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Linguistic Correlates of Asymmetric Motor Symptom Severity in Parkinson's Disease

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Abstract

Asymmetric motor severity is common in Parkinson's Disease (PD) and provides a method for examining the neurobiologic mechanisms underlying cognitive and linguistic deficits associated with the disorder. In the present research, PD participants ($N = 31$) were assessed in terms of the asymmetry of their motor symptoms. Interviews with the participants were analyzed with the Linguistic Inquiry and Word Count (LIWC) program. Three measures of linguistic complexity – the proportion of verbs, proportion of function words, and sentence length – were found to be affected by symptom asymmetry. Greater left-side motor severity (and hence greater right hemisphere dysfunction) was associated with the production of significantly fewer verbs, function words, and shorter sentences. Hence, the production of linguistic complexity in a natural language context was associated with relatively greater right hemisphere involvement. The potential neurobiological mechanisms underlying this effect are discussed.

Linguistic Correlates of Asymmetric Motor Symptom Severity in Parkinson's Disease

The initial motor symptoms of Parkinson's disease (PD) are typically asymmetric, presenting as more severe on either the left or right side (Djaldetti et al., 2006; Uitti, Baba, Whaley, Wszolek, & Putzke, 2005). This asymmetry may persist for some time; even in later stages of the disease when bilateral involvement is common, one side is often more strongly affected than the other. This asymmetry has important theoretical implications and researchers have examined some of its neuropsychological consequences. The results of this research have been ambiguous and there have not been any attempts to examine spontaneous language performance as a function of this asymmetry. In this research we examined some of the language production correlates of motor symptom asymmetry in PD, controlling for

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background patient variables, as well as output size (length) variables using a computerized analysis of the language produced by PD participants during brief informal interviews.

Language Correlates of Parkinson's Disease

Research has documented a variety of language deficits associated with PD. With regard to speech and language production, PD patients often exhibit fluency and motor speech disorders, word-finding difficulties, and grammatical difficulties (McNamara & Durso, 2000). They tend, for example, to use simplified sentence structures with relatively more silent hesitations and pauses at critical sites in a sentence (Illes, Metter, Hanson, & Iritani, 1988). Many PD patients exhibit difficulty in generating words to a target stimulus; this fluency deficit is correlated with speech production deficits (McNamara, Obler, Au, Durso & Albert, 1992) and is particularly pronounced for verbs (Bertella et al., 2002; Peran et al., 2002). PD patients also tend to produce a smaller number of grammatical utterances than healthy individuals (Murray 2000), and tend to use a larger number of words to describe similar themes (Obler, Mildworf, & Albert, 1977). PD patients also often exhibit mild to moderate sentence comprehension deficits (Lieberman et al., 1990; 1992; Geyer & Grossman, 1994; Grossman et al., 1991, 1992a, 1992b, 1993, 1994; 2000; Grossman, 2001; McNamara, Krueger, O'Quin, Clark, & Durso, 1996; Kemmerer, 1999).

There is also some evidence of pragmatic impairment in PD. Using the Prutting and Kirchener (1987) inventory of pragmatic language skills, McNamara and Durso (2003) found that patients with PD were significantly impaired on selected measures of pragmatic communication abilities, including the areas of conversational fluency/appropriateness, speech act production and comprehension, topic-coherence, prosodics and proxemics. Bhat, Iyengar and Chengappa (2001) reported similar results in a series of case studies of PD patients who also evidenced deficits in contextual inferencing and in humor appreciation. Berg, Bjornram, Hartelius, Laakso, and Johnels (2003) reported 'high-level' language dysfunction in PD including a significant inferencing deficit (i.e., drawing appropriate inferences from short narratives about social interactions) in mid-stage patients. Lewis, Lapointe, Murdoch & Chenery (1998) found that PD patients are at a disadvantage interpreting figurative language, ambiguity, and semantic verbal fluency.

There is some dispute regarding the mechanisms responsible for language deficits in PD. One possibility is that they reflect an overall decline in cognitive capabilities. Cognitive dysfunction is typically mild in early PD involving a generalized slowing of cognitive processing speed (bradyphrenia) and subtle deficits in so-called executive cognitive functions or ECFs (Owen et al., 1992; Lange et al., 1993; Lees & Smith, 1983; Levin et al., 1989; Taylor & Saint-Cyr, 1991; 1995; Troster and Woods, 2003; McNamara et al., 2008); PD patients typically perform abnormally on ECF tests of planning (such as the Tower of London or its automated analog 'Stockings of Cambridge'), and cognitive inhibition (such as the Stroop color-word interference tasks) (Bayles et al., 1996; Dubois et al., 1991; McNamara & Durso, 2000; Piccirilli et al., 1989; Troster & Woods, 2003; Wolters & Scheltens, 1995). It is possible, then, that language comprehension deficits in PD are due to these executive deficits which limit the cognitive resources available (Geyer & Grossman, 1994). Similarly, pragmatic deficits may also reflect cognitive impairment (McNamara & Durso, 2003), although there have been some demonstrations of pragmatic impairment independent of cognitive impairment (Berg et al., 2003). Other neural pathways that are independent of cognitive functioning (but not considered traditional language areas) may be implicated in PD language deficits as well (Lieberman, 2000). For example, the impairment of the cortical motor regions in PD may underlie the demonstrated greater difficulty that PD participants have with action verbs, relative to other syntactic categories (Boulenger, Mechtoff, Thobois, Broussolle, Jeannerod, & Naxir, 2008). And recent evidence suggests the basal ganglia can play a role in the production of meaningful

speech (Watson & Montgomery, 2006) as well as syntactic integration during comprehension (Friederici et al., 2003).

Motor Symptom Asymmetry in PD

One way to examine the neurobiological underpinnings of language deficits in PD is to examine their relation to disease asymmetry. Motor symptom asymmetry is very common in PD. In a recent, relatively large-scale study ($N = 1277$), there were differences between total right side and total left side Unified Parkinson's Disease Rating Scale (UPDRS) scores for 90% of the sample, with an absolute difference greater than or equal to five scale points for almost half (46%) the sample (Uitti et al., 2005). Moreover, the distribution of difference scores was approximately normal; hence, motor asymmetry appears to be a matter of degree.

Positron emission tomographic (PET) scan, cerebral blood flow and neurochemical studies of PD patients have consistently demonstrated correlations between asymmetrically reduced striatal and prefrontal dopaminergic activity and the motor, mood and cognitive dysfunctions of PD (Direnfeld et al., 1984; Tomer, Levin, & Weiner, 1993; Tomer & Aharon-Peretz, 2004; Kaasinen et al., 2001). For example, Direnfeld et al., (1984) compared right-sided and left-sided PD patients with control participants on a battery of neuropsychological tests (e.g., Boston Naming test; WAIS digit span) as well as levels of homovanillic (HVA) in the cerebral spinal fluid (CSF). PD participants with greater left side severity (and hence greater right hemisphere dysfunction) performed more poorly than right side severity participants on all tests, (with the differences significant for tests of memory and visual-spatial functions) and they had lower, overall, HVA levels. The authors suggest that the asymmetry in cognitive performance was a function of differences in dopaminergic systems, either anatomically (dopaminergic cell loss) or physiologically (dopaminergic modulation).

Similar results were reported by Tomer et al., (1993; see also Starkstein et al., 1992; Bentin, Silverberg, & Gordon, 1981) who administered an extensive neuropsychological battery to unilateral PD participants whose initial symptoms were either left-sided or right-sided. Relatively large and consistent differences were found, with left-side symptom onset participants demonstrating poorer performance than right-side symptom onset participants on almost all measures including memory, visuospatial skills, reasoning/abstraction, and attention. Consistent with the conclusions of Direnfeld et al., (1984), Tomer et al. suggest that their data indicate an overall role for right hemisphere dopaminergic systems in the modulation of cognition.

Other research has suggested that cognitive deficits as a function of motor symptom asymmetry depend on the specific motor symptom. For example, Katzen, Levin and Weiner (2006) found impaired cognitive performance for left-sided PD, relative to right-side PD, only for tremor. In contrast, PD with bradykinesia/rigidity displayed cognitive impairment, but the degree of impairment was independent of presenting side. In addition, the effects of left-side severity may depend on the specific cognitive task that is investigated (Starkstein & Leiguarda, 1993; Taylor, Saint-Cyr, & Lang, 1986). Finally, there also have been studies demonstrating some cognitive impairments to be associated with greater right-sided rather than left-sided symptoms. Starkstein, Leiguarda, Gershanik, and Bertheir (1987) reported significantly poorer performance on the WAIS (verbal and total but not performance) and WCST for PD participants with greater right-side motor severity than PD participants with greater left-side severity. Huber, Miller, Bohaska, Christy, and Bornstein (1992) reported that PD participants with more severe right-side symptoms performed significantly more poorly than left-sided PD participants on tests of intelligence, verbal (but not visual) memory, and concentration. Spicer, Roberts, and LeWitt (1988) reported significantly poorer performance by right-sided PD than left-sided PD on serial digit, learning, visual naming, and word fluency tasks.

Overall, then, past findings on the cognitive consequences of PD motor symptom asymmetry are somewhat mixed, with research demonstrating cognitive deficits associated with both greater right-side and greater left-side motor symptom severity. These differences appear to be due to the use of different tasks, the nature of the asymmetry (e.g., onset vs. current), and the failure to control critical variables such as PD severity and duration.

Conversational Language Production and PD Motor Symptom Asymmetry

In this research we focused on spontaneous language production as a function of motor symptom asymmetry. The production of language in a conversation (as opposed to performance on laboratory language tasks) engages a range of diverse processes. Syntactic processes are engaged, of course, but so are various other cognitive and pragmatic processes. For example, it requires substantial memory resources to hold in mind over extended pieces of discourse the referent of a pronoun. Similarly, thematic roles need to be assigned when accessing verbs and their argument structures, particularly verbs of causality and cognitive processes. These types of verbs typically occur as sentential complements that require intact working memory capacity for efficient and fluid processing. Pragmatic processes are extensively engaged as interactants must monitor their language production for contextual appropriateness and they must generate conversational inferences as required.

The role of multiple processes in conversation leads to competing predictions regarding the role of symptom asymmetry in conversational linguistic complexity. On the one hand, because of the relative specialization of the left hemisphere for syntactic and some semantic processing, greater right-side motor severity (and therefore increased left-hemisphere dysfunction) might be expected to be associated with decreased linguistic complexity. On the other hand, spontaneous production in conversations engages pragmatic and cognitive resources, resources that have been associated with right hemisphere specialization. Hence, greater left-side motor severity (and therefore increased right-hemisphere dysfunction) might be expected to be associated with decreased linguistic complexity.

To explore this issue, we examined spontaneous language production in a group of mid-stage PD patients. Our primary interest was in the production of linguistic complexity which we operationalized as the occurrence of verbs, function words (pronouns, adverbs, articles, conjunctions, and prepositions) and sentence length. The language output of PD patients was analyzed with the Linguistic Inquiry and Word Count program (LIWC; Pennebaker, Booth, & Francis, 2007), a program that provides objective measures of our three variables. In addition, the LIWC program measures a range of cognitive and emotional markers and we conducted exploratory analyses of the relationship between these measures and motor symptom asymmetry.

Method

Participants

Participants were 31 (1 female) individuals diagnosed with idiopathic Parkinson's disease (mean age = 69.8) and recruited from the Boston University School of Medicine/Boston Medical Center Movement Disorders Clinics and the Boston VA Parkinson/Movement Disorder Clinics. All participants were right-handed, and the majority (> 93%) were either level two or three on the Hoehn and Yahr scale ($M = 2.6$). Most (88%) of the participants had completed high school with just over half (51%) having completed some college. All participants displayed initial motor symptom asymmetry.

More advanced Stage III, IV, or V patients were excluded during the recruitment process. The patient's diagnosis was agreed upon by a specialist in PD (Dr. Durso) and at least one other

neurologist. All patients were required to have had at least one CT- or MRI scan during their illness to rule out history of brain injury. Patients with Parkinsonism from known causes (e.g., encephalitis, trauma, carbon monoxide exposure, manganese poisoning, hypoparathyroidism, a multi-infarct state or medications (such as neuroleptics) interfering with dopaminergic functions) were excluded. Similarly, other degenerative diseases mimicking PD (e.g., striatonigral degeneration, progressive supranuclear palsy or olivopontocerebellar degeneration) were excluded. PD patients with concurrent Alzheimer-like dementia were excluded.

Other exclusion criteria included: 1) An abnormal CT or MRI scan showing basal ganglia atrophy or calcification and or stroke. 2) For patients who had received levodopa (LD) for more than 1 year, a history of no response to LD even in the initial stages of the disease, as this would be consistent with striatonigral degeneration rather than PD. 3) The presence of pyramidal, downward gaze or cerebellar dysfunction on examination, as these would be consistent with other diagnoses such as multi-infarct state, progressive supranuclear palsy or olivopontocerebellar degeneration respectively. 4) Other: (a) inability to obtain informed consent from patient due to an incapacity on the part of patient to understand purpose and risks of study, as these individuals are likely demented; (b) history of ongoing alcohol or drug abuse; (c) patients with a history of psychiatric or psychotic disorder and patients currently on antidepressant or anti-psychotic medications as these medications may influence communication functions.

Medication information was obtained from each patient by the Neurologist (R.D.) and Levodopa equivalent dosages were calculated based on previous reports with 100 mg Levodopa=83 mg Levodopa with a COMT inhibitor=1 mg Pramipexole=1 mg Pergolide (Harris, Atkinson, Lee, Nithi, & Fowler, 2003; Lee, Harris, Atkinson, Fowler, 2001). There was no significant difference in levodopa dosage equivalents between PD participants with greater right side motor severity and those with greater left side motor severity.

Measures

Linguistic Analysis—Interviews were conducted with each participant individually and consisted of questions regarding their family, background, daily activities, etc. Interviews lasted approximately 15 minutes, and were conducted while the patient was on medication. All interviews were transcribed (with the interviewer's questions and comments deleted) and submitted to the Linguistic Inquiry and Word Count (LIWC) program.

We used the most recent version of LIWC (Pennebaker et al., 2007) to obtain unbiased estimates of language performance. This program counts the occurrences of words within its dictionary, as well as categories (e.g., verbs, emotion words, etc.) that constitute a subset of those words. The program analyzes text documents with a base dictionary of almost 4,500 words and word stems. There are 22 standard linguistic and 32 psychological construct categories, all of which can be compared to a standardized frequency table. The LIWC has been shown to have good internal consistency and temporal reliability (Pennebaker et al., 2007). It has been shown to be a valid method for measuring personal expression of emotion (Pennebaker & King, 1999; Mehl & Pennebaker 2003; Mehl, Pennebaker, Crow, Dabbs & Price 2001; Kahn, Tobin, Massey, & Jennifer, 2007), personality traits (e.g., extraversion, neuroticism) assessed with the five-factor model (Pennebaker & King, 1999), self-esteem (Bosson, Swann, & Pennebaker, 2000), as well as linguistic markers of age (Pennebaker & Stone 2003), gender (Mehl & Pennebaker, 2003), and deception (Bond & Lee, 2005; Newman, Pennebaker, Berry, & Richards (2003). More recently, it has been successfully used to analyze linguistic expressions in a brain damaged population. Blonder et al. (2005) used the LIWC program to study aprosodic versus aphasic stroke patients and found that right hemisphere

damaged patients produced more emotion words compared to left hemisphere damaged individuals.

In this study our focus was on linguistic performance and so we used two high-level linguistic categories – proportion of verbs and proportion of function words – along with mean number of words per sentence. The verb category counted the occurrence of 383 common verbs of any tense, and the function word category counted the occurrence of 464 words that included pronouns, articles, prepositions, and conjunctions. Both the verb and function word variables were adjusted for total number of words produced and were expressed as percentage of total words that were verbs or function words.

Motor asymmetry—Motor severity was assessed using a modified Unified Parkinsons Disease Rating Scale (UPDRS). The UPDRS has been the standard tool for assessing motor severity in PD and has demonstrated adequate interrater reliability (Martinez-Martin, 1993; Rabey et al., 1997). This scale assesses the cardinal motor features of PD, the potential motor complications of LD treatment (including dyskinesias, fluctuations and some autonomic signs) and activities of daily living. Following Uitti et al. (2005), a motor score was computed for each side based on UPDRS items 20 (tremor at rest), 21 (action or postural tremor of hands), 22 (rigidity), 23 (finger taps), 25 (rapid alternating movement of hands), and 26 (leg agility), plus an item assessing arm swing that used the same five-point scaling (0 = normal; 1 = slight reduction; 2 = moderate reduction; 3 = severe reduction; 4 = marked reduction). Assessments were made by a single individual (a masters level research assistant trained by Dr. Durso, a Parkinson's specialist) who was blind to the experimental hypotheses. The seven items were combined to create total left and total right motor severity scores. Reliability analyses indicated that the standardized alpha coefficients were low to moderate (right side = .70; left side = .62). Because of the relatively low reliability of the combined motor severity measures, we conducted (and present) analyses for each symptom separately in addition to analyses based on the overall scores.

A motor symptom asymmetry score was computed for each participant (both overall and for each symptom separately) consisting of the difference between the total right and total left severity scores divided by the total severity score (total left plus total right). Larger scores indicate greater right-side severity relative to the left-side severity. Scores for overall asymmetry ranged between -1 and +1 with a mean of .0067 (sd = .62) and median of .143. Participants with initial greater right-side motor severity had significantly higher asymmetry scores (.36) than did participants with greater initial left-side motor severity (-.55), $t(29) = 5.77$, $p < .01$.

Cognitive Measures—Participants completed two measures of executive cognitive performance including the Stroop color-word interference task, semantic and letter verbal fluency tasks and an autobiographical memory task (recall as many names from childhood as you can within one minute; See McNamara et al., 2008).

Results

Descriptive statistics are presented in Table 1. All variables, with the exception of sentence length, displayed an approximately normal distribution. Attempts to transform this variable to more closely approximate a normal distribution were not successful; hence, the results for this variable should be viewed with some caution. Inspection of the plots of the residuals indicated a lack of heteroscedasticity, again with the exception of the sentence length variable.

We used multiple regression for our primary analyses because motor symptom asymmetry appears to be distributed continuously (Uitti et al., 2005). In the first set of analyses, the

proportion of function words, proportion of verbs, and mean sentence length served as the criterion variables. Our interest was in whether relatively greater left-side or right-side motor symptom severity would predict language performance independent of variables known to be associated with language performance. Hence, we used a step-wise procedure and at step 1 simultaneously entered four variables (Age, education level, HY stage, and initial presenting side) known to be related to language performance. Overall symptom asymmetry was then entered at step 2.

The results for verbs, function words, and sentence length are presented in Table 2. The inclusion of symptom asymmetry resulted in a significant ($p < .05$) R^2 change for proportion of verbs, $F(1,24) = 7.88$, proportion of function words, $F(1,24) = 4.48$, and sentence length, $F(1,24) = 9.67$, and corresponding significant negative beta weights for verbs (.71), function words (.57), and sentence length (.66).¹ Hence, greater left-side motor severity (greater right hemisphere dysfunction) was associated with the use of fewer verbs, fewer function words, and shorter sentences. The effect of motor symptom asymmetry was substantial, explaining between 20% (verbs) and 13% (function words) of the variability in this criterion beyond that explained by age, education, disease stage, and presenting side. In order to determine if it was simply overall motor severity (rather than asymmetry) that was largely responsible for this effect, parallel multiple regression analyses were conducted in which total severity was substituted for symptom asymmetry. Total severity was not significant for verbs ($\beta = -.21$, $t = -1.13$, $p > .25$), function words ($\beta = .13$, $t < 1$), or sentence length ($\beta = .12$, $t < 1$). Hence, for the linguistic variables examined in this research, it is not overall symptom severity that predicts performance but rather the asymmetry of that severity.²

Next, multiple regression analyses were run in which an asymmetry score (computed in the same manner as the total asymmetry score) for each UPDRS item constituted the predictor variable in step 2 (replacing the overall asymmetry score). These analyses were run separately for each of the three criterion variables. The results are summarized in Table 3. Each of the separate symptoms was positively correlated with the production of verbs, and the effect was at least marginally significant ($p < .10$) for the tremor, action, and rigidity items. The pattern was roughly similar for function words and sentence length, although here there were some negative (though nonsignificant) β 's.

Additional analyses were then conducted in order to assess the uniqueness of these results as well as possible boundary conditions. First, analyses were conducted in order to specify more clearly the nature of the effect for sentence length. Specifically, was the effect an artifact of participants with left-sided symptoms simply talking less than participants with stronger right-sided symptoms? To examine this, multiple regression analyses were conducted using overall word count and number of sentences as criterion variables. The number of words spoken did not vary as a function of symptom asymmetry ($\beta = -.12$, ns). There was, however, a marginally significant relationship between symptom asymmetry and number of sentences ($\beta = -.45$, $p < .06$), with greater left-side severity associated with the production of more sentences. Hence, greater left-side symptom severity was associated with shorter sentences but more of them. Left-sided PDs talked as much as their right-sided counterparts but did so with shorter sentences.

Second, exploratory analyses were conducted to examine some of the possible cognitive consequences of asymmetric motor severity. Correlations were computed between symptom

¹We report both the R^2 change and the beta weights even though the statistical tests are identical given the model we are testing here.

²This issue was also investigated by conducting multiple regression analyses that included total symptom severity in the first step (along with the other predictor variables). The effect of symptom asymmetry (entered at step 2) remained significant and substantial for all three criterion variables.

asymmetry, language performance, and several different cognitive indices. There were no significant correlations (all p s > .1) between degree of symptom asymmetry and measures of verbal fluency (FAS: $r = .02$; total category fluency: $r = -.07$), Stroop interference ($r = .13$), or autobiographical memory (names: all r s < $\pm .15$; events: all r s < $\pm .26$). In addition, with the exception of a negative correlation between category fluency and verb production ($r = -.4$, $p < .05$), there were no significant correlations between cognitive indices and language performance (FAS: all r s < $\pm .14$, Stroop interference: all r s < $\pm .25$, total category fluency: all r s < $\pm .11$; autobiographical memory for names: all r s < $\pm .34$; autobiographical memory for events: all r s < $\pm .31$). Finally, the relationship between levodopa dose equivalent (LDE) and language performance was examined. There were no significant correlations between LDE and any of the language performance variables.

Finally, to examine whether symptom asymmetry was related to any of the psychological processes assessed with the LIWC program, multiple regression analyses were conducted with each of the five, major psychological process categories as criterion variables: social (455 words; e.g., talk, husband) affect (915 words; e.g., sweet, fearful), cognitive processes (730 words; e.g., cause, should), perceptual processes (273 words; e.g., hear, feel) and biological processes (567 words; e.g., eat, flu) as criterion variables. There were no significant effects in these analyses.³ The only marginally significant effect occurred for cognitive mechanisms ($\beta = .60$, $t = 2.26$, $p < .05$), and two subcategories of cognitive mechanisms – insight (e.g., think, know, consider) and cause (e.g., because, effect, hence) were especially strong in this regard (insight: $\beta = .81$, $t = 3.15$, $p < .01$; cause: $\beta = .58$, $t = 2.43$, $p < .05$). None of the other psychological processes were related to symptom asymmetry (all p s > .50). The words in the cognitive mechanism category, and especially the insight and cause subcategories, overlapped with the verb category and suggest that verbs dealing with causality and cognitive processes are especially influenced by motor symptom asymmetry.

Discussion

Previous research has demonstrated that linguistic production tends to be impaired in PD, and one prominent manifestation of this deficit is decreased linguistic complexity (Bertella et al., 2002; Boulenger et al., 2008; Illes et al., 1988; Peran et al., 2002). The neurobiological basis for this deficit is not clear, partly because language use engages a variety of different processes and associated neurobiological mechanisms.

The present results were relatively clear. We found in a convenience sample of mid-stage PD patients that greater left-side motor severity was associated with the production of significantly fewer verbs, significantly fewer function words, and significantly shorter sentences. Overall, then, PD patients with more severe left-side motor symptoms (and hence greater right hemisphere dysfunction) tended to produce relatively less complex utterances. This language deficit was independent of overall motor symptom severity. However, the effects of motor symptom asymmetry on language performance was greater for some symptoms (in particular tremor and rigidity) than for other symptoms (e.g., leg agility).

This pattern of data is consistent with previous research demonstrating left-side motor severity to be associated with increased cognitive deficits (Direnfeld et al., 1984). In the present study, however, symptom asymmetry was not significantly correlated with any cognitive measures. Keep in mind, however, that our assessment of cognitive performance was extremely limited, and given our relatively small sample size, power for detecting such patterns was reduced. Hence, whether the asymmetry effect we found is related to certain types of cognitive

³Because we conducted multiple analyses in an exploratory fashion, we adjusted the critical alpha levels based on the number of tests conducted (i.e., the Bonferroni procedure).

dysfunction remains, we believe, an open question. This is because there may be certain cognitive capacities – short-term memory, for example – that we did not examine but which very likely may mediate the effects of symptom severity on language performance. The class of linguistic materials examined here might be particularly vulnerable to left-sided disease because they require significant processing resources in discourse related settings. In addition, our exploratory analyses of psychological processes suggest that the relationship between motor symptom asymmetry and verb production is especially pronounced for verbs dealing with causality and cognitive processes.

It is also possible, of course, that the language decrement found here may be relatively independent of any cognitive deficits. For example, there is some research suggesting that the right hemisphere plays a relatively strong role in the pragmatics of language use (Jung-Beeman, 2005), and it may be that the language decrement associated with left-side severity reflects a pragmatic deficit. Although the measures used here were not standard pragmatic measures, language performance in this context (i.e., language use rather than performance on a standardized language task) was likely influenced by pragmatic considerations. This decreased ability to handle the pragmatics of language use could then show up as decreased linguistic complexity (the measures that we used).

Neurobiology of PD Language Production Deficits

Although several other neurotransmitter systems are implicated in PD, the primary pathology involves loss of dopaminergic cells in the substantia nigra (SN) and in the ventral tegmental area (VTA; Agid et al., 1987), although the temporal course of this dysfunction is not clear (Braak, et al., 2003; Burke, Dauer, & Vonsattel, 2008). Importantly, these two subcortical dopaminergic sites give rise to two projection systems important for cognitive functioning. Moreover, because dopaminergic neurons in the prefrontal cortex exhibit very high firing and turnover rates (Bannon, Bunney, & Roth, 1981; Wurtman, Hefti, & Melamed, 1980; Gardner and Ashby, 2000), the prefrontal cortex is acutely sensitive to even small modulations in its supply of dopamine. Optimal levels of dopaminergic stimulation may, therefore, effect significant enhancement in frontal functions (Dreher and Burnod, 2002). For example, Bradberry et al. (1989) and Tam et al. (1990) have shown that while moderate reductions in CNS levels of the dopamine precursor tyrosine have little or no effect on dopamine synthesis in the striatum, such reductions are associated with profound impairment of dopamine synthesis in the prefrontal cortex.

In general, cognitive and language tasks appear to be sensitive to various dopaminergic agents (Marie and Defer, 2003; Kimberg and D'Esposito, 2003; Peretti, Gierski and Harrois, 2004) with Levodopa (LD) and Bromocriptine (BRC) exhibiting the most consistent effects. Lange et al. (1995), for example, found that PD patients were dramatically impaired on 'frontal' or executive function tests (Tower of London task, verbal fluency, set shifting, working memory, and spatial attention span) only when withdrawn from L-dopa medication. Performance on nonfrontally-mediated tests, such as visual memory tests, was not impaired when patients were off LD. In terms of language tasks, Grossman et al., (2001) demonstrated impaired comprehension of grammatically complex sentences when participants were off medication, suggesting that dopamine supports the executive resources that contribute to sentence comprehension in PD. Importantly, there is some research demonstrating that these effects are greater in the RH than in the LH. Cools et al., (2002) used PET to examine cortical and subcortical blood flow changes in relation to executive function performance in a group of PD patients both on and then off levodopa. These authors demonstrated that levodopa-related improvement in PD Tower of London and spatial working memory performance deficits was associated with blood flow changes in the right dorsolateral prefrontal cortex. Taken together, prior research suggests that the language variability that we observed is most likely associated

with dopaminergic networks in the right frontal lobes (see also Direnfeld et al., 1984; Tomer et al., 1993). Also, although human studies have not been conducted, animal studies (Giardino, 1996) have demonstrated a neurochemical asymmetry for dopamine systems, with greater dopamine receptor density in the right basal ganglia. One possibility, then, is that greater LS/RH damage has more negative, cognitive consequences, as seen in this research.

We note here several potential limitations of this study. First, the present sample was relatively small and hence statistical power suffered accordingly. Although this is not relevant for the significant effects we report for our primary analyses, it is somewhat problematic for some of our ancillary measures (e.g., cognitive tasks). Second, our sample was almost exclusively male. This is because our patients were recruited from an elderly VA population. Subsequent research is required to replicate the effects we observed with female participants, as well as other, more diverse samples of PD participants. Third, general caution is urged in inferring contralateral hemispheric dysfunction from motor symptom asymmetry, due, in part, to the extensive communication that can occur between hemispheres, including the two basal ganglia. Finally, participants were tested while on rather than off medication. Because dopaminergic medication can enhance performance on certain cognitive and linguistic tasks (e.g., Grossman et al., 2001; Lange et al., 1993), the present results need to be viewed with some caution. Still, if it is dopaminergic networks in the right frontal lobes that underlie the type of linguistic complexity investigated in this research, then testing participants while on medication (especially since medication level was not associated with symptom asymmetry) probably represents a conservative test of the hypothesis.

Simplified linguistic output has been identified as characteristic of PD (Bertella et al., 2002; Boulenger, et al., 2008; Illes, et al., 1988; Peran et al., 2002). The present research is the first to demonstrate that this language deficit is associated with greater left-side motor symptom severity and hence greater right hemisphere dysfunction.

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Table 1

Descriptive Statistics for all Variables

Variable	Minimum	Maximum	Mean	Standard Deviation
Verbs	12.18	21.85	16.42	2.05
Function Words	50.63	68.20	61.26	3.44
Words/Sentence	8.25	53.73	17.22	10.71
Age	34	83	69.87	11.54
Education	7	20	13.39	2.84
H-Y stage	1	4	2.57	.63
Total Severity	5	20	9.74	3.51
Symptom asymmetry	-1	1	.007	.62

Table 2

Multiple Regression Summary: Symptom Asymmetry and the Proportion of Verbs, Proportion of Function Words, and Sentence Length

	Verbs			Function Words			Sentence Length		
	β	t		β	t		β	t	
Step 1									
Age	-.37	-2.01*		-.17	-.94		-.12	-.77	
Education	-.22	-1.18		.11	.59		.46	2.88***	
HY stage	-.05	-0.25		-.12	-.65		-.16	-.96	
Original Side ^I	.12	.65		-.31	-1.17		-.13	-1.86*	
	$R^2 = .18$			$R^2 = .18$			$R^2 = .39^{**}$		
Step 2									
Asymmetry	.71	2.81***		.57	2.12**		.66	3.11***	
	$R^2 = .38^{**}$			$R^2 = .30^*$			$R^2 = .57^{***}$		
	$R^2_{\text{change}} = .20^{***}$			$R^2_{\text{change}} = .13^{***}$			$R^2_{\text{change}} = .17^{***}$		

* p < .10
** p < .05
*** p < .01
^I Keyed so that right-side = 2 and left-side = 1

Table 3
Summary of Specific Symptom Asymmetry and Proportion of Function Words, Verbs and Sentence Length

	Function Words			Verbs			Sentence Length		
	β	t		β	t		β	t	
Symptom									
Tremor	.33	1.29		.56	2.32**		.30	1.35	
Action	.40	2.12**		.38	1.97*		.46	3.01**	
Rigidity	.37	1.73*		.36	1.73*		.43	2.52**	
Arm Swing	-.2	< 1		.29	< 1		-.02	< 1	
Finger Taps	.27	1.13		.36	1.56		.25	1.24	
Alt. Hands	-.12	< 1		.13	< 1		.26	1.57	
Leg	.01	< 1		.13	< 1		.16	< 1	

**
p < .05

*
p < .10