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Final lengthening in Parkinsonian French Speech: Effects of position in phrase on the duration of CV syllables and speech segments

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Abstract
This study had two objectives. The first was to analyse the impact of Parkinson's disease (PD) on the duration of CV syllables and their components in different positions within phrases in French; the second was to examine the distribution of final lengthening (FL) on syllable sub-components. Two main tendencies emerged: (1) PD patients produced normal FL, and (2) FL influenced vowels more than consonants. These findings suggest that PD speakers had no difficulty with FL and that there is a progressive lengthening across the sub-constituents of the final syllable. More fundamentally, these results indicate that the syntactic function of prosody is intact in PD patients, at least during the early and mild stages of the disease.

Keywords: *Final lengthening, duration of syllables consonants and vowels, Parkinson's disease, read speech, French*

Introduction

Investigations of the speech produced by patients suffering from Parkinson's disease (PD), a neurological disease resulting from an impairment of basal ganglia (BG), have revealed a similar syllable duration in Parkinsonian speech (PS) and control speech (CS) in American English (Ludlow, Connor, and Bassich, 1987), German (Ackermann, Konczak, and Hertrich, 1997), and French (Duez, 2006). Examinations of syllabic rates in sentence utterances produced by patients have also shown relatively unimpaired duration patterns (Ackermann and Ziegler, 1991). More recently, a comparison of sentences and oral diadochokinesis in Parkinsonian dysarthria and apraxia of speech confirmed the absence of bradykinesia (Ziegler, 2002). The similar duration of syllables in PS and CS may seem at odds with the slowness of movement observed in studies on the orofacial movement (Caligiuri, 1987; Forrest, Weismer, and Turner, 1989). This is explained by PD patients producing normal syllabic rates and durations at the expense

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of movement amplitude (Ackermann and Ziegler, 1991; Ackermann et al., 1997; Ziegler, 2002).

Studies on durational patterns in various languages have also shown a tendency to preserve linguistic contrasts in PS as in CS. For example, German speaking PD patients were shown to maintain linguistic contrasts such as phonemic length (Ackermann, Gräber, Hertrich, and Daum, 1999) and lexical stress (Ackermann and Ziegler, 1991). Phrase-final syllables were also found to be lengthened in both French PS and CS, although this result should be further evaluated since non-phrase final syllables and phrase-final syllables were not of similar syllabic structures (Duez, 2006).

There are different explanations to the causes of final lengthening (FL) in speech. On one hand it is considered a motor phenomenon (Weismer and Ingresano, 1979) which influences human activities such as speech and music (Lindblom, 1978). On the other hand, it is also viewed as a speaker's manipulation of temporal patterns to mark the boundaries of linguistic units (Klatt, 1975; Scott, 1982). It seems likely that FL is a motor aptitude whose linguistic use constitutes an acquired behaviour: for example, in European languages such as English (Smith, 1977) and French (Konopczynski, 1990), FL was shown to be learned during the early ages of childhood. FL offers speakers an extra fraction of timing, during which the following phrases can be planned (Cooper and Paccia-Cooper, 1980) and signals syntactic boundaries to the listener (Klatt, 1976; Streeter, 1978; Scott, 1982).

Duration interacts with other phonetic cues such as pause, fundamental frequency (F_0), intensity, and voice quality, to signal a syntactic boundary. Out of these cues, F_0 fluctuations and the different degrees of lengthening are essential in the structuration of the message, different degrees of lengthening being the most important (Lehiste, 1973). The different degrees of lengthening of final syllables of words give rise to different prosodic units (prosodic words, accent groups, or prosodic phrases, intonational groups or phrases, sentences) which may correspond to syntactic units (words, minor phrases, major phrases, and sentences), this depending on speech rate, length of constituents, and speech style (Fónagy, 1979). In read speech the congruence of prosodic units and syntactic units is particularly strong compared to spontaneous speech, where the pragmatic function is predominant. This results from readers having access to the structure of the whole sentence and being able to evaluate the length of its parts and semantic relations, as well as organize its production (Vaissière and Michaud, 2005).

Since the pattern of duration of syllables conveys information about the constituent structure of an utterance, temporal distortions may impair linguistic information. Thus, examining the impact of PD on the duration of syllables and their speech segments in different positions in different languages should help confirm if basal ganglia dysfunction impairs FL processing while revealing language-specific effects. For this reason, PD effects on the duration of CV syllables, consonants, and vowels were investigated in read French PS. Analysing FL in French is of particular interest because French is a non-lexical stressed language (Fónagy, 1979; Vaissière, 1991) whose rhythmic pattern is mainly based on the lengthening of final-phrase syllables.

The current study had two main objectives. The first was to examine the impact of PD on the duration of CV syllables in French and ascertain whether FL is produced normally or is distorted. The second was to determine how FL affects syllable components (consonants and vowels) and determine whether the distribution of FL is similar in PS and CS. Such analysis of FL in PS can also tell us whether the syntactic function of prosody, predominant in read speech, is intact.

Method

Participants

There were 24 French native speakers composed of 12 individuals (nine males and three females) diagnosed with Parkinson's disease (age, M = 62.16; SD = 13) and 12 age- and gender-matched control speakers (age, M = 58.8; SD = 12.1). The PD participants were between 7–19 years post-PD diagnosis (M = 8.3; SD = 5.34), recruited by the Department of Neurology at the Hospital of Aix en Provence. 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 were experiencing motor fluctuations in response to their treatment. They had adequate vision with corrective lenses and claimed not to suffer from hearing loss.

L-dopa affects the speech of PD patients with high variability (Pinto et al., 2004). However, perceptual studies have reported a systematic improvement of intelligibility (Nakano, Zubick, and Tyler, 1973; De Letter, Santens, and Van Borsel, 2005). The temporal organization of speech, especially read speech, has been shown to improve (Rigrodsky and Morrison, 1970). Therefore, in order to make the effects of PD more discernable, anti-Parkinsonian medications including L-dopa were withheld overnight and the first recordings started after at least 10 hours without medication. Before recording, the motor disability of each patient (M = 43.12; SD = 10.3) was assessed using the Unified Parkinson's Disease Rating Scale (UPDRS), especially dysarthria severity (M = 1.9; SD = 0.9) as defined by item 18 (Fahn, Elteon, and members of the UPRDS Dev. Committee, 1987). The characteristics of each speaker are listed in Table I.

Speech sample and recording equipment

The read speech sample was a paragraph of *La chèure de Monsieur Seguin* ('Mr Seguin's goat', a tale written by Daudet in 1869). Read speech was chosen for the following reasons:

Table I. Speaker, patient, and group characteristics. The motor disability of each patient was assessed by means of 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 were pooled across subjects.

Patients	Age	Sex	Years of post-PD diagnosis	UPDRS in Off state	Dysarthria severity	Control speakers	Age	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	62.16		13	43.1	1.9		58.8	
SD	8.3		5.34	10.3	.9		12.1	

(1) The relationship between syntactic structure of sentences and temporal organization in read French speech is well documented (Grosjean et al., 1979; Di Cristo, 1984); and
(2) the similarity between syntactic constituents and prosodic constituents facilitates understanding of the impact of PD on the syntactic function of prosody (Vaissière and Michaud, 2005).

Each subject was asked to read at his habitual 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 AKG C410 head mounted microphone and recorded directly onto a PC hard disk at a sampling rate of 20 KHz.

Temporal measurements

Temporal acoustic measures were obtained by hand, using the Praat programme (Boersma and Weenik, 2000). 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 recording was segmented into pauses and sounded sequences; each sounded sequence was then segmented into syllables. Syllables were then segmented into consonants and vowels. The limits between consonants and vowels were carefully marked using a set of consistent rules which utilize spectral changes and formant transitions.

Sonorants. Formant discontinuity is a reliable marker between vowels and consonants such as nasals and liquids, therefore the limits of these consonants were placed at the point of maximum spectral changes. The sonorant /R/ is a multiform context-dependent consonant. In the vicinity of an unvoiced obstruent, it has a voiceless fricative 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.

Glides. The change in formant darkness was used as a boundary cue between glides and vowels.

Fricatives. Voiceless fricatives were recognized by the onset and the offset of noise while voiced fricatives were identified by a visible discontinuity in the F1 region (they exhibit high energy concentrations at low frequencies).

Occlusives. Their limits coincide with preceding vowel offset (which coincides with the beginning of the voice bar or the silence) and following vowel onset.

The duration of each consonant and vowel was measured twice for PS and CS by the first author. Both groups showed a similar error magnitude (consonant error measurements in CS: 1.4 ms and in PS: 1.6 ms, while errors of vowel duration were <3 ms). An illustration of segmentation can be seen in Figure 1.

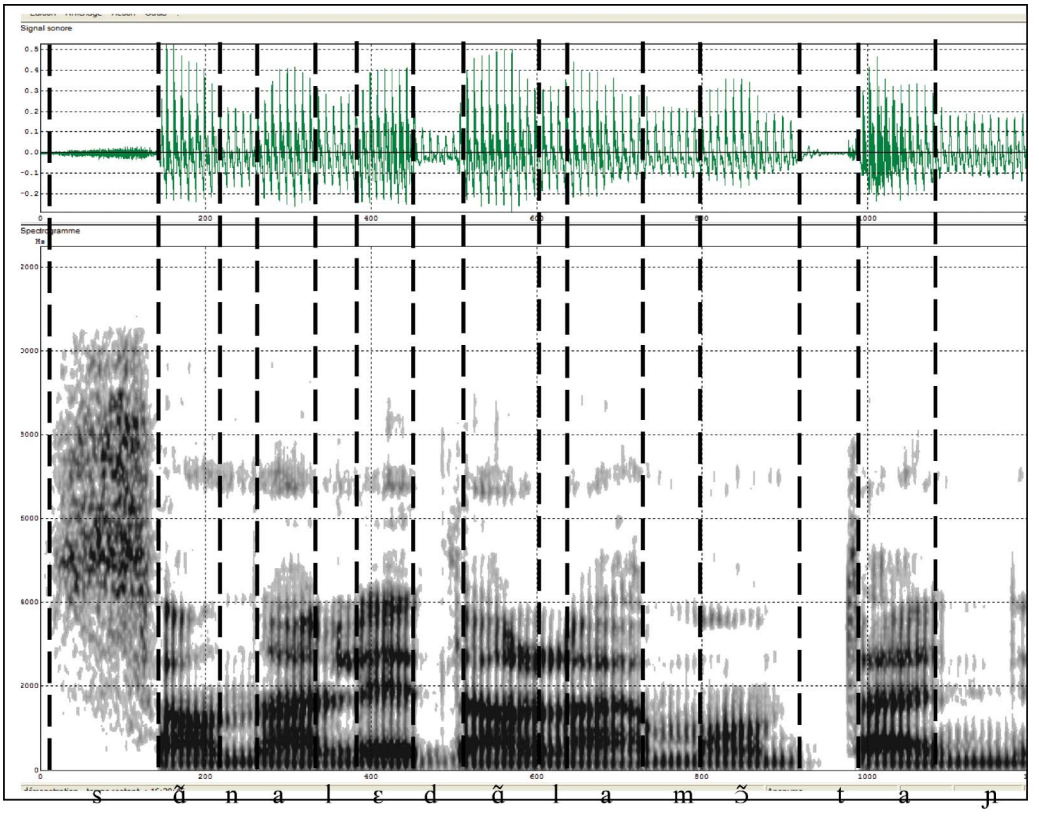

Figure 1. Spectrogram and oscillogram of the sentence 's'en allait dans la montagne: went to the mountain' produced by a patient. This utterance contains six CV syllables, only the last syllable is of the CVC type.

Syllables, vowels, and consonants

A syllable is a linguistic unit which contains an onset (optional or not) and a rhyme consisting of a nucleus (obligatory) and a coda (optional). The number of components strongly influence the duration of syllables and their components (Farnetani and Kori, 1986; Duez, 1987; Rietveld and Frauenfelder, 1987). To neutralize this effect, the present study was limited to CV syllables which are predominant in French (Delattre, 1966). In French there is also a tendency to isosyllabicity of successive non-final syllables (Duez and Nishinuma, 1986) where differences in duration are inferior to the durational perception threshold of 20% found by Rossi (1972). The analysis was limited to intended CV syllables where C's and V's were effectively produced, thus excluding intended CV's with an omitted speech segment (mostly a C); complex syllables (e.g. /CVC, CVCC, CCV/) produced as [CV] were also excluded from the analysis. In total, 3875 CV syllables were analysed (1969 in PS and 1926 in CS).

Consonants and vowels have an intrinsic duration. For example, studies on consonant duration in French sentences and paragraphs reported voiceless fricatives and occlusives

longer than their voiced counterparts, fricatives longer than occlusives, and occlusives longer than sonorants and glides. Concerning vowels in French, Di Cristo (1984) 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. However, due to the small number of samples taken by category, all consonants and vowels were pooled, thereby imposing a limitation to the scope of the present study.

Position

In French, there is no lexical stress and only the last syllable of the last word of a group of words is lengthened (Delattre, 1966). In most cases this unit (the sense group or prosodic phrase) corresponds to a minor syntactic phrase ending with a lengthened final syllable and a small rise. At the higher-level unit, the intonational phrase corresponds to a major syntactic phrase which ends with a sharp F_0 rise, a lengthened syllable, and (not always) a pause. The realization of FL is highly probabilistic and sense groups may lose their acoustic characteristics, especially in the case of fast or casual speech. However, all syllables located at the edge of minor and major phrases (as defined by Blanche-Benveniste, Bilger, Rouget, and van den Eynde, 1990) were considered as phrase-final syllables, either pre-pausal or non-pre-pausal. Syllables located within phrases were considered as non-final.

To focus on phrase-FL, syllables containing the so-called mute [ə] produced before a pause and non-phrase-final syllables before within-phrase or within-word pauses were excluded from the analysis (the number of syllables as a function of position in both PS and CS can be seen in Table II). Consonants and vowels were classified as phrase-final and non-phrase final following the same criteria. The durations obtained for phrase-final syllables, consonants, and vowels were compared with the durations of non-phrase final syllables, consonants, and vowels in both PS and CS. The distribution of the lengthening effect was further investigated by calculating the percentage of lengthening that is accounted for by the consonants and vowels of syllables, these percentages were compared in both PS and CS.

Statistical analysis

Repeated-measure ANOVAs were conducted with duration as the dependent variable and between-subjects factor as the group (PD or control); the following variables were selected as within-subject factors: syllables, segment type (C or V), syllable, and segment locations (non-phrase final, phrase final with and without a silent pause). There were 12 entries per group, individual entries being the mean duration for each speaker, each syllable, and each speech segment location.

Table II. Number of syllables as a function of position within phrases in Parkinsonian speech (PS) and Control speech (CS). The distribution is as follows: non-phrase final (NF), phrase final without a pause (F), phrase final with a pause (F+).

	NF	F	F+	All
PS	1523	235	202	1960
CS	1493	231	202	1926
All	3016	466	404	3886

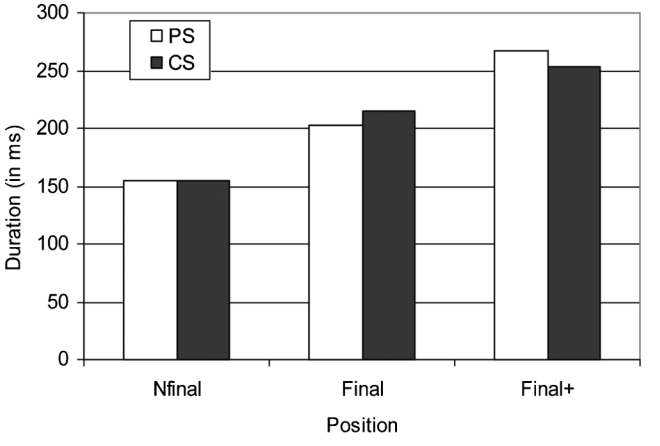

Figure 2. Duration of syllables (in ms) as a function of position within a phrase in Parkinson speech (PS) and control speech (CS). Syllables are non-final (NF), final without a pause (F), and final followed by a pause (F+).

Results

Syllable duration as a function of position within phrases

Figure 2 shows a similar pattern of FL in both PS and CS with the mean duration of pre-pausal final syllables greater than the mean duration of non-pre-pausal final syllables, the latter being longer than the mean duration of non-final syllables. However, the FL range for pre-pausal syllables was slightly greater in PS speech (73.1%) than in CS (64.25%) although, for non-pre-pausal final syllables, the tendency was inversed with percentages of 30.7% and 39.25% in PS and in CS, respectively.

A two-way repeated measures analysis of variance conducted on syllable duration showed significant effects for syllable position [$F(2,44) = 206$, $p<.0001$] but no significant effects for speaker group [$F(2,44) = .002$, $p=.1$). There was significant interaction between the two factors [$F(2,44) = 3.12$, $p = .0.5$].

As seen in Figure 3(*a*), all patients exhibited a normal FL pattern with non-final syllables shorter than final ones. There was also a clear tendency for non-pre-pausal-final syllables to be shorter than pre-pausal-final ones, only P10 having pre-pausal-final syllables shorter than non-pre-pausal ones. However, there was considerable variability in the degree of lengthening among the 12 patients: the range was 33–108% for pre-pausal-final syllables and 8% (P1) to 45% (P6) for non-pre-pausal final syllables. As seen in Figure 3(*b*), each control speaker lengthened final syllables. However, control speakers lengthened non-pre-pausal final syllables more than PD patients (from 21% for C1 to 50% for C6 and C9).

Consonant duration as a function of syllable position within phrases

Figure 4 shows that all consonants had similar patterns of lengthening in both PS and CS, although consonants in non-prepausal syllables lengthened less in PS (6%) than in CS (14%). A two-way repeated measures analysis of variance conducted on consonant duration demonstrated significant effects for consonant position ($F(2,44) = 46.198$, $p=.01$)

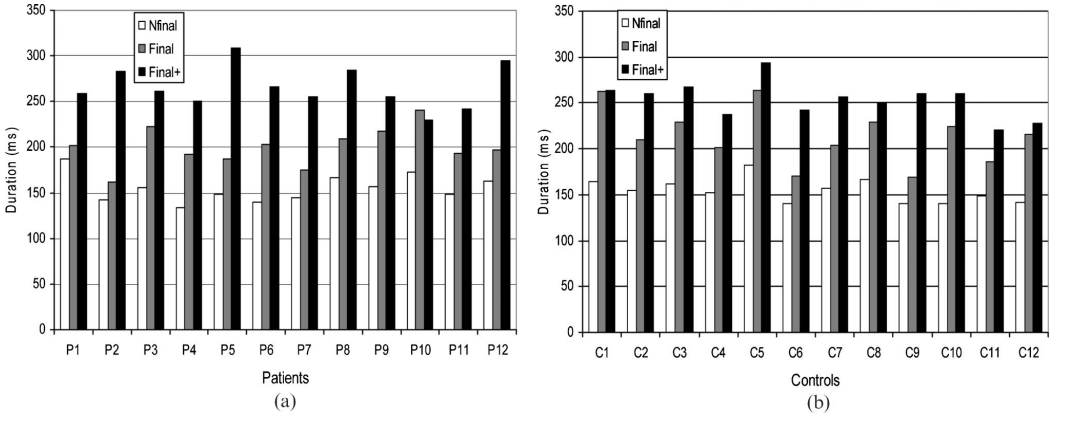

Figure 3. (*a*) and (*b*) Duration of syllables (in ms) as a function of position by patient (P) and control speaker (C). Syllables are non-final (NF), final without a pause (F), and final followed by a pause (F+).

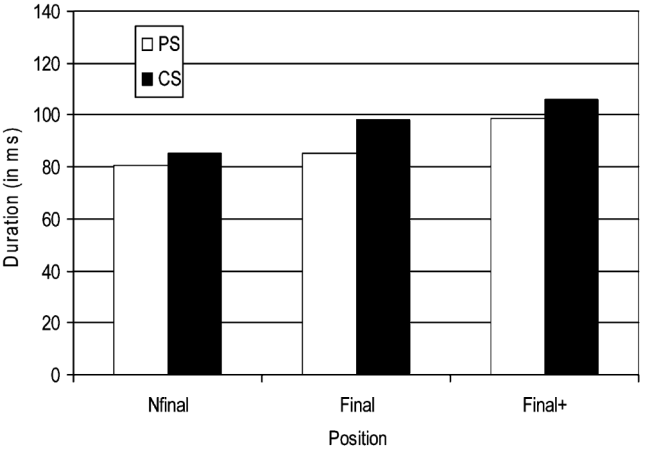

Figure 4. Duration of consonants (in ms) as a function of position within phrases in Parkinson speech (PS) and control speech (CS). Consonants are non-final (NF), final without a pause (F), and final followed by a pause (F+).

and speaker group [F(l,22) = 6.53, p = .05] but no significant interaction between the factors. Planned comparisons revealed a significant effect of group for the non-pre-pausal final position [F(1,22) = 6.77, p = .016]; there was no effect of group for the two other positions.

Figure 5(*a*) shows that, for all patients, consonants belonging to pre-pausal-final syllables (from 0.03% for P1 to 0.59% for P12) were longer than consonants located in non-final syllables. There was less concordance in the lengthening pattern for consonants belonging to non-pre-pausal final syllables: some were shorter than consonants belonging to non-final syllables (P1 = − 16%, P5 = − 17% and P7 = − 0.11%), some were of the same duration (P2, P3), and, finally, the remaining consonants belonging to non-pre-pausal final syllables were lengthened (at least slightly). These patterns could not be related to a

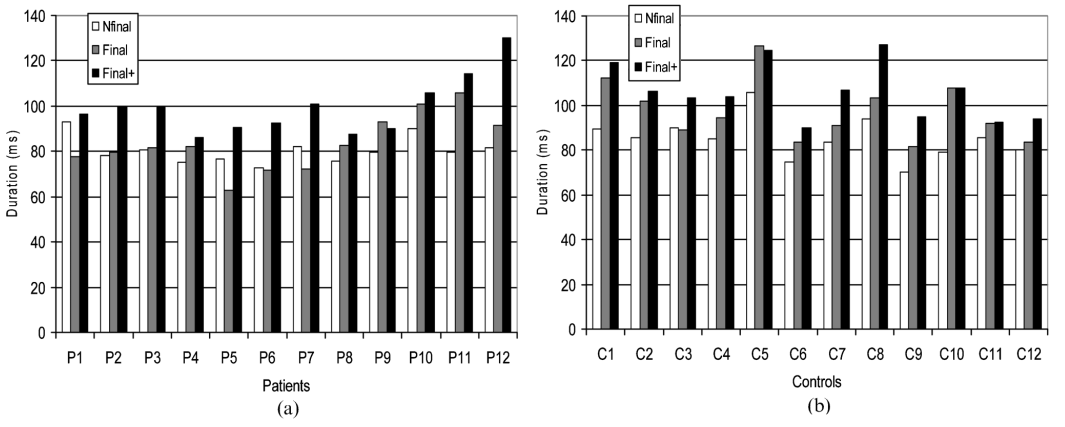

Figure 5. (*a*) and (*b*) Duration of consonants (in ms) as a function of position by patient (P) and control speaker (C). Consonants are non-final (NF), final without a pause (F), and final followed by a pause (F+).

specific degree of dysarthria: P1, P5, and P7 had level 2, 3, and 1, respectively; P2 had level 1 and P3 level 3. The results reported in Figure 5(*b*) for the control group exhibit slightly less variability in the degree of lengthening for non-pre-pausal final consonants (from 0% for C3 to 0.36% for C10) and pre-pausal final consonants (from 0.08% for C11 to 0.36% for C10).

Vowel duration as a function of syllable position within phrases

As seen in Figure 6, FL strongly affects the nucleus both in PS and CS. The mean duration of non-final vowels (M = 74.5 ms; SD = 34.24) was 57.5% less than the mean duration of non-pre-pausal-final vowels (M = 117.34; SD = 58.61) and 125.2% less than pre-pausal-final vowels in PS (M = 167.83; SD = 59.28). FL effects were comparable in

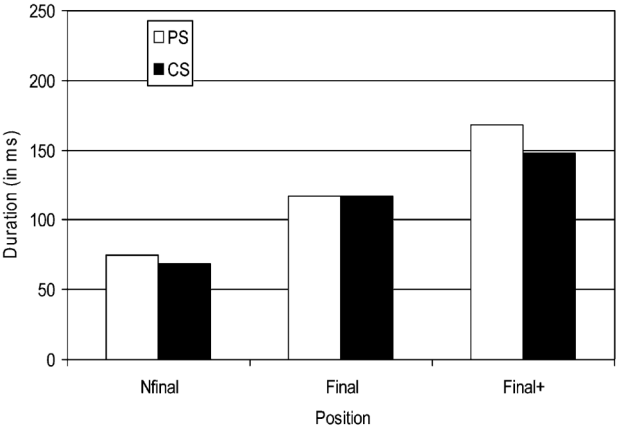

Figure 6. Duration of vowels (in ms) as a function of position within phrases in Parkinson speech (PS) and control speech (CS). Vowels are non-final (NF), final without a pause (F), and final followed by a pause (F+).

CS with a mean duration of non-final vowels (M = 78.9ms; SD = 25.46) 69.8% shorter than the mean duration of non-pre-pausal final vowels (M = 117.15; SD = 60.06) and 114.2% shorter than pre-pausal-final vowels (M = 147.8; SD = 51.73). A two-way repeated measures analysis of variance conducted on vowel duration yielded significant effects for position within phrases [$F(2,44) = 166$, $p < .0001$], but no significant effects for speaker group [$F(1,22) = 3.26$, $p = .08$) nor significant interaction between the factors [$F(2,44) = .32$, $p = .13$]. Planned comparisons revealed a significant effect of group for the pre-pausal-final position [$F(1,22) = 4.71$, $p = .04$], but no effect of group for the two remaining positions.

As seen in Figure 7(*a*), there was a high variability amongst patients in the magnitude of lengthening: for non-pre-pausal final vowels, the range of lengthening percentages extends from 27.1% (P11) to 87.19% (P3); for pre-pausal-final vowels, it was somewhat greater: from 49.7% (P10) to 203.45% (P5). As can be seen in Figure 7(*b*), a broad range of lengthening was evident in the control group for non-pre-pausal-final vowels (from 25.59%: C9 to 116.31%: C12) and pre-pausal-final vowels (from 67.75: C8 to 148.01: C10).

Discussion and implications

The principal finding of the present study is the normal production of FL by PD speakers, all of whom exhibited significant lengthening of final syllables, whether or not followed by a pause. Pre-pausal-final syllables were also longer than non-pre-pausal final syllables, in conformity with the literature for normal speech (Klatt, 1975).

The results obtained for consonants and vowels in different positions within phrases also reveal lengthening in both groups. The degree of lengthening was slightly less for consonants in PS than in CS, whereas it was the opposite for vowels. This may be the consequence of the different impact of PD on the duration of consonants and vowels, where the former tend to be reduced and the latter lengthened (Duez, 2009). There was an effect of group for consonants in the non-pre-pausal-final position. This may be due to most control speakers lengthening consonants (at least slightly) whereas some patients exhibited non-pre-pausal-final consonants shorter than non-final consonants. The

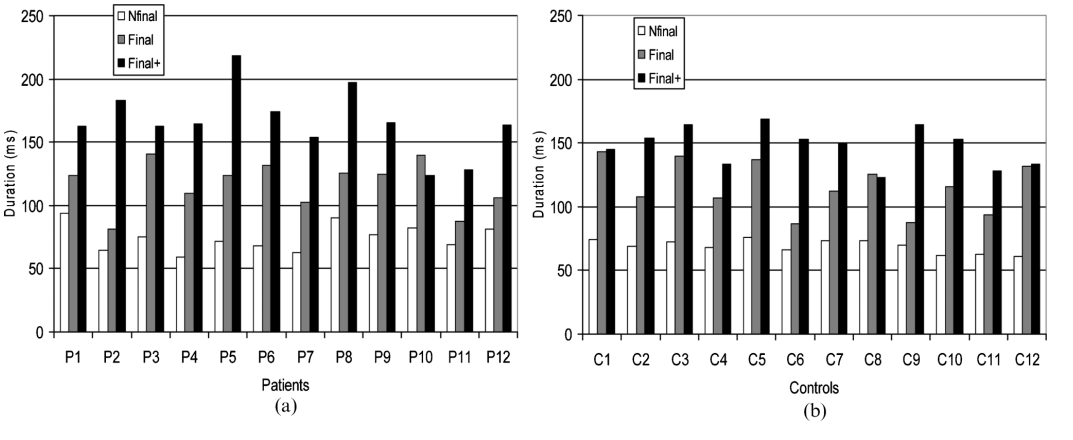

Figure 7. (*a*) and (*b*). Duration of vowels (in ms) as a function of position by patient (P) and control speaker (C). Vowels are non-final (NF), final without a pause (F), and final followed by a pause (F+).

impairment of consonant-lengthening contrasts could not be correlated to the severity of the disease. Further analysis of a corpus of consonants from the same categories in different positions within phrases should permit a clarification of the relationship between consonant lengthening and the severity of PD. Concerning vowels, there was an effect of group for vowels in the pre-pausal position: patients produced vowels significantly longer than controls. This suggests a greater slowing down of articulators for PD patients before a pause.

There was considerable variation in the extent to which individual control speakers and patients produced lengthening patterns of syllables, consonants, and vowels. Although most patients and controls exhibited patterns typical of French speech, there were several exceptions. In addition, among those who did show lengthening patterns, the variations were significant. Such variability in lengthening patterns may be the consequence of articulation rate variability which is known to be speaker-dependent and highly variable within a same speaker production (Miller, Grosjean, and Lomanto, 1984), and have a strong impact on the duration of syllables and vowels (Miller, 1981). The relationship between articulation rate and the duration of syllables, vowels, and consonants was not investigated. However, a re-analysis of the results as a function of articulation rate is envisaged; this should provide a better understanding of how articulation rate interacts with FL in both PS and CS.

Final-syllable vowels were proportionally lengthened more than final-syllable consonants in both PS and CS, suggesting a progressive lengthening in final syllables. Studies on FL revealed that, within final closed syllables, the lengthening effect increases across the rhyme, i.e. the vowel and final consonant. The increasing lengthening pattern has been observed for syllables with final fricatives (Oller, 1973; Berkovits, 1993) and final stops in both normal speech (Berkovits, 1991) and ataxic speech (Bell-Berti, Gelfer, Boyle, and Chevrier-Muller, 1991). Since, in the present study, syllables were of the CV type, the assumption of a progressive FL in syllables needs to be confirmed in closed syllables. Such an analysis would indicate how FL is implemented in PS and CS. In PS, patients tend to shorten consonants (Duez, 2009) and to omit final consonants (Duez, 2006), thus how they cope with FL in closed syllables is of great interest.

Despite the discrepancies reported for consonants, PD patients exhibited the lengthening pattern typical of French speech. Interestingly, this finding suggests that patients had no difficulty with FL production. In their study of the articulatory kinematics of FL, Edwards, Beckman, and Fletcher (1990) observed that FL is a local tempo, unaccompanied by any significant difference in articulator displacement, which does not require stronger movements or increased effort and amplitude of articulators. They also reported considerable variation across different conditions and speakers and concluded there may be different strategies for lengthening the overall duration of final syllables. These findings may explain why PD patients achieved a normal pattern of FL and why there was a high variability in the lengthening patterns of both patients and controls.

In normal speech, lengthened syllables are often superimposed with F_0 variations while PS is characterised by a flattened F_0 (Darley, Aronson, and Brown, 1969; Laures and Weismer, 1999). This raises the question of how do patients mark prosodic boundaries; do they rely exclusively on final-syllable lengthening or are they able to produce F_0 variations in the correct place? However, the strong correlation of FL with the syntactic structure of sentences in PS and CS is in agreement with the results reported in the literature for normal English speech (Klatt, 1975; Cooper and Paccia-Cooper, 1980), German (Kohler, 1983), and French (Delattre, 1966; Vaissière, 1991). This suggests that the syntactic function of prosody is largely preserved in PD patients, at least during the early and mild stages of the disease,

although one must acknowledge that the visual cue during a reading task may help PD patients to retain FL. The linguistic representation of prosody is thus maintained, at least qualitatively, even though the spatio-temporal architecture can be slightly changed due to the basal ganglia dysfunction.

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