Influence of prosodic boundary on Japanese domain-final consonants

Akiko Onaka

Macquarie Centre for Cognitive Science,
Speech Hearing and Language Research Centre
Division of Linguistics and Psychology
Macquarie University, Australia
aonaka@maccs.mq.edu.au

Abstract

The purpose of the present paper is to extend the previous findings on the prosodic boundary effects in consonants by examining the extent to which the strength of the prosodic boundary influences pre- and post-boundary phonetic segments and identifying the locale of such effects. The experiment presented in this paper was acoustic and electropalatographic data obtained from Japanese speakers. The results showed while domain-initial consonants in higher prosodic domains were accompanied by an increase in acoustic durations, domain-final consonants were associated with an articulatory durational increase but with little acoustic durational difference. The results suggest that, articulatory variations found at edges of prosodic boundaries in Japanese are strongly correlated with articulatory durational variations. Further, the results suggest that variations found at the edges of prosodic boundaries may be indicative of phonological difference, rather than positional or boundary effects per se. These findings shed light on the close relationship between lengthening and strengthening in Japanese.

1. Introduction

Recent research has shown that prosodic structure influences acoustic and articulatory patterning of speech segments (e.g., Pierrehumbert & Talkin, 1992; Fougeron & Keating, 1997). For example, acoustic-phonetic and articulatory properties of speech segments at edges of prosodic boundaries have been found to vary as a function of prosodic boundary strength (e.g., Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992; Fougeron & Keating, 1997). In particular, initial consonants are found to be articulated more strongly when they are in higher prosodic domains (Fougeron & Keating, 1997). This domain-initial strengthening has been observed across languages but with different degree of realisation (e.g., Keating, Cho, Fougeron & Hsu, 2003).

The previous studies (Onaka, 2003; Onaka, Watson, Palethorpe, & Harrington, 2003) examined the effect of prosodic domains on acoustic and articulatory properties of speech segments in Japanese. The domain-initial consonants in Japanese were, in general, found to be produced with greater linguopalatal contact and longer acoustic and articulatory duration in higher prosodic domains than lower prosodic domains. This strengthening effect in Japanese was found to be strongly correlated with lengthening as in Korean (Cho & Keating, 2001), suggesting that domain-initial strengthening can be accounted for under the articulatory undershoot model (Lindblom, 1963). Furthermore, the domain-final vowels were also found to be associated with less linguopalatal contact and longer duration in higher prosodic domains. The domain-final vowels became acoustically more peripheral in higher prosodic domains, as shown by F1 and F2 values, indicating hyperarticulation. We have previously suggested (Onaka et al., 2003) that domain-final vowels could also undergo acoustic and articulatory changes due to prosodic position. While domain-initial strengthening occurs in Japanese, it is not as strong as might have been expected, suggesting that for Japanese domain-initial strengthening could be realised as a mutual effect between domain-final and domain-initial segments rather than being realised as an effect localised in domain-initial position.

The aim of the present study is to further explore these positional differences observed at prosodic boundaries, by asking whether prosodic strengthening is restricted to the domain-initial position, or whether it instead also affects domain-final consonants.

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2. Methods

2.1. Speech material

The speech material (based on Ueyama, 1997) was constructed to compare consonants immediately adjacent to a prosodic boundary (i.e., a sequence of C#C, where # is a prosodic boundary). In this study, the domain-final consonant that immediately preceded a prosodic boundary was a moraic nasal /N/ and the domain-initial consonants that immediately followed a prosodic boundary were /n/ and /t/. The consonants were placed in 5 different prosodic positions, i.e. utterance (U), intonational phrase (IP), accentual phrase (AP), word (W) and mora (M). The consonant sequence was preceded and followed by the same vowel /a/ to keep the contextual influence on consonant production a minimum. For all the test sentences, the target consonants were placed at the same mora positions to factor out possible declination effects (Keating et al., 2003). The (phonetic) contexts surrounding the target consonants were balanced as far as possible in keeping with the need to formulate meaningful sentences. A set of examples is given below where the target consonants are in bold, and surrounding vowels are underlined.

U Nakunatta rashii obaas<u>a</u>**n**. **T**<u>a</u>kayama-san mo ittemashita.
‘I heard that an old lady pasted away. Mr Takayama also said so.’

IP Tooi shinrui no obaas<u>a</u>**n**, **t**<u>a</u>chigigi da kedo, nanbyoo rashii.
‘I overheard that an old lady who is distantly related is suffering from an incurable disease.’

AP Tooi shinrui no obaas<u>a</u>**n** **t**<u>a</u>ssha da to, Nakata-san ga ittemashita.
‘I heard from Mr Nakata that an old lady who is distantly related (to him) is still going strong.’

W Tooi shinrui no obaas<u>a</u>**n** **t**<u>a</u>ra, dorobou ni atta rashii.
‘(Believe it or not) I heard that an old lady who is distantly related had a burglary.’

M Kouen de obaasan no d<u>a</u>**nt**<u>a</u>i ni aimashita.
‘At park I saw a group of old ladies.’

2.2. Speakers and procedures

Recordings were made from two female speakers of Tokyo Japanese. The test sentences were presented in Japanese orthography, one sentence at a time. Since it was important to obtain a consistent prosodic contour for a given sentence, the sentences were not randomised and presented in the order of the prosodic levels (Keating et al., 2003). A set of 5 test sentences for a particular prosodic positions and consonants formed a block. The blocks were recorded twice in quasi-randomised order, with the sentences in the second block given in a reverse order to avoid list effects. Thus, each sentence was repeated at least 10 times in total, giving approximately of 200 tokens (5 prosodic levels x 10 repetitions x 2 (domain-initial) consonants x 2 speakers).

The speech data was recorded in a sound-treated studio at the Speech Hearing and Language Research Centre, Macquarie University. Articulatory and acoustic data were recorded simultaneously using a Laryngograph EPG 3 eletro-palatograph (EPG). EPG and acoustic data were sampled at 100 Hz and 20 kHz, respectively and digitized directly onto a SUN workstation. The segmentation and phonetic labelling were carried out in the EMU speech data management system (Cassidy & Harrington, 2001). The labelling criteria followed those described in Croot and Taylor (1995). Based on auditory and pitch contour analysis, the utterances whose intended prosodic structure was not met were eliminated from the analysis.

2.3. Acoustic and articulatory measurements

The present paper focuses on the durational measurements. Acoustic durations of the target consonants /n/ and /t/, and the voice onset time (VOT) of /t/ were extracted from the labelled data.

The duration of articulatory movement, i.e. seal duration, was taken from EPG data. Seal duration was measured by identifying the first data frame showing a complete closure in the front region of a palate, and the last data frame before this closure ends. The time between these two frames was then calculated (cf. Cho & Keating, 2001). For this study, the time between the first frame of a complete closure (or onset of linguopalatal contact) and the maximum linguopalatal contact, and the time between the maximum linguopalatal contact and the last frame of a complete closure (or offset of linguopalatal contact) was also measured. These are referred as onset-to-maximum seal duration and maximum-to-offset seal duration, respectively.

3. Results

In the following analysis, a one-way analysis of variance (ANOVA) was carried out for each speaker with prosodic position as a main variable for each consonant context. When an ANOVA was significant, post-hoc Bonferroni tests at the 0.01 level of significance were also carried out. A two-tailed t-test at the 0.05 level of significance was performed when there were only two levels of prosodic positions available for comparison.

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The results from a one-way ANOVA will be given in the text, where appropriate.

This experiment was looking at possible strengthening effects on a consonant sequence at a prosodic boundary, i.e. domain-final and domain-initial consonants. Since the domain-initial and domain-final consonants had the same place of articulation, at some prosodic hierarchy position the two consonants were produced as a blend, rather than two separate consonants. Because of this, measurements taken in this study included subsets. The subsets were different for each speaker, for each consonant. Table 1 gives the subsets used in the study, and they are as follows.

For acoustic measurements for the consonant /t/ context, the measurements were calculated for the domain-initial consonant /t/ and the domain-final consonant /N/ (hereafter /N_t/) across all the domains for both speakers. For the consonant /n/ context, acoustically it was difficult to determine the boundary between the domain-final consonant /N/ (hereafter /N_n/) and the domain-initial consonant /n/ for IP (for Speaker 2) or AP (for Speaker 1) and the lower levels. Thus, there were subsets for both speakers. For Speaker1, the subsets were: (1) the domain-final consonant /N/ and the domain-initial consonant /n/ for U and IP, and (2) AP and lower levels for a blended consonant sequence (corresponding to the domain-final consonant /N/ and the domain-initial consonant /n/; /Nn/, hereafter). For Speaker 2, the subsets were: (1) the domain-final consonant /N/ and the domain-initial consonant /n/ for U, and (2) IP and the lower levels for /Nn/.

For articulatory measurements, the domain-final consonant /N/ and the domain-initial consonants /n/ or /t/ resulted in spatial overlap at some prosodic domain for both speakers for both consonants; there was a single articulatory movement observed for these domains. Thus, the measurements were taken for the following subsets: for the consonant /t/ context, for Speaker 1, (1) the domain-final consonant /N/ and the domain-initial consonant /t/ for U and IP, and (2) AP and the lower levels for a blended consonant sequence (corresponding to the domain-final consonant /N/ and the domain-initial consonant /t/; hereafter /Nt/), and for Speaker 2, /Nt/ for all the domains. For the consonant /n/ context, the subsets were: (1) the domain-final consonant /N/ and domain-initial consonant /n/ for U, and (2) IP and the lower levels for a blended consonant sequence (corresponding to the domain-final consonant /N/ and the domain-initial consonant /n/; hereafter /Nn/) for Speaker 1, and /Nn/ for all the domains for Speaker 2.

Table 1: Subsets analysed in the study. x = initial consonant; N_x = final nasal; Nx = consonant blend.

Acoustic Measurements	**Speaker 1**	**Speaker 2**
/t/, /N_t/	U,IP,AP,W,M	U,IP,AP,W,M
/n/, /N_n/	U,IP	U
/Nn/	AP,W,M	IP, AP,W,M
Articulatory Measurements	**Speaker 1**	**Speaker 2**
/t/, /N_t/	U, IP	na
/Nt/	AP,W,M	U,IP,AP,W,M
/n/, /N_n/	U	na
/Nn/	IP,AP,W,M	U,IP,AP,W,M

3.1. Acoustic duration

Table 2 summarises results of acoustic duration for the domain-final consonants /N_t/ and /N_n/, the domain-initial consonants /t/ and /n/, and the consonant sequence /Nn/.

3.1.1. Domain-final and domain-initial consonants

Comparisons were made for the following subsets: for the domain-final consonant /N_t/ for all prosodic levels for both Speaker 1 and Speaker 2; for the domain-final consonant /N_n/, the comparison was only made for Speaker 1 for U and IP. For the domain-initial consonant /t/, comparisons were made across all the domains for both speakers; for the domain-initial consonant /n/, the comparison was only made for Speaker 1 for U and IP. For Speaker 2, a measurement was available only for U for the domain-final and domain-initial consonants and thus no comparison was made for these consonants.

For the domain-final consonant /N/, the only significant difference was found for Speaker 1 where the duration of the domain-final consonant /N_t/ was significantly longer for IP than U, AP and W ($F(4,45) = 5.956$, $p = 0.001$). For Speaker 2, the difference was non-significant in both consonantal contexts.

For the domain-initial consonant /t/, there was an overall tendency for the consonant durations to become longer in higher prosodic domains. The total duration of /t/ and /t/ closure in higher-level domains (U and IP) was found to be significantly longer than that in lower-level domains (AP, W and M) (for the total duration of /t/, $F(4,45) = 32.501$, $p = 0.001$; for /t/ closure, $F(4,45) = 69.578$, $p < 0.0001$). For Speaker 2, there was no significant difference for the total duration of /t/ or /t/ closure. VOT is generally seen to be longer in higher prosodic domains for both speakers. For Speaker 1, VOT in higher prosodic domains (U, IP, AP) was found

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to be significantly longer than that in lower-level domains (W and M) ($F(4,45) = 49.248$, $p < 0.0001$). Among higher-level domains, VOT for IP was further found to be significantly longer than U and AP. For Speaker 2, higher prosodic domains (IP and AP) had significantly longer VOT than lower prosodic domains (M) where AP was also found to have significantly longer VOT than W ($F(4,42) = 8.119$, $p < 0.0001$). For the domain-initial consonant /n/, although the duration of the domain-initial consonant /n/ for IP appears to have longer duration than U for Speaker 1, the difference was non-significant.

Table 2: Mean duration (ms) and standard deviations (in parentheses) for the target consonants in different prosodic positions.

	Prosodic Domain				
Spk 1	**U**	**IP**	**AP**	**W**	**M**
/N_t/	67.31 (12.17)	84.1 (15.48)	65.23 (5.05)	67.11 (6.28)	72.69 (6.52)
total /t/	75.93 (12.64)	75.00 (11.33)	43.69 (4.86)	44.31 (6.98)	42.55 (10.54)
/t/ closure	100.33 (12.03)	111.99 (9.2)	72.49 (6.26)	62.44 (6.90)	58.83 (9.28)
VOT	24.4 (5.51)	36.99 (3.93)	28.8 (4.41)	18.13 (1.49)	16.28 (1.96)
/N_n/	65.88 (9.06)	74.77 (10.27)	na	na	na
/n/	50.26 (8.96)	56.05 (11.18)	na	na	na
/Nn/	na	na	113.25 (7.66)	109.42 (6.49)	103.12 (9.14)
Spk 2	**U**	**IP**	**AP**	**W**	**M**
/N_t/	73.71 (9.62)	84.27 (12.27)	82.99 (16.89)	81.97 (5.86)	83.5 (12.24)
total /t/	68.38 (18.05)	75.27 (19.59)	85.57 (16.90)	68.69 (16.62)	72.7 (13.71)
/t/ closure	42.72 (13.15)	48.69 (18.95)	55.02 (13.73)	46.54 (15.50)	54.62 (14.6)
VOT	25.65 (6.65)	26.58 (3.68)	30.55 (7.34)	22.15 (3.97)	18.08 (3.78)
/N_n/	63.31 (22.60)	na	na	na	na
/n/	54.92 (23.61)	na	na	na	na
/Nn/	na	128.75 (13.76)	141.91 (17.63)	92.6 (8.39)	102.12 (11.52)

3.1.2. /Nn/ blended consonant sequences

Subsets compared for the consonant sequence /Nn/ were AP and lower prosodic levels for Speaker 1, and IP and lower levels for Speaker 2.

For /Nn/, there was a trend for consonant duration to become longer in higher prosodic domains. For Speaker 2 the difference was significant between higher prosodic domains (IP and AP) and lower prosodic domains (W and M) ($F(3,32) = 28.789$, $p < 0.0001$). For Speaker 1 there was no significant difference.

3.2. Articulatory duration

Results of articulatory durational differences (i.e., seal duration) for the domain-final consonants /N_t/ and /N_n/, and the domain-initial consonants /t/ and /n/, and the consonant sequences /Nt/ and /Nn/ are presented in Figures 1 and 2.

3.2.1. Domain-final and domain-initial consonants

Analyses made here were for the domain-final consonant /N_t/ and the domain-initial consonant /t/ for U and IP for Speaker 1.

As can be seen in Figure 1a, while there appeared to be longer seal duration for the domain-final consonant /N_t/ for IP than U, the results were non-significant. For the domain-initial consonant /t/ (as can be seen in Figure 1b), there were significantly longer seal durations for U than IP for maximum-to-offset seal duration at $p = 0.057$, slightly above the chosen level of 0.05.

3.2.2. /Nt/ and /Nn/ blended consonant sequences

The subsets analysed were as follows: for the consonant sequence /Nt/, AP and the lower levels for Speaker 1, and /Nt/ for all the domains for Speaker 2. For the consonant sequence /Nn/, IP and the lower levels for Speaker 1, and /Nn/ for all the domains for Speaker 2.

In the consonant sequence /Nt/ (as shown in Figures 1c and 1d), for Speaker 2, U was found to have significantly longer seal duration than other prosodic domains from onset to maximum, and than IP and M from onset to offset (onset-to-maximum: $F(4,42) = 72.953$, $p < 0.0001$; onset-to-offset: ($F(4,42) = 75.122$, $p < 0.0001$). From maximum to offset, the difference was significant between U and IP, M ($F(4,42) = 7.243$, $p < 0.0001$). No significant differences were found in any seal duration measurements for Speaker 1.

For the consonant sequence /Nn/, as Figures 2c and 2d show, in general, higher prosodic domains were observed to have longer seal duration than lower prosodic domains. For Speaker 1, IP was found to have significantly longer seal duration from onset to maximum, and from onset to offset than other prosodic domains ($F(3,36) = 109.763$, $p < 0.0001$; $F(3,36) = 121.527$, $p < 0.0001$, respectively). From the maximum to offset, IP had a significantly longer seal duration than M ($F(3,36) = 6.562$, $p = 0.001$). For Speaker 2, overall, longer seal durations were observed for higher prosodic domains than lower prosodic domains. U was found to have significantly longer seal duration than other prosodic domains from onset to maximum, from maximum to offset, and from onset to offset

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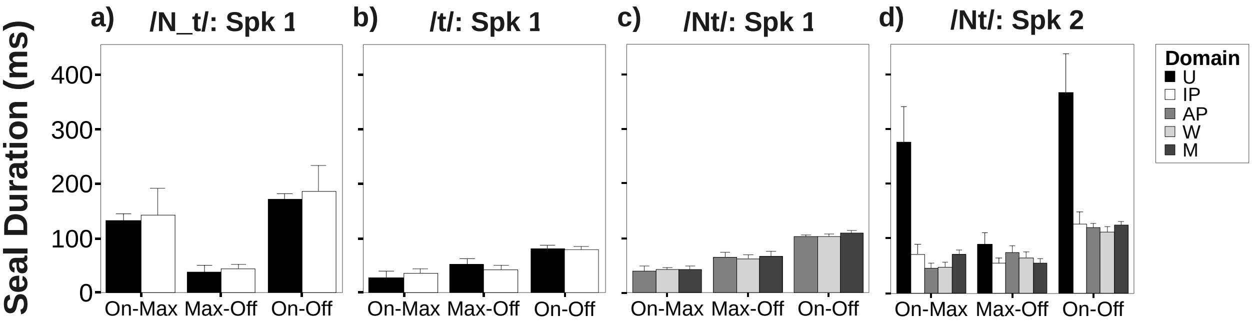

Figure 1: Mean seal durations and standard deviations of the domain-final and domain-initial consonants, and the consonant sequence /Nt/.

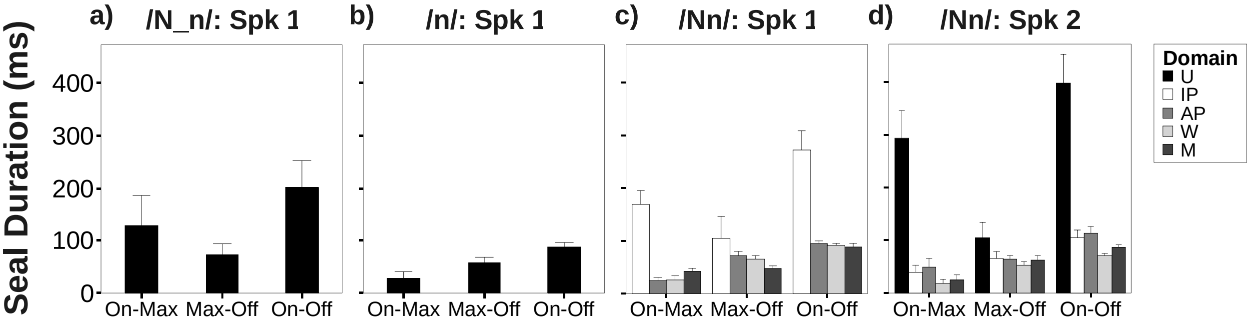

Figure 2: Mean seal durations and standard deviations of the domain-final and domain-initial consonants, and the consonant sequence /Nn/.

(onset-to-maximum: $F(4,40) = 111$, $p < 0.0001$; maximum-to-offset: $F(4,40) = 10.121$, $p < 0.0001$; onset-to-offset: $F(4,40) = 149.847$, $p < 0.0001$).

3.3. Relative seal duration

The consonant seal duration was further analysed by calculating the relative duration of onset-to-maximum seal duration to onset-to-offset seal duration. The comparison for Speaker 1 was for the domain-final consonant /N_n/ for U and the consonant sequence /Nn/ for IP and below levels, and the domain-final consonant /N_t/ for U and IP, and the consonant sequence /Nt/ for AP and below levels. For Speaker 2, /Nn/ and /Nt/ for all the prosodic domains was compared.

The relative duration of onset-to-maximum seal duration to onset-to-offset seal duration was found to be longer for higher prosodic domains than lower prosodic domains. For the consonant /t/ context, a significantly longer relative seal duration was observed for higher prosodic domains for both speakers ($F(4,45) = 38.409$, $p < 0.0001$ for Speaker 1; $F(4,42) = 18.141$, $p < 0.0001$ for Speaker 2). For Speaker 1, the difference was significantly different between higher prosodic domains U/IP and lower prosodic domains AP/W/M. For Speaker 2, U had significantly longer relative duration than other prosodic domains and IP also had significantly longer relative duration than AP and W.

For the consonant /n/ context, for both speakers a longer relative seal duration was observed for higher prosodic domains than lower prosodic domains. For Speaker 1, U and IP were found to have significantly longer relative durations than AP and W ($F(4,45) = 16.582$, $p < 0.0001$). For Speaker 2, the relative seal duration for /Nn/ was significantly longer for U than other prosodic domains and AP was also significantly longer than W ($F(4,40) = 18.62$, $p < 0.0001$).

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4. Discussion and Conclusions

The results from the acoustic data showed the effects of prosodic positions on duration for the domain-initial consonant /t/. In particular, VOT in higher prosodic domains had significantly longer VOT than lower prosodic domains. This effect of prosodic position on VOT, which was not found in our previous study (Onaka, 2003), may suggest hyperarticulation as the consonant /t/ becomes more stop-like in higher prosodic domains.

When the articulatory duration was examined, onset-to-maximum seal duration was significantly longer for higher prosodic domains. Furthermore, the relative duration of onset-to-maximum seal duration to total seal duration (i.e., onset-to-offset seal duration) was also found to become longer for higher prosodic domains suggesting consonant constriction was formed relatively later for higher prosodic domains or formed earlier in lower prosodic domains. Taken together, these results support previous findings (Onaka, 2003) that strengthening in Japanese is closely associated with longer duration, providing some support for the undershoot account of strengthening (Cho & Keating, 2001).

The results have also shown that there was no difference across prosodic domains in the domain-final consonant. A previous study demonstrated that a nasal in Japanese could be perceived as a moraic nasal even in onset position when a certain duration was maintained (Otake & Yoneyama, 1996). In this study, the domain-final consonant is a moraic nasal. It can be therefore postulated that, in order to maintain its moraic identity, which could be also important across different prosodic domains and at prosodic boundaries, the domain-final consonant could not significantly be lengthened or shortened in domain-final positions. At the same time, it is perhaps also important for the domain-initial consonant /n/ not to be lengthened so that it can still be perceived as a nasal but not as a moraic nasal. Furthermore, the results could also be interpreted in light of articulation (of the domain-final consonant). As can be seen in the figures, there was a pattern for the seal duration for onset-to-maximum to be longer than for maximum-to-offset. In contrast, for the domain-initial consonants, onset-to-maximum seal duration was shorter than maximum-to-offset seal duration. These may indicate that consonant constriction was formed later for the domain-final consonants. Thus, these findings could be a reflection of a longer inherent duration for a moraic nasal, or could be attributed to a different articulatory process involved in moraic nasals.

The question as to whether durational variations found at prosodic boundaries were derived from prosodic positional effects or categorical differences could be better evaluated in a follow-up study using a consonant such as a bilabial stop as the domain-initial consonant in order to be able to more carefully evaluate the effect of prosodic position on tongue movement.

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