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The impact of executive functions on verb production in patients with Parkinson's disease

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ABSTRACT

A growing number of studies suggest that language problems in Parkinson's disease (PD) are a result of executive dysfunction. To test this hypothesis we compared Dutch verb production in sentence context in a group of 28 PD patients with a control group consisting of 28 healthy participants matched for age, gender and education. All subjects were assessed on both verb production in sentence context as well as on cognitive functions relevant for sentence processing.

PD patients scored lower than healthy controls on the verb production ability-scale and showed a response pattern in which performance was worse (1) in base than in derived position; (2) in present than in past tense; (3) for intransitive than in transitive verbs. For the PD group the score on the verb production ability-scale correlated significantly with set-switching and working memory. These results provide support for previous research suggesting that executive dysfunctions underlie the performance of the PD patients on verb production. It is furthermore suggested that because of failing automaticity, PD patients rely more on the cortically represented executive functions. Unfortunately, due to the disturbed intimate relation between the basal ganglia and the frontal cortex, these executive functions are also dysfunctional.

1. Introduction

Studies on impaired verb production have often focused on people with agrammatic Broca's aphasia. In this regard it has been shown that for agrammatic Dutch speakers finite verbs are more difficult to produce than non-finite verbs (Bastiaanse, 2008), and that the ability to produce finite verbs decreases when syntactic complexity increases (Bastiaanse et al., 2002). For agrammatic English speakers, problems with the production of transitive verbs (Thompson et al., 1994, 1997; Thompson, 2003) as well as with the regularity of the past tense (Ullman et al., 1997) have been reported. However, the latter has not been replicated for German (Penke et al., 1999; Penke and Westermann, 2006) or for Dutch speakers (Bastiaanse, 2008; Penke and Westermann, 2006). Interestingly, several studies have also revealed specific verb

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processing deficits in Parkinson's disease (PD), a neurodegenerative disease mainly characterized by motor symptoms (i.e., tremor, rigidity and bradykinesia) and caused by significant dopaminergic striatal denervation (Wolters and Bosboom, 2007). For example, Grossman et al. (1994) showed impaired verb learning and Whiting et al. (2005) showed impaired thematic role mapping in patients with PD. In addition, Ullman et al. (1997) reported on the results of a sentence completion task, which required the participants to read aloud randomly ordered sentence pairs and to fill in a verb. Ullman et al. (1997) reported a correlation between right-side hypokinesia and the impaired production of rule-generated (regular) past tense forms in PD. The authors concluded that PD leads to the suppression of both motor activity and grammatical rule application. In essence, Ullman et al. (1997) and Ullman (2001) proposed that the frontal–basal ganglia system constitutes the procedural memory system that regulates grammar and that the mental lexicon depends on declarative memory, embedded in the temporal lobe. In the following years, the vast majority of studies on verb production in PD focused on testing the Declarative–Procedural hypothesis of Ullman et al. (1997), but the PD data of the Ullman-study could not be replicated (Almor et al., 2002; Longworth et al., 2003, 2005; Penke et al., 2005; Terzi et al., 2005). In their replication study, Longworth et al. (2005) found a tendency in English speaking PD patients to perseverate on the cue (i.e., verb stem) rather than to produce a past tense as requested. This finding is in line with the conclusions of Robles et al. (2005) for perseveration on the previous picture in a naming task during direct stimulation of the dominant head of the caudate nucleus. Verb retrieval abilities in PD were specifically tested by Piatt et al. (1999a, 1999b) using an action fluency task (for more details see the methods section of this article). Piatt et al. (1999a, 1999b) concluded that action fluency was particularly sensitive to the fronto-striatal pathophysiology of PD with dementia. According to these authors action fluency reflects the underlying integrity of frontal lobe circuitry, and could therefore indicate deficits in executive functioning. Péran et al. (2003) developed a French word-generation task that required a semantic and grammar driven selection of single words over a limited time period. Compared to healthy control subjects, PD patients showed a higher rate of grammatical errors in the noun → verb-generation task than in the verb → noun-generation task. Péran et al. (2003) hypothesized that this discrepancy might be due to the combined effect of impaired set-switching and a grammatical impairment in verb production. The authors suggested that in the verb → noun task, the impact of impaired switching is compensated by the easier noun production, whereas in the noun → verb task both switching and production of the verb were dysfunctional. Evidence for a selective verb production deficit in PD was previously reported by Bertella et al. (2002). More recently, Boulenger et al. (2008) corroborated this finding of a selective deficit for the processing of action verbs in PD patients off their dopaminergic medication. More in particular these researchers hypothesized that the access to action verbs partly relies on the motor system. According to their view, the nigrostriatal sytem, that is affected in PD, seems to modulate action word processing in the motor areas.

The PD studies reviewed above evidence that dysfunctional frontal–striatal circuits influence verb processing and reveal that basal ganglia, are critical in verb processing. Moreover, several other studies in PD provide us with evidence for the involvement of the fronto-striatal circuits in other aspects of language processing, than just verb processing. Illes et al. (1988) were the first to report grammatical deficits in the spontaneous speech of PD patients. It was found that PD patients limit their speech to short and syntactically simple structures (Illes, 1989; Illes et al., 1988). In a study of sentence comprehension, Lieberman et al. (1992) reported that speech motor deficits accompanied the grammatical and cognitive deficits in PD patients. The common neurological basis for these deficits was suggested to be the disruption of the circuits between subcortical structures and prefrontal cortex. Following this statement, Lieberman et al. (1992) and Lieberman (2000, 2006) claimed that as language is neurologically intertwined with cognition and motor control it can't be modular in nature.

Several independent studies consistently found reduced comprehension of syntactically complex sentences as well as long sentences (e.g., Grossman et al., 1991, 1992, 1993; Hochstadt et al., 2006; Lieberman et al., 1990, 1992; Natsopoulos et al., 1991, 1993) and deficits in lexical ambiguity resolution in PD (Copland et al., 2000, 2001). Another consequence of the dysfunctional fronto-striatal circuits such as in PD is a delay in lexical activation during semantic priming studies (Angwin et al., 2004; Arnott et al., 2001). Neuroimaging studies in healthy subjects lend additional evidence to the finding that fronto-striatal circuits contribute to language processing. In an attempt to separate syntactic and semantic aspects of sentence processing with functional Magnetic Resonance Imaging (fMRI), Ni et al. (2000) found activity in the head of the caudate nucleus at about 10 sec after a syntactic anomaly. Similar findings were obtained in a study using $H_2^{15}O$ Positron Emission Tomography (PET) by Moro et al. (2001) who reported a selective activation of the left caudate nucleus during a syntactic anomaly condition. Using fMRI, Grossman et al. (2003) showed striatal activation in healthy senior volunteers during the comprehension of sentences with a long noun-gap linkage [e.g., Object-relative, long linkage: (The messy boy)$_i$ who Janet the very popular hairdresser grabbed t_i was extremely hairy] compared to sentences with a short linkage [e.g., Object-relative, short linkage: (The flower girl)$_i$ who Andy punched t_i in the arm was five years old]. Stowe et al. (2004) reported activation in the right basal ganglia of healthy subjects during a syntactic disambiguation task.

What is of great importance to the present study is that dysfunctional fronto-striatal circuits affect more cognitive functions than just the discussed linguistic functions. Neuropsychological assessment has found that, visuospatial, memory, and executive functions are impaired in non-demented PD patients (Dubois and Pillon, 1997; Pillon et al., 2003). It has been proposed (Dagher et al., 2001; Owen et al., 1998) that the executive deficits may be caused by disruption of basal ganglia outflow resulting in frontal dysfunction in the different loops connecting the prefrontal cortex, basal ganglia, and thalamus (Alexander et al., 1986). A [18F]fluorodopa PET study (Bruck et al., 2001) and a ^{11}C–S-Nomifensine