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Domain-initial strengthening on French vowels and phonological contrasts: Evidence from lip articulation and spectral variation

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ABSTRACT

Domain-initial strengthening has primarily been studied for consonants. This paper examines whether vowels also undergo boundary-induced phonetic variation and questions how this effect interacts with phonological contrast in a dense vowel system such as that of French. The labial articulation and the acoustic properties of the 10 French oral vowels /i, e, ɛ, a, y, ø, œ, u, o, ɔ/ are examined in Intonational Phrase-initial vs. Word-initial position. The vowels' phonetic properties are found to be affected by position but not in a uniform way. First, while all vowels are found to have a larger lip opening and width in IP-initial position, the effect is larger and more robust for unrounded vowels than rounded vowels leading to an enhanced distinction between vowels contrasting in rounding. No effect is found on lip protrusion. The distinction between these vowels is also found to be increased in IP-initial position by the enhancement of the spectral characteristics making unrounded vowels more 'unrounded-like' and – to a lesser degree – by the enhancement of the properties making rounded vowels more 'rounded-like'. The contrast between front and back vowels is also maximized by a tendency toward a higher *F*2 for front vowels and a lower *F*2 and *F*2–*F*1 for back vowels. Open and mid-open vowels also tend toward a higher *F*1. These results suggest that initial strengthening indeed contributes to maximizing phonetic contrasts between vowels in IP-initial position.

1. Introduction

Over the years, many studies have shown that the prosodic organization of an utterance may affect the articulatory and acoustic realization of its segmental content (see Cho, 2011, for a recent review). Among the locii of prosodically driven segmental variations, we find edges of prosodic domains, initial and final positions, and prominent syllables, such as syllables under focus, phrasal accent or stress. The term "(prosodic) strengthening" has been used quite extensively in the literature to refer either to the phenomenon per se, i.e. the interaction between prosody and the segmental realization of sounds, and/or to the specific phonetic manifestations of the phenomenon. In this latter use, prosodic strengthening refers to the spatial and/or temporal expansion of articulatory gestures observed for segments in strong prosodic positions (pre- or post-boundary, or under prominence) reflecting the prosodic strength of the location. Two seminal examples of this strengthening effect are (i) the cumulative lengthening of domain-final segments reflecting the prosodic level of the domain/following boundary (Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992); and (ii) the cumulative increase in linguopalatal contact observed for English /n/ when initial in domains of increasingly higher levels in the prosodic hierarchy (Fougeron & Keating, 1997). This latter case is an example of domain-initial strengthening. The present paper focuses on this type of boundary effect, affecting the phonetic realization of segments in *initial position* in a prosodic domain according to the strength of the preceding prosodic boundary.

Variations in the articulatory or acoustic properties of domain initial segments have been studied in a large variety of languages, but these variations are mostly reported for consonants (Byrd, 2000; Byrd & Saltzman, 1998; Cho, Jun, & Ladefoged, 2002; Cho & Keating, 2001; Fougeron & Keating, 1997; Fougeron, 2001; Onaka, 2003, Kuzla, Cho, & Ernestus, 2007; Kuzla & Ernestus, 2011; Bombien, Mooshammer, Hoole, Rathcke & Kühnert, 2007; Cho, Lee, & Kim, 2011). Observations of the lingual, glottal, velum, or jaw articulation of domain-initial consonants (#C) have supported the idea that it is the *consonantal* properties of the consonants that are reinforced according to the strength of the preceding boundary (see Fougeron, 1999; Cole, Kim, Choi, & Hasegawa-Johnson, 2007, or Cho, 2011 for reviews). For example, when initial in higher prosodic domains, stops have been found to be more constricted in English (Fougeron & Keating, 1997; Cho, 2001), Korean (Cho, 1998; Cho & Keating, 1999), French (Fougeron, 1998, 2001), and Japanese (Onaka, 2003), and nasal consonants have been found to be less sonorous with reduced nasal airflow in French (Fougeron, 2001) and reduced nasal energy in English (Cho & Keating, 2009).

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The first objective of our study is to investigate prosodic strengthening on domain initial vowels. The question is whether the articulatory and acoustic properties of vowels immediately following a prosodic boundary, are also modified according to the strength of the boundary, which properties are affected, and what is the direction of the modifications. Several studies have looked at boundary effects on vowels, which are not strictly domain-initial, but are the nucleus of the initial syllable of a domain (#CV). In these studies, the interest is whether initial strengthening goes beyond the edge of a domain and extends to segments past the first consonant (Barnes, 2002; Byrd, 2002; Byrd & Choi, 2006; Cho, 2006, 2008; Cho & Keating, 2001, 2009; Cho & McQueen, 2005; Fougeron & Keating, 1997; Keating, Cho, Fougeron & Hsu, 2003; Krivokapic, 2007). In Cho et al. (2011) for example, boundary effect is reported in Korean on the acoustic cues (i.e. *F*1 and *F*2 values) of the vowel following an initial /p^h/ (/a/, /i/ and /u/ in #p^{h}V). Very little is known however about vowels immediately following a prosodic boundary (i.e. absolute initial vowel, #V). Fougeron (1998, 2001) studied the lingual articulation of /i/ (with EPG, two speakers) and the nasal articulation of /$\tilde{a}$/ (with nasal flow, four speakers), in Intonational Phrase-, Accentual Phrase- and Word-initial positions in French (IPi, APi and Wi). Similar to what was found for initial consonants, /i/ had more linguopalatal contact after stronger boundaries (IP and AP) compared to W-initial position for the two speakers. Moreover, /i/ was more frequently glottalized (after AP boundary for one speaker and after IP boundary for the other) while no effect was found on its acoustic duration. Spectrally, no effect of boundary type was found on *F*1, while *F*2 was higher for one speaker in AP and IP-initial positions, and a cumulative increase of *F*3 (W<AP<IP) was found for the two speakers. For the nasal vowel /$\tilde{a}$/, an effect of boundary was found for two of the four speakers, showing a decrease of nasal air flow in IP-initial position compared to W-initial position (with a three way distinction W>AP>IP found for one speaker). Note that this decrease in nasal airflow was also found for the consonant /n/ in IPi for three out of four speakers. In a large scale study of over 30 h of broadcasted speech, Gendrot, Gerdes, and Adda-Decker (2011) also found boundary effects on the acoustic realization of French and German vowels. Even though the distribution of the vowels forced them to collapse absolute initial vowels and vowels in initial CV syllables, their results are worth mentioning here. In both languages, they observed an expansion of the acoustic space formed by the peripheral vowels in IP-initial position, accompanied by a lengthening of the vowels, especially in German. Moreover, their analysis of specific vowels in French showed that some of the distinctive properties of the vowels, such as the merging of *F*3–*F*2 typical for /y/ or *F*4–*F*3 typical for /i/, were reinforced after stronger boundaries. Two other recent studies in English have provided further evidence that domain-initial vowels are also affected by initial strengthening. In their ultrasound study, Lehnert-LeHouillier, McDonough, and McAleavey (2010) analysed differences in tongue contours (at the most advanced position of the tongue body) for English /ɛ/ and /ɔ/ between IP-, AP-, and W-initial positions. They report an effect of boundary type on the lingual articulation of the vowels and larger differences in tongue contour between the two extreme positions (IPi and Wi). Unfortunately, no indication is given on the direction of the changes (horizontal or vertical tongue position) linked to the effect observed for each vowel. More recently, Kim and Cho (2012) looked at the effect of boundary on the lip and tongue kinematics of English /æ/. They observed a larger and longer opening movement of the lips in IP-initial position but no effect on either the vertical or horizontal dimensions for the tongue dorsum.

Considering these results, it appears that domain-initial strengthening may affect vowels as well as consonants, but it is unclear what properties of the vowels are subject to variation when initial in higher prosodic domains. This leads us to the second objective of our study. As pointed out some time ago by Fougeron and Keating (1997) and discussed more extensively in the recent review by Cho (2011), despite the substantial amount of data collected in the literature, the nature of the prosodic strengthening phenomenon is still an open question. What is the mechanism governing the observed phonetic variations and, do these variations have a linguistic function? The present paper tackles this latter question by asking whether the properties affected by boundary strength and the direction of the variation observed relate to phonological contrast.

Two hypotheses have been put forward in the literature to explain how boundary-related phonetic variations could be linguistically driven in order to maximize the contrast between segments. According to the first hypothesis, domain-initial strengthening contributes to an enhancement of the syntagmatic contrast between the initial segment and its neighbours. As stated earlier, the variations found for consonants following a strong prosodic boundary could be interpreted as a reinforcement of their consonantal nature. As proposed by Fougeron and Keating (1997) for example, within a V#CV sequence, the increased constriction of the consonant, accompanied by a larger opening of the pre-boundary (final) vowel, could be interpreted as an enhancement of the contrast between the segments straddling the prosodic boundary. According to the second hypothesis, boundary effects would contribute to reinforce the paradigmatic contrast between segments. Following De Jong (1995) proposal for accented vowels, prosodic strengthening could be viewed as a local hyperarticulation leading to an enhancement of the distinctive properties of the segment. Cho and Jun (2000) tested these hypotheses on the three-way contrast between lenis, fortis, and aspirated stops in Korean. Their results showed that boundary effects differed according to the stop type as predicted by the paradigmatic contrast enhancement hypothesis. Fortis and aspirated stops showed VOT and airflow variations in IP-initial positions that were consistent with an enhancement of their distinctive laryngeal specifications: [+constricted glottis] and [+spread glottis] respectively. However, for the lenis stops, the variation was similar to that observed for the aspirated stop (longer VOT and more airflow). This lack of contrast maximization between the aspirated and lenis categories was explained by the fact that lenis stops are unspecified for both [spread glottis] and [constricted glottis]. The variation found for the lenis stop was thus interpreted as a syntagmatic enhancement of the contrast between the more 'consonantal' lenis stops and the surrounding vowels.

Vowels offer another interesting test case to determine what is strengthened domain-initially and how this effect interacts with linguistic contrast. To address these issues in the present study, we investigate boundary effects on the 10 oral vowels of the French vowel system /i, e, ɛ, a, y, ø, œ, u, o, ɔ/. We test whether the effects of boundary strength affects all vowels in the same ways or whether differential effects apply in the system according to the distinctive properties of the vowels. In such a rich system, height (with 4 levels of aperture), backness, and roundedness are at play in an intricate way and degrees of freedom are relatively reduced. Both acoustic and articulatory data will be examined. From an acoustic point of view, we investigate which of the spectral dimensions, defined by *F*1–*F*2–*F*3 and used to mark contrasts within the oral French vowel system, are affected by boundary effects. Most studies looking at prosodic effects on vowels (often concerned with variation under accent or in final position) are restricted to a few vowel categories. In order to address the question of the relationship between prosodically induced variation and paradigmatic contrast, it is however necessary in our view to investigate a full system of contrast (although excluding here nasal vowels). If one considers peripheral vowels only, predictions on how spectral changes relate to the vague notions of 'hyperarticulation', 'distinctiveness' or 'clarity' are rather straightforward: one would expect vowels to be more peripheral. As far as mid vowels are concerned, however, it is unclear what to expect from an 'extreme' realization. In the present study the effect of boundary on the acoustic properties of vowels is therefore examined first from a systemic point of view by looking at the degree of dispersion of the vowels in the *F*1/*F*2 and *F*2/*F*3 acoustic spaces defined by the vowel system. Then, the effect of boundary on the defining spectral and durational characteristics of each vowel is analysed. The realization of focal vowels of French (that is /i, y, u, o, ɔ/) is also investigated to test whether boundary effects target their focal properties.

From an articulatory point of view, we examine the effect of prosodic boundary on the labial configuration (lip aperture, lip width and lip protrusion, i.e. the three degrees of freedom of the lips as proposed by Ladefoged, 1979) of the 10 French vowels according to their rounding specifications.