Word segmentation based on prosody in Parkinson's Disease

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Abstract

While Parkinson's Disease (PD) impacts the production of prosody and may lead to dysprosody, its effect on the perception of prosody is less clear. In the current study, we investigated how people with PD (PwPD) segment continuous speech using prosodic cues. We used phonemically identical and prosodically different sequences in French. Twenty-three PwPD and 30 controls took part in the study. PwPD showed similar performance to controls (mean difference in terms of correct responses = 2%, 95% confidence interval = [-4%; 8%]). Using Bayesian statistics, our data is 3.6 times more in favour of the null model compared to the alternative model (i.e. difference between PwPD and controls). It thus seems unlikely that PD impacts the perception of prosody systematically. Furthermore, the cognitive performance of PwPD predicted their performance in our segmentation task. This suggests interesting pathways for future research on the mechanisms underlying the impact of PD on speech processing. Clinically, our findings suggest that adequate evaluation of the cognitive capacity of PwPD would help speech and language therapists in assessing speech processing skills in PwPD and in managing their speech impairments.

Keywords: Prosody, Parkinson's Disease, speech perception, word segmentation

Introduction

Parkinson's Disease (PD) impacts spoken communication (Miller, 2017; Moreau & Pinto, 2019), and production of prosody is one of the aspects that may be impaired (Duffy, 2013). For instance, people with PD (PwPD) tend to produce less effective intonation cues compared to controls (e.g. Basirat et al., 2018; Ma et al., 2010), make fewer and inappropriate pauses when speaking (e.g. Skodda & Schlegel, 2008), and suffer from rhythmic disturbance while producing sentences (e.g. Lowit et al., 2018). At the receptive level, a growing body of evidence suggests the impact of PD on the recognition of emotion while listening to spoken stimuli (i.e. emotional prosody; for reviews, see Gray & Tickle-Degnen, 2010; Péron et al., 2012). While this has been linked to the contribution of the basal ganglia in the processing of emotional prosody (Grandjean, 2020), the impact of PD on the linguistic functions of prosody at the receptive level is less clear. Since the 1980s, a few studies (e.g. Darkins et al., 1988; Scott et al., 1984) have investigated various prosodic functions such as the placement of lexical stress (e.g. stress on the first *vs.* second syllable), sentence modality (e.g. declarative *vs.* interrogative), and focus (i.e. identification of the highlighted information in the utterance). Overall, the results suggest that PwPD perform as well as controls in the perception of linguistic prosody (Martens et al., 2016; Basirat et al., 2018), with putative impairments only in some PwPD when a single case study approach is adopted (Lloyd, 1999).

Interestingly, Pell (1996) observed that PwPD performed worse than controls when the task was to identify the prosodic pattern (e.g. to indicate whether a sentence is a command, question or statement), but not in a discrimination task when participants were asked to distinguish between two different prosodic patterns. The author concluded that the deficit concerns the mapping of prosodic cues onto their linguistic or affective communicative representations, and is thus likely related to the affective and semantic processing involved in prosody comprehension tasks rather than to the processing of prosody cues. However, the study was done with a small sample (*n=11*) and the results needed to be replicated. In a more recent study with a larger sample of PwPD (*n* = 22), Martens et al. (2016) tested the perception of various prosodic functions including linguistic and emotional prosody. The authors did not observe any difference between PwPD and controls. However, the assessments in this study suffered from a ceiling effect. For instance, the median of accuracy scores of PwPD for the perception of focus, sentence mode and emotional prosody was 100%. In addition, the two groups were not matched for their hearing capacity using objective measures. It is thus possible that a different pattern would be observed if hearing capacity was controlled for and if the task required participants to exploit more subtle prosodic cues.

The main goal of the current study was to address this issue, i.e. the perception of subtle prosodic cues. The secondary goal was to explore the influence of potential predictors of PwPD performance such as hearing and cognitive capacities, an issue not addressed until now (Pell, 1996; Lloyd, 1999; Martens et al., 2016; Basirat et al., 2018). We used ambiguous French sentences that could be disambiguated only by prosodic cues such as 'l'affiche' /l#afiʃ/ ('the poster' in English) *vs.* 'la fiche' ('the sheet' in English) /la#fiʃ/ (# indicating the word boundary) (Spinelli et al., 2010). Although these sequences are phonemically identical, subtle prosodic cues (Spinelli et al., 2007) enable French listeners to segment them above chance level without any contextual information (Spinelli et al., 2010; Strauß et al., 2015; Basirat, 2017; Ogane et al., 2020). This type of stimulus is highly relevant when investigating the perception of prosody in clinical populations. For instance, even when perception of phonemes and word identification are perfectly restored by a cochlear implant, these ambiguous sequences cannot be identified (Basirat, 2017).

Materials and Methods

Participants

Participants were 27 PwPD and 30 age-matched controls. They had to be native French speakers with normal or corrected-to-normal vision, normal hearing to mild hearing loss and normal cognition to mild cognitive deficit. Four PwPD were excluded based on these criteria, two because of their moderate hearing loss and two because they were bilingual but French was not their first language. Thus, the study included 23 PwPD (11 females) and 30 controls (17 females). There was no difference between the PwPD and the control group regarding age, hearing and cognitive performance (Table 1). Hearing thresholds were assessed using a screening audiometer at three frequencies (500, 1000 and 2000 Hz) for each ear. The thresholds were then averaged for each participant to obtain a mean hearing threshold. Acceptable hearing level was set to less than 40 db HL. Cognitive performance was tested using the Montreal Cognitive Assessment (MOCA) (Nasreddine et al., 2005) which is a screening tool for detecting cognitive impairment in various clinical conditions including PD (Dalrymple-Alford et al., 2010). The cut-off was set to 22. These two criteria were used to include participants with normal hearing to mild hearing loss and normal cognition to mild cognitive deficit. PwPD were under their usual medication (i.e. "on" drug state), in line with previous studies (e.g. Pell, 1996; Martens et al., 2016; Basirat et al., 2018). The study was conducted in accordance with the tenets of the Helsinki Declaration and approved by the local ethics committee (N° 2018-298-S63). Before testing, all participants gave their written informed consent.

TABLE 1

Stimuli

The stimuli consisted in phonemically identical and prosodically different pairs such as 'l'affiche' /l#afiʃ/ (V-onset word) and 'la fiche' /la#fiʃ/ (C-onset word) (# indicating the word boundary) inserted at the end of a neutral carrier sentence 'c'est' (/se/, 'This is' in English). We used the same acoustic material as that recorded in Strauß et al. (2015), which included 17 pairs of phonemically identical and prosodically different pairs based on the study of Spinelli et al. (2010). This set of stimuli benefited from a detailed analysis of acoustic and lip movement measures, showing that the intensity/F0 and the lip aperture dissociated C-onset and V-onset words. We used both C-onset and V-onset stimuli for each pair to assess participants' performance as in previous studies (Spinelli et al., 2010; Strauß et al., 2015; Basirat, 2017; Ogane et al., 2020): If participants were able to use acoustic prosodic cues to segment sentences beginning by /sela…/, a C-onset word had to be segmented as /la#…/ and the corresponding V-onset word segmented as /l#a…/.

The stimuli consisted in three different repetitions of each sentence spoken by a native French male speaker. They were digitally recorded at a sampling frequency of 44.1 kHz. One of the pair (/lapœzɑ̃tœʁ/) was used for the training session. The other 16 pairs (/lalaʁm/, /lavaʁis/, /latʁaksjɔ̃/, /la.ʁɛn/, /lataʃ/, /lavɛʁsjɔ̃/, /latɛ̃t/, /lami/, /lafiʃ/, /lalɛn/, /latɑ̃sjɔ̃/, /lav(ə)ny/, /latɑ̃t/, /lamɑ̃t/, /lanɔtasjɔ̃/, /lalɔkasjɔ̃/) were used in the experimental session. The detailed psycholinguistic properties of these words can be found in Spinelli et al. (2010).

Procedure

During the experiment, participants were asked to listen to the sentences through headphones. The sound was presented at a comfortable level. Each trial began with the presentation of one of the stimuli. Then, both possible words, i.e. V-onset and C-onset words, were presented on the screen, one on the left and the other on the right. The participants were asked to identify the word they perceived. They made a forced choice between two possible words by pressing one of the two response keys on the keyboard (left and right arrow keys corresponding to left and right choices, respectively). After each key-press, the next trial began automatically. This procedure was in line with previous works using the same segmentation task (Spinelli et al., 2010; Strauß et al., 2015; Basirat, 2017; Ogane et al., 2020) and enabled us to ensure that the procedure was similar for all participants. In sum, 96 experimental trials were presented (16 pairs x 2 conditions (V-onset and C-onset) x 3 repetitions). The presentation order was randomized. The response key order was counterbalanced across participants. All participants performed 6 familiarisation trials (1 pair x 2 conditions (V-onset and C-onset) x 3 repetitions) before the experiment began. Stimuli were presented and responses collected with Psychtoolbox (http://www.psychtoolbox.org/) running on GNU Octave (https://www.gnu.org/software/octave/).

Data analysis

For each participant and each condition, we calculated the probability that he/she identified the presented sequence as a C-onset word, i.e. judgement probability. We performed an ANOVA with condition as within-subject and group as between-subject factors. If PwPD differed from controls in performing the task, we would expect a significant interaction between condition and group. We used one-sample t-tests to examine the performance of participants against chance level (50%). We estimated the performance by calculating the proportion of correct responses across both conditions. We also examined whether the performance of PwPD could be predicted by disease duration, hearing threshold and cognitive performance using linear regression analyses. Note that the MOCA scores of four PwPD were not available due to data loss. Thus, the regression analysis using cognitive performance as predictor was performed on the subset of PwPD for whom the MOCA score was available (n = 19).

In addition to these classical inference analyses, we compared the model suggested by our data to an alternative model based on the literature. To do so, we calculated a Bayes factor, which is expressed in terms of a ratio and quantifies the relative model evidence. We followed the procedure described in Harms and Lakens (2018) for a t-test. We based our alternative model on a meta-analysis of the deficit in the perception of emotional prosody in PD (Gray & Tickle-Degnen, 2010). To date, there has been no such meta-analysis of the perception of linguistic prosody in PD. Gray and Tickle-Degnen (2010) estimated a deficit effect size of 0.70 (95% CI: [0.54 0.87]). We thus assumed that if we found a prosody deficit in PwPD in the current study, the difference between PwPD and controls might have a similar effect size.

Results

Figure 1 shows the mean judgement probability for each condition and each group as well as individual judgement probabilities. For PwPD, mean judgement probabilities were 0.33 (SD = 0.16) and 0.66 (SD = 0.18) for V-onset and C-onset words, respectively. For controls, these values were 0.33 (SD = 0.14) and 0.69 (SD = 0.15), respectively.

FIGURE 1

Classical inference analysis

The judgement probability was larger in the C-onset condition than in the V-onset condition (F(1, 51) = 145.201, $p < 0.001$). The effect of group and the interaction between condition and group were not significant (respectively, F(1,51) = 0.118, $p = 0.73$; F(1,51) = 0.378, $p = 0.54$). Performance was above chance in PwPD (mean = 0.66, 95% CI = [0.62; 0.71], t(22) = 7.22, $p < 0.001$) and controls (mean = 0.68 , 95% CI = [0.64; 0.72], t(29) = 9.74, $p < 0.001$). In agreement with the results of the ANOVA, the performance of PwPD did not differ from that of controls (95% CI = [-0.04; 0.08], t(51) = 0.61, $p = 0.55$). Table 2 shows the results of simple linear regression analyses using MOCA score, hearing threshold and disease duration as predictive factors. MOCA score significantly predicted the performance of PwPD (coefficient = 0.02, t(17) = 2.29, $p < 0.05$) and the model was significant (F(1,17) = 5.25, $p < 0.05$, $R^2 = 0.24$). Neither hearing threshold nor disease duration predicted performance (see Table 2).

TABLE 2

Bayes factor

To be able to draw an informed conclusion concerning the performance of PwPD in prosody perception, we analysed the ‘null effect’ (i.e. no difference between two groups) obtained using the above-mentioned classical inference analysis. Following the procedure mentioned in Data Analysis, we obtained a Bayes factor of 3.6. This suggests that our observed data is 3.6 times more in favour of the null model compared to the alternative model based on the literature.

Discussion

Our results show that French listeners can disambiguate stimuli and segment words using subtle prosodic cues. This is in line with previous studies using the same type of stimuli (Spinelli et al., 2010; Strauß et al., 2015; Ogane et al., 2020; Basirat, 2017). The current study is the first to examine speech segmentation in PwPD using subtle prosodic cues, thus avoiding the ceiling effects observed in Dutch listeners by Martens et al. (2016). Nevertheless, we did not observe any significant difference between PwPD and controls in exploiting prosodic cues, in agreement with the findings of Martens et al., (2016). Although moderate, the evidence obtained with our analysis based on the Bayes factor suggests that the null model is more likely than a model with a difference between PwPD and controls. Therefore, PD probably does not impact the perception of linguistic prosody. Our findings are compatible with the claim by Pell (1996) that PD impacts the affective and semantic processing involved in understanding prosody rather than the processing of prosodic cues (see Introduction).

Using a case-study approach, Lloyd (1999) observed that some PwPD had deficits in the perception of linguistic prosody. Moreover, the author observed a different pattern of deficit in these PwPD and hypothesized that these differences could be due to the fact that PD causes different lesions in different localizations. This hypothesis remains to be validated. Overall, even though deficits in the perception of linguistic prosody can be observed, the impact of PD on the receptive level of prosody processing might not be as systematic as its impact on the level of expression (i.e. dysprosody) (Duffy, 2013).

Cognitive performance predicted the performance of PwPD in our segmentation task. Although this finding should be interpreted with caution because of the relatively small sample size, it deserves consideration. A growing body of evidence on speech production in PD suggests a link between prosody production and cognitive performance. Rektorova et al. (2016) observed that the impairment in prosody production in PwPD predicted cognitive changes. Thies et al. (2020) observed that the production of prominence in PwPD was correlated with their task-switching skills. The authors suggested that this link might be due to problems in allocating cognitive resources, which is a well-known consequence of PD (Dirnberger & Jahanshahi, 2013). To our knowledge, our study is the first to demonstrate a link between the perception of linguistic prosody and cognitive performance in PD. This link could be related to our task and the ambiguity of our stimuli which might require significant cognitive resources (Mattys & Wiget, 2011). Further research using more specific cognitive assessment is necessary to investigate how constraints related to cognitive functions might impact the perception of linguistic prosody in PD. Note also that the amount of variance explained by cognitive performance in our study was 24% (see Table 2), which suggests that other predictive factors not included in our analyses were also involved. More detailed neuropsychological assessments would be helpful to clarify which factors influence the processing of speech prosody in PD. The understanding of these factors is crucial to improve the clinical management of speech communication deficits in PD.

Conclusion

In this study of the impact of PD on the segmentation of ambiguous speech sequences using prosodic cues, we did not observe any significant difference between PwPD and controls. Thus, it seems unlikely that PD systematically impacts the processing of linguistic prosody at the receptive level. Since the performance of PwPD was related to their cognitive performance, future research could investigate the ways in which PD impacts the processing of prosody. Our findings are clinically relevant (Hargrove, 2013) and suggest that appropriate evaluation of the cognitive capacity of PwPD would help speech and language therapists when they assess the speech processing skills of PwPD and manage their speech impairments.

Conflict of interest

The authors have no conflict of interest to report.

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	Control		PwPD		Test statistic
	Mean	**SD**	**Mean**	**SD**	
Age (years)	65.9	8	67.1	9	t(51) = -0.51, *p* = 0.61
Disease duration (years)	-		8	6	-
Hearing threshold (db HL)	18.4	8.5	20	10.3	t(51) = -0.61, *p* = 0.54
MOCA (/30)	27.3	2	26.6	2.8	t(47) = 1.02, *p* = 0.31

Table 1: Characteristics of controls (n=30) and PwPD (n=23, except for MOCA score where n=19 since scores for four PwPD were not available - see Data analysis). Groups were matched for age, hearing threshold and MOCA score, as shown by corresponding t-tests.

Parameter	**Coefficient**	**t-value**	**p-value**	**R^2**
Disease duration	-0.00	-0.59	0.56	0.02
Hearing threshold	-0.00	-1.70	0.10	0.12
MOCA	0.02	2.29	0.03	0.24

Table 2: Influence of disease duration, hearing threshold and MOCA on the performance tested by simple linear regression models.

Figure

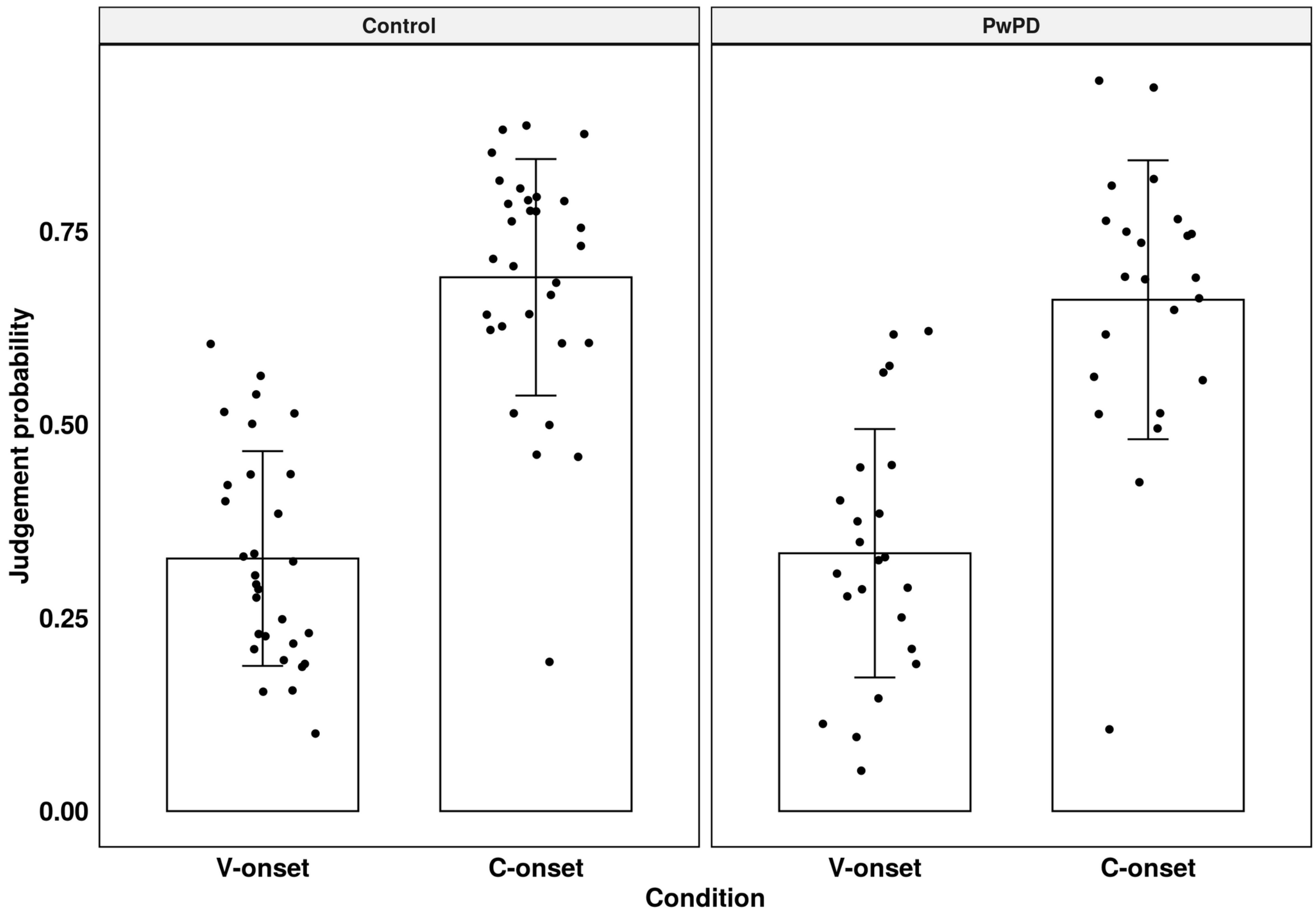

Figure 1: Mean judgement probability for sentences containing V-onset words (e.g. 'l'affiche' /l#afiʃ/) and those containing C-onset words (e.g. 'la fiche' /la#fiʃ/). Error bars represent standard errors.