Consonant and Vowel Duration in Parkinsonian French Speech

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Abstract

The current study compared vowel and consonant duration in speech read by 10 French Parkinsonian speakers and 10 control speakers. The results show a different impact of Parkinson's disease (PD) on speech segments. Consonants were shortened in PD speech while vowels were significantly longer. This results from the concomitance of articulatory movements of reduced amplitude of articulatory movements and orofacial bradykinesia. As a consequence syllabic productions are of the same overall duration in PD speech as in normal speech. The durational contrast of consonants was maintained, although for vowels there was less agreement with the normal pattern of intrinsic durations, especially for high vowels.

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.

At the acoustic and perceptual level, these disorders can be reflected by abnormalities of temporal speech patterns. Acoustic studies on the duration of speech segments have indicated a complex effect of PD on consonants and vowels. Consonants were shown to be reduced and shortened in PD speech (PDS) compared to control speech (CS) [1, 2, 3]. The results were less consistent for vowels, found both longer [4], shorter [5; 3] in PDS than in CS, or of the same duration [6].

However, despite distortions in segment duration, there is a persistence of linguistic contrasts in PDS. For example, the voicing contrast effect of the postvocalic consonant is present in French PDS as in CS [5]. In German, PD patients tend to preserve phonemic vowel length distinctions [7]. The results above suggest that PD dysfunction affects temporal speech patterns in different ways, compounded by interrelationships between speech duration and the phonological structure of languages. In this context, it was decided to review how PD affects the duration of vowels and consonants when reading French, a non-phonemic length language, with a pattern of vowel reduction where most unaccented vowels are full vowels [8, 9].

The current study had two main objectives: 1) to examine the effect of articulatory undershoot and bradykinesia on vowel and consonant duration in French and to ascertain whether it is "compensatory adaptation" [3] between vowel and consonant duration that enables PD syllable duration to match normal speech [10;11] and 2, to investigate the impact of PD on the inherent duration of consonants and vowels. To achieve this, vowel and consonant durations were compared in a standard text read by ten French subjects with mild to moderate PD and ten French healthy control subjects. Consonant durations were analysed as a function of manner (occlusives, fricatives and sonorants) and voicing (voiced/unvoiced), vowels as a function of manner (oral or nasal) and tongue height high, mid and low).

2. Method

2.1. Subjects

Table 1. Subject characteristics including age (A) and gender(G), years post-diagnosis of disease (Y). The motor disability of each patient was assessed by means of Unified Parkinson's disease rating scale (UPDRS). Dysarthria severity (DS) 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 [12].

	PD Patients					Control		
P	A	G	Y	UPRDS	DS	C	A	G
P1	57	M	12	34	2	C1	58	M
P2	43	M	12	30	1	C2	47	M
P3	60	M	8	44	1	C3	60	M
P4	67	M	19	61	3	C4	70	M
P5	69	M	15	40	1	C5	55	M
P6	52	M	7	42	2	C6	59	M
P7	73	M	25	52	3	C7	67	M
P8	72	F	9	45	2	C8	62	F
P9	59	F	10	44	1	C9	62	F
P10	52	F	11	58	1	C10	53	F

The data were collected from 20 French native speakers composed of 10 individuals (7 males and 3 females) diagnosed with Parkinson disease and 10 age and gender matched control speakers. The PD participants were between 7 and 19 years post-PD diagnosis (M=10), selected by the Department of Neurology at the Hospital of Aix en Provence. All met the following criteria: (1) they were diagnosed as having mild to moderate idiopathic PD, (2) they had no histories of neurological, respiratory, laryngeal, speech and voice diseases or disorders, apart from those associated with PD, (3) they were being treated with L-Dopa and had no surgical treatment, 4) they were experiencing motor fluctuations in response to their treatment and 5) they had adequate vision with corrective lenses and claimed not to suffer from hearing loss. Subject profile including age, year of PD diagnosis and month and year of recording can be seen in Table 1

To make the effects of PD more salient, the recordings started after at least 10 hours without antiparkinsonian medication. Before recording, the motor disability of each patient was assessed using the Unified Parkinson's Disease Rating Scale (UPDRS), especially, dysarthria severity as defined by item 18 [12]. The ten control subjects were non-neurologically impaired and had adequate vision with lenses and did not report problems of hearing. Their characteristics are also listed in Table 1.

2.2. Speech sample and recording equipment

The read speech sample was a paragraph of *La chèvre de Monsieur Seguin* [13]. Each subject was asked to read at his normal speech rate. High-quality recordings were obtained in a sound-treated room of the Hospital of Aix en Provence. The acoustic signal was transduced using an AKG C410 head mounted microphone and recorded directly onto a PC hard disk at a sampling rate of 20 KHz.

2.3. Analysis

2.3.1. Transcriptions.

The author transcribed readings orthographically.

2.3.2. Temporal measurements.

Temporal acoustic measures were obtained by hand, using the Praat program [14]. They 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 first pulse and the last pulse were the limits of vowels. Fricatives boundaries were the onset and offset of the frication noise, stop durations were assigned the acoustic segments corresponding to the time of oral closure (silence for unvoiced stops, voice bar for voiced stops) and the ensuing burst (if any). Boundaries of nasals, /l/ and glides coincided with sudden jumps in amplitude. /ʁ/ is a multiform consonant: in the vicinity of an unvoiced obstruent it has a fricative spectrum, when following a vowel or a voiced consonant, it exhibits formants. In the former case, the limits were the appearance and disappearance of noise, in the latter the boundary was the rapid amplitude change in formants. In some cases, there was no perceptible and no acoustic trace of speech segments : they were considered as omitted.

2.3.3. Features for French phonemes.

French possesses twenty consonants in all : six fricatives, six occlusives, five sonorants and three glides. The three voiceless fricatives /f, s, ʃ/ are labial, dental and prepalatal, respectively. their voiced counterparts are /ʋ, z, ʒ/. Out of the six occlusives, three are the voiceless /p, t, k/ and the voiced (/b, d, g/): /p and b/ are bilabial, /t and d/ dental, /k and g/ are velar in a back vowel context, palatal before front vowels. Out of the five sonorants, there are three nasals : /m/ (labial), /n/ (dental) and /ŋ/ (prepalatal), one /ʁ/ (uvular) and one /l/ (dental). The three glides are the prepalatal /j/, the labiopalatal /ɥ/, and the labiovelar /w/. Consonant duration in French has been extensively investigated in CV and CVC sequences and paragraphs [15]. Fricatives were shown to be longer than occlusives, which in turn are longer than sonorants, voiceless fricatives and occlusives are longer than their voiced counterparts. Therefore, we examined and compared the duration of consonants as a function of manner and voicing in PD and control speech.

The vocalic system of French has 11 oral and 3 nasal vowels. Oral vowels classified as a function of tongue height are high (/i, y, u/), mid high (/e, ø, o/), mid low (/ɛ, œ, ɔ/) and low (/a/). There is also a mute [ə], whose spectral pattern is very close to that of /ø/. In addition, French has three nasal vowels (/ɛ̃, ɔ̃, ɑ̃/) which are of the same height as their oral counterparts. According to [9], 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, these variations being greater in non final syllables (non accented) than in final ones (accented). Cointrinsic variations depend both of preceding and subsequent consonants, only the latter having a significant effect. In the present study, vowel durations were analysed as a function of the four classes determined (high, mid-high, low and nasal) and compared in both groups. Consonant and vowel durations were first measured in all contexts (non-final and final, prepausal or not), then to focus on intrinsic variations, consonant and vowel durations were investigated in non-final CV syllables. Cointrinsic variations were not examined : the same vowels were rarely produced in open and closed syllables.

3. Results

3.1. Duration of consonants and vowels in all locations

Table II. Mean durations (M in ms), standard deviations (SD) and number of speech-sound categories (N). Ten PD patients and ten control speakers. Consonants (C's) are Voiced (V+) and Unvoiced (V-) Occlusives (O) and Fricatives (F), Sonorants (S) and Glides (G). Vowels (V) are Oral (Or) and Nasal(N), Orals are High (H), Mid (M) and Low (L).

			PD Speech			Control Speech		
Type			M	SD	N	M	SD	N
C	O	V-	104.1	34.8	542	112.3	37	557
		V+	77.8	31.2	376	77.7	25.8	346
	F	V-	118.1	38.7	445	127.5	35.4	456
		V+	71	27.7	233	80.8	25.4	233
	S		60.6	29.4	1143	65	27.3	1176
	G		52.5	24.8	155	55.1	24.2	189
	All		80.6	39.3	2894	85.6	39.4	2957
V	O	H	90.2	56.8	425	79.4	42.4	420
		M	83.5	48.5	1024	72.3	39.7	991
		L	89.3	36.7	800	86.3	42.5	420
	N		134.7	62.9	298	120.8	54.6	294
	All		92.5	51.1	2547	83.6	45.5	2494

Table II presents the average durations of all vowels and consonants in all locations in PDS and CS. On average, each consonant category is shorter in PDS than in CS, except for voiced occlusives which are roughly of the same duration. Fricatives are longer than occlusives in both groups, with the voiceless cognates exceeding the voiced ones. However, the differences between voiced and voiceless consonants are less accused in PDS (occlusives: 25%; fricatives: 39%) than in CS (occlusives: 31%; fricatives: 58%).

Average vowel durations in PDS exceed those of CS, the slightest difference is for low vowels (3.4%). Nasals are longer than orals in both groups: 48% and 51% in PDS and CS, respectively, this is in agreement with previous results on intrinsic durations [9]. There is less agreement for oral vowels in PDS since low and high vowels are roughly of the same duration; in CS low vowels are the longest (of about 9%), as expected. Surprisingly, mid vowels are shorter than high vowels in both groups, this may be due to the fact that vowels incorporate prepausal and final ones and the mute [ə] which may be very short [15].

A two-way ANOVA (2 groups X 6 categories) on Consonant duration yielded a significant main effect of Disease [F(1, 5839)=33.6, p=0.0001], of Consonant category [F(5, 5839)=702, p=0.0001] and a significant interaction of both factors [F(5, 5839)=3, p=0.009]. Similarly, a two-way ANOVA (2 groups X 4 categories) on Vowel duration yielded a significant main effect of Disease [F(1, 5033)=44, p=0.0001], Vowel category [F(3, 5033)=180, p=0.0001] and a significant interaction of both factors [F(3, 5033)=3, p=0.02].

Data for the individual speakers in the two groups indicate a high variability across speakers. In PDS the range of mean duration of consonants varies from 69.1 ms to 93.4 ms, for vowels from 74.2 ms to 114.4 ms. For CS mean durations have a similar range for consonants (from 74 ms to 97.8 ms) and a smaller one for vowels (from 77.5 ms to 96.8 ms). The patterns of duration for consonants and vowels are highly different across groups. Vowels are consistently longer than consonants for nine of the ten PD patients. For the control group, five speakers have slightly longer consonants, three longer vowels and two consonants and vowels of about the same duration. A two-way ANOVA performed on mean duration in PD speech revealed a significant effect of Segment type [F(1, 5425)=98, p=0.0001], Speaker [F(9, 5425)=23, p=0.0001] and a significant interaction of both factors [F(9, 5425)=9, p=0.0001)]. In CS, the two-way ANOVA performed on segment duration yielded a significant effect of Speaker [F(9, 5432)=16, p=0.0001, no effect of Type [F(1, 5432)=3, p=0.07 and a significant interaction of both factors [F(9,5432)=3, p=0.0003].

3.2. Durations of consonants and vowels in non-final CV syllables

Table III. Mean durations (M in ms), standard deviations (SD) and number of speech-sound categories (N). Ten PD patients and ten control speakers. Consonants (C's) are Voiced (V+) and Unvoiced (V-) Occlusives (O) and Fricatives (F), Sonorants (S) and Glides (G). Vowels (V) are Oral (Or) and Nasal(N), Orals are High (H), Mid (M) and Low (L).

			PD Speech			Control Speech		
Type			M	SD	N	M	SD	N
C	O	V-	98.9	27.5	208	108.4	30	218
		V+	73.7	31.1	185	72.1	21.3	173
	F	V-	115.8	38.5	293	126.7	31	295
		V+	69.6	26.9	94	79.8	22	93
	S		58.3	26.2	472	59.9	26.1	480
	All		81.6	38.3	1252	87.1	38	1259
V	Or	H	73.2	44.7	186	62.7	25.1	187
		M	68.4	29.4	677	63.1	22.3	678
		L	77.7	26	324	73.1	24	322
	Na		110.8	46.6	116	94.8	29.4	114
	All		75.2	35.1	1303	68.3	25.7	1301

Table III shows patterns of duration similar to those reported in Table II: Fricatives and voiceless occlusives are about 10% shorter in PDS, sonorants and voiced occlusives tend to be of the same duration in both groups. Voiceless fricatives exceed their voiced cognates of 40% and 37% in PDS and CS, respectively; for occlusives, the corresponding percentages are 25% and 33%. This confirms that PD patients maintain duration consonantal contrasts. Vowels are longer in PDS than in CS, the percentages reach 17% for high and nasal vowels, they are lower for mid (7.9%) and low vowels (5.5%). In both groups, nasal vowels are longer than high vowels (50% and 51% in PDD and CS, respectively). Intrinsic variations between high and low vowels in CS (17%) correspond roughly to previous results [9]. They are inferior in PDS (5%), mainly because of PD lengthening effect of high vowels. This questions the validity of duration contrasts between high and low vowels in PDS. A two-way ANOVA (2 groups X 5 categories) on Consonant duration yielded a significant main effect of Disease [F(1, 2501)=21.1, p=0.0001], of Consonant class [F(4, 2501)=486, p=0.0001] and a significant interaction of both factors [F(4, 2501)=4, p=0.001]. Similarly, a two-way ANOVA on Vowel duration yielded a significant main effect of Disease [F(1, 2596)=42, p=0.0001], of Vowel class [F(3, 2596)=112, p=0.0001] and a significant interaction of both factors [F(3, 2596)=3, p=0.02].

There is high variability across speakers within each group. Mean duration differences across PD patients are particularly great for sonorants and voiceless fricatives : their duration ranged from 50.1 ms to 80.9 ms, from 107ms to 139.2ms, respectively. In CS, variability is greater for unvoiced fricatives and occlusives (from 102.5 ms to 145.1 ms and from 70.3 ms to 106 ms, respectively). Both groups show a similar effect of manner and voicing on consonant duration: voiceless fricatives are the longest consonants, sonorants the shortest; voiceless fricatives and occlusives are longer than their voiced counterparts (PD group: at least 7% and 20%, respectively; Control group: at least 27% and 21%, respectively). A two-way ANOVA performed on consonant duration in the PD group yielded a significant effect of Patient [F(9, 1666]=5, p=0.0001] and Class [F(4, 1666)=237, p=0.0001)], and a significant interaction of both factors [F(36,1666)=1.5, p=0.02]. For the control group there is a significant effect of Speaker [F(9, 1639]=19, p=0.0001], Class [F(4, 1639)=446, p=0.0001)], and a significant interaction of both factors [F(36,1639)=2, p=0.0002].

Concerning vowels, fluctuations are particularly salient for nasal vowels whose duration ranged from 105.7 ms to 170. 6 ms in the PD group and from 106.4 ms to 167.8ms in the control group. All nasal vowels are longer than low vowels, which is in total conformity with previous results [9]. The pattern of intrinsic differences between high and low vowels is highly variable across speakers. In the PD group, only three patients had longer low vowels: (on average only 4%, 5%, and 7% longer than high vowels), the other seven patients produced high vowels longer than low vowels (from 2% to 14%). In the control group, it is the opposite tendency: seven speakers produced longer low vowels (from 4% to 15%), the three others had slightly shorter low vowels (1%, 5% and 8%). All mid-high vowels were shorter than high vowels, especially in the control group. The discrepancies observed in the two groups may reflect a high speaker variability. They may also be due to the fact that phonetic-acoustic contexts and number of syllables within phrases were not controlled. A two-way ANOVA performed on vowel duration in the PD group yielded a significant effect of Speaker [F(9, 1720]=10, p=0.0001] and Class [F(3, 1720)=94, p=0.0001)], but no significant interaction of both factors [F(27,1720)=1, p=0.4]. For CS there is also a significant effect of Speaker [F(9, 1681)=7, p=0.0001] and Class [F(3, 1681)=111, p=0.0001)], and no significant interaction of both factors [F(27,1681)=0.9, p=0.5].

3. Conclusions

The principal finding of the present study is the different impact of PD on consonant and vowel duration. Consonants are shortened in PDS, this being the result of consonant weakening, caused by small and rapid ranges of movements [2]. This can result in a loss of segment features (burst, aspiration or an entire segment) or/and increase in sonority (voicing, fricatisation and sonorisation).

In addition, the data indicate that hypokinesia does not affect consonant production in the same way and suggest an effect of the complexity and the precision needed in producing the required movements. Unvoiced occlusives and fricatives were significantly shortened, probably because of an increased difficulty in executing an additional laryngeal abduction gesture. Voiced fricatives were also shortened, contrary to voiced stops. This may be due to the fact that fricatives closures require more control and thus more effort than stops, the acoustic modeling of fricatives needing more than simply adjusting the oral constriction of a stop. Sonorants and glides were not shortened, these vocalic consonants requiring less effort.

All vowels were significantly longer in the PD group than in the control group. The magnitude of lengthening was particularly great for nasal and high vowels, suggesting a greater difficulty in producing them. Nasal vowels may take more time because they require velum lowering gesture in addition to tongue movement. Concerning high vowels, PD patients might not reach the target tongue height, thus producing a lower tongue height gesture [6]. The longer duration of high and nasal vowels may also reflect slower velocities of lip and velar movement in PD.

The different impact of PD on consonants and vowels is in agreement with the supposition that consonants and vowels have two different modes of production. Speech signal can be viewed as the superposition of consonant productions over a continuum stream of vowels [16]. In PDS, one may assume that there is superposition of short reduced consonantal gestures over a significant slow vowel continuum stream. Syllabic productions which result from the co-production of a shorter consonant and a longer vowel are thus of the same duration as in normal speech. The concomitance of orofacial bradykinesia and articulatory movements of reduced amplitude results in normal syllable duration [10, 11].

Interestingly, the general pattern of intrinsic duration of consonants was maintained: voiceless fricatives and occlusives were significantly longer than their voiced counterparts, as shown for normal French speech [15]. In PDS, voiceless consonants are often reduced: they often have a voice bar and/or are spirantised [2]. The fact that PD patients can maintain the durational contrast between voiced and voiceless consonants may partly compensate the loss of information. Concerning vowels, there is less agreement with the normal pattern of intrinsic durations. Nasal vowels were significantly longer than oral vowels, but high vowels were as long as low vowels. The longer duration of high vowels is at odds with previous results [5] who found low and high vowels reduced in the same proportion and interpreted this as a form of contrast transposition. In contrast, it is in agreement with the tendency observed for errors in the production of high vowels, considered as "nonprototypical" tokens [6]. This raises the question of the intelligibility of "nonprototypical" of segments and the boundary between normal and pathological speech segments.

4. References

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