Segmental Duration in Parkinsonian French Speech

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Key Words

Parkinsonian dysarthria • Consonant and vowel duration • Intrinsic duration • Durational contrasts

Abstract

Objectives: The present study had 2 main objectives: (1) examine the effect of Parkinson's disease (PD) on vowel and consonant duration in French read speech and (2) investigate whether the durational contrasts of consonants and vowels are maintained or compromised. **Results:** The data indicated that the consonant durations were shortened in Parkinsonian speech (PS), compared to control speech (CS). However, this shortening was consonant dependent: unvoiced occlusives and fricatives were significantly shortened compared to other consonant categories. All vowels were slightly longer in PS than in CS, however, the observed differences were below the level of significance. Despite significant shortening of some consonant categories, the general pattern of intrinsic duration was maintained in PS. There was slightly less agreement for vowels with the normal contrast of intrinsic durations, possibly because vowel durational contrasts are more sensitive to PD disorders. **Conclusion:** Most PD patients tended to maintain the intrinsic duration contrasts of both vowels and consonants, suggesting that low-level articulatory constraints operate in a similar way and with the same weight in PS and CS.

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Introduction

Studies on the impact of Parkinson's disease (PD) on syllable components have reported complex alterations in durations. The consonant durations were found to be reduced in Parkinsonian speech (PS) compared to control speech (CS) in American English [1–3] and German [4]. However, this reduction was shown to be consonant dependent [3]. Vowels in PS, when compared to CS, were found to be shorter in American English and French [3, 5], longer in American English [6] or of about the same duration [7]. Potential sources for the divergent findings on speech segment durations may lie in the different corpora used in the studies on PD speech (a few short sentences read by a small number of patients) and/or the differing degrees of severity of the disease amongst patients [7].

The duration of a segment is consistently associated with an underlying physiological pattern and articulatory requirements. For example, voiced occlusives are shorter than unvoiced occlusives because of aerodynamic constraints [8]. Most studies on vowels in European languages have confirmed that intrinsic duration is directly related to jaw position and tongue body height [9]. Basic production constraints are reflected by duration patterns manipulated by speakers to convey information on speech segment identity; in turn, duration is one of the cues that can be used by listeners to identify speech segments [10].

Table 1. Speaker, patient and group characteristics

Patients	Age years	Sex	Years of post-PD diagnosis	UPDRS in off state	Dysarthria severity	Control speakers	Age years	Sex
P1	57	M	12	34	2	C1	58	M
P2	71	M	12	30	1	C2	69	M
P3	64	M	19	40	3	C3	60	M
P4	60	M	8	44	1	C4	60	M
P5	67	M	18	61	3	C5	69	M
P6	50	M	11	30	3	C6	39	M
P7	69	M	15	40	1	C7	62	M
P8	52	M	7	42	2	C8	47	M
P9	73	M	25	52	3	C9	77	M
P10	52	F	11	58	1	C10	37	F
P11	72	F	8	unknown	unknown	C11	67	F
P12	59	F	10	44	1	C12	61	F
Mean $\pm$ SD	62.16 $\pm$ 8.3		13 $\pm$ 5.34	43.1 $\pm$ 10.3	1.9 $\pm$ 0.9	58.8 $\pm$ 12.1		

The motor disability of each patient was assessed by means of the Unified Parkinson's Disease Rating Scale (UPDRS). Dysarthria severity was estimated with item 18 of the UPDRS: 0: normal; 1: slight loss of expression, diction and/or volume; 2: monotone, slurred but understandable, moderately impaired; 3: marked impairment, difficult to understand; 4: unintelligible. Means and Standard deviations (SD) per group pooled across subjects.

The pattern of duration of individual segments conveys information about the linguistic content of an utterance. As a consequence, PD distortions in speech segment durations may impair linguistic information. Thus, examining the impact of PD on speech segment duration in different environments in different languages should both permit a better understanding of how basal ganglion dysfunction impairs temporal speech processing and clarify language-specific effects. In this context, PD effects on the duration of speech segments were investigated in read French speech. French is a non-phonemic-length language, with a pattern of vowel reduction where most unaccented vowels are full vowels and a pattern of accentuation based on final prominence [11, 12]. Therefore, most of the variation in segment duration involves inherent duration contrasts.

The ensuing study had 2 main objectives. The first was to examine the impact of PD on vowel and consonant duration in French and ascertain whether 'compensatory adaptation' [3] between vowel and consonant duration enables PS syllable duration to match normal syllable duration [13, 14]. The second objective was to investigate the impact of PD on the inherent duration of consonants and vowels and examine whether durational contrasts are maintained or compromised.

Methods and Materials

Participants

The data for this study were collected from 24 French native speakers composed of 12 individuals (9 males and 3 females) diagnosed as having PD and 12 age- and gender-matched control speakers. The PD participants were recruited by the Department of Neurology at the Hospital of Aix en Provence. All were diagnosed as having mild to moderate idiopathic PD; they had no histories of neurological, respiratory, laryngeal, speech and voice diseases or disorders, apart from those associated with PD. They were being treated with L-Dopa and experienced motor fluctuations in response to their treatment, they had adequate vision with corrective lenses and claimed not to suffer from hearing loss. Antiparkinsonian medications were withheld overnight and the first recordings started after at least 10 h without medication. Before recording, the motor disability of each patient was assessed using the Unified Parkinson's Disease Rating Scale, especially dysarthria severity as defined by item 18 [15]. The 12 control speakers were not neurologically impaired and had adequate vision with reading spectacles as appropriate and did not report hearing problems. The recordings were made in conformity with the rules defined by the local ethics committee. The nature of the study was carefully explained to each patient and control speaker, and they signed a written consent form prior to being recorded. The profiles of the patients and control speakers are detailed in table 1.

Procedure and Materials

Each speaker was asked to read a paragraph of 'La chèvre de Monsieur Seguin' [16] at his normal speech rate. High-quality recordings were obtained in a sound-treated room of the Aix en Provence Hospital. The acoustic signal was transduced using an

Table 2. Number of consonants and vowels produced (P) and omitted (O) in PS and CS

		Consonants							Vowels				
		occlusives		fricatives		sonorants	glides	all	high	mid	low	nasal	all
		V–	V+	V–	V+								
PS	P	642	446	525	268	1,326	205	3,412	514	1,172	1,025	366	3,074
	O	36	14	11	31	157	40	291	14	22	16	7	59
CS	P	646	442	525	292	1,403	229	3,538	503	1,117	1,020	361	2,999
	O	10	3	–	5	39	18	73	2	1	–	–	3

Consonants include voiceless (/p, t, k/) and voiced (/b, d, g/) occlusives, voiceless (/f, s, ʃ/) and voiced (/v, z, ʒ/) fricatives, sonorants (/m, n, ɲ, l, R/) and glides (/w, j, ʏ/). Vowels are high (/i, y, u/), mid (/e, o, ə, ø/), low (/ɛ, ɔ, œ, a/) and nasal (/ɛ̃, ɔ̃, ɔ̃/).

AKG C410 head-mounted microphone and recorded directly onto a PC hard disk at a sampling rate of 20 kHz.

Transcriptions

The author transcribed the readings orthographically. Table 2 lists the number of produced and omitted consonants and vowels in PS and CS.

Temporal Measurements

Acoustic measures were obtained by hand, using the Praat program. Measurements were made 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 overall recordings were segmented into consonants and vowels, whose limits were carefully marked by applying the following rules relating to spectral changes and formant transitions.

Sonorants and Glides. The onsets and offsets of nasals and vowels are normally marked by an abrupt discontinuity in the F1 region and the sudden darkening of the higher formants. When these occurred, nasal boundaries were placed at the point of maximum spectral changes. Formant discontinuity is also a reliable marker between an /l/ and its surrounding vowels: the juncture was determined by a formant discontinuity (in F1 and F2) and a reduced level of high-frequency energy (in F3). Glides are weaker than vowels and exhibit less energy and much lighter formants. The change in formant darkness was used as a boundary cue between glides and vowels. The sonorant /R/ is a multiform consonant, strongly dependent on the context. In the vicinity of an unvoiced obstruent, it has a voiceless F spectrum; when followed or preceded by a vowel, it exhibits formants. In the former case, boundaries were defined as the appearance and disappearance of noise; in the latter at the point of maximal discontinuity in the F2 and F3 formants.

Fricatives. Voiceless fricatives have no voice bar, while voiced fricatives exhibit high energy concentrations at low frequencies. Voiceless fricatives were recognised by the onset and the offset of noise. Voiced fricatives were identified by a visible discontinuity in the F1 region. The spectrogram in figure 1 shows the transition of the voiceless /s/ to a following /e/.

Occlusives. Two events were identified: preceding vowel offset which coincides with the beginning of the voice bar or the silence and following vowel onset. The duration of the closure and the VOT (the interval between stop release and vowel onset) were not examined here, although there are significant voicing cues. Some voiceless occlusives were changed into their voiced counterparts, some voiced occlusives into fricatives and nasals. Figure 1 shows the formants of the /d/ changed into approximant and the voice bar of the voiced /t/.

In a few cases, there were sequences of 2 consecutive vowels. The boundaries between the 2 vowels were mainly based on the change in blackness in the F2 and F3 regions; discontinuity in the fundamental frequency was also used as a boundary clue. When there was no visible clue, the sequence was excluded. In some cases there was neither a perceptible nor an acoustic trace of speech segments; these were considered as omitted. In the word 'caractère' (fig. 1), 3 consonants were omitted: the initial /R/ and the final /k/ of the second syllable and the final /R/ of the third syllable. There was no measurable occlusion for /k/ and no visible formants for /R/s.

The duration of each consonant and vowel was measured twice for PS and CS. Both groups showed a similar error magnitude (consonant error measurements in CS: 1.4 ms and in PS: 1.6 ms, while the errors of vowel duration were <3 ms). The measurements for 1 PD patient with a high level of dysarthria (stage III) were not integrated in the analysis: segments could not be reliably identified.

Intrinsic Duration

Consonant duration in French has been extensively investigated in both CV and CVC sequences [12] and in paragraphs [17]. Voiceless fricatives and occlusives were found to be longer than their voiced counterparts, fricatives longer than occlusives, and occlusives longer than sonorants and glides. Therefore, the duration of consonants was analysed as a function of manner and voicing.

Concerning vowels in French, Di Cristo [12] quantified intrinsic variations in different corpora and found that high vowels are 15% shorter than mid-high vowels, which are 13% shorter than low vowels, which in turn are 40% shorter than nasal vowels. He also observed that intrinsic variations are greater in non final-

Fig. 1. Sequence ‘au caractère de ses bêtes’ /okaRaktεRdεsεbεt/ produced by a patient. In the word ‘caractère’, the /t/ is totally voiced, and there is omission of the initial /R/ and the final /k/ of the second syllable and the final /R/ of the third syllable; the /d/ of the word ‘de’ is very short and exhibits formants.

Table 3. Mean number of syllables, standard deviation (SD) and total number of syllables as a function of location in PS and CS.

	PS					CS				
	prominent		non-prominent			prominent		non-prominent		
	F	F+	NF	[ə]+	NF+	F	F+	NF	[ə]+	NF+
Mean	78.5	69.0	396	22.1	3.2	73.9	69.5	393	14.1	0.6
SD	19.0	20.8	26.8	17.9	4.5	12.7	12.9	9.4	7.3	0.8
Number	942	829	4,763	266	39	887	834	4,716	170	8

Syllables are prepausal and non-prepausal phrase-final syllables (F+ and F), non-final (NF) and syllables with a [ə] before a pause and non-phrase final syllables before a pause (NF+). Mean, standard deviation and total syllable number per location pooled across patients and controls.

phrase syllables (non-accented) than in phrase-final ones (accented). Cointrinsic variations were also found to depend both on preceding and subsequent consonants, only the latter having a significant effect. In the present study, vowel durations were analysed using the 4 classes determined by Di Cristo (high, mid-high, low and nasal).

Consonant and vowel durations were investigated for all syllables, i.e. syllables located at the edge of major and minor phrases (as defined by Blanche-Benveniste et al. [18]), prepausal and non-prepausal, non-phrase-final syllables, syllables containing the so-called mute [ə] produced before a pause, and non-phrase-final syllables occurring before within-phrase or within-word pauses (their frequency can be seen in table 3). All phrase-final syllables were considered as prominent, the remaining syllables as non-prominent. Then, to focus on intrinsic variations, consonant and vowel durations were investigated in non-phrase-final CV syllables. Cointrinsic variations were not examined in the present study:

there were few cases where the same vowels were produced in both open and closed syllables, thus preventing a reliable comparison.

Statistical Analysis

Repeated-measure analyses of variance (ANOVA) were conducted with duration as the dependent variable and group as the between-subjects factor (PD or control); the following variables were selected as within-subject factors: segment type (C or V), consonant categories (voiced and voiceless fricatives, voiced and voiceless occlusives, sonorants and glides) and vowel categories (high, mid, low and nasal). There were 12 entries per group, where each entry was the mean duration for each speaker and each speech segment category. Independent t tests were conducted to compare mean duration differences between the different categories of consonants and vowels. These analyses were performed for all speech segments and for speech segments located in non-final-phrase CVs.

Table 4. Mean durations (M in milliseconds) and standard deviations (SD) for the different categories of consonants in PS and CS: data for all syllables

		Occlusives		Fricatives		Sonorants	Glides	All
		voiceless	voiced	voiceless	voiced			
PS	M	103.82	77.37	115.75	72.29	60.54	54.27	80.67
	SD	6.55	8.26	10.57	7.55	7.78	6.3	23
CS	M	112.74	77.98	129	80.09	64.42	58.28	87.08
	SD	12	11.5	13.8	7.14	6.4	7.8	27

Results

Durations of Consonants and Vowels in All Syllables (All Positions and Structures)

As seen in table 4, the PD speakers had shorter mean consonant durations than the control speakers, the sole exception being for voiced occlusives. A 2-way repeated measures ANOVA on the consonant duration showed a significant effect of speaker group [$F(1, 22) = 4.8$, $p < 0.03$], a significant effect of category [$F(5, 110) = 430$, $p < 0.0001$] and a significant interaction of factors [$F(5, 110) = 3.1$, $p = 0.009$]. Planned comparisons revealed a significant effect of group for unvoiced occlusives [$F(1, 22) = 5$, $p = 0.03$], unvoiced fricatives [$F(1, 22) = 6.9$, $p = 0.02$] and voiced fricatives [$F(1, 22) = 6.7$, $p = 0.02$]. There is a strong tendency to preserve differences in manner of articulation and voicing contrast in both PS and CS. On average, fricatives were longer than occlusives, which in turn were longer than sonorants and glides, with the voiceless fricatives and occlusives exceeding their voiced counterparts. Post hoc tests showed significant differences between voiceless occlusives and fricatives and their voiced counterparts in both CS and PS ($p < 0.0001$). Consonantal contrasts were maintained; however, voicing contrasts were slightly less marked for occlusives in PS, particularly for P3 (degree of dysarthria: stage 3).

As seen in table 5, the average vowel durations in PS (M: 98.18 ms, SD: 23.76) exceed those of CS (M: 91.2 ms, SD: 21). Oral and nasal vowels were longer in PS than in CS; the differences were less marked for low vowels. A 2-way repeated measures ANOVA conducted on duration showed significant effects for vowel category [$F(3, 66) = 179$, $p = 0.0001$], but no significant effects for speaker group and no significant interaction of both factors. Nasals were longer than orals in both groups. There is less agreement for orals: in PS low and high

Table 5. Mean durations (M in milliseconds) and standard deviations (SD) for the different categories of vowels in PS and CS: data for all syllables

		High	Mid	Low	Nasal	All
PS	M	89.47	83.52	90.23	129.5	98.18
	SD	12.4	14.9	12	20.79	23.76
CS	M	82.06	73.28	86.26	123.19	91.2
	SD	8.16	6.3	8.08	11.38	21

vowels were of almost identical duration; in CS low vowels were only 5% longer than high vowels. Mid vowels were shorter than high vowels in both groups. Post hoc comparisons revealed significant differences between nasal and low vowels in both groups ($p = 0.0001$), but no significant differences between high, mid and low vowels.

Most speakers had nasals at least 20 ms longer than orals in PS and CS, the lone exception being P3, whose nasals were 5 ms longer than low vowels. The high/low contrast was compromised in PS and CS. Four patients had low vowels slightly shorter than high vowels, 2 had a high degree of dysarthria (P5 and P6), and 2 were mildly impaired (P2 and P8). Four control speakers had low and high vowels of about the same duration (C3, C6, C7 and C12), C9 produced longer high vowels than low vowels. This finding partly contradicts previous results on intrinsic durations [12], possibly because of long phrase-final vowels (prepausal or not). Mid vowels were shorter than high vowels in both CS and PS, the sole exception being P1. This finding is also in disagreement with previous results, possibly because mid vowels incorporate short [ə]s [17].

Table 6. Mean durations (M in milliseconds) and standard deviations (SD) for the different categories of consonants in PS and CS: data for non-phrase-final CV syllables

		Occlusives		Fricatives		Sonorants	All
		voiceless	voiced	voiceless	voiced		
PS	M	98.38	73.07	112.94	70.07	57.9	82.47
	SD	5.58	12.28	10.95	9.21	7.28	22.22
CS	M	109.61	71.95	126.95	77.29	58.78	88.9
	SD	13.03	11.26	14.79	8.21	6.2	27.71

Table 7. Mean durations (M in milliseconds) and standard deviations (SD) for the different categories of vowels in PS and CS: data for non-phrase-final CV syllables

		High	Mid	Low	Nasal	All
PS	M	71.66	68.88	79.02	105.81	91.34
	SD	8.06	10.7	12.6	22.9	20.5
CS	M	63.01	63.83	72.38	98.43	81.2
	SD	5.47	5.6	6.34	11.44	16.24

Durations of Consonants and Vowels in Non-Phrase-Final CV Syllables

As seen in table 6, the patterns of duration were similar to those reported in table 4, with consonants shorter in PS than in CS. The PD effects also varied with consonant category: voiceless occlusives and fricatives and voiced fricatives were about 10% longer in CS than in PS, while voiced occlusives and sonorants were of similar duration. The tendency to maintain consonantal contrasts was also confirmed. On average, fricatives were longer than occlusives, which were longer than sonorants. In addition, voiceless fricatives exceeded their voiced cognates by 60 and 64% in PS and CS, respectively; for occlusives, the corresponding proportions were 35 and 53%. A 2-way repeated-measures ANOVA conducted on consonant duration did not yield significant effects for speaker group ($p = 0.055$), while there were significant effects for consonant category [$F(4, 88) = 275, p < 0.0001$] and a significant interaction of both factors [$F(4, 88) = 253, p = 0.002$]. Planned comparisons revealed significant effects of group for unvoiced occlusives [$F(1, 22) = 7.5, p = 0.01$] and unvoiced fricatives [$F(1, 22) = 6.92, p = 0.02$]. Post hoc comparisons indicated significant differences in duration between voiced and voiceless fricatives and occlusives in PS

($p = 0.0001$). The PD speakers produced voiceless fricatives and occlusives longer than their voiced counterparts, the sole exception being P3, who produced voiceless and voiced occlusives of similar duration. All control speakers had voiceless consonants longer than their voiced cognates.

The results reported in table 7 confirm the pattern of duration displayed in table 5, with vowels slightly longer in PS than in CS; the attained proportions were 14.4% for high vowels but only 8% for mid vowels, 9.7% for low vowels and 7.49% for nasals. In both groups, nasal vowels were longer than low vowels (PS: 32.9%; CS: 36.11%) and low vowels longer than high vowels (PS: 11%; CS: 14.8%). A 2-way repeated-measures ANOVA conducted on vowel duration showed significant effects for vowel category: $F(3, 66) = 99, p < 0.0001$, but there was no effect of group and no significant interaction of the 2 factors. Post hoc t tests indicated significant differences between nasal and low vowels in both PS and CS (0.0001) and high and low vowels in PS (0.02) and CS (0.05).

The control speakers had nasal vowels longer than low vowels and low vowels longer than high vowels, the sole exception being C1, whose means of high and low vowels were of similar duration. Eleven PD patients maintained the nasal/low vowel contrast, the lone exception being P3. Five patients did not maintain the low/high contrast, 2 had a high degree of dysarthria (P3 and P6), and 3 were mildly impaired (P4, P7, P12). The high/mid contrast was strongly compromised in both PS and CS; this may be due to the mid-vowel group including short [ə]s [17].

Conclusions

The principal finding of the present study is the different impact of PD on consonant and vowel duration. Consonants were shortened in PS compared to CS. How-

ever, this shortening was consonant dependent. Unvoiced occlusives and fricatives were significantly shortened compared to other consonant categories. This may reflect a strong tendency for unvoiced consonants to be voiced [1]: voicing, a gesture difficult to sustain, may result in an important shortening. There was also a tendency for voiced fricatives to be shortened, contrary to voiced occlusives. This may be due to the fact that the production of fricatives requires more control and thus more effort than stops, the acoustic modeling of fricatives imposing more than simply adjusting the oral constriction of a stop [19]. Sonorants and glides were not shortened, probably because they require less effort.

All vowels were slightly longer in PS than in CS. However, the observed differences were below the level of significance. As already mentioned, there exist contradictory results on the impact of PD on vowel duration: vowels were reported as shorter [3, 5], significantly longer [6] or non-significantly longer [7]. The current results support the latter findings. Although the magnitude of lengthening was similar for each category of vowels, it was slightly greater for high vowels, suggesting that PD patients have greater difficulty in executing high-vowel gestures.

Interestingly, the different impact of PD on consonants and vowels is in agreement with the supposition that a speech signal is a succession of vowels upon which consonants are produced [20]. In PS, one may assume a superposition of shortened and reduced consonantal gestures over an unusually slow vowel continuum stream, explaining how syllabic productions combining shorter consonants and longer vowels have the same duration as normal speech [13, 14].

Despite significant shortening of some consonant categories, the general pattern of intrinsic duration was maintained in PS. Voiceless fricatives and occlusives were significantly longer than their voiced counterparts, which agrees with previous results obtained for normal French speech [12, 17]. The fact that PD patients maintain the durational contrast between voiced and voiceless consonants may partly compensate the loss of spectral information in consonant identification. Concerning occlusives, it is well known that closure duration is a main voicing contrast cue. Further analysis should investigate the impact of PD on the 2 main temporal acoustic features (closure duration and VOT).

There was less agreement for vowels with the normal contrast of intrinsic durations [12], possibly because vowel durational contrasts are more sensitive to PD disorders than consonant durational contrasts. The degradation of durational contrasts between high and low vowels seems

to have been due to the lengthening of high vowels: PD speakers may take or need more time to execute the high-vowel tongue gesture or they may produce high vowels with a lower height gesture [5]. The variability across PD speakers was particularly high for nasals and in the high/low vowel contrast. However, there was no clear relationship between the impairment of duration contrasts and the severity of the disease. Further analysis should clarify the relationship between duration and the severity of PD.

The articulation rate is known to be speaker dependent, to be highly variable within a speaker's production and have a strong impact on the duration of vowels. The relationship between articulation rate and the duration of vowels and consonants was not investigated here. A re-analysis of the results as a function of the articulation rate is intended; it should provide a better understanding of how the articulation rate affects the different segment categories in PS and CS.

However, notwithstanding the above discrepancies, durational vowel contrasts tended to be maintained in the PD group. Furthermore, most PD patients tended to maintain the intrinsic duration contrasts of both vowels and consonants, suggesting that low-level articulatory constraints operate in a similar way and with the same weight in PS and CS. As such, the observed abnormalities of consonant shortening and vowel lengthening and the impairment of the low/high vowel contrast would seem to reflect disturbed articulatory processes rather than cognitive deficits, at least at the early and mild stages of the disease.

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