Domain initial strengthening and height contrast in French: acoustic and ultrasound data

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Abstract

This paper investigates how prosodic boundary strength (IPi vs. IPm) affects the production of the vowels /i, e, ɛ, a/, which contrast on a four degrees of height scale in French. Acoustic and tongue configuration data are examined for four speakers. Results show an expansion of the vowel space in IP-initial position that is achieved by a rising of F2 for /i, e, ɛ/ and of F1 for /ɛ, a/. Differences in tongue configuration also contribute to an expansion of the articulatory space in IP-initial position are also observed. Measurements on the highest point of the tongue show a narrowing of the constriction for /i, e, ɛ/, accompanied by fronting for /e, ɛ/, and a widening and backing of the constriction for /a/ for most speakers. These variations in IP-initial position lead to a maximization of phonetic contrasts in terms of height and frontness within the pairs /e-ɛ/ and /ɛ-a/ for most speakers, but not within the pair /i, e/, probably due to articulatory/acoustic constraints.

Keywords: vowels, prosodic boundary, French, height contrast

1. Introduction

Several studies have reported an effect of prosodic position on vowels, with a modification of their acoustic or articulatory properties when accented or close to a prosodic boundary (see the review by Cho 2011; and recently Kim & Cho 2011, 2012; Georgeton & Fougeron, 2014). Except for the last reference, most studies have been limited to the investigation of only a few types of vowels, usually peripheral vowels. Consequently, it is not clear whether all vowel types are modified in the same way, nor whether prosodically driven segmental variations may be modulated by the density of the phonological inventory.

In order to address these questions, the purpose of this study is to investigate prosodic effect on vowels in a dense dimension of contrasts, namely the four levels of height on which the four front vowels /i, e, ɛ, a/ are contrastive in French. Variations in the lingual and acoustic properties of these vowels are tested according to the strength of the prosodic boundary, i.e. according to whether they are initial or medial in an Intonational Phrase (IPi or IPm).

Few studies have investigated variations in the lingual articulation of vowels in absolute domain-initial positions (#VC sequences) and their results show that vowels are influenced by prosodic strengthening (as consonants do) with a global increase in gestural magnitude in higher prosodic constituents, which interacts with vowel in different directions. In a study investigating lingual variation of the two vowels /ɛ/ and /ɔ/ in English, Lehnert-Lehouillier and colleagues reported a greater articulatory magnitude in IP initial position, without more description on the direction of the changes in lingual configuration (Lehnert-Lehouillier, McDonough McAleavey, 2010). Kim and Cho (2011, 2012) observed that for all the three front English vowels /i, ɪ, æ/, boundary induced variation resulted in a featural enhancement of [+/-high] properties in such a way that, in IP-initial position, the high front vowels /i, ɪ/ were higher while the low front /æ/ was lower. For the vowel /æ/, this variation in height was accompanied by more anterior tongue position.

In French, prosodically driven lingual variations on vowels have been mostly investigated under focal accentuation or in domain-final position. Loevenbruck (1999, 2000) observed a similar expansion in height contrast between /i/ and /a/ under focal accentuation, with a higher tongue body for /i/ and a lower tongue body for /a/. Tabain & Perrier investigated domain final /i/ (2005), /a/ (2003) and /u/ (2007) in different prosodic constituents. A lower tongue body before stronger prosodic boundaries was also found for the low vowel /a/, but for /i/ the effect was lesser and speaker-dependent: one of their three speakers showed a backing of the tongue but the other two tended to raise and front their tongue body. For the vowel /u/, they observed tongue dorsum backing coupled with raising or lowering depending on the speaker. The authors concluded that these different strategies concurred to a common acoustic goal: the raising of F3 for vowel /i/, and the lowering of F2 for vowel /u/ in order to prevent a perceptual confusion with /y/. These results suggest that articulatory variations induced by prosodic boundaries may depend on the language's phoneme inventory and the preservation of vowel contrasts (see also Cho & Jun 2000 for consonantal contrasts). In a recent study (Georgeton & Fougeron, 2014), we also observed contrast-dependent variation in domain-initial position, by looking at the labial articulation and acoustic properties of the 10 oral vowels of the French system. While all vowels showed an increase in lip area in IP-initial position, this effect was found to be larger for the unrounded vowels. Consequently, the contrast between front rounded and unrounded vowels was found to be maximized in IP-initial position.

In the present paper, we address further this question by investigating changes in tongue configuration and acoustic property for the four front (unrounded) French vowels /i, e, ɛ, a/. Within these four levels of height, density-dependent limitations on phonetic variation may be at play (as suggested by Manuel, 1990 for example). According to the literature cited above, an enlargement of the oral constriction can be expected for the lower vowel /a/, while predictions are not clear for the vowel /i/, and absent for the non-peripheral vowels, the mid-closed /e/ and mid-open /ɛ/. We will therefore examine how prosodic effect modifies the articulation of these domain-initial vowels and whether it interacts with vowel contrasts in this dense system.

2. Material and method

The lingual configuration and acoustic properties of the four front oral vowels /i, e, ɛ, a/ have been investigated in two prosodic conditions: in an Intonational phrase-initial (IPi) vs. a IP-medial (IPm) position. For the IPm position, vowels were initial in the second word of a fake compound first name. The four vowels were produced in controlled sentences in a [ip#VC] context. C is /p/ for /i, e, a/ and /v/ for mid-open /ɛ/, in order to prevent its pronunciation as mid-closed (see Georgeton & Fougeron 2014 for the description of a similar corpus). Four female speakers were recorded with a Midray DP600 ultrasound (60 i/sec) with head stabilization (Articulate Instruments Ltd, 2008).

Each sentence was produced 10 times in a random order but repetitions with un-exploitable tongue contours have been discarded from the analysis. Table 1 summarizes the number of renditions analyzed per vowels and prosodic positions (IPi, IPm) for the 4 speakers (SA, SC, SL, SZ).

Table 1: *Number of renditions analyzed by speaker, prosodic position and vowels.*

	SC		SL		SZ		SA	
	IPi	IPm	IPi	IPm	IPi	IPm	IPi	IPm
/i/	10	10	10	10	11	9	5	5
/e/	10	10	10	10	8	9	6	6
/ɛ/	10	10	10	10	9	9	6	6
/a/	10	10	8	8	11	9	5	6

Target vowels were segmented and labeled in Praat in order to extract acoustic duration and formant values. F1 and F2 were taken at three successive points in the middle of target vowels and then averaged. For lingual configuration, one to three (depending on vowel duration) successive tongue contours were traced manually in the middle of the vowel with Articulate Assistant Advanced (Articulate Instruments Ltd, 2012) and then averaged for each vowel/position condition. An estimation of vowel height and place of articulation was done by quantifying the height (y-axis) and front-back location (x-axis) of the highest point of the tongue, which was automatically extracted from individual contours.

In order to test whether F1, F2, duration and coordinates of the highest point of the tongue vary according to prosodic position, analyses by speaker are done with sample t-tests for each vowel. In order to test the interaction of boundary effects with height contrast between each pair /i-e/, /e-ɛ/ and /ɛ-a/ two-factor ANOVAs (position, vowel) were conducted for each speaker. (Note that due to space limitations, statistical details are not given here and only significant differences are reported; for speaker SA, given his small number of renditions, only tendencies are reported).

3. Results

3.1. Boundary effect (IPi vs IPm) on the lingual and acoustic properties per vowel types

Differences in tongue contours and in spectral properties according to prosodic positions are illustrated in Figure 1. For all speakers, an effect of prosodic position is observed, with speaker- and vowel-dependent patterns. Looking at F1 and F2 of vowels in IP-initial position compared to IP-medial position, the following variations are observed:

- /i/ has a higher F2 for all speakers except SZ, and no variation is found on F1;
- /e/ has a higher F2 for all speakers and a higher F1 for one speaker (SL)
- /ɛ/ has a higher F2 and a higher F1 for all speakers;
- /a/ has a higher F1 for all speakers. An effect on F2 is found for speakers SL and SZ but in an opposite direction: higher F2 for SZ and lower F2 for SL.

These spectral variations are not accompanied by systematic differences in acoustic vowel duration. Speakers SL, SC and SA have longer /i/ in IPi, but for the other vowels, few differences in vowel duration appear, and these differences are speaker- and vowel-dependent. A lengthening in IPi is found for /e/ for SC, a shortening is found for /ɛ/ for SL, for /a/ for SL and SZ, and for the nine other comparisons there is no change in vowel duration.

Considering articulatory variations, the differences in tongue contours between the two positions presented in Figure 1 appear to be larger for speakers SL, SZ and SA than for speaker SC, and are clearly vowel dependent.

As explained in the method section, a quantification of the differences in lingual configuration is made to estimate the degree and location of the constriction at the highest point of the tongue. In IP-initial position, the following variations are observed:

- /i/ has a narrower constriction with a rising of the highest point of the tongue for all speakers except SZ, who rather shows a baking of the constriction.
- /e/ has a narrower constriction for all speakers and a fronter constriction for speaker SL and SA;
- /ɛ/ has a narrower constriction for all speakers and a fronter constriction for all except SC.
- /a/, on the other hand, has a wider constriction for all speakers, and a backer constriction for all except SC.

Overall, from a systemic perspective, the variations observed in IP-initial compared to IP-medial position contribute to an expansion of the acoustic and articulatory spaces. This expansion is achieved by an enlargement of the spaces both in the vertical dimension (constriction height, F1) and horizontal dimension (constriction location, F2).

3.2. Boundary effects on the contrast between vowels pairs

The effect of prosodic position is further tested here on the acoustic and articulatory contrast between adjacent vowels along the vowel height dimension of contrast. For this, we test whether the effect of boundary depends on the vowel identity within the three vowel pairs (/i-e/, /e-ɛ/, /ɛ-a/), and therefore whether the contrast between the members of the pairs is affected by prosodic position.

For the /i-e/ pair, a significant interaction is found on constriction height for all speakers: both /i/ and /e/ have a narrower constriction in IPi, but the amplitude of the tongue rising for /e/ is larger than that for /i/. Consequently, /e/ gets closer to /i/ and the contrast in height dimension between these two vowels is not maximized in IP-initial position. An interaction is also found on dimensions linked to place of articulation: front-back position of the constriction for SL and SC, and F2 for SZ and SA. For all speakers except SC, both vowel are modified in the same way (higher F2 for SZ and SA and fronter constriction for SL) but with a larger change for /e/. Consequently /e/ gets closer to /i/. Speaker SC is the only one showing a larger contrast in constriction location between /i/ and /e/ in IPi, with a fronting of the constriction for /i/ and a backing for /e/.

For the pair /e-ɛ/, an interaction is found on the dimensions linked to vowel height: F1 for all speakers except SL, and constriction height for SL. This interaction reflects a maximization of the distinction between the mid-closed and mid-open vowels in IPi for all speakers, with a greater narrowing of the constriction for /e/ than /ɛ/ (SL), and a large rising of F1 for /ɛ/ (SC, SZ, SA). Interactions are also found on the dimensions linked to place of articulation for all speakers except SC: on F2 for SL and SA, on the front-back position of the constriction for SL and SZ. Again the contrast between the two vowels is maximized in IPi for SL and SA with a larger F2 rise for /e/ than /ɛ/ (SL and SA) and more fronting of the constriction (SL). For SZ however, the two vowels get closer in IPi with a slight backing of the constriction for /e/ and a slight fronting for /ɛ/.

For the pair /ɛ-a/, interactions are found on constriction height for all speakers, on F1 for all speakers except SA, on constriction location for all except SC and on F2 for all except SZ. The two vowels are more distinct in IPi position with a wider constriction and higher F1 for /a/ than /ɛ/ for all speakers except SA, and with a backer constriction for SL, SA, SZ, and a lower F2 for SL, SC, SZ.

4. Discussion and conclusion

In this study, we investigated the effect of prosodic position on the lingual and acoustic properties of the front unrounded oral French vowels /i, e, ɛ, a/ in IP-initial vs. IP-medial positions. As found in the other studies presented in the introduction, we show that prosodic position influences the articulation and acoustic properties of the vowels. In IP-initial position an expansion of the articulatory and acoustic spaces is observed in height and front-back dimensions of the lingual constriction (estimated from the highest point of the tongue) as well as in F1 and F2 dimensions.

The observation of more than two degrees of vowel height provides interesting results on the direction of this boundary effect. Different sets of vowels can be distinguished. On the dimension related to tongue height (vertical position of the highest point of the tongue), the non-low vowels /i, e, ɛ/ pattern together with a narrower constriction degree in IP-initial position for most of the speakers (three for /i/, four for /e, ɛ/). On the other hand, the low vowel /a/ shows a widening of the oral constriction for all speakers, as observed in other studies. Regarding the location of the constriction in the front-back dimension, a fronting of the constriction is observed in IPi for /e, ɛ/ (two speakers for /e/, and three for /ɛ/), while /a/ has a backer constriction (three speakers). These measurements made on the highest point of the tongue appear to be well suited to quantify some of the differences in tongue contours illustrated in Figure 1. However, they do not capture the overall modifications in tongue shape and location. Modifications in the oral cavity resonators are therefore better accounted for by the variations in F1 and F2. In IP-initial position, the vowels /i, e, ɛ/ also pattern together with a rising of F2 for at least three speakers. In terms of F1, the non-high /ɛ, a/ are both characterized by a rising of F1 for all speakers (also for /e/ for one speaker).

Our data further show that in a dense system of contrast, where vowels have little room for phonetic variations, prosodic boundary effects may contribute to maximize the contrast between adjacent vowels. An increase of phonetic distinctiveness is observed on our articulatory and/or acoustic measurements with differences according to speakers and vowel pairs. Overall, for all pairs but /i-e/, the distinction between the vowels is maximized in IP-initial position in at least one dimension for all speakers. The contrast between the mid-open and mid-closed vowels is mainly increased in the height dimension (F1 and constriction height), and the contrast between the mid-open and open vowels is mainly increased in height and/or frontness of the constriction. In most cases, the direction of the articulatory and/or acoustic variations in IP-initial position is similar for the two vowels of the pair, but is larger for one of them, leading to an increase of contrast between the two. A similar tendency was observed in Georgeton & Fougeron (2014) for the labial configuration resulting in an increase of contrast between front rounded and unrounded vowels (see also Cole et al. 2007 for consonants). For the pair /i-e/, however, no increase of contrast is found, except for the location of the constriction for SC. Acoustic and physiological limitation can explain that the tongue rising in IPi is more constrained for /i/ and is thus smaller than that for /e/. Similarly, boundary induced variation at the lips were found to be larger for unrounded vowels than for the more constrained rounded vowels in Georgeton & Fougeron (2014). Taken together these results suggest that phonetic contrasts between vowels tend to be maximized in IP-initial position in dimensions that are less constrained by articulatory and/or acoustic limitations. Cross-linguistic comparisons between languages with different vowel inventories are now necessary to determine how these limitations comply with the language system of contrasts.

5. Acknowledgements

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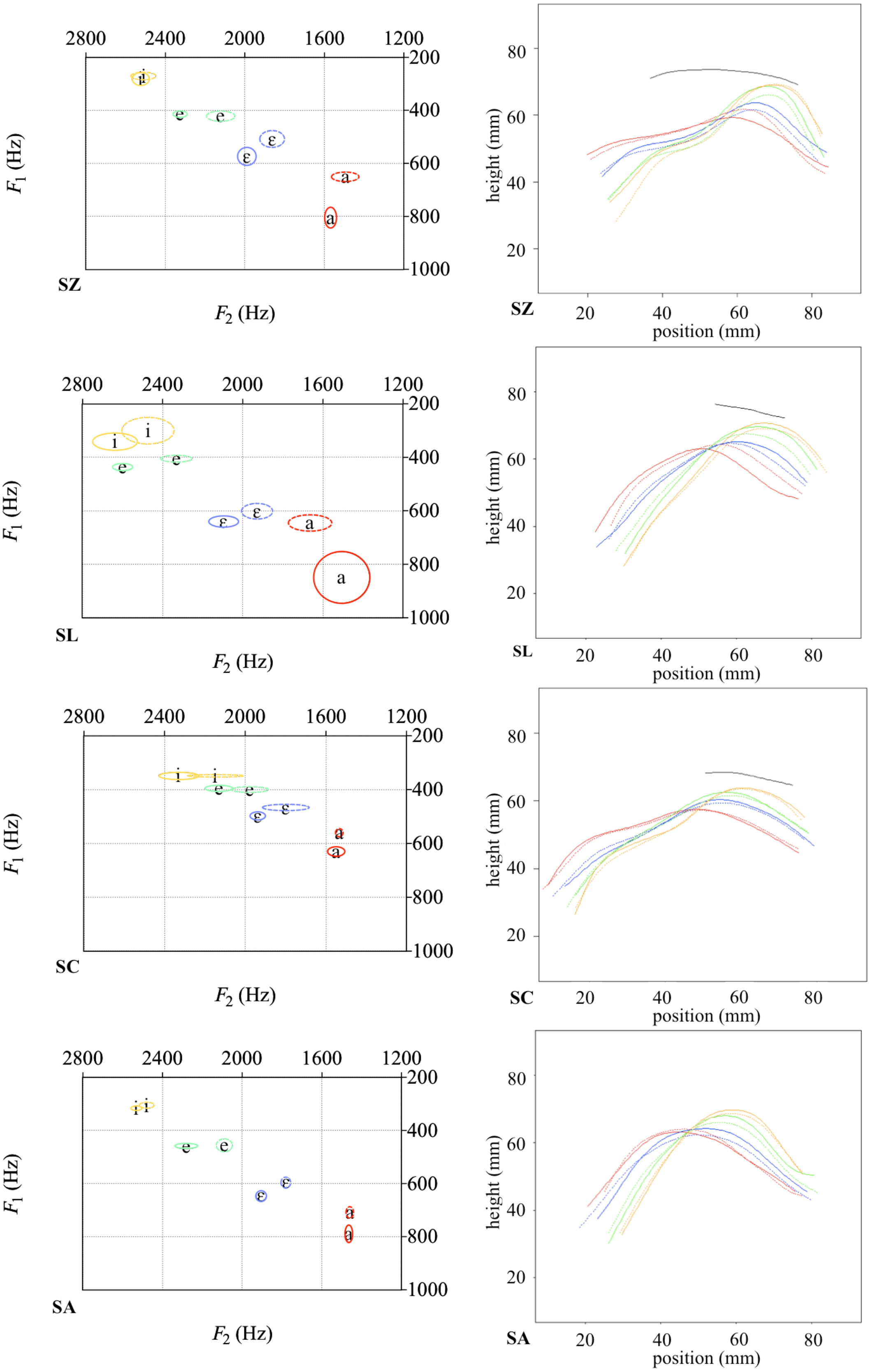

Figure 1: Mean tongue contours and F1/F2 values of the four vowels /i/ (orange), /e/ (green), /ɛ/ (blue) and /a/ (red) in IPi (solid line) and IPm (dotted line) for the four speakers (SZ, SL, SC, SA).