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Preboundary lengthening in Japanese: To what extent do lexical pitch accent and moraic structure matter?[a)]

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In this acoustic study, preboundary lengthening (PBL) in Japanese is investigated in relation to the prosodic structure in disyllabic words with different moraic and pitch accent distributions. Results showed gradient progressive PBL effects largely independent of the mora count. The domain of PBL is better explained by the syllable structure than the moraic structure. PBL, however, is attracted toward a non-final moraic nasal, showing some role of the mora. The initial pitch accent does not attract PBL directly, but it suppresses PBL of the final rime as a way of maintaining the relative prominence, showing a language-specific PBL modulation.
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I. INTRODUCTION

Preboundary lengthening (PBL) refers to a temporal stretch of segmental materials in a word on the left of prosodic juncture, with the effects being more robust before a larger prosodic boundary than a smaller one (e.g., Edwards *et al.*, 1991; Berkovits, 1993; Byrd *et al.*, 2006; Turk and Shattuck-Hufnagel, 2007; Katsika, 2016). PBL may be taken to be a universally applicable low-level effect, as most languages show some degree of PBL (e.g., Fletcher, 2010; Cho, 2015). A growing number of phonetic studies, however, have revealed that the phonetic implementation of PBL may be fine-tuned by language-specific, higher-order linguistic structures, engendering cross-linguistic variations [see Fletcher (2010) or Cho (2015) for review]. In the present study, we explore the influence of linguistic structure on PBL in Japanese by focusing on the effects of the moraic structure and the pitch accent system, about which our understanding is limited or non-existent to the best of our knowledge.

A fundamental question of the present study concerns the phonetic nature of PBL in Japanese. PBL has been generally considered to be gradient in nature: the PBL effect, all else being equal, is strongest near a prosodic boundary and progressively decreases as a segment gets farther away from the boundary as found in acoustic studies on Hebrew and Finnish (Berkovits, 1993; Nakai *et al.*, 2009). The progressive PBL process may also be understood in gestural terms (e.g., Byrd and Saltzman, 2003): a non-tract variable "prosodic" (π-)gesture modulates the temporal realization of articulatory gestures near the prosodic juncture, with its effect gradually attenuating as an articulatory gesture becomes distal from the prosodic juncture. A recent articulatory-kinematic study on Korean (Kim *et al.*, 2019) indeed shows that PBL extends to the first lip closing gesture (C1 in disyllabic CVCV(C) words) largely in a progressively attenuating fashion. Given the cross-linguistic evidence, the present study explores the extent to which PBL in a disyllabic word in Japanese would be progressively gradient as a segment becomes distal from a prosodic boundary.

The present study also addresses an important theoretical issue with respect to what kind of the phonological unit that PBL may operate on. In English, PBL is assumed to operate primarily on the syllable structure, especially on the final syllable rime (e.g., Turk and Shattuck-Hufnagel, 2007), although the onset often undergoes a small but significant PBL effect (Byrd *et al.*, 2006; Kim *et al.*, 2017). Given that the mora is considered to be an important timing unit in Japanese (Kubozono, 1989, 1995; Otake *et al.*, 1993), one might hypothesize that PBL in Japanese operates in reference to the moraic structure rather than the syllable (rime) structure. [See Kubozono (2017) for review on the mora and the syllable in Japanese.] One way to test this possibility is to compare PBL effects on the final mora in CV.C<u>V</u> vs CV.CV<u>N</u> where a singleton vowel and a nasal coda each form a separate mora. If

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[a)]Part of this work with the TAKA word subset was presented at the *26th Japanese/Korean Linguistics Conference* in November 2018 and preliminary results on that subset data will appear in the *Proceedings of International Congress on Phonetic Sciences (ICPhS) 2019*.

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PBL operates on the mora, the magnitude of PBL on the final mora V in CV.CV will be more or less comparable to that on the final mora N in CV.CVN. Alternatively, if PBL operates on the syllable structure as in English, the PBL effect on the final V in CV.CV (which alone forms a rime) will be comparable to a combined sum of PBL effects on V and N in CV.CVN (in which V and N together form a rime). Another way to test the mora versus the syllable account is to examine whether PBL on the first vowel is constrained by the number of the following moras. The first V is followed by one mora in CV.CV but by two moras in CV.CVN (as V and N are separate moras). If the distribution of PBL is determined based on the mora count, the leftward extension of PBL to the first V is expected to be larger in CV.CV than in CV.CVN. Alternatively, if PBL operates in reference to the rime, the PBL effect on the first V (the rime of the penultimate syllable) will be comparable in both contexts, irrespective of the number of the following moras.

Finally, the present study investigates an interaction of PBL with the prominence system. Recent studies have indicated that lexical stress attracts PBL: PBL may be attracted to a non-final syllable if it is (lexically) stressed in English (Turk and Shattuck-Hufnagel, 2007) and Greek (Katsika, 2016). Japanese employs a prominence system which differs from that of English or Greek. It has a lexically determined pitch accent system (Haraguchi, 1988; Vance, 2008), and the phonetic saliency of Japanese pitch accent is mainly marked by F0 rise without necessarily involving change in duration and amplitude (Beckman, 1986, cf. Venditti, 2005). [See Beckman and Pierrehumbert (1986) and Venditti (2005) for more information on the Japanese prosodic structure.] Thus, Japanese provides a testbed for exploring the generalizability of the interaction between PBL and prominence across languages which employ different prominence systems. If PBL is indeed implemented in reference to the prominence itself regardless of the differences in the prominence-marking system, one might hypothesize that the initially pitch-accented syllable in Japanese may also serve as a distal locus of PBL, showing an attraction of PBL to the first syllable. Alternatively, if the PBL-prominence interaction is confined to languages with lexical stress which is marked by both F0 and duration, we might not find the prominence-induced attraction of PBL in Japanese.

II. METHOD

A. Participants, speech materials and recording procedure

Fourteen native speakers of Tokyo Japanese (7 females and 7 males, $M_{age} = 24.2$ years, range 19–29 years). As shown in Table I, two sets of target words (TAKA set vs SAKE/SAKO set) were used. Each set contained four different syllabic/moraic structures: **CV.CV** (2 μs), **CV.CVN** (3 μs), **CVN.CV** (3 μs), and **CVN.CVN** (4 μs) in two pitch accent conditions (unaccented vs initially accented), yielding 16 test words in total. Note that the two sets are not fully balanced in terms of segmental makeups: the TAKA set contains segmentally matched minimal pairs in terms of lexical pitch accent, but the SAKE/SAKO set differed in terms of the final vowel (/e/ vs /o/). (We could not devise two full target word sets that provided all the test conditions with identical segmental makeups.) The vowels used here are phonemically short (mono-moraic). Given that the lexical-level prominence effect may be further modulated by the sentence-level prominence especially induced by focus [as in English; cf. De Jong (2004); Cho (2015); Cho *et al.* (2017); Kim *et al.* (2017)], we included the focus factor to examine whether any observed interaction between boundary and pitch accent may be further conditioned by focus. As shown in Table II, the target words were embedded in carrier sentences consisting of a question-answer pair: the question (prompt) sentence (A) and a target-bearing sentence as an answer (B). The target word was placed in a phrase final position (IP-final) or in a phrase-medial position (IP-medial). [Note that in the IP-medial context, the target word was produced with a following particle (e.g., "to") which was encliticized, so that the target word itself was not phrase-final.] It was either focused (with corrective contrast between the target word and a word in the question sentence, TAKA vs SAKE) or unfocused (with corrective contrast on the preceding word, SONO vs KONO).

The participants were presented with each mini-dialogue on a computer screen, and heard a prompt question (prerecorded by a 25-year-old female native speaker of Tokyo Japanese). Then the participants read the target-bearing sentence in response to the (auditorily and visually presented) question sentence. The data were recorded in a soundproof

TABLE I. A list of target words. The TAKA set contains minimal pairs in terms of lexical pitch accent with the vowel /a/ across the board, but the SAKE/SAKO set contains near-minimal pairs with different vowels and consonants as compared with those in the TAKA set. The target words in the initially pitch-accented TAKA set were written in katakana. They are pseudo-words (resembling load words) where pitch accent falls on the first syllable.

Word types	TAKA				SAKE/SAKO			
Structure	CV.CV ($2\sigma, 2\mu$)	CVN.CV ($2\sigma, 3\mu$)	CV.CVN ($2\sigma, 3\mu$)	CVN.CVN ($2\sigma, 4\mu$)	CV.CV ($2\sigma, 2\mu$)	CVN.CV ($2\sigma, 3\mu$)	CV.CVN ($2\sigma, 3\mu$)	CVN.CVN ($2\sigma, 4\mu$)
Unaccented	鷹 TAKA *hawk*	炭化 TANKA *carbonization*	多感 TAKAN *sensibility*	短観 TANKAN *short-term survey*	酒 SAKE *alcohol*	産気 SANKE *labor pains*	差遣 SAKEN *dispatch*	三権 SANKEN *three powers*
Initially pitched-accented	タカ TA'KA	タンカ TA'NKA	タカン TA'KAN	タンカン TA'NKAN	迫 SA'KO *personal family name*	三個 SAN'KO *three units*	左近 SA'KON *personal name*	サンコン SAN'KON *personal name*

TABLE II. Example sentences with TAKA as the target word. The target word is underlined and it is in bold when it is meant to receive contrastive focus.

Boundary	Focus	Example sentences	
IP-final	FOC	A. 今度もその酒、試しに使ってみる？ [kondo-mo][sono-**sake**], [tameʃi-ɲi-ʦɯkat-te-mirɯ]? A. Do you try and use that **SAKE** this time again?	B. いいえ、今度はその鷹、試しに使ってみる。 [iie]$_{IP}$, [kondo-ɰa]$_{IP}$[sono-**take**]$_{IP}$, [tameʃi-ɲi-ʦɯkat-te-mirɯ]$_{IP}$. B. No, this time I try and use that **TAKA**.
	No FOC	A. 今度もこの鷹、試しに使ってみる？ [kondo-mo][**kono**-sake], [tameʃi-ɲi-ʦɯkat-te-mirɯ]? A. Do you try and use **THIS** sake this time again?	B. いいえ、今度はその鷹、試しに使ってみる。 [iie]$_{IP}$, [kondo-ɰa]$_{IP}$[**sono**-taka]$_{IP}$, [tameʃi-ɲi-ʦɯkat-te-mirɯ]$_{IP}$. B. No, this time I try and use **THAT** taka.
IP-medial	FOC	A. これは、その酒と一緒に置きますか？ [kore-ɰa], [sono-**sake**-toiʃʃo-ni-oki-masɯ-ka]? A. Do you put this with that **SAKE**?	B. いいえ、今度はその鷹と一緒に置きます. [iie]$_{IP}$, [kondo-ɰa]$_{IP}$[**sono**-taka-to-iʃʃo-ni-oki-masɯ]$_{IP}$. B. No, this time I put it with that **TAKA**.
	No FOC	A. これは、この鷹と一緒に置きますか？ [kore-ɰa], [**kono**-take-to iʃʃo-ni-oki-masɯ-ka]? A. Do you put this with **THIS** taka?	B. いいえ、今度はその鷹と一緒に置きます. [iie]$_{IP}$, [kondo-ɰa]$_{IP}$ [**sono**-taka-to-iʃʃo-ni-oki-masɯ]$_{IP}$. B. No, this time I put it with **THAT** taka.

booth with a Tascam HP-D2 digital recorder and a SHURE KSM44 microphone at a sampling rate of 44 kHz. In total, 5376 tokens were collected (2 target word sets × 4 mora structures × 2 pitch accents × 2 focus conditions × 2 boundaries × 6 repetitions × 14 speakers). 406 tokens that deviated from the intended prosodic renditions as agreed upon by the authors were excluded from the further analysis.

B. Measurements and statistical analyses

We measured the duration of each segment in the target words by using PRAAT (Boersma and Weenink, 2018). The measurements were made by comparing the waveform and the spectrogram. VOTs for Cs were generally very short with no considerable change due to Boundary (as confirmed by preliminary statistical analyses), so that they were included as part of the vowel duration as suggested by Turk *et al*. (2006). The durational measures included C (closure duration: from the end of F2 of the preceding vowel to the closure release), V (VOT plus vowel duration: from the release to the end of the vowel as marked by F2 in CVCV or from the release to the onset of nasal murmur in CVN.CVN), and N (nasal murmur as indicated by an overall weakening of (especially higher) formants which are reorganized due to nasal zeros and poles).

A series of linear mixed effects regression (LMER) models were fitted to each measure for each target word type, using the lme4 package (Bates *et al*., 2015). Fixed effects were contrast coded and included prosodic boundary (henceforth boundary, IP-final vs IP-medial), pitch accent (initially accented vs unaccented), focus (focused vs unfocused), and segmental context (TAKA vs SAKE/O series) and their interactions. Because of the segmental mismatch between the TAKA and SAKE/KO sets, we included the segmental context only as a control factor whose effect will not be reported in the present study. The random-effect structure was implemented with random intercepts for participant and random slopes for boundary, pitch accent, and focus. [5 out of 20 models did not converge, so that the random slope for focus was included without an interaction term (4 out of 5) or focus was excluded (1 out of 5)]. When there was an interaction between boundary and pitch accent, planned comparisons (i.e., the boundary effect as a function of pitch accent) were carried out by fitting the subset of the data to LMER models. Finally, additional models were fitted to Δ(IPf-IPm) when it was necessary to test the difference in PBL effects between conditions (e.g., the effect of the moraic structure of the final syllable on the preceding syllable as in CV.CV vs CV.CVN). Note also that statistical analyses revealed no three-way interaction that involved focus (i.e., boundary × pitch accent × focus), indicating that the PBL effect related to pitch accent was not further conditioned by focus. The report of the results will therefore be limited to effects of boundary and pitch accent and their interactions.

III. RESULTS

Results of LMER models with respect to the boundary effect on durational measures (henceforth the PBL effect) are summarized in Table III and Figs. 1 and 2. Note that although the LMER models were based on values in each condition for a given factor, the figures were drawn to illustrate the magnitude of PBL in both the absolute and relative terms [i.e., defined as Δ(IPf-IPm)] and as %-increase [i.e., Δ(IPf-IPm)/(IPm*100)].

A. CV.CV and CV.CVN

There were significant PBL effects up to V1 in both CV.CV and CV.CVN [Table III (a, b)]. As visualized in Figs. 1(a) and 1(b), the PBL effect was prominent near the boundary, and attenuated as the segment became farther away from the boundary, showing a leftward spread of PBL up to V1, regardless of the number of moras/segments in the final syllable. Put differently, for both CV.CV and CV.CVN, there was a gradually increasing (rightward) progression of PBL from V1 onwards. The gradual progression appears to be broken at the

TABLE III. A summary of the results of linear mixed effects models with regard to the boundary effect (B) and the interaction between boundary and pitch accent (B × PA). $^{*}p < 0.05$. $^{*}p < 0.01$. $^{***}p < 0.001$.

(a)		C1	V1	C2	V2		
B	CVCV	*n.s.*	$\beta = 4.84$, $t = 7.35^{**}$	$\beta = 15.67$, $t = 10.47^{***}$	$\beta = 26.3$, $t = 5.39^{***}$		
B × PA		*n.s.*	*n.s.*	*n.s.*	$\beta = -20.06$, $t = -6.3^{***}$		
(b)		C1	V1	C2	V2	N2	
B	CVCVN	*n.s.*	$\beta = 4.44$, $t = 8.14^{***}$	$\beta = 6.55$, $t = 5.34^{***}$	$\beta = 15.78$, $t = 6.31^{***}$	$\beta = 15.41$, $t = 2.46^{*}$	
B × PA		*n.s.*	*n.s.*	*n.s.*	$\beta = -13.82$, $t = -9.03^{***}$	$\beta = -7.36$, $t = -2.43^{*}$	
(c)		C1	V1	N1	C2	V2	
B	CVNCV	*n.s.*	$\beta = 3.26$, $t = 3.92^{**}$	$\beta = 7.75$, $t = 6.12^{***}$	$\beta = 25.2$, $t = 15.87^{***}$	$\beta = 35.78$, $t = 6.78^{***}$	
B × PA		*n.s.*	*n.s.*	*n.s.*	$\beta = 5.29$, $t = 4.33^{***}$	$\beta = -20.85$, $t = -6.05^{***}$	
(d)		C1	V1	N1	C2	V2	N2
B	CVNCVN	*n.s.*	$\beta = 2.58$, $t = 3.69^{***}$	$\beta = 4.52$, $t = 4.27^{***}$	$\beta = 14.13$, $t = 11.13^{***}$	$\beta = 22.23$, $t = 8.02^{***}$	$\beta = 18.63$, $t = 3.03^{**}$
B × PA		*n.s.*	*n.s.*	*n.s.*	*n.s.*	$\beta = -10.17$, $t = -4.43^{***}$	$\beta = -7.43$, $t = -1.8$

end in the absolute term Δ(IPi-IPm) [Fig. 1(b), upper panel]: in CV.C**VN** the PBL effect on N was not necessarily larger than on the preceding V. Such discontinuity, however, disappeared in the relative term (%-increase, lower panel). The results also indicated that the single effect of PBL on the last mora V2 in CV.C**V** [Fig. 1(a)] was far greater than that on the last mora N2 in CV.CV**N** [Fig. 1(b)] in both the absolute and relative term. The PBL effect on V2 in CV.C**V** is rather comparable to a combined PBL effect of V2 and N2 which together form a rime [Fig. 1(b′)]. As for the effect of the moraic structure (or the mora count) of the final syllable, the magnitude of the PBL effect on V1 was largely comparable across the two conditions CV.CV and CV.CVN [Figs. 1(a), 1(b)], regardless of the number of moras in the final syllable. There was indeed no effect of the final moraic structure on Δ(IPf-IPm) of V1 ($\beta = -0.75$, $t = -1.11$, $p > 0.1$). Finally, it is noteworthy that Δ(IPf-IPm) of the onset (C2) of the last syllable was significantly larger in the open syllable (CV.**C**V) than in the closed syllable (CV.**C**VN), ($\beta = -9.17$, $t = -8.88$, $p < 0.001$), indicating that the magnitude of PBL on the onset is further modulated by the number of segments in the rime.

B. CVN.CV and CVN.CVN

These two word types also showed a general leftward spread of PBL up to V1 [see Table III (c, d) and Figs. 1(c), 1(d)]. As was the case with CV.CV(N)words, the PBL effect on N2 alone in CVN.CV**N** was far smaller than the PBL effect on V2 in CVN.C**V**. Instead, a combined effect of V2 and N2 in CVN.C**VN** [Fig. 1(d′)] was more or less comparable to the PBL effect on V2 in CVN.C**V**. Furthermore, there was no effect of the moraic structure of the final syllable (CVN.CV vs CVN.CVN) on the PBL of V1 as reflected in Δ(IPf-IPm) ($\beta = -0.75$, $t = -1.12$, $p > 0.1$), indicating that the PBL effects on the preceding vowel (V1) did not differ as a function of the number of segments or moras in the final

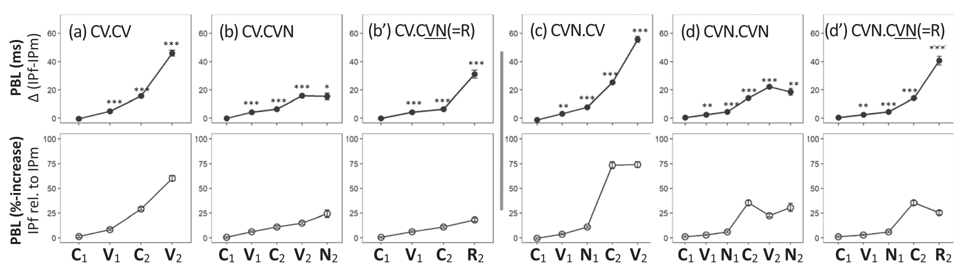

FIG. 1. The magnitude of increase from IP-medial to IP-final position for each segment pooled across accent types in absolute terms (in ms, upper panels) and in relative terms (%-increase, lower panels). The indicated significance ($^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$) was obtained from LMER models which were fitted to the data of each condition of the boundary factor, but the means provided in the figure refers to the magnitude of PBL [Δ(IPf-IPm) in ms].

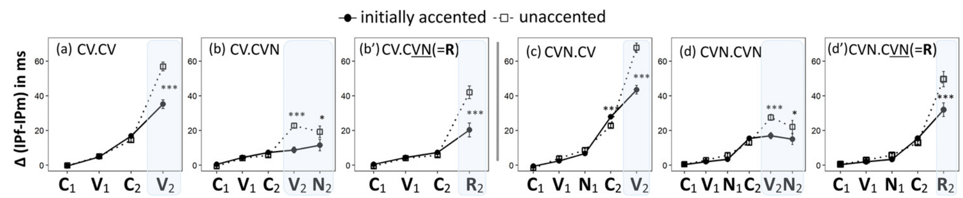

FIG. 2. (Color online) The magnitude of absolute increase from IP-medial to IP-final position as a function of pitch accent type. Solid lines with filled circles refer to initially pitch-accented words, and dotted lines with empty squares unaccented words. The indicated significance in the figure (*p < 0.05; **p < 0.01; ***p < 0.001) was obtained from LMER models which were fitted directly to the magnitude of PBL [Δ(IPf-IPm) in ms].

syllable. Again, as was the case with CV.CV(N), Δ(IPf-IPm) of the onset (C2) of the last syllable was significantly larger in CVN.**CV** than in CVN.**CVN**. Unlike the case of CV.CV(N), however, an additional interesting pattern was observed in conjunction with the nasal consonant (N1) in the middle of CVN.CV(N). Notice that the PBL of C2 after N in CVN.CV(N) increased abruptly [Figs. 1(c)–1(d)]. While the abrupt increase for C2 was evident in both the absolute and relative term, it was particularly noticeable in %-increase [lower panels of Figs. 1(c)–1(d)]. This indicates that the gradual progression of PBL at least at the acoustically defined segmental level may be broken by the medial NC cluster.

C. Interaction between boundary and pitch accent

Figure 2 visualizes the boundary × pitch accent interaction effects in terms of Δ(IPf-IPm) (see Table III for a statistical summary). All four word types [Figs. 2(a)–2(d)] showed some interactions between boundary and pitch accent mostly on the segments in the final syllables. Crucially, it is not that the initially pitch-accented syllable attracts PBL (i.e., no effect of pitch accent on the PBL of the initial syllable), but that the PBL effect is suppressed on the final rime when in the initially pitch-accented condition. This suppression, as highlighted in gray in Fig. 2, was observed across all word types, especially clearly on the final rimes.

IV. SUMMARY AND DISCUSSION

A basic finding of the present study is that Japanese showed PBL effects on all segments except for the onset (C1) of the first syllable—i.e., a leftward spread of PBL up to the first vowel across all four disyllabic word types: **CV.CV** (2 μs), **CV.CVN** (3 μs), **CVN.CV** (3 μs), and **CVN.CVN** (4 μs). The leftward spread further illustrated a general tendency towards a progressive PBL effect in a largely gradient fashion. This was especially true in the sense that the PBL effects were larger on the final syllable than on the preceding syllable, and larger on the rime than on the onset. On a related point, there was some phonetic proximity effect at least within the final syllable. The PBL effect on the onset C was larger in the open syllable (CV(N).**C**V) than in the closed syllable (CV(N).**C**VN). Given that the onset C is phonetically more proximal to the prosodic boundary in CV# than in CVN# (where # = a prosodic boundary), the asymmetry may be interpreted as suggesting that the PBL effect is modulated at least in part by the segment's phonetic proximity to the boundary. (The rime duration was indeed on the average 94.5 ms shorter in CV# than in CVN#.) These results are largely in line with assumptions of the π-gesture theory (e.g., Byrd and Saltzman, 2003). The observed gradual progression effect is consistent with the view that the influence of prosodic boundary on the temporal realization of articulatory gestures gradually waxes and wanes across the prosodic juncture; and the asymmetric effect on C in CV# vs CVC# is consistent with the view that the domain of the influence of the π-gesture is more or less fixed, so that the effect is larger when a gesture is phonetically more proximal to the boundary.

The results, however, indicated that the progressive PBL effect, however, may not be strictly linear in some aspects. First, the PBL effect on the final N in CV(N).CVN was not necessarily larger than that on the preceding vowel in the absolute term Δ(IPf-IPm), presumably reflecting the intrinsic durational difference between V and N within the last syllable. However, such discontinuity disappeared in the relative measure (%-increase), still maintaining the gradual progression from V to N. It is also noteworthy that the progression effect in the relative term, though not in the absolute term, is still consistent with the π-gesture theory. Furthermore, even in the absolute term a gradual progression emerged when the PBL effects on V and N were considered as a combined PBL effect to form a rime.

Second, recall that there was an abrupt boosting-up effect on C in the NC cluster in CV**N**.**C**V(N). This added some discontinuity to the gradual progressive PBL effect, especially in the relative (%-increase) measure. This may be seen as suggesting that the word-internal moraic structure (with N forming a mora) does play some role in distribution PBL. However, it is not entirely clear why the augmented PBL effect was not found on the N itself but on the following C. While this issue remains to be further elucidated, we can offer a rather speculative explanation. In Japanese, a nasal consonant N in the NC cluster becomes homorganic with the following C (cf. Vance, 2008). Given that C in NC is [k] in this study, the actual phonetic form of N would be [ŋ]. Crucially, the nasal [ŋ] in the homorganic [ŋk] cluster may be at least partially devoiced due to a possible coarticulatory devoicing effect coming from the voiceless [k] (cf. Myers, 2002). Thus, the measured duration of the voiceless closure for C may contain the devoiced nasal component. It is therefore possible that the lengthening of C reflects the PBL effect on the devoiced portion of [ŋ], and the phonetic realization of the mora is integrated into the consonant cluster as a whole. If this were the case (although it would be subject to further corroboration), the extended C duration might be interpreted as an attraction of PBL to the nasal. The attraction effect may enhance the moraic representation by the temporal extent embedded in the NC cluster (through the augmented voiceless percept associated with the mora), presumably to remain phonetically salient in relation to the temporal extent of the following moraic vowel which undergoes a substantial PBL effect.

Our results also elaborate on information regarding the phonological units on which PBL may be implemented. Recall that the PBL effect on V2 in the open syllable [CV(N).C**V**] was far greater than that of either V2 or N2 in the closed syllable [CV(N).C**VN**], and that the effect on V2 in the open syllable was comparable to a combined effect of V2 and N2 in the closed syllable. These results suggest that the final moraic N does not serve as an independent PBL-bearing unit, but that PBL operates primarily on the rime. In other words, as far as the final syllable is concerned, the distribution of PBL appears to be better accounted for by the syllable structure rather than the moraic structure (see Kubozono, 2017, more discussion on phonological roles of the syllable in Japanese). Furthermore, the mora count of the final syllable had no significant effect on the PBL of the preceding vowel (V1). More generally, the PBL effect was observed on the first vowel across all four disyllabic word types regardless of the number of moras that followed. This general pattern implies that the scope of PBL is determined in reference to the syllable structure, rather than the mora structure.

Finally, the findings with respect to the interaction between PBL and pitch accent illuminate the nature of how PBL may be constrained by the prominence system in Japanese. We observed that when the initial syllable was pitch accented, the PBL effect on the final rime was suppressed in all four disyllabic word types. This appears to run counter to what was found in English or Greek (e.g., Turk and Shattuck-Hufnagel, 2007; Katsika, 2016). The restriction on PBL in the final rime when the word is initially pitch accented is presumably due to the possibility that too much lengthening on the final syllable would make the final syllable too salient to maintain the relative prominence of the pitch-accented initial syllable. An unrestricted PBL in the final syllable would have blurred the syntagmatic relationship in the prominence distribution between the accented initial syllable and the final syllable. This is somewhat reminiscent of Finnish, in which vowel quantity interacts with PBL, which may be driven by the maintenance of paradigmatic contrast in the distribution of long *versus* short vowels under the influence of the PBL effect (Nakai *et al.*, 2009). Seen from a different angle, the suppression of PBL in the final rime in the initially pitch-accented condition can be considered as a language-specific way of enhancing the prominence of the pitch-accented syllable in Japanese: the suppression of the final rime would render the pitch-accented initial syllable more salient relative to the final syllable. It is then reasonable to assume that the cross-linguistic difference (i.e., the suppression of PBL in the final rime in Japanese and the expansion of PBL in the stressed non-final syllable in English) can be taken to be driven by the same principle—i.e., the maintenance of some kind of syntagmatic contrast in the prominence distribution in conjunction with the distribution of boundary-related PBL. As a reviewer suggested, however, it remains to be further elucidated how the durational effect comes into play when maintaining syntagmatic contrast, especially given that the pitch accent in Japanese is known to be marked primarily by F0 cue. But our preliminary results (Kim *et al.*, in preparation) suggest that although the temporal realization of the first syllable is not generally affected by the pitch accent, the rime of the second syllable is significantly shorter in the initially pitch-accented condition than in the unaccented condition.

In conclusion, Japanese shows a general progressive PBL effect in line with cross-linguistic patterns, and the PBL effect spreads up to the first vowel in most cases of disyllable words largely independently of the mora count, although the phonetic content (e.g., the number of segments within the last syllable) appears to influence the magnitude of the PBL effect in a gradient fashion. More broadly, the results imply that the exact way that PBL is distributed over the disyllable words is systematically fine-tuned in a language-specific way (i.e., in reference to the language's higher-order rhythmic structure that involves the moraic structure and the lexical pitch accent in the case of Japanese). It remains to be seen how the current findings may generalize to other words with more than two syllables in Japanese and how they are exploited in speech comprehension.

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