Sentence production in Parkinson's disease

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Abstract

While growing evidence reports changes in language use in nondemented individuals with Parkinson's disease (PD), the presence and nature of the deficits remain largely unclear. Researchers have proposed that dysfunctioning fronto-basal ganglia circuit results in impaired grammatical processes, predicting qualitatively similar language impairments between individuals with PD and agrammatic Broca's aphasia, whereas others suggest that PD is not associated with language-specific grammatical impairment. In addition, there is a paucity of research examining syntactic production in PD at the sentence-level. This study examined sentence production of individuals with PD, healthy older adults, and individuals with agrammatic Broca's aphasia. In Experiment 1, using a Cinderella story-telling task, proportion of grammatical sentences, number of embedded clauses, and production of verb arguments in sentences were examined. In Experiment 2, a structured sentence elicitation task was used in which syntactic complexity of sentences (canonical vs. non-canonical word order) was systematically manipulated while minimizing demands for non-syntactic processing. Only the participants with agrammatic Broca's aphasia showed significantly impaired syntactic production in both experiments. Participants with PD did not show impaired syntactic production in either task, despite impairments in lexical retrieval, repetition of words and sentences, and speech production. These findings suggest that impaired syntactic processing may not be a core deficit underlying the changes in language use in nondemented PD. Changes in language use in PD are qualitatively different from language deficits in aphasia.

Introduction

Parkinson's disease (PD), a neurodegenerative disorder caused by dopaminergic deficiency in the basal ganglia, results in disrupted motor speech control and higher-level cognitive deficits from a relatively early stage of the disease, including reduced attention, executive function, inhibition, and memory. Changes in language use have also been reported. Individuals with PD may show deficits in comprehending sentences with increased length and syntactic complexity (Grossman, Kalmanson, Bernhardt, Morris, Stern, & Hurtig, 2000; Hodstadt, 2009; Kemmerer, 1999; Lieberman, Friedman, & Feldman, 1990; Natsopoulous, Grouios, Bostantzopoulou, Mentenopoulos, Katsarou, & Logothetis, 1993 and others), verb inflection errors (Colman, Koerts, van Beilen, Leenders, Post, & Bastiaanse, 2009; Longworth, Keenan, Barker, Marslen-Wilson, & Tyler, 2005; Mohan & Huber, 2014; Ullman, Corkin, Coppola, Hickok, Growdon, Koroshetz, & Pinker, 1997; Zanini, Tavano, & Fabbro, 2010), reduced production of grammatical sentences and information content in connected speech (Illes, Metter, Hanson, & Iritani, 1988; Illes, 1989; Murray, 2000), and impaired lexical-semantic processing with particular difficulty in verb retrieval (Copland, 2003; 2006; Lee, 2017; Péran, Rascol, Demonet, Celsis, Nespoulous, Dubois, & Cardebat, 2003; Piatt, Fields, Paolo, Koller, & Troster, 1999).

However, careful examination of the existing literature reveals that the presence and nature of language deficits remains largely unclear for nondemented individuals with PD, while it has been consistently shown that various aspects of language use are impaired in individuals with PD who have dementia (e.g., Lewis, LaPointe, Murdock, & Chenery, 1998; Murray & Lenz, 2001; Small, Lyons, & Kemper, 1997). For example, some studies report impaired verb inflection in individuals with nondemented PD (Ullman et al., 1997; Zanini et al., 2010), while others don't (Longworth et al., 2005; Terzi, Papapetropoulos, & Kouvelas, 2005). Reduced production of grammatical sentences was reported in a picture description task (Murray, 2000), but not in conversational speech samples (Murray & Lenz, 2001), highlighting the importance of inter-task examination of language production in PD. The current study focuses on syntactic production in mild PD.

A group of researchers proposed a neuroanatomical dissociation of language, which holds that implicit rule-based linguistic processes are subserved by the frontal-basal ganglia procedural system, whereas lexico-semantic information is processed in the temporo-parietal declarative system (Ullman et al., 1997; Ullman, 2001; 2006; Zanini et al., 2010). In PD, the dysfunctioning basal ganglia projects impaired signals to frontal regions of the brain, including Broca's area. Based on this theory, PD would result in compromised use of grammatical rules during language comprehension and production, similar to grammatical deficits seen in individuals with Broca's aphasia, often associated with frontal lesions (Dominey & Inui, 2009; Ullman et al., 1997; Ullman, 2001; 2006). Both individuals with PD and persons with frontal aphasia (e.g., Broca's aphasia) made more errors in generating regular verb forms (*walk* – *walked*), a rule-governed process, whereas those with posterior (Wernicke's) aphasia or Alzheimer's disease made more errors with irregular verb forms (*drive-drove*), assumed to be stored in the lexicon as independent lexical items (Ullman et al., 1997). Similarly, Zanini et al. (2010) reported that Friulian-Italian bilingual speakers with PD made phonological, morphological, and syntactic errors when they produced a story in their first language, but not in their second language. The authors suggested that this dissociation was due to the dysfunctional basal ganglia, resulting in impaired implicit rule-based processing, which is responsible for acquisition of grammatical processes in the first language. On the other hand, grammatical processes of the second language are acquired later, and utilize explicit memory represented in the neocortical areas; thus, they remain relatively preserved in PD.

Others suggest that PD is not associated with language-specific grammatical deficits as such, rather that impairment in attention-based cognitive control underlies changes in language use in individuals with PD (Almor, Kempler, Andersen, McDonald, Hayes, & Hintiryan, 2002; Bastiaanse & Leenders, 2009; Chan, Ryan, & Bever, 2013; Colman et al., 2009; Friederici, Kotz, Werheid, Hein, & von Cramon, 2003; Grossman, Morris, Stern, & Hurtig, 2002; Katsarou, Stavrakaki, Alexiadou, Anagnostopoulou, Kafantari, & Bostantjopoulou, 2003; Lee, 2017; Longworth et al., 2005). For example, it has been suggested that basal ganglia dysfunction in PD results in impaired inhibitory control of competing alternatives during post-linguistic integration processes, leaving processing of linguistic representations intact (Arnott, Chenery, Murdoch, & Silburn, 2001; Copland, Sefe, Ashley, Hudson, & Chenery, 2009; Friederici et al., 2003; Longworth et al., 2005). As evidence for this, the dissociation between regular vs. irregular verb inflection in PD has been difficult to replicate in later studies (Fredrick, Dick, & Lee, 2016; Longworth et al., 2005; Terzi et al., 2005). Longworth et al. (2005), using the same stimuli from Ullman et al. (1997), failed to find a dissociation between regular and irregular verb forms in both production and comprehension tasks in individuals with subcortical vascular disease, mild PD, and Huntington's disease. However, these patients showed difficulty suppressing inflected forms of semantically-related alternatives when trying to inflect novel verbs in production, suggesting that while automatic activation of morphological rules and lexical representations remain intact in individuals with PD, they have difficulty suppressing information that becomes incompatible during the post-linguistic integration stage.

Parallel evidence has been shown in studies examining sentence comprehension. For example, electrophysiological evidence during comprehension of sentences shows that individuals with PD demonstrate normal early left anterior negativity (ELAN) in response to syntactic violations, indicating intact automatic activation of syntactic representations. However, the P600, thought to reflect late attention-based integration of activated linguistic representations, is either absent or reduced in PD (Friederici, Kotz, Werheid, Hein, & von Cramon, 2003; Frisch, Kotz, von Cramon, & Friederici, 2003; see also Kotz, Frisch, von Cramon, & Friederici, 2003). This finding differed from the authors' previous study (Friederici, von Cramon, & Kotz, 1999), in which individuals with agrammatic Broca's aphasia showed abnormal ELAN as well as P600, indicating that their deficit arises from an early stage of linguistic processing (see also Lee, 2017; Lee, Yoshida, & Thompson, 2015). Caplan and Waters (1999) found similar evidence using a set of sentence comprehension tasks, which varied in terms of non-syntactic vs. syntactic processing demands. Their participants with PD had greater difficulty completing a sentence-picture matching task compared to healthy older adults and the group difference was exacerbated under a concurrent working memory (digit load) task. Importantly, the group differences were significant only when the sentences contained an increased number of propositions (e.g., *The tired* *waitress served the customer* vs. *The tired waitress served the customer that made the mess*). However, no group difference was found when the sentences differed in syntactic complexity only (canonical vs. non-canonical word order). For example, the PD group performed equally well as healthy older adults both in sentences with subject relative clauses (e.g., *John saw the man who was chasing the boy*) and those with object relative clauses (e.g., *John saw the boy who the man was chasing*), because the non-syntactic factors (e.g., same number of propositions; same lexical items) were kept constant. These findings suggest that individuals with PD have the intact ability to "structure sentences syntactically" (p. 89), independent of the cognitive changes (e.g., reduced working memory) that affect non-syntactic aspects of language-related tasks.

Studies examining PD speakers' syntactic processing in a sentence production context are sparse, yielding mixed findings. Previous studies largely focused on morphological processing and sentence comprehension, even though syntactic production, i.e., assigning thematic roles (agent, theme) to words and sequencing them into the correct order, is a crucial part of rule-based linguistic processes. Among the few studies available, Small et al. (1997) examined written sentence production in individuals with PD, using the Mini-Mental Status Examination. They found that grammaticality of written sentences was not impaired in either mild or moderate PD participants, although the information content was reduced for participants with moderate PD. However, their study was based on analysis of only one written sentence response from each participant. Lee (2017), using an 'eyetracking-while-speaking' paradigm, examined sentence planning units (word-by-word vs. advanced planning) in a picture description task. Participants described three pictures of objects, using a predefined sentence structure (e.g., *The toaster and the sofa are above the clock*). Some pictures were low codable objects allowing multiple competing lexical labels (e.g., *sofa/couch, skillet/pan*), while others were highly codable pictures allowing only one lexical label (e.g., *pencil, clock*). PD participants' gaze duration data showed normal word-by-word planning units as well as increased gaze durations as an effect of lower lexical codability, suggesting intact ability to activate lexical representations and coordinate them into a given sentence structure. However, they produced more word substitution errors (e.g., *chair* for *sofa/couch*; *horse* for *donkey/mule*) and disfluencies in off-line production compared to healthy older adults in sentences with low codable pictures but not in those with highly codable pictures, suggesting that their reduced inhibitory control made it difficult to suppress competing items. However, in Lee (2017), the participants used a predefined sentence structure; thus, the study did not examine 'syntactic' production.

Troche and Altmann (2012) examined repetition and generation of sentences with different complexity, comparing sentences with one proposition (*The tired waitress served the customer*) vs. two propositions (e.g., *The angry nurse cleaned up the mess that the doctors made*). In both repetition and generation tasks, the participants with PD showed reduced accuracy, fluency, and completeness compared to controls. However, the group difference was no longer significant when their cognitive deficits in executive function and working memory were controlled for in the sentence repetition task. In contrast, for the sentence generation task, although cognitive ability accounted for significant variance in the participants' performance, the group difference remained significant even when the cognitive scores were controlled for. It was argued that there may be language-specific impairment in PD independent of their cognitive changes.

The purpose of this study was to systematically examine sentence production in individuals with PD using two different production tasks. In Experiment 1, a set of clinical measures of syntactic production was examined in a Cinderella story re-tell task. In Experiment 2, production of syntactically simple (canonical) vs. complex (non-canonical) sentences was compared in a structured sentence elicitation task with non-syntactic factors constrained. In addition to healthy age- and education-matched older adults, we included a group of individuals with agrammatic Broca's aphasia. We examined if participants with mild PD would show impaired grammatical processing in those experiments compared to healthy older controls and, if so, whether they would show qualitatively similar syntactic deficits as seen in agrammatic Broca's aphasia.

Method

Participants

Data are from 16 participants with idiopathic PD (7 females, 9 males), 16 healthy older controls (9 females, 7 males), and 10 participants with mild-moderate Broca's aphasia (4 females, 6 males). Demographic and medical information related to PD and aphasia are provided in Table 1 and 3, respectively. All participants with PD were diagnosed with the disease at least 1 year prior to the study (M (SD) = 7.2 (3.7) yrs) and were taking PD-related medications at the time of testing. They were tested while they were "on" medication state. The participants with PD and healthy older adults were matched in age (PD: M (SD) = 68.7 (6.2) vs. HOA: 69.4 (8.2) yrs old, t (30) = .27, p = .79), although the participants with Broca's aphasia (M (SD) = 59.8 (9.3) yrs old) were younger than the PD and healthy older participants (t's > 2.936, p's < .05). The three groups were matched in years of education (PD: M (SD) = 17.0 (2.7) years; HOA: 16.6 (3.0); aphasic: 17.1 (3.3); t's < .424, p's > .66).

Table 1. Background information for participants with PD.

Participant	Age (yrs)	Education (yrs)	Time since diagnosis (yrs)	PD-related medications
PD01	68	18	2.7	Azilect, Pramipexole
PD02	74	18	3.3	Azilect
PD03	74	16	8.6	Carbidopa-Levodopa, Mirapex, Comtan
PD04	74	15	10	Mirapex
PD05	71	22	6	Carbidopa-Levodopa, Neupro
PD06	75	18	1.7	Pramipexole
PD07	60	16	11	Sinemet, Sinemet ER
PD08	60	15	4.5	Carbidopa-Levodopa, Ropinirole
PD09	66	12	11.7	Comtan, Sinemet, Mirapex
PD10	76	18	6	Ropinirole, Selegiline
PD11	64	18	10.8	Azilect, Stalevo 200,
PD12	66	20	7	Carbidopa-Levodopa, Trihexyphenidyl
PD13	71	20	8.5	Carbidopa-Levodopa, Ropinirole HCL
PD14	57	16	11	Carbidopa-Levodopa
PD15	76	12	1	Carbidopa-Levodopa
PD16	67	19	11	Sinemet, Mirapex, Amantadine
Mean	68.7	17.1	7.2	
SD	6.2	2.7	3.7	

A set of cognitive-linguistic tests was administered with participants with PD and healthy older adults, as shown in Table 2. As a screening test for the participants' overall cognitive-linguistic skills, the Cognitive Linguistic Quick Test (CLQT, Helm-Estabrooks, 2001) was administered. All healthy older participants performed within normal limits (WNL) on the CLQT as indicated by the Clinical Severity Rating (CRS) of 3.8 or higher. Participants with PD obtained WNL-mild CRS, indicating none had dementia. Participants with PD scored lower than healthy older adults on the subsections of the CLQT, although the differences were not statistically reliable (Mann-Whitney U's $< .925$, p's $> .269$). In addition, participants' ability to repeat words and sentences with increasing length and complexity was examined using the Repetition subsection of the Western Aphasia Battery-Revised (WAB-R, Kertesz, 2006). Participants with PD showed greater impairment in repetition than healthy older adults ($U = 81$, $p = .045$), in line with the results from Troche & Altmann (2012). Action naming was examined using the Verb Naming Test of the Northwestern Assessment of Verbs and Sentences (NAVS, Thompson, 2011). Participants with PD showed significantly reduced retrieval of single verbs from action-related pictures compared to the healthy older adults ($U = 51.5$, $p = .003$), consistent with previous studies showing impaired verb retrieval in PD (Péran et al., 2003; Piatt et al., 1999).

A severity rating of the participants' speech production was conducted by three raters who had a Master's degree in speech-pathology with specialized experience in motor speech disorders and were blind to the purpose of the study. For each of the PD and healthy older participants, a representative speech sample (20 secs in duration) was clipped from the audio recordings of their Cinderella story re-tell. The speech samples were presented to each rater via a headset in a randomized order. The rater was asked to judge the severity of the participants' speech impairments by marking on a 150-millimeter line, with one end being 'normal' and the other being 'very severe'. Raters listened to each sample once. The distance from the normal end to the raters' mark was measured in millimeters and converted to percentages (of the total line distance). The higher values indicate greater speech impairment. Participants with PD presented significantly greater speech impairment compared to healthy controls ($U = 56.5$, $p = .003$).

Table 2. Cognitive-linguistic testing and speech intelligibility ratings for healthy older adults and participants with PD (means and standard deviations).

	CLQT						WAB-R	NAVS	
Group	Attention (215)	Memory (185)	EF (40)	Language (37)	VS (100)	CSR (4.0)	Repetition (10)	VNT (%)	Speech Severity Rating (%)
Healthy Older Adults									
OA1	201	173	38	35	103	4	10.0	100	7
OA2	190	161	29	33	87	4	10.0	100	6
OA3	206	166	36	33	102	4	10.0	100	5
OA4	191	175	30	37	83	4	10.0	96	12
OA5	202	168	33	35	93	4	10.0	82	3
OA6	202	154	28	31	90	4	10.0	86	8
OA7	199	168	30	35	90	4	9.8	100	4
OA8	209	169	38	36	99	4	10.0	100	0
OA9	200	175	30	37	89	4	9.8	100	10
OA10	211	184	35	36	101	4	10.0	96	2
OA11	163	178	26	35	72	4	9.4	100	2
OA12	178	176	26	33	86	3.8	10.0	91	3
OA13	188	155	27	32	85	4	10.0	100	8
OA14	204	162	34	34	96	4	10.0	96	18
OA15	180	184	26	36	78	4	9.6	96	1
OA16	191	171	30	33	93	4	10.0	100	6
Mean	**194.7**	**169.9**	**31.0**	**34.4**	**90.4**	**4.0**	**9.9**	**96.3**	**5.9**
SD	**12.8**	**9.0**	**4.2**	**1.8**	**8.7**	**0.1**	**0.2**	**5.6**	**4.5**
Participants with PD									
PD1	152	181	22	33	76	3.4	10.0	82	3
PD2	203	160	31	32	95	4.0	10.0	77	9

PD3	204	180	33	35	97	4.0	10.0	96	18
PD4	166	132	24	29	71	3.8	9.4	82	11
PD5	179	173	22	35	74	4.0	8.4	64	15
PD6	199	185	34	37	94	4.0	10.0	100	13
PD7	211	184	35	36	101	4.0	10.0	91	27
PD8	199	168	31	35	91	4.0	9.8	96	21
PD9	203	159	30	31	95	4.0	9.8	86	11
PD10	193	182	27	34	87	4.0	9.2	77	18
PD11	192	166	30	33	91	4.0	10.0	91	2
PD12	187	153	30	30	91	3.8	9.8	91	9
PD13	163	178	26	35	72	4.0	9.4	96	13
PD14	196	159	30	31	95	4.0	10.0	96	27
PD15	190	175	21	32	81	4.0	9.4	96	3
PD16	201	162	30	29	98	4.0	9.4	96	28
Mean	**189.9**	**168.6**	**28.5**	**32.9**	**88.1**	**3.9**	**9.6***	**88.4***	**14.2***
SD	**16.7**	**14.2**	**4.4**	**2.5**	**10.0**	**0.2**	**0.4**	**9.7**	**8.5**

Note: EF = Executive Function; VS = Visuospatial skills; CSR = Clinical Severity Rating; CLQT = Cognitive-Linguistic Quick Test; WAB-R = Western Aphasia Battery; NAVS = Northwestern Assessment of Verbs and Sentences; Speech Severity Rating: higher percentage indicates greater impairment; * = significantly more impaired than healthy older adults.

All participants with aphasia suffered a single ischemic or hemorrhagic stroke (9 left-hemisphere stroke; 1 right-hemisphere stroke; see Table 3). All participants with aphasia were in the chronic phase with a minimum of 1 year post onset of stroke (M (SD) = 5.9 yrs (4.3)). They presented with moderate to mild Broca's aphasia profiles (Aphasia Quotient: 60.4 – 85.0) on the Western Aphasia Battery-Revised (Kertesz, 2006). Their verbal expression was characterized by slowed and effortful speech with reduced syntactic complexity (Fluency scores 5/10 or less), impaired repetition of words and sentences, and impaired naming (both nouns and verbs). Their auditory comprehension of words and sentences was relatively preserved (WAB-R Auditory Comprehension scores 7/10 or higher) in the face of impaired verbal expression. When compared with the participants with PD, the participants with aphasia showed greater deficits in repeating words and sentences (PD: M (SD) = 9.6 (0.44) vs. Aphasic: M (SD) = 8.0 (1.8); $U = 37.0$, $p = .031$); however, action naming was equally impaired between the two groups (PD: M (SD) = 88 (9.7)% vs. Aphasic: M (SD) = 79 (18)%; $U = 52.5$, $p = .144$).

All participants were monolingual native speakers of American English and passed a pure-tone hearing screening at 500, 1000, and 2000Hz at 40 dB in at least one ear. No participants reported visual deficits. The same participants were tested in Experiments 1 and 2, except for one participant with aphasia (A7) who could not complete Experiment 2.

Experiment 1

Stimuli and Procedure

A Cinderella story-retell task was used to examine sentence production in narrative speech. Participants briefly looked at a wordless picture book of Cinderella. Then, they were asked to tell the story of Cinderella without looking at the book. No time limit was provided. Participants received only neutral feedback (e.g., *you are doing fine*). Narrative speech samples were recorded using the Praat software (Boersma & Weenink, 2015).

Data Analysis

Each speech sample was transcribed verbatim and was segmented into individual utterances based on syntactic and prosodic indicators. Each utterance was then linguistically analyzed. Utterance

Table 3. Background information for participants with agrammatic Broca's aphasia

Participant	Handedness	TOP	Lesion	WAB Fluency (10)	WAB AC (10)	WAB Repetition (10)	WAB Naming (10)	WAB AQ (100)	NAVS Verb Naming
A1	R	3.2	L watershed infarct in frontal, temporal, and parietal lobes	5	7.9	7.5	4.3	67.4	73%
A2	R	5.0	L frontal gray and white matter, encompassing insula	5	8.2	9.4	9.2	81.5	86%
A3	R	2.4	L MCA infarct	4	8.1	5.2	8.4	65.3	50%
A4	R	1.1	L MCA infarct	5	7.5	8.7	6.8	73.9	73%
A5	R	14.0	L CVA	5	9.6	9.1	9.8	83.0	91%
A6	L	7.8	R inferior and middle frontal gyri and pre and post central gyri	5	9.0	9.5	10	85.0	91%
A7	R	3.3	L MCA infarct	4	8.0	3.8	6.4	60.4	45%
A8	R	10.4	L temporal lobe, L frontal and parietal opercula	5	10.0	9	6.8	79.6	95%
A9	R	5.6	L superior division MCA	5	10.0	10	9.2	83.0	97%
A10	R	2.8	L frontotemporal junction	5	9.1	8	8.7	77.5	86%
Mean (SD)		5.6 (4.1)		4.8 (0.4)	8.7 (0.9)	8.2 (2.0)	8.0 (1.8)	75.6 (8.6)	79 (18)%

Note: TOP = Time post onset of stroke in years; WAB = Western Aphasia Battery –Revised; AC = Auditory Comprehension; AQ = Aphasia Quotient; NAVS = Northwestern Assessment of Verbs and Sentences segmentation and linguistic analyses were conducted following the guidelines provided in the Northwestern Narrative Language Analysis (NNLA; Thompson, 2013). Three measures of interest were obtained for each participant: proportion of grammatically correct sentences, mean number of embedded clauses, and production of sentences with correct verb argument structure (VAS). Proportion of grammatically correct sentences was calculated by dividing the total number grammatically accurate sentences by total number of sentences produced. An utterance was considered as a 'sentence' when at least a subject noun and a main verb was produced (e.g., *Cinderella cried)*. The mean number of embedded clauses per sentence was calculated by dividing the total number of embedded clauses (e.g., complement clauses, relative clauses, adjunct clauses, etc.) by the total number of sentences that the participant produced in the Cinderella story. The proportion of sentences with correct production of VAS was calculated by counting the number of sentences with correct use of a verb and its arguments (e.g., agent, theme, and goal) and dividing it by the total number of sentences. For example, the sentence, *the prince found*, was counted as an incorrect production of VAS because the obligatory theme argument is omitted at the post-verbal position. In addition, we also computed general language measures including the mean length of utterances in words (MLU word) and the total number of utterances produced by each participant. For all samples, the data analysis was completed by the first (JD) and second (JF) authors who were graduate students with training on the NNLA protocol. During the training phase, these authors established a minimum of 95% accuracy based on a set of Cinderella story practice samples provided in the NNLA manual (Thompson, 2013). Any point-by-point differences between the two coders were resolved through discussions with the senior author (JL), who has years of experience in using the NNLA.

Results

The results of Experiment 1 are summarized in Table 4. Individual participants' data are provided in Appendix 1. Nonparametric tests were used because some of our measures were not normally distributed. For each measure of interest, a Kruskal-Wallis test was conducted with the alpha level at .05. When a significant group effect was found, post-hoc comparisons were conducted using Mann-Whitney tests with alpha-level corrected for multiple comparisons (.05/3 = .017). A significant group effect was found for the mean length of utterances. The aphasic group produced shorter utterances than the healthy older adults ($U = 3.74$, $p < .001$) and PD group ($U = 16.0$, $p < .001$). However, no group effect was observed for the mean number of utterances, indicating that both participants with PD and aphasia produced similar numbers of utterances as healthy older adults in their Cinderella stories. For all three measures of syntactic production, significant group effects were noted. The participants with PD did not differ reliably from healthy older adults on any of the three measures (p's > .086). In contrast, the Broca's aphasia group performed significantly worse than healthy older adults in all three measures of syntactic production (% grammatical sentences: $U = 9.0$, $p < .001$; mean number of embedded clauses, $U = 22.0$, $p = .002$; % sentences with correct VAS: $U = 13.5$, $p < .001$). Additionally, the aphasia group performed worse than the PD group (% grammatical sentences: $U = 12.5$, $p < .001$; mean number of embedded clauses, $U = 17.0$, $p = .001$; % sentences with correct VAS: $U = 20.5$, $p = .001$).

Table 4. Narrative production data (mean, standard deviation) and Kruskal-Wallis test results for healthy older, PD, and aphasic groups, Experiment 1 (*p <.01, ** p <.001).

Measure	Older	PD	Aphasic	χ^2 (2)
MLU word	10.69 (2.20)	10.59 (2.06)	6.25 (2.73)	15.89**
Total number of utterances	26 (14)	19 (8)	23 (8)	2.889
% Grammatical sentences	93 (8)	88 (11)	59 (29)	17.59**
Mean number of embedded clauses	0.61 (0.24)	0.64 (0.21)	0.30 (0.22)	13.12*
% Sentences with correct VAS	99 (1)	99 (3)	88 (28)	18.12**

Note: MLU = Mean length of utterance; VAS = verb argument structure

Experiment 2

Stimuli and Procedure

In order to examine the production of sentences with different syntactic complexity in a structured task, we used the *Sentence Production Priming Test* (SPPT) of the *Northwestern Assessment of*

Verbs and Sentences (NAVS, Thompson, 2011). The SPPT assesses the participant's ability to produce both syntactically simple (canonical) and complex (non-canonical) sentences (n=15/each). Sentences with canonical word order included active sentences (e.g., *the boy is pulling the girl*), subject wh-questions (e.g., *who is chasing the cat?*), and sentences with subject relative clauses (e.g., *Pete saw the man who is saving the woman*). Non-canonical sentences included passive sentences (e.g., *the girl is pulled by the boy*), object wh-questions (e.g., *who is the dog chasing?*), and sentences with object relative clauses (e.g., *Pete saw the woman who the man is saving*). Non-canonical sentences are associated with increased syntactic complexity compared to their corresponding canonical sentences because of the mismatch between the thematic roles of the nouns (agent, theme) and the surface word order (pre-verbal subject, post-verbal object position) in the sentence. For sentences with one proposition (no embedded clause), passives and object-wh questions are more complex than actives and subject-wh questions, respectively, because the theme appears in the pre-verbal position. Likewise, for sentences with two propositions (with an embedded clause), sentences with object relative clauses are more complex than those with subject relative clauses. Similar to the stimuli used in Caplan and Waters (1999), the non-syntactic factors were matched between the canonical and non-canonical sentences used in the SPPT. The number of prepositions were matched and the same lexical items (nouns and verbs) were used between the canonical and non-canonical sentences. This allowed us to specifically examine the participant's ability to assign thematic roles to the nouns and arrange them in the correct word order (i.e., syntactic production).

Sentence priming was utilized to elicit the target structures in the SPPT. The participant was presented with a pair of pictures. The examiner provided a prime sentence with the targeted structure for the first picture (e.g., *for this picture, I could say 'Pete saw the woman who the man is saving'. For this picture (pointing the target picture) you could say*). A set of 3 practice trials preceded the test trials to ensure that the participant understood the task. No feedback on the accuracy of responses was given during the experimental trials.

Data Analysis

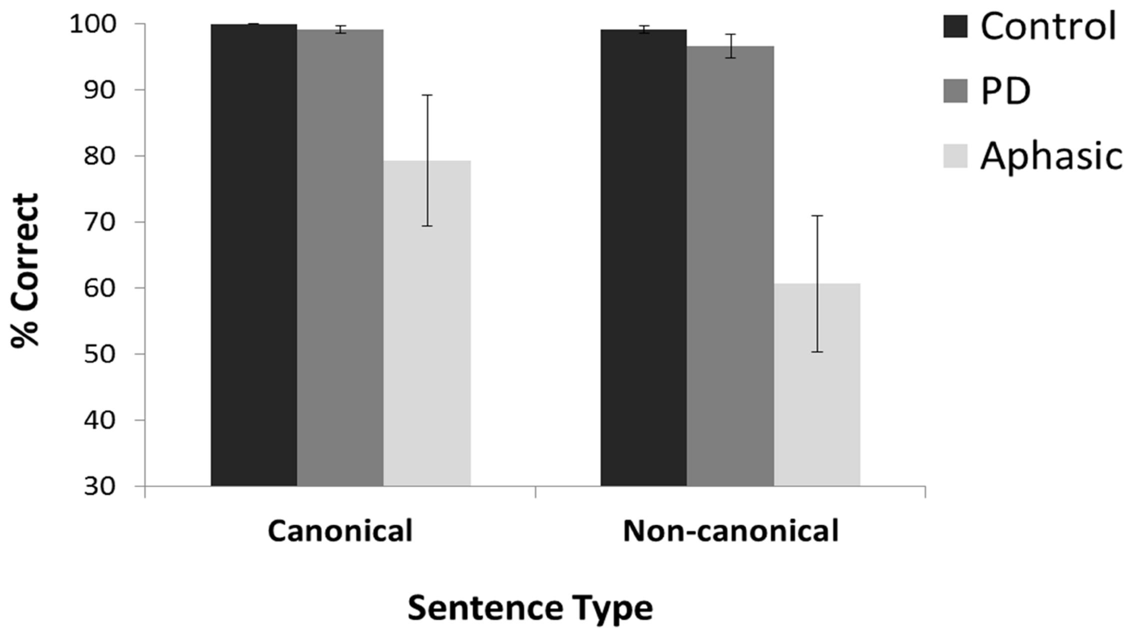
Participants' responses were transcribed online verbatim and audio-recorded using the Praat software (Boersma & Weenink, 2015) for transcription and scoring reliability. Responses were scored as correct if the participant produced all the required words in the target structure, following the scoring criteria of the NAVS. Intelligible phonological errors and different forms of verb inflections (e.g., *pushed, pushing*) were accepted. Inter-scorer reliability was established at 100% for a randomly selected 30% of the data.

Results

Figure 1 shows production accuracies of canonical and non-canonical sentences for each participant group (see Appendix 2 for individual data). A series of nonparametric tests was used. All of our healthy older participants showed 100% accuracy on the canonical sentences, as was expected based on previous studies (Cho & Thompson, 2012; Thompson, 2011). Thus, for canonical sentences, we used one-sample Wilcoxon tests to determine if the PD and aphasic groups' performances were statistically different from 100%. For non-canonical sentences, we used Mann-Whitney tests to make between-group comparisons. Lastly, in order to determine if there was a significant effect of syntactic complexity within each group (more errors with non-canonical vs. canonical sentences), we used 2-related sample Wilcoxon tests within the PD and aphasic groups.

The performance of the participants with PD did not differ from that of healthy older adults for either canonical ($Z = -1.342$, $p = .180$) or non-canonical sentences ($U = 111.5$, $p = .279$). In addition, the effect of syntactic complexity was not significant in the participants with PD, as indicated by equally well-produced canonical and non-canonical sentences (99% vs. 96%; $Z = 1.219$, $p = .223$). However, the participants with agrammatic Broca's aphasia showed reliably lower scores in both canonical and non-canonical sentences compared to healthy older adults (canonical: $Z = -2.524$, $p = .012$; non-canonical: $U = 1.000$, $p < .001$). Importantly, they showed significantly lower production accuracy for non-canonical sentences compared to canonical sentences (60% vs. 79% $Z = -2.552$, $p = .011$), indicating the effect of syntactic complexity.

Figure 1. Production of canonical and non-canonical sentences (with standard errors) for each group, Experiment 2.



Discussions

Although changes in language use have been reported in nondemented individuals with PD, the presence and nature of the deficits remain largely unclear. Some researchers suggest that there are language-specific grammatical impairments in PD, similar to agrammatic Broca's aphasia (Troche & Altmann, 2012; Ullman et al., 1997; Ullman, 2000; 2006; Zanini et al., 2010), while others suggest that grammatical processes as such are preserved in PD (Bastiaanse & Leenders, 2009; Caplan & Waters, 1999; Friederici et al, 2003; Lee, 2017; Longworth et al., 2005; Terzi et al., 2005). In addition, little evidence is available on whether and how syntactic production is affected in individuals with PD. To address these gaps in the literature, we examined sentence production in adults with mild PD, healthy older adults, and adults with agrammatic Broca's aphasia. Participants' syntactic production was assessed in two different contexts: a narrative story-telling task (Experiment 1) and a structured sentence elicitation task (Experiment 2). It was examined if participants with mild PD would show impaired grammatical processing, compared to healthy older controls and, if so, whether they would show qualitatively similar syntactic deficits as seen in agrammatic Broca's aphasia.

The results did not support the hypothesis that there are language-specific syntactic impairments in PD. Our participants with agrammatic Broca's aphasia showed clearly impaired syntactic production in both experiments. In the Cinderella story (Experiment 1), although they produced an equal number of utterances as healthy older adults, their utterances consisted of significantly fewer grammatically correct sentences, a reduced number of embedded clauses, and fewer sentences with correct verb argument structure. In Experiment 2, they showed a syntactic complexity effect in the production of canonical (actives, subject wh-questions, sentences with subject relative clauses) and non-canonical word order (passives, object wh-questions, and sentences with object relative clauses). These results from our participants with aphasia are well in line with abundant evidence showing impaired syntactic processing in agrammatic Broca's aphasia in both structured sentence elicitation and narrative production contexts (Bastiaanse & van Zonneveld, 2004; 2005; Cho-Reyes & Thompson, 2012; Lee & Thompson, 2004; Lee, Yoshida, & Thompson, 2015; Rochon et al., 2005; Saffran, Berndt, & Schwartz, 1989; Thompson, 2003; Thompson et al., 1995; 2003; 2013; and others). These findings also suggest that the tasks used in the current study are sensitive in detecting syntactic deficits in adult speakers.

Our participants with PD did not show impaired syntactic production in either experiment. In narrative speech production, PD participants' grammaticality of sentences was not compromised (Murray & Lenz, 2001; Small et al., 1997; cf. Murray, 2000). In addition, their sentences included as many embedded clauses as healthy older adults, and they were able to produce verb arguments correctly in the sentences, corroborating previous findings showing relatively preserved grammatical ability in PD (Bastiaanse & Leenders, 2009; Illes, 1989; Murray & Lenz, 2001; Small et al., 1997; Terzi et al., 2005; cf. Murray, 2000; Troche & Altmann, 2012). The parallel findings were observed in the structured sentence elicitation task of Experiment 2. They were able to successfully produce both canonical and non-canonical sentences similar to healthy older adults. In addition, they did not show a reliable difference between canonical and non-canonical sentences, hence, no syntactic complexity effect.

These divergent patterns of performance in participants with agrammatic Broca's aphasia and those with PD suggest that individuals with PD do not have the same syntactic deficits as seen in individuals with aphasia (Bastiaanse & Leenders, 2009; Caplan & Waters, 1999; Colman et al., 2009; Lee, 2017). It was expected that qualitatively similar syntactic deficits would be observed between PD and aphasic groups, if grammatical processing is indeed impaired in PD. However, only the participants with agrammatic Broca's aphasia demonstrated deficits in the syntactic measures, with increasing difficulty as the sentences increased in syntactic complexity. These findings are in line with the previous studies suggesting intact syntactic processing during comprehension in PD (Caplan & Waters, 1999; Friederici, von Cramon, & Kotz, 1999; 2003; Frisch, Kotz, von Cramon, & Friederici, 2003; see also ; Hochstadt, 2009; Kotz, Frisch, von Cramon, & Friederici, 2003).

One advantage of the stimuli used in Experiment 2 is that only syntactic complexity was varied between canonical (simple) vs. non-canonical (complex) sentences. The sentence types were matched in terms of the lexical items (nouns and verbs) and the number of propositions that have been shown to be impaired in PD (Copland, 2003; 2006; 2009; Copland et al., 2000; Piatt et al., 1999; Péran et al., 2003; Lee, 2017; see also Caplan and Waters, 1999). This manipulation allowed us to specifically assess the participants' ability to assign thematic roles such as agent and theme to the lexical items in relation to the verb, and arrange them into the correct order in the sentence. The results from our participants with PD suggest that their syntactic processing as such remains preserved in the domain of language production when the demands for non-syntactic processes are controlled for, extending previous sentence comprehension studies (Caplan & Waters, 1999; Friederici et al., 2003). This may explain the inconsistent findings between our study and Troche and Altmann (2012), in which the participants generated sentences with one vs. two propositions. The PD participants' increased number of errors in Troche and Altmann (2012)'s sentence generation task may be attributed to their difficulty with non-syntactic processing such as retrieval and selection of lexical items (nouns and verb) and/or message encoding.

One might think that cognitive-linguistic changes in our participants with PD were too mild to be detected in the current experimental tasks. This possibility can be ruled out because their ability to immediately repeat words and sentences and their speech intelligibility were impaired (Table 2). More importantly, despite their intact performance in the experimental tasks, they showed impaired action naming in a picture-based confrontation naming task (NAVS Verb Naming Test, Table 2) and their action naming deficits were comparable with those seen in our participants with aphasia (PD: M (SD) = 86 (8.4)% vs. Aphasic: M (SD) = 79 (18)%; Mann-Whitney U = 52.5, p = .144). It is also noteworthy to mention that 13 out of the current 16 participants with PD showed impaired noun naming in our previous study (Lee, 2017). In Lee (2017), the participants described three computer-displayed pictures of objects (two on the top and one on the bottom of the screen) in a predefined sentence structure, *the sofa and the clock are above the pencil*. The critical manipulation of the stimuli was the codability of the object pictures, i.e., name agreement, with some having low codabiltiy (e.g., *sofa/couch*) and some having high codabiliy (*pencil*). Note that in this case, because the participants described the items in a fixed word order, their lexical processing was examined with minimal demands for syntactic processing. The participants with PD made significantly more semantic errors (e.g., *chair* for *sofa/couch*) compared to healthy controls, particularly when sentences included low codable pictures, indicating difficulty selecting the target lexical item in the presence of semantic competitors (e.g., Copland et al., 2000; 2001). Together, these findings suggest that our participants with PD show changes in their language processing, and the finding that syntactic production is intact in the participants with PD was not an artifact of the complexity of the tasks or severity of our participants. Further systematic research is needed to clearly delineate the effects of syntactic and non-syntactic factors on language processing in PD. Intra and inter-individual variables also need to be considered in future studies, such as the influence of "on" vs. "off" medication states, differences in premorbid education levels, and disease progression.

Taken together, the current findings fit best with the view that there is no language-specific grammatical impairment in PD (Almor, Kempler, Andersen, McDonald, Hayes, & Hintiryan, 2002; Bastiaanse & Leenders, 2009; Caplan & Waters, 1999; Chan, Ryan, & Bever, 2013; Colman et al., 2009;

Friederici, Kotz, Werheid, Hein, & von Cramon, 2003; Grossman, Morris, Stern, & Hurtig, 2002; Katsarou, Stavrakaki, Alexiadou, Anagnostopoulou, Kafantari, & Bostantjopoulou, 2003; Lee, 2017; Longworth et al., 2005). The PD participants' ceiling performance on the set of various syntactic measures do not support the idea that the fronto-basal ganglia neural circuit as a whole is responsible for grammatical processes, as proposed by the declarative/procedural model (Ullman et al*.,* 1997). Our data are more in line with previous studies suggesting that basal ganglia dysfunction may not result in impaired grammatical processing per se, but rather that cognitive changes such as impaired attention-based inhibitory control are associated with PD, therefore affecting their language production and comprehension under some conditions (Bastiaanse & Leenders, 2009; Caplan & Waters, 1999; Friederici et al., 2003; Lee, 2017; Longworth et al., 2005). As proposed in previous studies, different cognitive-linguistic processes of sentence production may be assumed by cortical and subcortical structures within the fronto-basal ganglia network (Copland et al., 2000; 2003; Lee, 2017; Longworth et al., 2005). For instance, the lesions involving cortical areas may affect linguistic processes from early on, such as activating lexical and grammatical representations, whereas the basal ganglia are more responsible for domain general cognitive control such as inhibition of irrelevant information for later integration processes of various linguistic representations. However, the current study design is limited in clearly testing this hypothesis because the lesions of our aphasic participants extended to other cortical areas beyond the frontal lobe, and we did not include an additional experimental condition where the groups' non-syntactic abilities are examined. Thus, further investigation is warranted to delineate contributions of cortical and subcortical structures of the fronto-basal ganglia network to sentence production.

In conclusion, the current study examined syntactic production of individuals with nondemented PD, healthy older adults, and individuals with agrammatic Broca's aphasia in narrative and structured sentence production tasks. It was asked if individuals with mild PD would show impaired syntactic production, similar to that seen in Broca's aphasia, based on the view that the fronto-basal ganglia neural circuit is responsible for rule-based processing. Inconsistent with this hypothesis, the PD participants did not show impaired syntactic production in either a narrative story-telling or a structured sentence production task. Increasing syntactic complexity of sentences, controlling for non-syntactic factors, did not affect their performance, despite clear impairments in lexical retrieval, repetition of words and sentences, and speech intelligibility. The PD participants' performance contrasted with that of our participants with Broca's aphasia, who showed marked difficulty producing sentences, particularly when the syntactic complexity of the sentences increased. Together, these findings suggest that nondemented individuals with PD do not demonstrate language-specific syntactic deficits. Thus, changes in language use in PD are associated with different underlying impairments compared to those in agrammatic Broca's aphasia.

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Declaration of interest

The authors report no declarations of interest.

Appendix 1. Individual data for Experiment 1

Group	MLU word	Total number of utterances	% grammatical sentences	Mean number of embedded clauses	% sentences with correct VAS
Healthy Older Adults					
OA01	7.14	14	100	0.29	100
OA02	12.06	18	94	0.56	100
OA03	9.21	34	79	0.53	97
OA04	10.06	32	100	0.63	100
OA05	9.82	17	100	0.59	100
OA06	11.18	17	88	0.41	100
OA07	15.18	17	75	1.38	96
OA08	10.83	18	89	0.61	100
OA09	11.48	27	100	0.85	100
OA10	12.00	16	81	0.56	100
OA11	9.46	24	96	0.52	98
OA12	9.66	65	97	0.69	100
OA13	8.21	28	96	0.48	100
OA14	15.17	12	100	0.67	100
OA15	8.92	51	98	0.44	100
OA16	10.70	26	100	0.58	100
Mean	10.69	26	93	0.61	99
SD	2.20	14	8	0.24	1
Participants with PD					
PD01	8.86	35	94	0.43	100
PD02	8.50	12	100	0.58	100
PD03	12.78	18	100	0.50	100
PD04	6.13	15	73	0.47	90
PD05	12.74	34	73	0.88	96
PD06	12.85	26	96	0.88	100
PD07	12.50	14	93	0.79	97
PD08	10.26	19	89	0.56	98
PD09	10.48	21	81	0.57	100
PD10	11.42	12	92	0.58	100
PD11	9.00	6	83	0.50	100
PD12	11.31	16	87	0.69	100
PD13	10.69	26	85	0.81	100
PD14	8.00	10	100	0.30	100
PD15	10.53	15	93	0.53	100
PD16	13.32	25	64	1.12	98
Mean	10.59	19	88	0.64	99

SD	2.06	8	11	0.21	3
Participants with Aphasia					
A01	3.82	25	8	0.42	91
A02	5.00	18	91	0.12	95
A03	3.24	41	44	0.67	98
A04	7.16	20	53	0.45	97
A05	6.94	18	77	0.00	85
A06	9.04	22	71	0.11	60
A07	5.18	32	62	0.08	80
A08	8.91	20	50	0.27	93
A09	9.05	17	87	0.47	100
A10	4.15	16	50	0.38	82
Mean	6.25	23	59	0.30	88
SD	2.26	8	24	0.22	12

Appendix 2. Individual data (% correct) for canonical and non-canonical sentences in Experiment 2

Participants	SPPT Canonical	SPPT Non-canonical
Healthy Older Adults		
OA01	100	100
OA02	100	100
OA03	100	100
OA04	100	100
OA05	100	100
OA06	100	100
OA07	100	100
OA08	100	100
OA09	100	93
OA10	100	100
OA11	100	100
OA12	100	100
OA13	100	100
OA14	100	93
OA15	100	100
OA16	100	100

Mean	100	99
SD	0	2
Participants with PD		
PD01	100	100
PD02	100	100
PD03	100	100
PD04	100	100
PD05	93	73
PD06	100	100
PD07	100	100
PD08	100	93
PD09	100	100
PD10	100	93
PD11	100	100
PD12	100	100
PD13	100	87
PD14	100	100
PD15	93	100
PD16	100	100
Mean	99	97
SD	2	7
Participants with Aphasia		
A01	13	0
A02	93	73
A03	47	53
A04	87	67
A05	100	87
A06	100	93
A07	n/a	n/a
A08	87	33
A09	100	93
A10	87	47
Mean	79	61
SD	28	30

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