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The Role of Basal Ganglia in Language Production: Evidence from Parkinson's Disease

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Abstract. According to the dominant view in the literature, basal ganglia do not play a direct role in language but are involved in cognitive control required by linguistic and non-linguistic processing. In Parkinson's disease, basal ganglia impairment leads to motor symptoms and language deficits; those affecting the production of verbs have been frequently explored. According to a controversial theory, basal ganglia play a specific role in the conjugation of regular verbs as compared to irregular verbs. We report the results of 15 patients with Parkinson's disease in experimental conjugation tasks. They performed below healthy controls but their performance did not differ for regular and irregular verbs. These results confirm that basal ganglia are involved in language processing but do not play a specific role in verb production.

Keywords: Basal ganglia, language production, procedural memory, executive functions

Whilst the role of cortical structures in language processing is well documented, the contribution of subcortical structures in language processing is less well known and still debated. Among the subcortical anatomical substrates, the basal ganglia appear to be involved in various language tasks although their precise role remains unclear. According to the dominant view in the literature, basal ganglia do not play a direct role in language but are involved in cognitive control required by linguistic and non-linguistic processing. These structures are implicated in high-level mental control or executive processes, such as novel problem solving, shifting of mental sets, inhibition of prepotent or previous responses, and monitoring and updating of working memory representations [e.g., 1]. They are more particularly involved in maintenance, updating and manipulation of sequence information [e.g., 2], as well as in inhibition mechanisms, allowing the person to correctly select activities while suppressing competing ones [3, 4]. With respect to language, studies also suggest that left basal ganglia activity enhances the processing of language in the dominant hemisphere [5], and right basal ganglia activity plays an inhibition role, by suppressing or lessening the activation of the non-dominant right frontal cortex [4].

Parkinson's disease (PD), a neurodegenerative disease of the basal ganglia, is mainly characterized by motor symptoms but language impairments have also been reported [6, 7]. According to the Declarative/Procedural Model (D/PM) proposed by Ullman

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and his colleagues [8–10], declarative memory, which comprises semantic and episodic memory, depends on medial temporal lobe structures and underlies the mental lexicon, a long-term memory store comprising all arbitrary, idiosyncratic knowledge about words. Procedural memory, rooted in frontal/basal ganglia circuits, sustains the learning and processing of rules and, with respect to language, underlies the mental grammar, which is responsible for the acquisition and computation of rule-based linguistic procedures. Support for the D/PM comes from studies conducted with patients suffering from Alzheimer's disease [11], specific language impairment in children [12], aphasia [13], and PD [8]. Patients with PD showed a deficit selectively affecting the conjugation of regular verbs, sustained by procedural memory, whilst the conjugation of irregular verbs, sustained by declarative memory, was unaffected. However, this dissociation between regular and irregular conjugation was not confirmed in other studies conducted with PD patients in English [14] and in other languages [15–17]. For example, the 28 Dutch PD patients studied by Colman et al. [17] performed below the controls for verb conjugation but the authors did not find any differences in the processing of regular and irregular verbs. According to the authors, the impairment of automatic processes forces PD patients to rely on executive functions, which, unfortunately, are also affected by the disease. In the present study, we explored the contribution of basal ganglia in language processing through a neurolinguistic study conducted with French-speaking PD patients.

Fifteen participants, native speakers of Quebec French, with idiopathic PD were recruited in an outpatient clinic to participate in the study. They were assessed using the Unified Parkinson's Disease Rating Scale part III [18], and Hoehn and Yahr [19] staging (see Table 1). All PD participants received L-dopa medication and were tested in the ON state. The performance of PD participants was compared to the results of 15 healthy controls (HC) recruited from the Quebec community and closely matched with the patients on gender, age and education level. This research was approved by the Research Ethics Committee of the hospital concerned (Hôpital de l'Enfant-Jésus de Québec).

A neuropsychological assessment battery was administered to PD participants during two different testing sessions separated by a gap of one week. Their performance in each test was compared with normative data. Cognitive global functioning was assessed using the Montreal Cognitive Assessment [20], a scale developed to identify mild cognitive impairment in the elderly. As shown in Table 1, PD participants' performance was significantly lower than HCs' performance. However, their mean score was well above the cutoff score recently [21] suggested to detect cognitive impairment (i.e., $\leq$20). Construction abilities, assessed using direct copying of the Rey-Osterrieth complex figure test [22, 23], were impaired (PD = 23.6; 8.98/ norms (range) = 29–31.5), as reported in numerous studies conducted with the same population [24]. PD participants were also impaired (PD = 12.21; 3.7/ norms = 15.7; 0.7) for episodic verbal memory, assessed by means of the French adaptation of the Grober and Buschke [25] paradigm [26]. Semantic memory was assessed using the Pyramids and Palm Trees Test [27, 28] and the PD participants' performance was normal (PD = 49.13; 2.9/ norms = 49.44; 1.9). Lexical access in production, assessed with a confrontation naming test [29], was unimpaired (PD = 73.67; 5.15/ norms = 76.16; 3.33).

Table 1
Demographic, clinical and cognitive (working memory and executive functions) characteristics of PD and HC groups (mean, SD)

	PD	HC
Mean age	68.33 (7.14)	63.07 (9.86)
Sex (M: F)	9 : 6	11 : 4
Laterality (R: L)	12 : 3	15
Education (years)	12.07 (3.67)	14.2 (4.28)
MoCA	24.73 (2.37)	27.38 (1.5)**
Length of the disease	8.93 (4.39)	N/A
UPDRS-III	23.77 (8.73)	N/A
Severity of the disease (Hoehn & Yahr)	2.46 (0.24)	N/A
Working memory and executive functions tests		
- Digit span forward	6.47 (0.92)	6.73 (1.16)
- Digit span backward	4.47 (0.92)	5.13 (0.99)^t
- Brown-Peterson test		
- Total score without interference	10.67 (1.5)	11.8 (0.56)*
- Total score with interference	6.73 (2.28)	8.4 (2.2.)^t
- Verbal fluency		
- Free fluency	50.4 (13.1)	69.6 (16.7)**
- Letter fluency	18.47 (6.62)	28.47 (8.35)**
- Category fluency	18.53 (4.97)	26.73 (5.85)***
- Hayling test		
- Automatic condition (time)	61.93 (14.45)	50.13 (7.47)*
- Inhibition condition (time)	159.8 (39.07)	129.33 (18.21)*
- Brixton test (number of errors)	27.13 (7.59)	14.47 (5.42)***

^{t} = trend toward significance; $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Participants were also assessed with a battery of tests exploring working memory and executive functions. As shown in Table 1, PD participants showed no deficit in verbal short-term memory (Digit span forward) but their performance was lower than HCs for tests taping working memory and executive functions:

Digit span backward; Brown-Peterson test [30]; verbal fluency [31]; Hayling and Brixton tests [32].

Participants were asked to conjugate verbs and non-verbs, a task directly based on one of our recent studies [33]. Non-verbs were used to minimize recourse to lexical information and more directly assess the application of conjugation rules. For verbs, we selected an experimental list of 72 stimuli distributed between regular (48 stimuli) and irregular (24 stimuli) verbs. These verbs were matched for length (10 bisyllabic and 2 trisyllabic verbs of each type) and lexical frequency [34] (mean frequency: regular verbs = 180.05; irregular verbs = 189.9). The regular list comprised verbs ending with -er (e.g., manger 'to eat'), as well as verbs ending with -ir or -re (e.g., sortir 'to go out' and vendre 'to sell'). These verbs are conjugated by the application of inflection rules. For example, the conjugation of a verb ending with -er (manger 'to eat') in the third person plural of the future tense (ils mangeront 'they will eat') requires, after having retrieved the verbal root (mang-) in the lexicon, the application of the following two inflectional rules: (1) add the affix of the future tense: +er, and (2) add the affix for the third person plural of the future tense: +ɔ̃). In addition to regular verbs, the French verbal system also comprises highly irregular verbs (e.g., je vais 'I go', first person singular of the present tense; ils iront 'They will go', third person plural of the future tense), which are considered suppletive forms since their different conjugated forms are unpredictable and are therefore listed as separate lexical entries in the mental lexicon. Regular and irregular verbs were mixed in a single list and their presentation was counterbalanced across participants.

A list of 48 non-verbs was constructed from the list of regular verbs by keeping the infinitive ending with its adjacent consonant and substituting all the phonemes of the verb stem so that the corresponding verb could not be easily recovered. For example, the corresponding non-verb for the real verb finir 'to finish' was *bounir*. The presentation of non-verbs was counterbalanced across participants.

Subjects were tested with conjugation tasks in which they were asked to inflect a verb or non-verb presented in the third person plural in the present tense to the third person plural in the future tense and vice versa. They were tested with verbs, then with non-verbs. Stimuli were presented on a computer screen in random order. Stimuli were inserted in a short inducing phrase (e.g., present to future: "Aujourd'hui ils mangent" 'today they eat'), immediately followed by a carrying phrase ("Demain ils ... " 'tomorrow they...') that subjects were asked to complete orally, after the experimenter had read it aloud. The inducing phrase as well as the carrying phrase remained in front of the subject until he or she produced a response, with no time limit. For each task, 4 practice items were presented (2 regular and 2 subregular) and feedback was provided for correct and incorrect responses.

Table 2
Percentage of correct responses for PD and HC participants in conjugation tasks (mean score; SD)

Conjugation task	PD	HC
Regular verbs (48)	88% (42.2; 5.25)	95% (45.67; 3.09)
Irregular verbs (24)	75.5% (18.13; 4.36)	81% (19.4; 4.08)
Non-verbs (48)	76% (36.4; 3.22)	81.5% (39.13; 4.41)

The results of the participants of the two groups are presented in Table 2. A two-factor (conjugation type: regular vs. irregular; group: PD vs. HC) analysis of variance (ANOVA) on accuracy scores showed a significant effect of conjugation type ($F(1,28) = 41.83$; $p < 0.001$), but no significant effect of group ($F(1,28) = 1.8$; $p = 0.19$), and no significant interaction between the two factors ($F(1,28) = 0.22$; $p = 0.64$). This analysis suggests that all participants showed more difficulty to conjugate irregular than regular verbs, with no difference between the two groups. With respect to the difference between verbs and non-verbs, a two-factor (stimulus type: regular verb vs. non-verbs; group: PD vs. HC) analysis of variance (ANOVA) on accuracy scores showed a significant effect of stimulus type ($F(1,28) = 45.11$; $p < 0.0001$), a significant effect of group ($F(1,28) = 6.92$; $p < 0.05$), and no significant interaction between the two factors ($F(1,28) = 0.16$; $p = 0.69$). According to this analysis, the performance of all participants was better for verbs than for non-verbs and, as a whole, PD participants produced more errors than HC participants. However, the absence of interaction between the two factors indicates that this difference could not be attributed to the stimulus type.

These results are similar to those reported with PD patients in studies conducted in English [14] and in other languages [15–17]. As in these studies, we did not find evidence in French of an association between the impairment of the fronto-striatal network in PD and a selective deficit for the inflection of regular verbs. Like the German PD participants reported by Penke et al. [14], the French-speaking PD participants reported in our study performed better for regular than for irregular verbs. Moreover, the performance of PD participants did not differ from HC participants for non-verbs, a type of stimulus used to more directly assess the application of conjugation rules. These results are contrary to the claims of the D/PM [8, 9], which suggests that basal ganglia are involved in the application of rules required for the conjugation of regular verbs. Our study suggests that these structures, actually involved in language processing, do not play such a specific role in verb production.

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