883.

Tettemanti, M., Moro, A., Messa, C., Moresco, R. M., Rizzo, G., Carpinelli, A., et al. (2005). Basal ganglia and language: Phonology modulates dopaminergic release. *Neuroreport, 15, 16*(4), 397–401.

Titone, D., Holzman, P., & Levy, D. (2002). Idiom processing in schizophrenia: Literal implausibility saves the day for idiom priming. *Journal of abnormal psychology, 111*(2), 313–320.

Tompkins, C. A., Baumgaertner, A., Lehman, M. T., & Fassbinder, W. (2000). Mechanisms of discourse comprehension impairment after right hemisphere brain damage: Suppression in lexical ambiguity resolution. *Journal of Speech Language and Hearing Research, 43*(1), 62–78.

Tompkins, C. A., Bloise, C. G., Timko, M. L., & Baumgaertner, A. (1994). Working memory and inference revision in brain-damaged and normally aging adults. *Journal of Speech Hearing & Research, 37*, 896–912.

Tompkins, C. A., Lehman-Blake, M. T., Baumgaertner, A., & Fassbinder, W. (2001). Mechanisms of discourse comprehension impairment after right hemisphere brain damage: suppression in inferential ambiguity resolution. *Journal of Speech Language and Hearing Research, 44*(2), 400–415.

Ullman, M. T., Corkin, S., Coppola, M., Hickok, G., Growdon, J. H., Koroshetz, W. J., et al. (1997). A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. *Journal of Cognitive Neuroscience, 9*, 266–276.

Wallesch, C. W., & Papagno, C. (1988). Subcortical aphasia. In F. C. Rose, R. Whurr, & M. A. Wyke (Eds.), *Aphasia*. London: Whurr Publishers.

Warrington, E. K. (1984). *Recognition memory test manual*. Windsor: NFER-Nelson.