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Articulatory Manifestation of Prosodic Strengthening in English /i/ and /ɪ/

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ABSTRACT

The present study investigated the effects of two different sources of prosodic strengthening, i.e., boundary and accent, in the articulation of English high front vowels, /i/ and /ɪ/. The vowels were investigated in vowel-initial ('eat' vs. 'it'), /h/-initial ('heat' vs. 'hit') and /p/-initial words ('Pete' vs. 'pit'), which were placed in varying prosodic conditions. Using Electromagnetic Articulograph (EMA), the tongue dorsum positions in the x and y dimensions, the lip opening and the jaw opening (lowering) were measured. With respect to the boundary-induced strengthening, results showed that /i/ and /ɪ/ in vowel-initial words ('eat' - 'it') are produced with a higher tongue position in the domain-intial than domain-medial positions. The fact that the vowels only in the vowel-initial condition showed the domain-intial strengthening (DIS) effect suggests that the DIS effect is localized mainly to the initial position (the locality account). As for the accent-induced strengthening, vowels were produced with a more fronted tongue position and larger lip opening in accented than unaccented positions. This suggests that the presence of accent increases overall sonority of the vowels in various prosodic contexts, and enhances primarily the frontedness of the front high vowels. Taken together, the results indicate that the two types of prosodic strengthening are articulatorily realized differently, supporting the view that they are encoded separately in the speech planning process. The present study also showed the distinction between the two high front vowels in the tongue position (in both the frontedness and the height dimensions), while the jaw did not seem to contribute to the distinction robustly, suggesting that the tongue contributes more in distinguishing the two vowels than the jaw does.

Keywords: English, vowel, domain-initial strengthening, accent-induced strengthening, prosodic strengthening, EMA

1. Introduction

Prosody serves two important functions in speech: grouping prosodic constituents (or boundary-marking) and marking relative prominence between them (see, e.g., Pierrehumbert, 1999; Keating, 2006). These two functions are phonetically manifested in spoken utterances by both suprasegmental and segmental features. Prosodic grouping, for instance, can be phonetically marked by final lengthening (i.e., suprasegmental lengthening at the end of a prosodic group) (Klatt, 1975; Wightman, Shattuck-Hufnagel, Ostendorf & Price, 1992) and by domain-initial strengthening (i.e., segmental strengthening at the beginning of a prosodic group which gives rise to spatio-temporal expansion) (Fougeron & Keating, 1997; Keating, Cho, Fougeron & Hsu, 2003; Cho & Keating, 2001; Cho, 2005; Cho & Keating, 2009, among others). These phrase-final and phrase-initial strengthening effects work together to signal a prosodic boundary by which prosodic grouping is determined. The prominence-marking function of prosody, which is often realized under accent, is also phonetically manifested by a similar kind of segmental strengthening with a spatio-temporal expansion of articulation, although the exact pattern of prominence-marking strengthening may differ from that of boundary-marking strengthening (Beckman et al., 1992; Cho, 2005; Cho & Keating, 2009; de Jong 1995). The primary goal of the present study is to investigate how similarly or differently the prominence-marking versus the boundary-marking strengthening patterns are manifested

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in the production of English front high vowels /i/ and /ɪ/, by employing an instrumental technique with Electromagnetic Articulography.

Previous studies on domain-initial strengthening (henceforth DIS) have provided ample evidence for consonantal strengthening in the domain-initial position, but we have rather limited knowledge of its effect on vowel articulation. DIS effects on vowels have been found to be relatively weak, compared to those with the consonants, or inconsistent among speakers, or even null (Byrd, Krivokapic, & Lee, 2006; Cho & Keating, 2001; Cho, 2005; Fougeron & Keating, 1997; Onaka, Watson, Palethorpe, & Harrington, 2003).

Regarding the reason why the DIS effect is not robustly observed in the vowel articulation, roughly two possible explanations have been discussed in the literature (for relevant discussion, see Cho & Keating, 2009). Some studies attributed the weak or null DIS effects on vowels to their distance from a prosodic boundary. All of the above mentioned studies have examined DIS effects on vowels in the #CV context (where '#' refers to a prosodic boundary) in which the vowel is not immediately adjacent to the boundary. Thus, under the assumption that the DIS effect is localized to purely domain-initial segments (i.e., consonants in #CV), vowels in the #CV context are likely to show very weak or null DIS effects as it is farther away from the boundary (e.g., Fougeron & Keating, 1997). We will call this explanation as *the locality account*.

Another possibility can be thought of in light of the role of the vowel in marking prominence, which we will call *the stress marking account*—i.e., the weak DIS effect on the vowel is attributed to the fact that, at least in English, the vowel is subject to strengthening that arises with prominence or stress marking, but not with boundary marking. Barnes (2002), for example, compared the acoustic lengthening of vowels in #CV in English and Turkish, and found significant DIS effects on the vowel duration in Turkish, but not in English. He claimed that this cross-linguistic difference is due to the fact that English vowels are reserved for marking prominence associated with lexical stress while Turkish vowels are not. That is, according this claim, it is not the distance from the boundary that weakens the DIS effect on vowels in English, but the language specific role of the vowel in marking lexical stress. (An independent recent study by Cho, Lee, & Kim (2011) did find a significant domain-initial strengthening effect on vowels in the #CV context in Korean in line with Barne's argument. That is, the robust DIS effect on the vowel in #CV can be interpreted as coming from the fact that Korean, like Turkish, does not employ a lexical stress, thus not constraining the role of the vowel to marking stress.)

An important question then arises as to which of the two possibilities (the locality account versus the stress marking account) could better characterize the nature of DIS effects on vowels. This can be addressed by examining strengthening patterns of vowels directly in the domain initial position (i.e., #V), as compared with the vowels in #CV contexts. On the one hand, if the locality account holds, the vowel in the #V context should show a clear DIS strengthening effect, at least more robust than in the #CV context where the vowel is not local to the boundary. On the other hand, under the stress marking account, the DIS effect is not to be reflected in the vowel even when the vowel is strictly local to the boundary in the #V context. In the present study, we evaluate the two possible accounts by looking into articulatory patterns (as reflected in the tongue, the jaw and the lips) of English high front vowels /i/ and /ɪ/ in both the #V and the #CV contexts.

The two vowels are examined in three pairs of words: (1) a vowel initial pair (*eat* vs. *it*), (2) a /h/-initial pair (*heat* vs. hit), and (3) a /p/-initial pair (*Pete* vs. *pit*). The /p/-initial contexts are used because the articulation of /p/ guarantees the minimum coarticulation with the tongue during the consonant production. The /h/-initial pair is introduced to see whether the locality of DIS depends on phonological or phonetic distance from the boundary: The /h/-initial words are similar to vowel-initial words in that they both have the same supralaryngeal articulation (so that the vowels both in the /h/- and vowel-initial words are phonetically local to the boundary in the supralaryngeal level); yet from the phonological point of view, the /h/-initial words can be seen as similar to the /p/-initial words, in that they both have a phonological slot for the consonant in front of a vowel (so that the vowels in both the /h/- and /p/-initial words are phonologically non-adjacent to the boundary). If DIS depends solely on the phonetic locality in the supralaryngeal level, the DIS effect would be observed in both vowel-initial and /h/-initial words under the locality account, while the /p/-initial words show no such DIS effect. If, on the other hand, the abstract phonological structure affects the DIS, the strengthened vowels under the locality account would be observed only in vowel-initial words, but not in /p/- and /h/-initial words.

It should be noted, however, that in an articulatory study with ultrasound, Lehnert-LeHouillier and her colleagues (2010) also tested English mid vowels /ɛ/ and /o/ in the #V position, showing a possible DIS effect on the articulation of /ɛ/ and /o/. But they did not control for the prominence factor (i.e., the test vowel could be potentially either accented or unaccented), making it hard to interpret the data. In the present study, we therefore control for the accent factor, such that we can observe the effects of boundary-induced strengthening (i.e., the DIS effect) and of prominence-induced strengthening separately. In order to do so, vowels are placed in the accented (with a contrastive focus) or the unaccented condition in both boundary-initial and boundary-medial positions. It has been claimed that accent enhances a segment's intrinsic sonority, such that a vowel becomes more sonorant (the Sonority Expansion Hypothesis; Beckman et al., 1992), and that it enhances the distinctive features of segments, maximizing lexical distinctions (hyperarticulation; de Jong, 1995). But Farnetani & Vayra (1996) claimed that accent-induced prominence would be characterized by hyperarticulation (with the enhancement of place feature), whereas the boundary-induced prominence would be characterized by sonority expansion. Cho (2005), however, found that both sonority feature (i.e., larger lip opening) and non-sonority features (e.g., [+/- back], [+/-low]) may be enhanced by both boundary and accent. What is more important in his findings is that the factors of boundary and accent induced different types of articulatory strengthening in terms of the vocalic tongue movement. In #CV position, the English vowel /i/ was higher at a strong boundary (but not fronted), but it was fronted (but not higher) when accented. The vowel /a/ in the same position showed only lowering of the tongue when accented (but no backing), but it did not show apparent boundary-induced strengthening. Given these complicated patterns available in the literature, we will continue to examine whether, and if so how, the boundary versus accent-induced strengthening patterns are realized differently.

Finally, by comparing /i/ and /ɪ/, we investigate how the phonological contrast between /i/ and /ɪ/ are articulatorily maintained or maximized in the prosodic strengthening environments (boundary-induced versus accent-induced). In connection with this question, we will also examine the extent to which the /i/ and /ɪ/ contrast is observable in the tongue versus the jaw articulation. It has been controversial whether the main contributor to the linguistic vowel distinction is the jaw or the tongue. Wood (1979) viewed that the degrees of the vowel height or the vocal tract constriction are better characterized by the jaw height, whereas constriction location (i.e., frontedness) for vowels has more to do with the positioning of the tongue body in the horizontal (x) dimension. Lindblom & Sundberg (1971) also viewed that the jaw opening is more responsible for the vowel height distinction. However, in a recent study with x-ray microbeam and digital ultrasound imaging, Noiray, Iskarous, Bolanos, & Whalen (2008) showed that both the jaw and the tongue contribute to the distinction between /i/ and /ɪ/, but the tongue's contribution is greater than previously assumed. In the present study, we will look at both the tongue and the jaw articulation in order to understand how the /i/-/ɪ/ contrast is maintained and enhanced by the tongue versus the jaw.

2. Method

2.1 Participants

Seven (3 female, 4 male) native speakers of American English, who were in their 20's, participated in the experiment. They did not have any hearing or speaking disorder, and were paid for their participation.

2.2 Speech material

The articulation of English high front tense vowel /i/ and high front lax vowel /ɪ/ were examined in two vowel-initial (‘eat’ and ‘it’), two /h/-initial (‘heat’ and ‘hit’), and two /p/-initial words (‘Pete’ and ‘pit’).

Table 1: A list of carrier sentences with four prosodic conditions. Accented words are capitalized and marked in bold. The target word (in this case, ‘eat’) is underlined. ‘#’ indicates an IP boundary in A and B and an IP-medial word boundary in C and D.

A. IP-initial, accented
After **I** say ‘Diana,’ ‘**HEAT** again’ will be the next phrase to say. But after **THEY** say ‘Diana,’ # ‘**EAT** again’ will be the next phrase to say.
B. IP-initial, unaccented
After **I** say ‘Diana,’ ‘eat again’ will be the **NEXT** phrase to say. But after **THEY** say ‘Diana,’ # ‘eat again’ will be the **FINAL** phrase to say.
C. IP-medial, accented
To say ‘Diana **HEAT** again’ with me is going to be difficult. But to say ‘Diana # **EAT** again’ with me is going to be easy.
D. IP-medial, unaccented
To say ‘Diana eat again’ with **JOHN** is going to be difficult. But to say ‘Diana # eat again’ with **ME** is going to be easy.

The target words were located in IP-initial and IP medial positions in carrier sentences. Table 1 shows how boundary and accent factors were manipulated across test sentences with the target word 'eat.' Each prosodic condition (IP-initial, IP-medial) consisted of two sentences in order to control for the accent factor with a contrastive focus. The second sentence contained the target word. When 'eat' was the accented target word in the second sentence, the contrasting word was 'heat' in the first sentence (as in Table 1A, 1C). For target words 'heat' and 'Pete', the contrasting words in the first sentence were 'Pete' and 'eat', respectively. The same strategy was applied to create carrier sentences for 'it-hit-pit.'

Subjects read the carrier sentences three times in a pseudo-randomized order. The collected data were screened by two American English ToBI transcribers. The total number of measured tokens were 504 (2 boundaries x 2 accent conditions x 6 words x 3 repetitions x 7 speakers).

2.3 EMA data collection and measurements

The 2D Electromagnetic Articulograph (Carstens AG200) was used to track the movement of sensors that were attached to the tongue tip, the tongue body, the tongue dorsum, the jaw (at the lower incisor), and the upper and lower lips (at the vermilion border) as can be seen in Fig. 1. The tongue dorsum sensor was approximately 4~5cm away from the tongue tip sensor. As reference points, two additional sensor coils were attached to the upper incisor and the nose bridge, which were used to correct for the head movement inside the helmet. In addition, two sensors on a bite plate were used to obtain the occlusal plane (*x*-axis), to which the data were rotated. *Y*-axis was perpendicular to the occlusal plane.

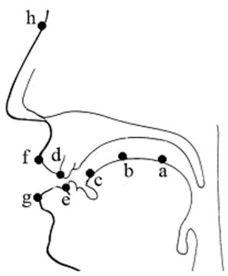

Figure 1. Locations of sensor coils: (a) the tongue dorsum; (b) the tongue body (c) the tongue tip; (d)-(e) the maxillary (upper) and mandibular (lower) central incisors; (f)-(g) the upper and lower lips; and (h) the nose bridge.
(This figure was adopted from Figure 1 in Son & Cho (2010).)

The entire articulatory movement data were sampled at 200Hz and low-pass filtered at a cut-off frequency of 20Hz. The obtained data were processed using Tailor and analyzed using Emalyse, both of which were softwares provided by Carstens.

For this study, we examined the extreme points (maxima) of the tongue dorsum (henceforth TD) and the lip and jaw opening maximum values, as follows.

(1) TD-x Extremum: the horizontal extreme point of the TD during the vowel production
(2) TD-y Extremum: the vertical extreme point of the TD during the vowel production
(3) Lip Opening Maximum: the maximum point of the lip aperture
(4) Jaw Opening Maximum: the maximum point of the jaw aperture

(Note that TD extrema in the *x* (horizontal) and *y* (vertical) dimensions were taken separately at different time points; the lip aperture was calculated as the euclidean distance between the upper and the lower lips, and the jaw aperture between the maxillary (upper) and mandibular (lower) central incisors.)

The horizontal and vertical tongue dorsum extrema and jaw opening maxima were measured in order to investigate whether and how the phonological features of vowels (i.e., vowel frontedness and height) are strengthened in different prosodic contexts. The lip opening maxima were measured to see how different prosodic factors affect sonority expansion.

2.4 Statistical analysis

A series of repeated measures analyses of variance (RM ANOVA) was conducted. (It should be noted that in order to avoid a possible violation of the sphericity assumption, Huynh-Feldt correction was made.) We tested three factors, Vowel (/i/ vs. /ɪ/), Accent (accented vs. unaccented), and Boundary (IP-initial vs. IP-medial) in each of the three word pairs (i.e., *eat-it, heat-hit*, *Pete-pit*), since the articulatory measures were not directly comparable between word pairs. T-tests were carried out when there was an interaction between factors.

Note that due to some abnormal trajectory patterns found in /p/-initial word pairs 'Pete-pit', the data from two participants were excluded for the Lip Opening Maximum measure, and the data from one participant were excluded for the Jaw Opening Maximum measure from the 'Pete-pit' pair.

3. Results

3.1 TD-x Extrema (index of the tongue frontedness)

There were significant effects of Vowel on TD-x Extrema in all three word pairs ('eat' vs. 'it': $F(1,6)=8.043$, $p=.03$; 'heat' vs.

'hit': F(1,6)=9.898, p=.02; 'Pete' vs. 'pit': F(1,6)=19.36, p=.005). Smaller values in the data indicate more fronted tongue position, suggesting that the tongue is more fronted for the tense vowel /i/ than the lax vowel /ɪ/ in all pairs, as shown in Fig. 2(a).

The effect of Accent was also significant in all three pairs ('eat' vs. 'it': F(1,6)=9.545, p=.021; 'heat' vs. 'hit': F(1,6)=17.923, p=.02; 'Pete' vs. 'pit': F(1,6)=19.766, p=.004), with accented vowels being more fronted than unaccented vowels, as shown in Fig. 2(b).

The Boundary factor yielded no significant main effect on the TD-x Extremum, but an interaction was found between Vowel and Boundary in the 'Pete-pit' pair (F(1,6)=7.131, p=.037). The interaction appears to be at least partially due to the fact that /ɪ/ showed smaller TD-x mean values (thus being more fronted) IP-initially than IP-medially whereas /i/ showed the opposite pattern. T-tests, however, showed that the differences were not significant in both cases.

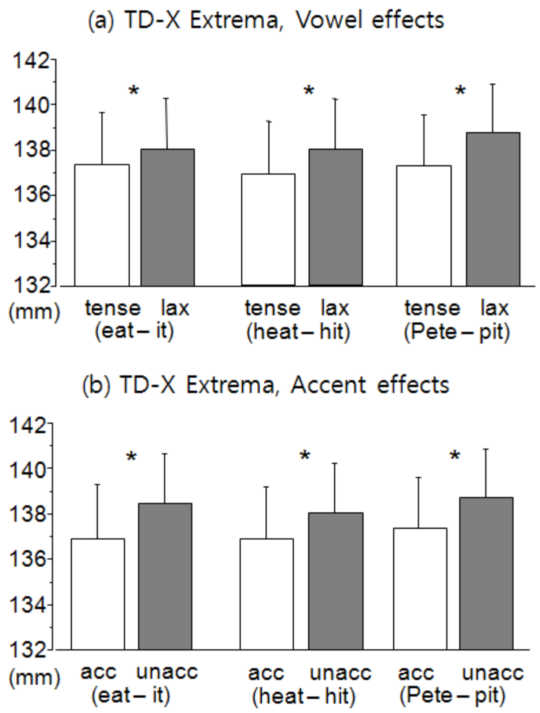

Figure 2. Effects of Vowel (a) and Accent (b) on TD-x Extrema. ('*' refers to p<0.05)

3.2 TD-y Extrema (index of the tongue height)

As with TD-x Extremum, the TD-y Extremum measure showed a main effect of Vowel in all three word pairs ('eat' vs. 'it': F(1,6)=39.202, p=.001; 'heat' vs. 'hit': F(1,6)=36.673, p=.001; 'Pete' vs. 'pit': F(1,6)=77.052, p=.000). As shown in Fig. 3(a), /i/ was produced with a significantly higher tongue position than /ɪ/.

The effect of Accent was significant only for the 'eat-it' pair, showing a significantly higher tongue position when accented than unaccented (F(1,6)=8.153, p=.029) (Fig. 3b).

TD-y Extremum also showed a significant Boundary effect in the vowel-initial ('eat-it') pair (F(1,6)=6.006, p=.05) (Fig. 3c), while the other two (/h/- and /p/-initial) pairs did not reveal a significant boundary effect. For the 'eat-it' pair, the tongue position was higher IP-initially than IP-medially, showing the domain-initial strengthening effect on the vowel in the tongue height dimension. In addition, there was a significant interaction between Vowel and Boundary with the vowel-initial words (F(1,6)=8.419, p=0.027). T-test results showed that the Boundary effect was significant with /ɪ/. (t(6)=3.14, p=.02), but not significant with /i/, although the difference in mean TD-y values for /i/ showed the same direction as /ɪ/ — i.e., the tongue was higher IP-initially than IP-medially.

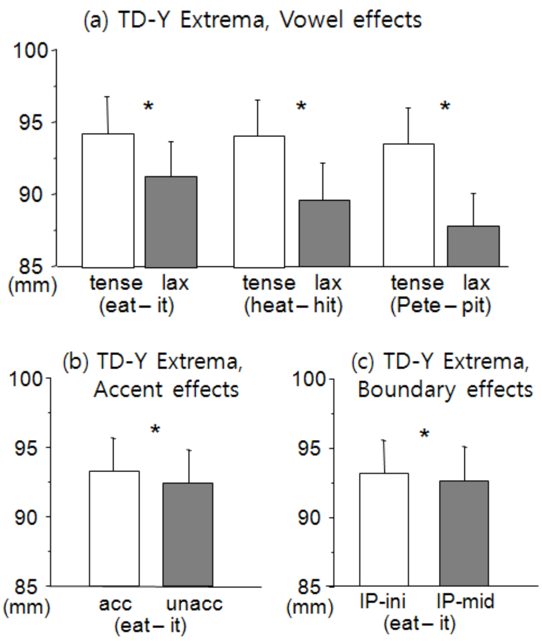

Figure 3. Effects of Vowel (a), Accent (b), and Boundary (c) on TD-y Extrema. ('*' refers to p<0.05)

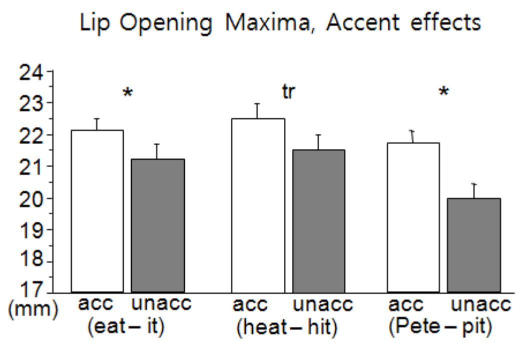

Figure 4. Effects of Accent on Lip Opening Maxima. ('*' refers to p<0.05; 'tr' refers to a trend p<0.06)

3.3 Lip Opening Maximum

As shown in Fig. 4, the Lip Opening Maximum values were significantly larger when accented than unaccented for the 'eat-it' pair (F(1,6)=7.206, p=.036), and for the 'Pete-pit' pair (Pete F(1,4)=8.955, p=.04), showing that accented vowels are produced with more lip opening than unaccented vowels in both vowel-initial and /p/-initial word pairs. A similar, though non-significant, trend was found with the 'heat-hit' pair as well (F(1,4)=5.382, p=.059). No other effects were found.

3.4 Jaw Opening Maximum

There was a significant main effect of Vowel on Jaw Opening Maximum values for the 'heat-hit' pair (F(1,6)=5.994, p=.05), with larger jaw opening for /ɪ/ than for /i/, as shown in Fig. 5(a).

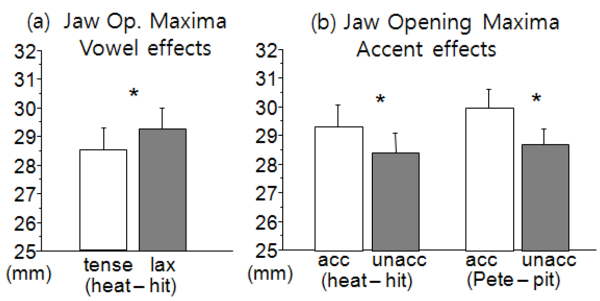

Figure 5. Effects of Vowel (a), Accent (b)on Jaw Opening Maxima. ('*' refers to p<0.05)

The Accent effect was also significant in the 'heat-hit' pair (F(1,6)=9.578, p=.021), and in the 'Pete-pit' pair (F(1,5)=18.498, p=.008). As shown in Fig. 5(b), the jaw opening was larger for the accented than unaccented words. Furthermore, there was a significant interaction between Vowel and Accent in the 'Pete-pit' pair (F(1,5)=6.678, p=.049). Results of t-tests showed that the jaw opening was significantly larger when accented than unaccented with both /i/ (t(5)=4.687, p=.005) and /ɪ/ (t(5)=4.605, p=.006). The interaction seems to be due to the fact that the mean difference between the accented and unaccented conditions was slightly larger for the lax vowel. (The mean difference was 1.7mm for the lax vowel and 0.8mm for the tense vowel.)

4. Discussion

The present articulatory study (using an EMA) has investigated how the English front high vowel /i/ and /ɪ/ are produced in prosodic strengthening environments, in the domain-initial position and the accented syllables. /i/ and /ɪ/ are tested in the vowel-initial condition (#V, 'eat'-'it') and the consonant-initial condition (#CV, 'heat'-'hit' and 'Pete'-'pit'). In what follows, we will discuss the results of the study along with research questions and hypotheses set forth at the outset of the paper.

One of the important questions that the present study aimed to answer was how the boundary effect (also referred to as the domain-initial strengthening, DIS, effect) on the vowel would be conditioned by the position of the vowel in the #V condition versus in the #CV condition. We found a significant main effect of boundary on the TD-y measure (in the tongue height dimension) for the vowel-initial 'eat-it' pair. That is, the tongue position of the high vowels /i/ and /ɪ/ in the 'eat'-'it' pair was higher in domain-initial than in domain-medial position, showing an enhancement of the [+high] feature. However, the same /i/ and /ɪ/ did not yield the DIS effect when they were in the /h/- and /p/-initial pairs ('heat-it' and 'Pete-pit'). This suggests that /i/ and /ɪ/ undergo DIS effects only when they occur at the left edge of the domain in the #V context (the vowel-initial condition), but not in the #CV context (the /h/-initial and /p/-initial conditions) where the vowel is not strictly adjacent to the boundary.

The results therefore appear to support the *strict locality account*. The weak or null domain-initial strengthening (DIS) effect that has often been observed on the vowel in #CV in the literature does not seem to be attributable to the possibility that the vowel is reserved for marking lexical stress in English as Barnes (2002) argues (the *stress marking account*). Instead, it appears to be better accounted for by the fact that the vowel in the #CV condition is not strictly local to the boundary, supporting the locality account.

The present study also tested whether the locality effect would depend on the phonological or phonetic distance from the boundary. It was hypothesized that /h/-initial words ('heat'-'hit') may pattern with vowel-initial words ('eat'-'it'), if the locality operates on a phonetic adjacency: Given that /h/ does not interfere with the vowel articulation in the supralaryngel level, the presence of /h/ would be considered 'invisible,' not blocking the boundary effect on the following vowel. Alternatively, if the locality operates on a phonological level, /h/-initial words should pattern with /p/-initial words ('Pete'-'pit') as both word types have the same phonological structure (i.e., #CV). The fact that only vowel-initial condition yielded the DIS effect, while both /h/-initial and /p/-initial word pairs did not, supports the second alternative: the locality effect of DIS is conditioned by the abstract phonological syllable structure.

Regarding the DIS effect on the tongue height (as reflected in the TD-y measure), however, it should be noted that there was an interaction effect between the vowel and the boundary factors:

The DIS effect was reliable only with /ɪ/, while /i/ showed the same direction without reaching a significant level. At this moment, we do not have a definite explanation for this, but the lack of the robust DIS effect on /i/ could be due to a ceiling effect. Since the tense vowel /i/ is produced with a higher tongue position to begin with, there appears to be less room available for the tongue to be raised even higher. This should, however, be taken with caution because some previous studies have shown that the test vowel /i/ in English can be produced with more extreme tongue height in prosodic strengthening environments (cf. Cho, 2005).

Another important question of the present study is how the prominence factor, the accent, would influence the articulation of /i/ and /ɪ/, and how the effect would differ from the boundary-induced DIS effect. We found effects of accent in all three word pairs ('eat-it', 'heat-hit' and 'Pete-pit') in the TD-x extremum (the tongue frontedness) dimension, indicating that the phonological feature of frontedness (e.g., [-back]) is enhanced when the words were accented regardless of the distance of vowels from the boundary. This accent-induced strengthening pattern is clearly different from that observed with the boundary condition which yielded no main effect in any of the three different word pairs.

The presence of accent also resulted in higher tongue position (TD-y extremum) in the vowel-initial pair 'eat-it' pair, similar to the pattern found with the boundary effect. Insofar as the tongue height is concerned, it was the vowels only in the vowel-initial pair ('eat-it') that showed a reliable tongue raising in both the domain-initial and the accented positions, which could be interpreted as enhancing the [+high] feature.

Interestingly, however, the consonant-initial word pairs ('heat-hit' and 'Pete-pit') showed the jaw opening pattern (as reflected in the Jaw Opening max) which was larger under accent. This is apparently orthogonal to the enhancement of [+high] with the tongue raising for the 'eat-it'—i.e., the jaw opening is expected to be smaller (narrowing the constriction) if the [+high] feature is enhanced. While we do not have an explanation to offer for why there is an asymmetry between the vowel-initial pair and the consonant-initial pairs, it appears that the tongue and the jaw articulation is modulated by the syllable structure difference (#V vs. #CV), and that the larger jaw opening increases the sonority of the vowel under accent at least in the consonant-initial word pairs. (Note that a greater degree of the mouth opening is generally assumed to increase the sonority.) The accent-induced sonority expansion was further evident in the lip opening pattern, which showed a strong tendency towards a larger lip opening when the vowel was accented, regardless of whether it was in the vowel-initial pairs or in the consonant-initial pairs.

The overall effects of prosodic strengthening on /i/ and /ɪ/ have thus indicated differential articulatory patterns associated with different sources of prosodic strengthening—i.e., prominence-marking versus boundary-marking. The presence of accent increases the sonority of the vowels and enhances the vowel frontedness feature such that front vowels are more fronted when accented than unaccented. The presence of larger boundary, on the other hand, is more likely reflected in the vowel height in the direction that the high vowels are produced with higher tongue position in the domain-initial position at a higher prosodic boundary. The difference between the two sources of prosodic strengthening can be interpreted as supporting the idea that the two types of prosodic information (boundary and accent) are encoded separately during speech production in line with the view that has been put forward in the literature (Keating, 2006; Cho & Keating, 2009).

Finally, the present study allowed us to test whether and how the phonological contrast between /i/ and /ɪ/ is reflected in the articulation of the jaw and the lips along with the lingual (tongue) articulation, especially given that the jaw is often considered to be one of the primary articulators for vowels. The tongue dorsum data showed a clear distinction between /i/ and /ɪ/ in both the tongue frontedness and the tongue height dimensions (as reflected in the TD-x and TD-y measures)—i.e., /i/ was more fronted and higher than /ɪ/. Jaw and lip opening maxima, however, did not show robust articulatory differences between the two vowels, except for one case with the 'heat-hit' pair in which /ɪ/ was produced with a larger degree of jaw opening. This suggests that the tongue plays a more role in maintaining the contrast between the two vowels /i/-/ɪ/ than the jaw does, when the vowels are produced in various prosodic contexts. These results are in line with Noiray et al. (2008)'s observation that, although the jaw and the tongue dorsum contribute to the distinction between the high front tense and lax vowels when they are produced individually without any context, the tongue appears to make greater contribution than the jaw at least in prosodic contexts tested in the present study.[3)]

3) It appears that since the two vowels are already high, the subtle difference between them in terms of the vowel height is articulatorily realized by the tongue rather than the jaw as the tongue is more flexible in its movement. Alternatively, the articulatory tension for /i/ is applied to the tongue, rather than the jaw, resulting in the observed difference.

5. Conclusion

The present study examined how the two English high front vowels /i/ and /ɪ/ are realized under different types of prosodic strengthening (boundary versus prominence) and in different syllable structures (#V versus #CV). As for the boundary-induced strengthening, the vowels were produced with a higher tongue position in IP-initial than in IP-medial positions, but only when they occurred in vowel-initial words ('eat-it'). This is in line with the locality account—i.e,. the domain-initial strengthening effect is localized to the very initial segment of the boundary. As for the accent-induced strengthening, the vowels were produced with a fronted tongue position and larger lip opening when accented than unaccented, in both vowel-initial and consonant-initial words. Taken together, these results suggest that two prosodic strengthening are differentially realized on vowels, with boundary-induced prominence likely enhancing the vowel height feature ([+high]), and accent-induced prominence mainly enhancing the vowel frontedness ([-back]) and the sonority feature. The present study also showed that the difference between /i/ and /ɪ/ was consistently maintained in the tongue height and the frontedness dimensions, regardless of the segmental (syllable) contexts in which they occur. The jaw opening maxima, on the other hand, did not reflect such consistent difference, suggesting more involvement of the tongue than the jaw in the distinction between the two high front vowels. All in all, the results of the present study suggest that the articulatory signatures of prosodic structure are manifested with various articulatory parameters in a synergistic way of expressing the dural functions of prosodic structure.

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