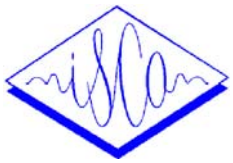
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Temporal Variables in Parkisonian Speech

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Abstract

Temporal variables were detailed and compared in a text read by ten French subjects with mild to moderate Parkinson disease (PDS's) and ten French healthy control subjects (CS's). Longer total pause times were found for PDS's, correlated to higher numbers of pauses and longer mean pause duration. The typical relationship observed between the distributional scheme of pauses and syntactic structure of the text remained largely intact for PDS's. However, PDS's also made strikingly long and unexpected within-phrase and within-word pauses, most often associated with a dysfluency. Pause time and pattern were found to be highly variable across PDS's, some of whom had a fast speech rate, others a slow one. The results can be viewed as manifestations of deficient timing of motor events which appears to be a strong pathomechanism in Parkinson disease.

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1. Introduction

Parkinson's disease (PD) is a progressive destruction of dopamine-producing neurons within the striatum of the basal ganglia; its external manifestations are movement deficits including rigidity or stiffness (muscles resistant to movements), akinesia (inability to initiate movement), bradykinesia (slowness of movement) and rest tremor.

Speech production problems resulting from PD, known as Parkinsonian dysarthria, or hypokinetic dysarthria, affect respiration, articulation and prosody. At the acoustic level there can be significant reduction of speech segments, limited formant frequency excursion for consonant-to-vowel and vowel-to-vowel segments, monotonous fundamental frequency and intensity, and disordered speech rate.

Speech rate is affected by a wide range of linguistic and stylistic factors, which makes its analysis especially complex. Notwithstanding, the investigation and comparison of temporal variables in the speech of neurological intact individuals and those with speech impairments is of crucial interest for understanding speech-timing mechanisms and explaining how neurological problems affect the different processes involved in speech production.

Previous research into how PD affects the temporal organization of speech compared the speech rate and pause time of speakers with PD (PDS's) and control speakers (CS's). The results were mainly inconclusive. For example, both faster as well as slower control speech rates were found for PDS's [1] and [2]. Similar discrepancies were observed for pause time. Some studies reported shorter breath groups and longer and more frequent pauses in the speech of PDS's [3], [2] and [4] while others did not reveal significant differences in pause durations between PDS's and CS's [1] and [5].

In the current study, temporal variables were measured and compared in a standard text read by ten French subjects with mild to moderate PD and ten French healthy control subjects. Temporal variables include speech rate, pause time, articulation time and each of their components. The frequency and duration of pauses were examined; also the distribution of pauses between utterances, sentences, clauses, phrases and within phrases and words. Articulation, which is highly variable across a same speech sample, was calculated for each sounded sequence. The presence of dysfluencies, common to individuals suffering from PD [6] was checked; when present they were expressed as a function of type (repetitions, filled pauses, drawls, false starts) and distribution. Omissions and additions of segments were included with dysfluencies.

Two specific research questions were addressed : 1) How does PD affect speech rate, pause time and articulation rate? 2) Does PD affect individuals differently?

2. Method

2.1. Subjects

The data were collected from 20 French native speakers including ten individuals (5 males and 5 females) diagnosed with PD and 10 age and gender matched CS's. The PDS's were between 7 and 19 year's post-PD diagnosis (M=10) and selected from the Department of Neurology at the Hospital of Aix en Provence by Dr Viallet's. All had been diagnosed as having mild to moderate idiopathic PD, but no histories of neurologic, respiratory, laryngeal, speech and voice diseases or disorders, apart from those associated with PD. They had adequate vision with corrective lenses and no history of hearing loss. Subject profile including age, year of PD diagnosis and month and year of recording can be seen in Table 1. The ten CS's were non-neurologically impaired and had adequate vision and hearing.

Table 1. Subject Characteristics including age and gender of control subjects, gender, age, years post-diagnosis of Parkinson's disease (PD) and medications of PDS's (S: Sinemet, SLP: Sinemet L-dopa; M: Modopar, MLP: Modopar L-dopa)

CS				PDS					
	Age	Sex			Age	Sex	PDY	Medication	UPDRS
C1	58	M		PD1	57	M	12	S LP	34
C2	53	F		PD2	52	F	11	M	58
C3	47	M		PD3	43	M	12	S, SLP	30
C4	60	M		PD4	60	M	8	S	44
C5	70	M		PD5	67	M	19	S	61
C6	55	F		PD6	51	F	12	S	10
C7	59	M		PD7	52	M	7	S	42
C8	67	F		PD8	72	F	8	M+MLP	Un
C9	62	F		PD9	57	F	7	M	24
C10	61	F		PD10	59	F	10	S	44

2.2. Speech sample and recording equipment

The speech sample was an excerpt of "La chèvre de Monsieur Seguin" (A. Daudet, 1869). During the recording sessions, each subject was asked to read aloud at its normal rate. Reading was preferred to conversation since it excludes hesitation pauses. The selected text was written on paper and held before the subjects by a research assistant. High-quality recordings were obtained in a soundproofed room of the Hospital of Aix en Provence. The acoustic signal was transduced using an AKG C410 head mounted microphone and recorded directly on a PC hard disk. To isolate PD effects, subjects were recorded in the morning before taking L-dopa.

2.3. Analysis

2.3.1. Transcriptions

Readings were transcribed orthographically by the author. All perceived dysfluencies (omissions, repetitions and additions) were reported in the transcription. A phonological transcription was then made by the author.

2.3.2. Temporal measurements and temporal variables.

Measurements were carried out on combined wideband spectrograms and oscillograms displayed on a screen, and by listening to selected segments of the waveform in regions of specific interest. The passage was segmented into sounded sequences and silent speech pauses. In order not to confuse a silent pauses with unvoiced occlusions, the former were never shorter than the average duration of an intervocalic stop increased by four standard deviations. A sounded sequence was a stretch of speech sounds bounded by a silent period whose duration ranged from 150 ms to 250 ms.

The *silent-pause ratio* was obtained by dividing the total duration of silent pauses by the total speech time and the *mean duration of a silent pause* by dividing the total pause time by the number of silent pauses. The *mean duration of a sounded sequence* was calculated by dividing the total articulation time (total speech time minus total pause time), by the number of sounded sequences. *Articulation rate* was computed for each sounded sequence by dividing the duration of each sounded sequence by the number of syllables produced per sequence. The average articulation rate was then calculated for each reading. *Speech rate* was obtained by dividing the total number of syllables by total speech time.

2.3.3. Pause location.

The location of silent pauses was studied by syntactic type. Six types were considered: (1) pauses located between paragraphs, (2) between sentences; (3) between clauses; (4) and pauses occurring between phrases, which result from the segmentation of sentences and clauses; (5) within phrase pauses, i.e. unexpected pauses within a sense group (e.g. between an article and a noun) and (6) pauses occurring within a word. The frequency of pauses as a function of location was calculated for each reading. To have a better understanding of the distributional scheme of pauses, the percentage of pauses produced was calculated for each syntactic boundary. The percentage was obtained by dividing the number of pauses made in each location by the number of utterance, sentence, clause and phrase boundaries.

2.3.4. Dysfluencies

Filled pause, false start, repetition and lengthened syllable are normally used in the investigation of spontaneous speech. Although they do not reflect the same cognitive processes, they were used for the study and defined as follows:

Filled pause: any occurrence of a French language hesitation or interjection such as euh, eh, hein.

Repetition: any unintended repetition of a sequence of phonetic segments, syllables, words and phrases which does not carry new information.

False start : any sequence of segments started, then interrupted. False starts can have phonetic, grammatical and/or lexical corrections (i.e. replaced by a sequence which is successfully completed) or no correction. The interruption can occur within or between words.

Lengthened syllable: any syllable perceived as abnormally lengthened

*Errors: (*word is used for an other*)*, *omissions and additions* of syllables, words and phrases were also included in the analysis. A syllable was considered as omitted when there was no perceptible trace of its components.

Dysfluencies were identified by comparing each reading with the phonological transcription and their presence was checked perceptually and acoustically.

They were classified by type, word class and location within a phrase. The total number of dysfluencies was calculated for each group. Their percentage was calculated by dividing their number by the total syllables in the phonological transcription.

3. Results

3.1. Overall temporal variables

As can be seen in Table 2, PDS's have a slower speech rate then CS's. This difference is partly explained by a greater pause time: 27% for PD speakers, 23% of the total speech time for CS's. The greater pause time in PDS's results from a longer mean pause duration and a higher number of pauses. An ANOVA performed on pause duration reveals a significant difference between PDS's and CS's [F(2, 820)=3.6, p=0.02). Mean articulation rates and mean sounded sequences durations are not significantly different.

Table 2. Temporal variables by CS's and PDS's. Total Speech Time (TST), Pause Ratio (PR), Mean Pause Duration (MPD), Mean Articulated Sequence Duration (MSSD), Articulation Rate (AR) and Speech Rate (SR) are expressed in syllables per second, TST, MPD and MSSD in ms, Standard deviations are in parentheses.

	TST	PR	MPD	PN	MSSD	AR	SR
CS	723"	23%	534 (337)	267	1660 (961)	5.47 (0.8)	4.5
PDS	637"	27%	609 (461)	287	1558 (938)	5.3 (0.9)	4.05

3.2. Pause number and duration

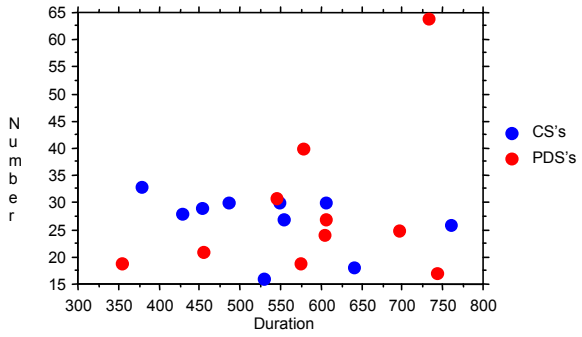


Figure 1. Mean pause numbers plotted as a function of mean pause duration (in ms) for each group.

Although mean pause numbers obtained for PDS's (28.7)) and CS's (26.7) are quite similar, coefficients of variation (0.20 and 0,49) indicate a high variability in the number of PDS's, compared to CS's. As seen in *Fig.* 1, there is a similar pause duration range for each group, but a wide range of pause number for PDS's (from 17 to 64), compared to CS's (from 16 to 33). The two extreme cases suggest different effects of movement disorders. Rare short pauses (M=354 ms, N=19) exemplify festination (i.e. movement acceleration), frequent long pauses (M=732 ms, N=64) bradykinesia (slowness of movements).

3.3. Distribution of silent Pauses

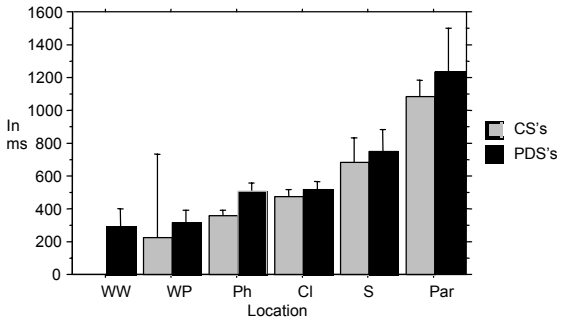


Figure 2. Mean pause duration (in ms) as a function of location (WW and WP: within words and phrases, Ph, Cl, S and Par: between phrases, clauses, sentences and paragraphs)

The results displayed in *Fig. 2* indicate a clear correlation between boundary strength and pause duration and frequency for both groups although there is a slight tendency for PDS's to produce longer pauses than CS's. An ANOVA performed on pause duration yields a significant effect of location [F(4, 847)=0.001). All paragraphs and sentences are separated with a long pause (20% shorter for the latter), a 25% decrease can be observed in the frequency and duration of pauses located at clause boundaries, finally there are only 30% of phrase boundaries associated with a silent pause. Pauses also occur within-phrase (20 in PDS's; only 2 in CS's) and within-word pauses (7 in PDS's), the repartition of pauses as a function of location is significantly different [χ^2= 23, p=0.009]. This distorts the strong correlation between syntactic-structure hierarchy and pause duration and frequency in PDS's.

3.4. Articulated sequences

The mean phrase lengths (in syllables and ms) of 8.5 and 1563 [SD: 5.5 and 938] and 8.9 and 1657 [SD: 5.1 and 955] for PDS's and CS's were not found to be significant [F(1, 571)=1.4; p=0.23]

3.5. Articulation rate

Average articulation rates and standard deviations for PDS's and CS's are shown in Table 3. An ANOVA revealed a significant main effect of Speaker [F(9, 556)= 20.9, p=0.0001 and a significant interaction of Group and Speaker [F(9, 556)=2.3, p=0.1]. A slightly slower articulation rate characterises PDS. The range of articulation rate is larger and more variable for PDS's (from 4.65 to 6.15 syll/sec), it is about one syllable for CS's (from 4.7 to 5.8 syll/sec).

Table 3. Mean articulation rate (M) and standard deviation (SD) for PDS's and CS's

PDS's				CS's		
Spk	M	SD		Spk	M	SD
PD1	4.65	9.98		C1	5.7	0.6
PD2	5.67	9.74		C2	5.8	0.8
PD3	6.15	0.66		C3	5.8	0.5
PD4	5.36	0.74		C4	4.7	0.6
PD5	6.05	0.46		C5	5.7	1.3
PD6	4.93	0.97		C6	5	0.7
PD7	5.17	0.5		C7	5	0.6
PD8	5.6	0.83		C8	5.5	0.7
PD9	5.72	0.57		C9	5.7	0.6
PD10	5.28	0.72		C10	5.3	0.5
All	5.31	0.92		All	5.47	0.78

3.6. Dysfluencies

PDS's produced 48 dysfluencies, CS's only 2 (1 omission and 1 addition of a grammatical word). The differences are significant [F(2,27)=5.1, p=0.01]. Total PDS dysfluencies concern 62 syllables out of 2300 (2.7%). Most dysfluencies occur between words (36) with repetitions of grammatical words (5), phrase fragments (1) and phrases (1), omissions of grammatical words (11) and lexical word (1), additions of grammatical words (5), false starts with grammatical corrections (7) and phrase corrections (2), one lexical error and 2 filled pauses. Out of the 12 dysfluencies occurring within words, 7 were associated with a silent pause : there were repetitions of syllables (2), grammatical word plus lexical word fragment (1) and word fragment (1), omissions of syllables (3), false starts without (2) and with lexical correction (3). *Fig*. 3 clearly demonstrates there is a great variability across speakers.

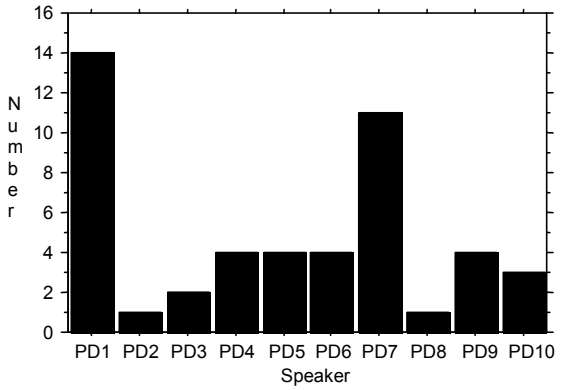


Figure 3. Number of dysfluencies per speaker

4. Concluding remarks

In the present study, pause time is significantly longer in PDS's than in CS's. This finding corroborates previous results [2], [3] and [4]. The relation typically observed in normal speakers between the distributional scheme of pauses and the syntactic structure of the text remained largely intact for the group of PDS's. However, PDS's also made strikingly long and unexpected within-phrase and within-word pauses. These pauses, most often associated with dysfluencies, distort the hierarchical pattern of pauses.

The observed pause time and pattern may be manifestations of deficient timing of motor events, a main pathomechanism of PD [7]. Speech timing relies on the repetition of structures at approximately equal intervals [8]. Pauses, which are group-boundary markers, are a fundamental element of speech rhythm. They make, in combination with other parameters, the cohesion of linguistic units. Abnormal pauses occurring within strongly linked elements and/or inappropriately long pauses disrupt the rhythmic pattern of discourse and break the perceptual coherence of prosodic structures.

Interestingly, pause time and pattern were found to be highly variable across PDS's, some of whom had a fast speech rate, others a slow one. This may exemplify different effects of internal clock disorders. The PDS group results may also reflect how the illness affects individual persons differently, thus complicating interpretation of the results. Further investigation into the effects of PD motor disorders on speech timing appears necessary.

5 Acknowledgements

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