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Review Article

High-Level Language Production in Parkinson's Disease: A Review

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This paper discusses impairments of high-level, complex language production in Parkinson's disease (PD), defined as sentence and discourse production, and situates these impairments within the framework of current psycholinguistic theories of language production. The paper comprises three major sections, an overview of the effects of PD on the brain and cognition, a review of the literature on language production in PD, and a discussion of the stages of the language production process that are impaired in PD. Overall, the literature converges on a few common characteristics of language production in PD: reduced information content, impaired grammaticality, disrupted fluency, and reduced syntactic complexity. Many studies also document the strong impact of differences in cognitive ability on language production. Based on the data, PD affects all stages of language production including conceptualization and functional and positional processing. Furthermore, impairments at all stages appear to be exacerbated by impairments in cognitive abilities.

1. Introduction

The current paper focuses on high-level, complex language production in Parkinson's disease (PD), in which "high-level, complex language" is defined as production of language at the sentence- or discourse-level in contrast to single-word production. In comparison to the extensive literature on motor impairments affecting articulation and intelligibility of speech (e.g., [1–6]) and neuropsychological reports of impaired picture naming and verbal fluency in PD [7–13], the literature on complex language production is somewhat limited. However, those few reports converge on a few common themes. First, while information content has been assessed in a variety of ways, including clinical judgment [14], correct information units [15], propositional content [16], or specific mention of the actors in a picture and an appropriate action [17], the findings uniformly support reduced information content. Second, although examined in only a few studies, fluency seems to be impaired [17–19]. Interruptions of fluency take many forms, including abandoned utterances, long pauses between or in the middle of sentences, or filled and unfilled pauses. The studies agree that disruptions of fluency can be attributed to difficulties in the early stages of language production (e.g., conceptualization and formulation) as well as problems during motor programming and articulation [17–19]. Third, grammaticality has also been reported to be impaired [15–17, 20]. Finally, syntactic complexity may also be impaired although this may be limited to individuals with moderately severe PD or to performance in more difficult language tasks [15, 16, 18, 19, 21].

Within this body of literature, there has been a strong tradition of correlating changes in language production with cognitive abilities [15, 17, 20, 22]. Recent studies have gone beyond this descriptive approach by seeking to define those subject and stimulus variables that exacerbate production difficulties in PD, examining the effects of complexity (syntactic and conceptual) on language production deficits [17, 23]. In this paper, we first briefly discuss the effects of PD on the brain and cognition and then present a review of the literature ending with discussions of our own recent experimental study that has broken new ground in this area.

Finally, working within the most commonly cited theoretical model of language production, we explore which stages of language production might be impaired in PD as well as which of these stages of the production process seem to be vulnerable to differences in cognitive ability. Finally, we present ideas for future research inspired by the preceding discussion.

Based on models which proposed that subcortical structures, specifically the basal ganglia and thalamus, were instrumental in language processing, several researchers predicted language impairments in PD before these were well documented [24–26]. More specifically, Crosson [27] suggested that basal ganglia damage could result in deficits of both motor programming and language formulation through their connections with the cortex. In particular, thalamic, putamen, and caudate function are impaired early in the progression of PD [28], and these structures are hypothesized to integrate or control attention to input from the superior and middle temporal gyri, (BA 41,42, 21,22) and dorsolateral prefrontal cortex (dlPFC), especially BA 44, 45, and 47, during language processing [25, 29]. Therefore, disruption of these large cortico-striato-pallido-thalamocortical circuits could impair aspects of language production [30–32]. Furthermore, several imaging studies have demonstrated that frontostriatal circuits are also active during executive function tasks that require set switching [33] and inhibition of prepotent responses [34], suggesting that damage to these circuits could impact both language and cognitive functions. Moreover, delayed transmission of information through these networks due to loss of connections resulting from PD related lesions [35, 36] could also interfere with the smooth flow of information between language areas. This could lead to impaired fluency of speech, if the language system has to wait for the next sentence elements to become available, or impaired computation of grammaticality if information necessary for computing agreement, for example, is no longer (or not yet) available when a verb is active [37]. Additionally, impairments affecting the continuous interaction between language areas could diminish information content in language output if the dynamics of conversational speech require a response to be started before specific conceptual information has been fully activated and made available to the language production system. In addition to subcortical structures, PD also impairs function of dlPFC, which also plays an instrumental role in many aspects of language use [29, 38] and in the cognitive abilities that support language such as working memory and executive function [14, 34, 39–44]. Thus, research supports the assertion that both cortical and subcortical structures contribute to cognitive processing and language use.

Cognitive impairments are common in PD with nearly 80 percent of persons with PD developing cognitive impairment [12, 14, 45, 46]. In fact, Muslimović et al. [46] reported that 100% of the 115 participants in their study were significantly impaired on at least one cognitive task. Deficits in cognition secondary to PD impact many domains, including memory, visuospatial function, and concept formation, with executive function and working memory (WM) being the first affected (e.g., [47–51]). Executive function impairments are most commonly reported to affect anticipation, planning, initiation, inhibitory processing, and set and task switching [46, 52–56]. Dual task performance, which is also considered to involve executive function [57], is also impaired in PD [58, 59]. As previously mentioned, working memory is impaired, especially when tasks require manipulation rather than storage or updating of information [55, 56].

As pointed out by Lewis et al. [60], language production may rely on many of these same cognitive abilities, such as initiation, planning, and inhibitory processing as well as concept formation and the manipulation of information, leaving language production vulnerable in PD. Based on this reasoning, it has become relatively common for researchers to compare cognitive abilities and language performance in studies of PD [15, 17, 20, 22, 23, 60–62]. Most recently, Bastiaanse and Leenders [63] commented that there was little doubt that the cognitive deficits in PD were fully responsible for the language impairments found in this population, and, therefore, there were no specific linguistic deficits secondary to this disease. However, our own research, described below, suggests that while working memory and executive function account for significant, substantial proportions of variance in many characteristics of language production in PD and healthy older adults, there are group differences in performance in many dimensions of language production that cannot be accounted for by performance on standard measures of cognitive abilities alone [17]. Our findings need not be considered to support a modular view of language and cognition; indeed, we find strong evidence that working memory, executive function, and speed of processing play critical roles in language production and comprehension [17, 64, 65]. However, while many cognitive and linguistic functions may share underlying neural mechanisms and task demands, there may also be neural circuits that are primarily used in language production that are independently damaged in PD.

2. Complex Language Production in PD

Studies investigating high-level, complex language in PD are relatively rare and have employed a variety of methodologies. Cummings and colleagues [14] were among the first to address deficits in complex expressive language in PD. These researchers compared individuals with PD but no dementia ($n = 35$), PD plus dementia ($n = 16$), and individuals with dementia of the Alzheimer's type ($n = 10$) on the Boston Diagnostic Aphasia Examination [66] and Western Aphasia Battery [67]. Those with dementia of the Alzheimer type performed more poorly on language tasks than participants with PD at comparable levels of dementia severity, demonstrating decreased information content and more impairment of word list generation and word finding. Nondemented persons with PD were reported to have "spared" language with lower information content and less complex syntax than expected in individuals of the same age, based on clinical observation.

In another early study, Illes et al. [19] reported that the language production of people with PD differed both

acoustically and linguistically from healthy older adults. They examined speech rate, fluency, syntactic complexity, lexical production, and the relative distribution of content and grammatical phrases in 10 persons with PD (5 mild, 5 moderate) and 10 age-matched controls while reading the Grandfather passage and producing spontaneous speech. In this study, people with PD tended to produce longer sentences than healthy older adults due to a tendency to list several events within a single sentence, leading to a greater proportion of content word phrases (i.e., noun, verb, and adjective phrases) than in the healthy older adult group. However, only the moderately impaired PD group produced sentences with lower syntactic complexity. Illes et al. also reported that the speech of the PD group was disfluent, marked particularly by more pauses and more pauses per word than the speech of the healthy older adult group. In addition, syntactic complexity correlated with dysarthria severity (motor speech impairment) and PD severity, as measured by the Webster scale. These researchers attributed the disfluencies and unusual syntactic constructions to difficulties with concept formulation as well as compensation for motor speech impairment.

In a companion study, Illes [18] analyzed responses to open-ended, autobiographical questions from individuals with PD ($n = 10$), Huntington's disease (HD) ($n = 10$), and Alzheimer's disease ($n = 10$) along with health older adults ($n = 10$). This study analyzed several temporal-acoustic, syntactic, and lexical dependent variables, including words per minute, location of pauses, number of fluency disruptions of several types (nonword fillers, pauses, false starts, and word repetitions) per word, syntactic complexity, and proportion of open class words. Illes reported that the PD groups overall did not differ from healthy older adults on most of these measures. However, the PD group included more pauses in their responses than controls, with perceptible silent hesitations at the initiation of sentences and between main clauses and optional clauses. These hesitations were reported to be followed by "a certain press of speech (p. 635)" in both the Huntington's and Parkinson's disease groups. The author described this pattern as a type of motor speech, or perhaps cognitive, "cogwheel" phenomenon (p. 635), leading to short periods of freezing or rigidity followed by a limited burst of action, speech in this case. Thus, Iles attributed the disfluencies within and between utterances in the PD group to difficulty activating concepts and formulating sentences, as well as to adaptation to the motor impairments of PD. In contrast, she described the complexity of syntax in PD as "relatively intact" and stated that their speech was highly informative relative to individuals with Alzheimer's or Huntington's disease.

Lewis et al. [60] used standardized testing to examine high level, complex language production in PD. They tested 20 persons with PD, half with dementia, and 20 healthy age-matched adults on a battery of tasks, including the Boston Naming Test, the WORD test, Test of Language Competence, Word Fluency Test, and Dementia Rating Scale, that assessed both cognitive and linguistic performance. In contrast to the tests used by Cummings et al. [14], the tests chosen in this study examined a number of more complex aspects of language, including the ability to identify synonyms and antonyms, incorporate specific words into a grammatical sentences, define words, and interpret complex and figurative language. Compared to the healthy adults, those with PD performed worse on tests of complex language production, such as providing definitions for words and generating sentences that included specified target words. In addition, more severe dementia was associated with increasing impairment in picture naming, interpreting metaphors, processing ambiguous sentences, defining words, and generating sentences. Lewis et al. argued that the "operational functions (p.200)" of language were intact in PD. Instead, they attributed the observed deficits in language use to cognitive impairment associated with frontal lobe dysfunction. This argument was based on face validity of the tasks used; the language tasks on which the PD group scored most poorly were those that required organization, planning, abstract thought, and integration of information, functions associated with the frontal lobe.

Berg and colleagues [22] assessed complex language production in 26 persons with PD and 26 control subjects with a test battery modeled after that used by Lewis et al. [60]. They tested sentence repetition, sentence production, and the ability to define words along with several receptive language tasks, using an instrument designed to test subtle impairments of complex language function in Swedish adults. Findings specific to complex language production were consistent with those of Lewis et al. [60]. Participants with cognitive dysfunction demonstrated significant impairments in the comprehension of metaphors and ambiguous sentences as well as in generating sentences; however, they performed similarly to controls when repeating sentences. Berg et al. also reported that overall performance on their test battery correlated with overall cognitive ability as measured by the mini-mental status exam (MMSE) [68], demonstrating that language impairment increased with increasing dementia severity.

While Illes [18] analyzed fluency and syntactic complexity, their use of unusual dependent variables for these, especially syntactic complexity, makes it difficult to directly compare their findings to other studies. Generalization from the studies by Lewis et al. [60] and Berg et al. [22] is limited by a lack of information about the actual language production output of the people with PD. These standardized tests did not yield any information about whether the language output was, for example, coherent, grammatical, or syntactically complex. Thus, although these studies provided converging evidence that complex language production (and comprehension) were impaired in PD, exactly how the impairment manifested was not addressed. Furthermore, attributing language impairments to frontal lobe impairments based on task analysis has face validity, and correlations with dementia severity are somewhat better. However, several researchers have begun to measure more detailed characteristics of the language output of individuals with PD as well as the component cognitive abilities underlying performance on dementia scales, using tasks that provide a better estimate of different types of cognitive abilities (e.g., working memory, inhibition, set shifting, and

speed of processing). Studies adopting these approaches are discussed below.

Small et al. [16] analyzed written sentence generation using sentences produced as part of the MMSE [68]. Sentences from 167 healthy older adults, 96 Nondemented individuals with PD, and 30 individuals diagnosed with PD plus dementia (14 mild and 16 moderate) were analyzed for grammaticality, syntactic complexity, and information content. Small et al. reported that only the PD group with moderate dementia produced shorter, less grammatically complex sentences with reduced information content (i.e., fewer propositions per word) as well as more sentence fragments compared to healthy older adults. However, they found no difference in sentence complexity or information content between healthy older adults and nondemented or mildly demented individuals with PD. Thus, while Small et al. provided a more complete characterization of the sentence generation capabilities of individuals with PD at different levels of dementia, they did not relate these patterns to more specific underlying cognitive deficits.

Murray [15] took a more advanced approach and compared the cognitive profiles (e.g., memory, attention, and lexical retrieval) and language functioning of 10 persons with PD, 10 with Huntington's disease, and 18 age-matched control subjects. Participants described the cookie theft [69] and grocery scene pictures [70]. Dependent variables included total number of utterances, grammaticality of sentences, syntactic complexity (proportion of simple sentences and the number of embedded clauses per utterance), and informativeness (proportion of Correct Information Units and proportion of informative utterances). Groups did not differ in total number of utterances produced or overall syntactic complexity; however, participants with PD in this study produced a smaller proportion of grammatical sentences and less information than control subjects. Murray also reported that individuals with PD who had better short-term memory and better attention produced longer, more syntactically complex utterances. Further, participants with PD who were more cognitively intact overall, as measured by dementia ratings scale scores (DRS) [71], produced more information.

In a companion study, Murray and Lenz [21] examined the conversational discourse of 10 persons with PD, 9 with Huntington's disease, and 17 controls, and reported no impairments in syntax among those with PD. However, they observed significant positive relationships between DRS, length of utterances and sentence complexity in the PD group. The authors attributed the difference in findings between this study and Murray's previous study [15] to differences in the degree of constraint the task put on responses. They suggested that individuals with PD performed more poorly in more constrained tasks (e.g., picture description) than in open ended tasks like conversation. The findings in Murray and Lenz are consistent with previous findings in the aging literature that syntactic complexity and sentence length are related to cognition, particularly working memory ability, in healthy older adults [72], and further suggest that these characteristics of language will be vulnerable as overall cognitive abilities decline.

In an interesting study examining spontaneous speech in bilingual individuals with PD, Zanini et al. [20] reported significantly more grammatical errors in 9 individuals with PD compared to age and education matched healthy adults. Furthermore, this difference was limited to performance in the first language of participants, Friulian, while performance in the second language, Italian, did not differ between groups. Interestingly, the number of grammatical errors produced in the first language correlated significantly with executive function tasks assessing task-switching ability. The authors attribute the grammatical impairments in the first language to differences in the representations of the two languages resulting from differences in the age of acquisition. Because the first language was learned from birth, the authors argued that the first language was more likely to be processed using implicit, procedural processing which engages basal ganglia structures [73]. In contrast, the second language, which was typically learned in these individuals when the person entered school, would be subject to more explicit processing which would tap neocortical representations. Thus, Zanini et al. argued that basal ganglia deficits such as in PD would be more likely to impair first language grammar which was learned and processed implicitly, rather than second-language grammar, which was learned explicitly in school. The correlations between grammatical errors and task switching are also consistent with other studies [17, 23] that have also reported correlations between grammatical errors and executive function tasks.

Recently, Colman et al. [23] examined the effects of cognitive abilities and task switching on language production in 28 persons with PD and 28 age matched healthy participants. The experiment required participants to provide an inflected form of a verb within a sentence context. Participants also completed a battery of cognitive tests. Those with PD performed more poorly than healthy adults on cognitive measures of task switching (the Trail Making Task, Odd Man Out) and, marginally, on action fluency ($P = .06$), but not on tasks assessing sustained and divided attention, working memory, inhibition, semantic fluency, or phonemic fluency. In the verb production task, participants saw a picture and read the sentence context aloud to activate the grammatical context and then generated the inflected form of an appropriate verb. Participants were instructed to produce a past tense verb when the context sentence included a time biasing adverb like "yesterday" and had to remember to produce a present tense verb elsewhere if there were no adverbial cue. Errors primarily consisted of participants producing past tense verbs when there was no cue, (i.e., when a present tense verb was required). The authors concluded that the verb production deficits in PD were due to cognitive deficits exaggerated by task specific demands, specifically, having to switch from past to present tense when no cue appeared in the sentence [23]. This conclusion was supported by the finding that accuracy in the choice of tense in the verb generation task correlated with performance on working memory and task switching measures. Unfortunately, the experiment did not include a condition in which tense switching was signaled by including a present tense adverb such as "now," which would have helped distinguish the

relative strength of the effects associated with memory for instructions versus tense switching. The findings of Colman et al. suggest that increasing experimental task demands (e.g., frequently switching between tenses with no overt cue in one condition) can reveal vulnerabilities in language production in PD. Additionally, they suggest that measures of working memory and task switching may index the degree to which grammatical sentence production will be affected in difficult tasks that specifically tax these abilities.

The study by Colman et al. raises an import issue: difficulties with verb access could seriously impact sentence production due to the centrality of the verb to the sentence construction process [74–76]. In fact, verb production in action fluency tasks seems to be particularly impaired in persons with PD whether they have dementia [77] or not [78, 79], while noun generation is relatively unimpaired. Individuals with PD also have been reported to have difficulty learning new verbs [80] and producing regular past tense forms of verbs [81]. However, this latter finding has been difficult to replicate (e.g., [23, 82, 83]). These findings suggest that verb activation and use may be particularly challenging for individuals with PD. The relationship between verb access deficits in PD and findings of diminished information content, impaired grammaticality, decreased syntactic complexity and impaired fluency has yet to be explored in the literature.

Very recently, we [17] examined the effects of differences in task demands and stimulus complexity on sentence production in PD. We compared 20 Nondemented individuals with PD to 20 age and education matched healthy older adults in two tasks, sentence repetition and sentence generation, in which the complexity of the stimuli was manipulated. Participants also completed a battery that included tests of set shifting (the Trail Making Test), inhibitory processing (Stroop), verbatim and working memory (digit span forward and backward), and the DRS in order to assess the impact of individual differences cognitive abilities on language production performance in the two tasks. Groups' scores did not differ in the resultant executive function or working memory factors, but the PD group's scores were significantly lower on the DRS, while still being within the Nondemented range. Composite variables were created from these measures using principle components analysis, because they were all significantly intercorrelated with each other. Set-shifting and inhibition tasks loaded on an executive function factor, and the memory tasks loaded on a working memory factor. Residualized DRS scores from which working memory and executive function were partialled out were also computed for use in the regression analyses.

Language production in each task was assessed using three language dimensions: fluency of production, grammaticality, and completeness. A fluent response was defined as being a sentence that was free of false starts, wholly or partially repeated words, and filled or unfilled pauses. Grammaticality was defined simply as being a grammatical utterance. Due to the nature of the tasks, completeness, our measure of information content, was defined differently in each task. In the repetition task, completeness referred to verbatim repetition; if a sentence was repeated verbatim, it was complete, and if there was any change, it was not. In the sentence generation task, participants were specifically asked to describe the event in the picture without using pronouns. Therefore, for this task, completeness required that a sentence mention each actor in the stimulus picture plus an appropriate action. Initial analyses consisted of group by complexity by language dimension multivariate analyses of variance.

The research questions in this study went beyond those addressed in previous studies. Not only did we ask whether the two groups differed in language production across tasks and whether cognitive abilities accounted for significant variance in these tasks, we also asked whether the two groups still differed when effects associated with cognitive variables were controlled. To address this final question, we employed hierarchical, stepwise, multivariate regression models, which are described in more detail in the Appendix. Regression models were only computed for dependent variables showing significant group main effects or interactions.

In the repetition task, participants repeated 20 sentences from Small et al. [84] that were controlled for word frequency and number of words, in which the complex sentences contained a relative clause (e.g., *The tornado that swept through the town destroyed several homes*) and the simple sentences contained a prepositional phrase (e.g., *The circus at the convention center attracted thousands of children*). The main effect of complexity was not significant; however, there was a significant main effect of group and a significant language dimension by group interaction. The two groups did not differ in the proportion of sentences repeated that were grammatical and complete, but the group with PD produced more disfluent responses and overall fewer acceptable sentences (sentences that were fluent, grammatical and complete) than the healthy adults, regardless of the complexity of the sentence. Moreover, the regression analyses revealed that 47% of the variance in fluency of production was accounted for by differences in working memory, executive function and DRS scores. Importantly, while group accounted for an additional 5% of the variance in both fluency and overall acceptability, these effects were not significant ($P > .06$ and $P < .09$, resp.). In other words, when the effects of cognitive ability were controlled, there were no longer significant group differences in performance on sentence repetition.

In the sentence-generation task, the same individuals produced a single sentence to describe each of 20 pictures that differed in the number of actors. Half of the pictures contained 2 actors (simple condition), and half included 3 actors (complex condition). Pictures showed scenes with people or animals doing common actions (e.g., a boy and a girl climbing a tree, a dog chasing a cat that was chasing a girl). The 3-actor picture was considered more complex than the 2-actor picture because additional concepts (i.e., the third actor and its associated activity) needed to be activated and integrated with the other information in the output sentence. All main effects were significant. Complexity interacted with language dimension; complexity of stimuli had significant effects on grammaticality and fluency but not completeness in both groups. The interaction between group and language

dimension was also significant. In the group with PD, fluency was disproportionately impaired relative to the healthy older adults, grammaticality was somewhat less impaired, and completeness was most preserved although the group differences were significant in all three dimensions. The regression analyses examining performance in each language dimension demonstrated that both working memory and executive function contributed significantly to fluency and completeness of responses as well as to overall performance, while grammaticality was only predicted by executive function scores. Furthermore, in each of these analyses, the effect of group remained significant, accounting for 10%–27% of the variance in performance, when cognitive variables were controlled.

Therefore, our study found significant predictive relationships between working memory, executive function and different aspects of language production, illustrating the strong impact of these cognitive abilities on language production performance; however, cognitive abilities did not fully account for the group differences in language performance. Thus, our findings present the additional, unexpected possibility that the deficits in PD language production extend beyond what can be explained by standard tests of working memory and executive function. This unanticipated finding suggests that more sophisticated statistical techniques than simple correlations may be necessary to determine whether the language impairments in PD are wholly attributable to cognitive impairments (e.g., [63]), or whether deficits exist in PD that are specific to language processing as well.

In summary, the studies described here provide converging evidence regarding the types of language impairment found in individuals with PD. First, information content is reduced. Second, grammatical sentence production is impaired, particularly in complex conditions or tasks. Third, fluency of production is impaired. The findings are mixed only with respect to complexity of sentences. An additional common theme is that most studies have found (or infer) that differences in cognitive abilities contribute to these deficits. Consistent with this, it also appears that language production in individuals with PD is particularly vulnerable to differences in the complexity of the eliciting task. In the section below, we situate this pattern of findings within the most commonly cited model of language production.

3. Producing Language

As shown above, from the very early years, researchers of language production in PD have focused on examining performance on a variety of dependent variables, often looking at both single-word and sentence or discourse production as well as comprehension [22, 60, 85]. Moreover, many of these studies have included cognitive covariates years before this became popular in the mainstream psycholinguistic literature (e.g., [15, 22, 60, 85]). Indeed, it is still unusual to find studies looking at the impact of executive function on language production in healthy young adults unless they are contrasted with other populations [64, 65, 86–88]. In the following section, we describe the most commonly cited model of language production, one stage at a time, and speculate about the types of errors we believe would result from dysfunction at each level. We also discuss whether these types of errors are found in PD and whether they are associated with individual differences in cognitive ability. Our goals are to determine which stages of the language production process are affected in PD and, to the extent we can from the limited studies available, which stages are vulnerable to cognitive limitations. While earlier studies compared performance to dementia severity or divided groups by dementia severity [14, 18, 22, 60, 84], more recent studies have begun to use a larger variety of tasks measuring both working memory [15, 17, 21] and executive function [17, 20, 23]. The consistent finding has been that, as cognition becomes more impaired, difficulties in language production increase.

The dominant model of sentence production today was first suggested by Garrett [89–91], and later refined by Levelt and Bock [75, 76, 92]. This model specifies five stages in the sentence generation process: the message level, functional processing, positional processing, motor programming, and articulation. The current paper has been primarily concerned with processing at the first three levels.

3.1. The Message Level. In general, the production of any intentional utterance begins with the activation of an idea or message to be communicated. Deficits at this stage of the production process would lead to reductions in information content, shorter sentences, and/or empty speech. In previous studies in healthy populations, information content has been statistically associated with working memory [93] and processing speed [72].

In the studies described above, there seems to be general agreement that information content is reduced in PD across various language tasks, including conversational discourse, picture description tasks, and written sentences [14–16, 94]. These deficits likely represent limitations in activation at the message level of sentence production [17–19]. Small et al. [16] and Murray [15] reported decreases in content associated with increasing dementia. Our study [17] reported that education, working memory and executive function all contributed significantly to information content in nondemented individuals with PD; furthermore, the groups differed even when these cognitive differences were accounted for. Therefore, limitations in information production may represent a primary characteristic of PD, occurring even in the absence of cognitive impairment.

3.2. The Functional Level of Processing. During the functional level of processing, the conceptual message activates the abstract representations of the word or words that have the greatest meaning overlap with the message [75]. Activation of these abstract word representations, often called lemmas [92, 95, 96], leads to the concomitant activation of grammatical information about the word, such as the argument structure of a verb [74] or grammatical gender in French or Italian [96]. Sentence generation differs fundamentally

from single word production in that at the functional level, the meanings and grammatical requirements of several words must be activated simultaneously and, importantly, integrated into a structure that conserves all the meaning-relevant information in the message (e.g., tense, aspect, definiteness of nouns, thematic roles of nouns, and perhaps even focus). This logic suggests that executive function resources may be required for computation of grammaticality.

Impairments at the functional level of processing that affect lemma selection could lead to semantic paraphasias (i.e., off-target word choices), disfluency, or incoherence. Impairments in the selection of verbs, however, would have a more pervasive impact on sentence and discourse production than impairments of noun selection, because of the importance of verbs to sentence structure [74, 76, 92]. As discussed briefly above, the verb is the primary determinant of the structure of a sentence in English and many other languages, because verbs place specific constraints on what types of nouns can act as their subjects and objects. Verbs also serve as constraints on how the resulting sentences are interpreted [74, 92]. For example, when using the verb *to bore*, native speakers know that it is ungrammatical for an active sentence to include an inanimate object (**Jerry bored the movie*). Similarly, English speakers know that *Jerry bored Joe* means that Joe is the person who lost interest and Jerry caused it. Therefore, because of its importance in determining sentence structure and the positions of the nouns in the sentence, slow or impaired access to verb lemmas and their associated grammatical constraints could potentially disrupt the grammaticality of the sentences produced as well as fluency of production (i.e., lead to more sentence-medial pauses, lexical and nonlexical fillers, and abandoned utterances). Another potential effect of impairments at the functional level might be simplified syntax. Complex sentences with embedded clauses, especially center-embedded relative clauses (e.g., that man who won the race was born in Jamaica), require that the messages and lemmas for both clauses are available simultaneously. Thus, limitations in the ability to activate the full set of items could lead to the production of less complex conjoined or consecutive sentences (e.g., that man won the race. He was born in Jamaica.). Limitations in syntactic complexity during language production have been associated with working memory limitations in healthy adults (e.g., [72]).

Evidence from the psycholinguistic literature suggests that grammaticality (e.g., verb agreement) may be particularly vulnerable in individuals with low working memory [97]. Furthermore, grammaticality has been found to be vulnerable in dual task settings in older adults with [98] and without stroke [87, 99] when the dual task becomes particularly difficult, suggesting that limiting available executive function resources can impair grammaticality. Grammaticality of oral language production is impaired in PD, particularly in more difficult tasks [15, 17, 20, 23]. Consistent with the above findings, grammatical language production has been associated with executive function in individuals with PD [17, 20]. These difficulties could be traceable to either functional level impairments or to impaired transfer of information from the functional level stage of processing to the positional stage of processing, based on findings that unusual amounts of grammatical errors were only found when language was generated, not repeated [17, 22].

In contrast, findings regarding the simplification of syntax in PD have been mixed. Two studies examining oral language production, Cummings et al. [14] and Murray [15], report impaired syntactic complexity in individuals with PD. Moreover, Murray also reported that sentence complexity correlated with measures of attention and short-term memory, which is consistent with findings from the healthy adult literature (e.g., [72]). In contrast, Small et al. [16] found reduced syntactic complexity only in more severely impaired individuals with PD, examining single written sentences. This variability in findings across studies may be attributable to differences in the demands of the elicitation tasks used [21]. Based on this analysis, it appears that functional level processing in PD is impaired. Furthermore, the evidence suggests that individual differences in executive function and/or working memory can account for these impairments to a large extent though not completely.

3.3. Positional Level Processing. From the functional level of processing, information flows to the positional processing level during which the phonological forms of words are activated and the linear structure of the sentence is generated [90–92]. Tasks requiring sentence repetition may begin the language process about here, since no message generation or grammatical formulation is required. Notably, in our study described above, only fluency was impaired in the repetition task in PD, regardless of grammatical complexity. Fluency is discussed below in Section 3.4. Other deficits that might be attributed to dysfunction at the positional level of processing would be increased tip-of-the-tongue phenomena, phonemic paraphasias, aberrant word order, and some types of grammatical errors. While word finding difficulties have been reported in PD [14], no experimental investigations of TOT phenomena in PD have been reported to our knowledge. Phonemic paraphasias would be difficult to distinguish in PD due to the prevalence of hypokinetic dysarthria. To our knowledge, there have been no reports of the production of sentences with aberrant word order in PD.

Positional level grammatical processing is associated with accessing phonetic forms of inflectional morphology and closed class words [89–91]. As mentioned above, Ullman and colleagues [81] have reported morphological difficulties affecting the production of regular past tense verbs in PD, which would implicate difficulties at the positional level of processing. However, several studies have failed to replicate this effect [23, 82, 83]. Further, while several studies detailed above have reported grammatical errors, none of the current studies on PD have distinguished between functional level and positional level grammatical errors; therefore, the etiology of grammatical errors in PD is unknown. Thus, there is little evidence that the grammatical errors in PD originate in dysfunction at the positional processing level although there may be fluency impairments at this level, as discussed below. We suspect the grammatical errors in PD occur before positional level processing during functional level,

grammatical formulation, or the transfer of information from functional to positional level processing, because they occur in generation but not repetition tasks.

3.4. The Monitor. Levelt and colleagues [92, 95] also include a monitor in their model of language production that checks planned language output (after or during positional processing) against the conceptual representation of the intended utterance. Levelt et al. [95] argue that monitoring focuses on either the phonetic or phonological level, as well as on overt speech, but it is unknown whether the monitor is equally adept at detecting all types of errors (e.g., semantic and phonemic paraphasias and grammatical errors). The typical effects of the monitor would be false starts, in which the speaker halts mid-sentence and begins again with a sentence plan that may or may not be completely different from originally intended utterance. Of the studies discussed, only Illes [18] specifically assessed self-corrections and found that individuals with PD produced about the same number of self-corrections as control subjects. However, the author does not report the proportion of potential corrections for each group, so it is unknown whether this self-correction rate represents preserved or impaired monitoring. However, reviewing the studies above, the prevalence of uncorrected grammatical errors suggests that monitoring of this type of error may be impaired in PD. On the other hand, few (if any) studies of grammatical error monitoring have been reported, so it is unknown how frequently healthy speakers detect and correct grammatical errors. Therefore, whether self-monitoring of language production is impaired in PD is an open question.

3.5. Fluency Impairments. Determining the etiology of difficulties with fluency of language production in PD presents a complex problem due to the motor speech problems associated with the disease. Perhaps as a result of this potential confound, few researchers have examined fluency of language production in this population. The evidence from the three studies reported here that examined fluency [17–19] suggests that fluent production of speech is a major problem for individuals with PD. Furthermore, all three studies agree that the fluency problem is due to difficulties at more than one level of processing. Based on our analysis above that sentence repetition primarily taps positional processing and subsequent motor programming, articulation, and monitoring, our study [17] suggests that a good deal of the fluency difficulty in PD can be traced to these levels. However, the available research cannot distinguish fluency disruptions at the positional level from those at the motor planning or articulation levels.

On the other hand, we found fluency was even more impaired in the sentence generation task than in repetition, which additionally requires message generation and functional level processing. This suggests that difficulties at the message level and/or functional level can also disrupt fluency although we cannot isolate the difficulty to one of these two levels. Additionally, we found that working memory and executive function predicted significant amounts of variance in fluency rates in repetition and sentence generation, but only in the latter task did the two groups differ in fluency when cognitive variables were controlled. In fact, group (PD versus healthy control subjects) accounted for more than 25% of the variance in fluency in sentence generation, but only 5% in repetition. This suggests that contrary to expectations, impaired fluency at earlier levels of language production (message and functional level) might be even more characteristic of PD than impaired fluency at later levels (positional processing, motor planning and articulation levels).

Expanding upon the suggestion by Illes [18], we hypothesize that fluency might be considered a measure of timing coordination within the language production system. If all stages of the language production process are working well and at a similar pace, then each element required for the intended sentence will be available when needed, and language production will be fluent. However, any variability in the timing of any essential component, (e.g., conceptual activation, lexical access, grammatical manipulation, sentence assembly, phonetic assembly, or motor planning) will potentially impair fluency. This hypothesis is consistent with findings that language production fluency is frequently impaired in dual task experiments [87, 99] which require coordination and planning of the timing of two tasks performed simultaneously, thus potentially interfering with timing (and accuracy of performance) in both. Studies looking at the effect of dual tasks on language production in PD are currently underway in our lab. One of the difficulties for future studies examining these issues will be distinguishing between disfluencies that are due to faulty timing, disfluencies that are to due to poor word choice to encode a message, and disfluencies due to self-monitoring. More research is certainly needed on ways to distinguish the etiology of fluency disruptions in PD and other populations.

4. Future Directions and Conclusion

Future studies examining PD language within a specific model of language production that includes hypotheses about cognitive contributions to each stage of processing will advance our understanding of the effects of PD on language production and communication as well as further the overall understanding of the relationship between language production and cognitive processing. As shown here, while the literature is not extensive, language production in PD has been well described; therefore, future studies on language production in PD should continue to embrace hypothesis-driven experimental methods (e.g., [17, 20, 22, 23]). This will allow a more precise delineation of the language impairments in PD that can then be developed into therapeutic strategies to circumvent these impairments.

Several topics suggest themselves for further research. First, it is highly likely that grammatical errors and fluency disruptions are not unitary constructs. Specific tasks could be designed, for example, that specifically target grammatical errors at the functional level versus the positional level of

language production. These studies should include a cognitive battery to determine whether each type of grammatical error is subject to the same cognitive constraints. Another important opportunity for research would be to explore the relationship between deficits in verb access in PD, cognitive abilities, and the various language impairments documented here (i.e., reduced information content, impaired grammaticality, reduced syntactic complexity, and reduced fluency). These types of studies would be theoretically enlightening, while also identifying potential therapeutic targets for intervention.

Similarly, analyses that examine different types of disfluencies might clarify which aspects of the language production process are most responsible for the fluency difficulties in PD. For example, fluency difficulties due to formulation difficulties (i.e., abandoned utterances and false starts) are relatively easily distinguished from those that signify synchronization difficulties (sentence-medial pauses, restarts, and filled pauses) but not so easily distinguished from the effects of self-monitoring. A testable hypothesis is that these two types of fluency difficulty will align differently with cognitive measures; specifically, synchronization disfluencies may correlate with timing measures, while formulation and monitoring disfluencies may relate to executive function abilities. A study testing this hypothesis is currently underway in our lab.

Another potential avenue of research could explore the effects of the decrease in information content and conceptual complexity on the adequacy of language output from the listener's point of view. Particular types of discourse could be contrasted in these studies, such as giving directions and procedural discourse (e.g., telling someone how change a flat tire) in which sufficiency of information would be a critical element for the listener. This issue should be explored using real-world communication scenarios involving complex topics to determine the extent to which crucial information is omitted during the discourse. This type of study is needed to determine if, for example, the decrease in information content in PD discourse might have functional consequences.

Along similar lines, to our knowledge, there is no research on the relationship between language impairments in PD, especially impaired information content and fluency, and the dynamics of the 3-way conversation between the individual with PD, the spouse, and an authority figure. Anecdotally, it is not uncommon in PD for the caregiver to increasingly take over as the "voice" of the patient with PD so that their chances of participating in discussions about complex topics may diminish over time. It is possible that this change is directly related to the language production difficulties in PD such as reduced information content and impaired fluency. This type of study could lead to important insights into doctor-patient communication that could fundamentally change the communication dynamic in the examination room. This research could lead to family interventions to maximize the opportunities of the individual with PD to express their own thoughts and opinions. A related and completely unstudied avenue of research is the relationship between language production deficits, instrumental activities of daily living, and quality of life in PD. For example, there may be a direct relationship between a person's ability to communicate clearly and their ability to make appointments, take down telephone messages, communicate concerns to their physician, or discuss financial and legal issues.

In summary, language production in PD has been well described with studies converging on several themes. There is general agreement that information content is reduced in PD across various language tasks, including conversational discourse, picture description tasks, and written sentences [14–17]. These deficits likely represent limitations in activation at the message level of sentence production and in sentence formulation [18, 19]. Grammaticality of oral language production also appears to be vulnerable to impairment in PD, particularly in more difficult tasks [15, 17, 20, 23]. Findings regarding the simplification of syntax have been mixed but suggest that in more difficult, constrained tasks such as picture description and syntax may be simplified [14, 15], while in easier tasks like spontaneous conversation, syntactic complexity may be unimpaired [18, 19, 21]. Fluency is a common problem in PD language production [17–19] and should be investigated as a language impairment as well as motor speech impairment. An additional common theme throughout the complex language production studies reviewed above has been the contribution of cognitive ability to language performance. All of the impaired aspects of language production in PD have now been shown to be vulnerable to cognitive impairment [16, 17, 19, 20, 23]. In addition, newly popular statistical procedures such as hierarchical linear modeling and multivariate regression offer a means to simultaneously determine the effects of group, cognitive covariates, experimental conditions, and their potential interactions. Continuing research on language production in PD is needed to provide practitioners with evidence-based targets for intervention.

Appendix

Multivariate regression models allow the inclusion of group by predictor interaction terms and group variables in the model to address the question of whether predictor variables have a different intercept and slope for each group. As in a logistic regression, a group variable is constructed so that one group, usually the group of primary interest, is coded as 1 and the control group is coded as 0. The interaction term is the product of the group variable times the independent variable in question.

Multivariate regression allows the testing of many types of hypotheses that cannot be tested within a standard multiple regression. Specifically, if an interaction term is significant, the slope of the regression line for the two groups is significantly different. If the group variable is significant, the intercept for the two groups is significantly different. Furthermore, the researcher has the option of using multiple regression approaches or other approaches, such as hierarchical stepwise models, to test their hypotheses.

In our study described above [17], the following interaction terms were included in the model: Group by Working

Memory, Group by Executive Function, and Group by DRS. The regression analyses used a hierarchical, stepwise approach, with age and education allowed to enter in step 1; main effects associated with executive function, working memory, and DRS were allowed to enter in step 2, because these would signal factors affecting both groups. In step 3, the interaction terms between groups and cognitive factors were allowed to enter, and only in step 4 was the main effect of group allowed to enter. This approach was chosen to impose the most stringent criteria possible on any emergent group effect.

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