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# How language flows when movements don't: An automated analysis of spontaneous discourse in Parkinson's disease

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ABSTRACT

To assess the impact of Parkinson's disease (PD) on spontaneous discourse, we conducted computerized analyses of brief monologues produced by 51 patients and 50 controls. We explored differences in semantic fields (via latent semantic analysis), grammatical choices (using part-of-speech tagging), and word-level repetitions (with graph embedding tools). Although overall output was quantitatively similar between groups, patients relied less heavily on action-related concepts and used more subordinate structures. Also, a classification tool operating on grammatical patterns identified monologues as pertaining to patients or controls with 75% accuracy. Finally, while the incidence of dysfluent word repetitions was similar between groups, it allowed inferring the patients' level of motor impairment with 77% accuracy. Our results highlight the relevance of studying naturalistic discourse features to tap the integrity of neural (and, particularly, motor) networks, beyond the possibilities of standard token-level instruments.


## 1. Introduction

Affecting more than 1% of individuals above age 60, Parkinson's disease (PD) is the second most prevalent neurodegenerative disease worldwide (de Rijk et al., 2000; Samii, Nutt, & Ransom, 2004). It is characterized by progressive basal ganglia degeneration and dopamine depletion, which disrupts corticostriatal circuits involved in motor function and multiple high-level cognitive domains (Fearnley & Lees, 1991; Mattay et al., 2002; McKinlay, Grace, Dalrymple-Alford, & Roger, 2010; Muslimovic, Post, Speelman, & Schmand, 2005; Rodriguez-Oroz et al., 2009). Thus, the impact of PD goes well beyond the presence of movement disorders (Mattay et al., 2002; Svenningsson, Westman, Ballard, & Aarsland, 2012).

This is particularly evident in linguistic performance. Indeed, articulatory disorders in PD (Goberman & Blomgren, 2003; Goberman, Blomgren, & Metzger, 2010) are often accompanied by impairments in grammar (Bocanegra et al., 2015; Hochstadt, Nakano, Lieberman, & Friedman, 2006; Lieberman et al., 1992), pragmatics (Holtgraves & McNamara, 2010; Monetta & Pell,

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2007), verbal fluency (Raskin, Sliwinski, & Borod, 1992), and action-verb semantics (García & Ibáñez, 2014a; Bak, 2013; Bocanegra et al., 2015; Cardona et al., 2013). While these findings are quite revealing about the physiopathology of PD, it is hard to assess their impact in real life, since they stem from highly artificial tasks in which disconnected stimuli are processed in random or arbitrary succession. Also, the active demands of such often exhausting tasks render them limited as tools for prospective diagnosis criteria.

Our aim was to address both issues using automated tools. Specifically, we examined whether PD patients exhibit distinguishing discourse-level features as they produce naturally unfolding texts. This process, termed logogenesis, is based on the accumulation of interrelated lexico-grammatical selections which create distributed patterns above the word and sentence levels (Halliday & Matthiessen, 2004). Insights into this dynamic process could afford a more ecological understanding of how this disease impacts verbal communication.

## 2. Background and hypotheses

Discourse production involves construing supra-sentential textual relations and deploying diverse communicative strategies (Halliday & Matthiessen, 2004). Emergent distributed patterns can be detected by considering semantic fields, lexicogrammatical choices, and relations between adjacent or neighboring words (Bedi et al., 2014, 2015; Mota, Furtado, Maia, Copelli, & Ribeiro, 2014; Mota et al., 2012). Analyses of these and other text-level variables have revealed population-specific patterns in various neurological disorders, such as frontotemporal dementia (Ash et al., 2006) and aphasia (Fergadiotis & Wright, 2011). However, evidence on altered discourse-level patterns in PD has been produced sparsely.

Relative to controls, PD patients produce similar amounts of verbal output during spontaneous speech (Illes, 1989; Illes, Metter, Hanson, & Iritani, 1988; Murray, 2000; Murray & Lenz, 2001; Vanhoutte, De Letter, Corthals, Van Borsel, & Santens, 2012). Yet, they exhibit more digressive grammatical choices (e.g., open phrases around the main clause) (Illes, 1989; Illes et al., 1988) and construe less informative (Murray, 2000) and concise (McNamara & Durso, 2003) texts. Finally, they find it difficult to self-monitor and correct output errors (McNamara, Obler, Au, Durso, & Albert, 1992). Indeed, iteration of syllables and words in PD proves more common in advanced disease stages, irrespective of medication (Benke, Hohenstein, Poewe, & Butterworth, 2000).

Though highly valuable, this evidence is scant, based on rather small samples, and rooted in subjective impressions of a few examiners. These limitations can be partly circumvented by conducting *automated* analyses of spontaneous texts produced by large groups. In previous works, computerized analysis of free speech robustly discriminated methamphetamine users from ecstasy users and controls by detecting differential conceptual fields (Bedi et al., 2014). Those same methods, complemented with grammatical analyses, predicted future psychosis in young individuals (Bedi et al., 2015). Also, speech-graph measures captured distinctive discourse patterns (e.g., logorrhea, divergent and recurring thought patterns) in varied populations. For example, they sorted schizophrenics from maniacs (Mota et al., 2012) and bipolar subjects from schizophrenics and controls (Mota et al., 2014).

Here we examined the extent to which PD patients and controls can be discriminated and classified via the abovementioned tools. To create stringent assessment conditions, we considered only brief monologues (around one minute per participant). We specifically tested hypotheses regarding the emergence of semantic fields, the incidence of distinctive grammatical features, and word-repetition patterns. First, motor diseases involve distinctive deficits in processing action language, that is, verbal stimuli denoting motor actions, including idioms (e.g., *cut a rug*) and action verbs (e.g., *clap*), with relative preservation of words which do not necessarily involve physical movements, such as cognitive or affective verbs (e.g., *see*, *feel*) or nouns (e.g., *chair*) –for a review, see García and Ibáñez (2014a, 2016). Thus, we expected PD patients to rely less heavily on action- than non-action-related semantic fields. Also, based on evidence from discourse-level studies, we hypothesized that they would favor digressive, clause-peripheral constructions. Third, we expected word repetitions to positively correlate with disease severity.

## 3. Methods

### 3.1. Participants

The study included 51 non-demented PD patients (25 female) and 50 healthy controls (25 female) from the PC-GITA database (Orozco-Arroyave, Arias-Londoño, Vargas-Bonilla, González-Rátiva, & Nöth, 2014). All participants were monolingual Spanish speakers from Colombia. The patients had a mean age of 61.45 ($SD$ = 9.77), with 10.71 ($SD$ = 4.2) years of education. Mean values for these variables in the control sample were 60.9 ($SD$ = 9.47) and 10.98 ($SD$ = 4.54), respectively. Both groups were matched for age [$t(99) = -0.2878$, $p = 0.77$], education level [$t(99) = 0.3153$, $p = 0.75$], and gender [$\chi 2\,(1) = 137.9145$, $p = 0.99$]. Clinical diagnosis of PD was made by an expert neurologist (LM) in accordance with the United Kingdom PD Society Brain Bank criteria (Hughes, Daniel, Kilford, & Lees, 1992). Motor impairments were assessed with Section 3 of the Movement Disorder Society-sponsored revision of the Unified Parkinson's Disease Rating Scale (MDS-UPDRS-III) (Goetz et al., 2008). Disease stage was rated with the Hoehn & Yahr (H&Y) scale (Goetz et al., 2004). Mean scores for the PD sample were 38.71 ($SD$ = 19.61) in MDS-UPDRS-III and 2.2 ($SD$ = 0.7) in H&Y. At the time of testing, the patients' mean years post-diagnosis was 11.18 ($SD$ = 9.16). A phoniatric assessment indicated that most patients presented only intermediate levels of dysarthria, some had only very minor signs, and none exhibited severe symptoms. All patients were evaluated during the "on" phase of their medication –i.e., no more than three hours after intake. They were recruited from a larger patient population in Medellín with well-established language disorders (Bocanegra et al., 2015; Cardona et al., 2013; Melloni et al., 2015; Orozco-Arroyave et al., 2016a). None of them presented with other neurological disorders or major psychiatric conditions, which were also absent in controls.

All participants gave written informed consent. The study was carried out in accordance with the Declaration of Helsinki and it was approved by the Ethical Research Committee of Antioquia University's Faculty of Medicine. Additional participant data can be found in Table 1.

### 3.2. Data collection

#### 3.2.1. Discourse samples

Participants were asked to describe a typical day in their lives, speaking at their normal rate, pitch, and loudness. Their narrations were audio-recorded in a soundproof booth via a Shure SM63L dynamic omnidirectional microphone and a M-Audio Fast-Track computer audio interface, which offers high output for professional applications. All audio files were created on Cool Edit Pro 2.0 and sampled at 44,100 Hz with a resolution of 16 bits. The average duration of the monologues was 45 ($SD$ = 24) and 48 ($SD$ = 29) seconds for controls and PD patients, respectively.