Morphological boundary in high vowel devoicing in Japanese: Two production experiments*

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1. Introduction

Among the five short vowels *i*, *e*, *a*, *o*, *u* in standard Tokyo Japanese (hereafter Japanese), the high vowels *i* and *u* are frequently devoiced between voiceless consonants (e.g., *ki'sha* [ki̥'ɕa] 'train') and in final position after a voiceless consonant (e.g., *ka'shi* [ka'ɕi̥] 'confection').[1] High vowel devoicing (HVD) is almost categorical in some environments, and variable in others in the sense that the application may be blocked. The source of variability has been extensively investigated in the literature on HVD, especially in terms of the phonological factors conditioning the HVD (segmental and prosodic). For example, see Fujimoto (2015), Kilbourn-Ceron and Sondregger (2018), and Maekawa and Kikuchi (2005). However, the morphological condition has not been studied well enough. It has been argued in the HVD literature that HVD can be sensitive to morphological boundaries. For example, McCawley (1968) observed that accent shifting in verb and adjective alternations triggered by HVD occurs within the stem. Vance (1992), looking at compounds with two potential undergoers of HVD in successive syllables, found that the presence of a morphological boundary prohibits HVD.

The visibility of word-internal structures in HVD is a challenge to some phonological theories. According to Lexical Phonology (e.g., Kiparsky 1982), for example, processes in the post-lexical domain do not refer to word-internal structures (only phonological information is available in that domain). Yet, HVD is a post-lexical process, as it can apply across a word boundary (e.g., *ha'shi totte* [ha'ɕi̥ totte] 'give me chopstick(s)' cf. *ha'shi dashite* [ha'ɕi daɕi̥ te] 'take out chopsticks (from, for example, the drawer)') (for other characteristics of HVD as a post-lexical process, see Hirayama 2009). The reference to word-internal information is not expected in some prosody-morphology/

syntax interface hypotheses (e.g., Nespor and Vogel 1986, 2007): phonological/phonetic rules refer only to prosodic structure and not directly to morphological/syntactic structure.

The visibility and invisibility of morphological information in processes in the post-lexical domain have been discussed in other languages as well. For example, in North American English, there is a post-lexical process called flapping. It is post-lexical as it can apply across a word boundary (e.g., *see you* [ɾ]*omorrow*). The literature offers different results with respect to the involvement of morphology in this process. In Patterson and Connine (2001), as reported in Herd *et al.* (2010), it was found that monomorphemic words showed more flapping than did bimorphemic words. In contrast, Herd *et al.* (2010) found that the number of morphemes in a lexical item does not affect the flapping rates.

In this paper, I explore the effects of morphological boundaries in HVD in two production experiments. The results suggest that HVD is not sensitive to such boundaries. The rest of this paper is organized as follows. I first discuss studies on HVD that consider morphological boundaries a factor that blocks HVD (section 2). I point to the need for a study in which factors are well controlled for, as it is ambiguous whether the claimed effect is morphological or phonological. I present my experiments, in which I control for those factors and disentangle the morphological and phonological information to test their effects separately (sections 3 and 4). I show that there is no effect of morphological boundaries of the kind explored in my experiment. Section 5 discusses the findings in this study together with those in the literature. Section 6 presents a summary and directions for future research.

2. HVD literature

Kondo (1997), Vance (1992), Yoshida (2004), and Imai (2004) examined morphological boundaries as a blocking factor in HVD. I show that different types of morphological boundaries are discussed in the literature. I will further show that a study with a more controlled experimental design is necessary.

As discussed below, scholars have claimed that morphological boundaries have a blocking effect in HVD. However, this effect has been reported in the environment of two devoiceable vowels in successive syllables. When there is only one devoiceable vowel in the word, morphological boundaries are usually not mentioned. There are two exceptions, however. Kondo (1997: 145) found that vowels are devoiced regardless of the following boundary when there is only one devoiceable vowel in the word, whereas Yoshida (2004) argued that there is a blocking effect at the boundary. Yoshida found that the devoicing rates are far lower (86.7% on average) before what he called the "compound boundary" than before the "morpheme boundary" (99.2% devoicing). His "morpheme boundary" appeared to refer to a boundary before a bound morpheme (he said it "never appears solely"), which also corresponds to one Chinese character (*kanji*). His "compound boundary," in contrast, appeared to refer to one before a free morpheme (Sino-Japanese). All words in this category have two Sino-Japanese words that are bimorphemic compounds themselves. However, if we look more closely at the words involving the "compound boundary" and their individual devoicing rates, the average percentage reported (86.7%) does not seem to represent the group in general. Over half the words (6 out of 11) have a 100% devoicing rate. Two words have 54.5%, and the remaining three have 72.7%, 80.0%, and 90.9%.[2] Yoshida suggested that his data may be better explained by the number of moras in the word components, although he did not investigate this possibility any further. These works thus suggest that there is no obvious boundary blocking effect when there is only one devoiceable vowel in the word.

Imai (2004: 84–89), examining HVD from sociolinguistic perspectives, reported the inhibitory effects of word-related boundaries. She made a distinction between bound and free morphemes (p. 44) and examined five types: morpheme-internal (no boundary), pause, bound morpheme boundary, compound boundary, and word boundary. Her "bound morpheme boundary" includes boundaries at the inflectional and derivational morphemes and "bound content morphemes" (p. 44), including those within Sino-Japanese bimorphemic compounds (binoms). Her compound boundary lies between free forms, including Sino-Japanese binoms (p. 44). She found that when the high vowel was morpheme-internal or followed by a bound morpheme, HVD was promoted (the weights were above 0.5 in the results of a logistic regression analysis conducted with GoldVarb), and if the vowel was followed by a pause, or word or compound boundary, HVD was disfavoured (weights were below 0.5). However, when vowels in the consecutive devoicing environments were excluded (Table 4.20, p. 88), only the compound boundary seemed to demote HVD with 35% devoicing, as opposed to morpheme-internal HVD (78%), HVD at the bound morpheme boundary (66%), and word boundary (71%) (no statistical results were provided). The compound boundary inhibits HVD even in a single devoicing environment.

Cases of blocking when there are two devoiceable vowels in successive syllables have been discussed extensively in terms of morphological boundaries.[3] For example, Imai (2004: 88, Table 4.20) found that the HVD rate is very low at the "compound boundary" (8% and 14% devoicing depending on whether the previous devoiceable vowel is not devoiced or devoiced, respectively) and about 50% at the "bound morpheme boundary."

Kondo (1997: 109–111, 145) found that devoiceable vowels may not be devoiced when they are accented, followed by an "internal word boundary," or both accented and followed by the boundary. These points require some discussion. First, the definition of the "internal word boundary" is stated intuitively rather than defined structurally. Kondo recognized a boundary in words in (1a), (1b), and (1c) ("+" indicates a boundary between components in a compound; meaning of words as a whole is mine), but she did not recognize a boundary in words in (1d). She said that words in (1a, b, c) have a "clear word boundary" while as for those in (1d), "[a] native speaker may not be aware of word boundaries in some words even though strictly speaking they are present" (p. 110).[4]

(1) a. *ryokuchi* 'green area' + *kooen* 'park' 'park'
kutsu 'shoe' + *koojoo* 'factory' 'shoe factory'
b. *hoochi* 'informing' + *ki* 'apparatus' 'alarm'
kooshu 'strangling' + *kei* 'punishment' 'death by hanging'

c. *desaki* 'local branch' + *kikan* 'office' 'branch office'
Toohoku 'north east' + *chihoo* 'district' 'Tohoku'

d. *boku* 'pastoral' + *chiku* 'livestock' 'cattle breeding'
koku 'hardship' + *fuku* 'to overcome' 'overcoming (something)'

Her division of the words in (1a, b, c) into one group and those in (1d) into another appears to have distinguished the level of compoundedness of the word. In the compounds in (1a, b, c), at least one of the components is a compound itself (e.g., [[ryoku-chi] [koo-en]], [[koo-shu] kei]; [ ] indicates a compound), whereas the compounds in (1d) comprise single morphemes (e.g., [boku-chiku]). Most of the words in (1) are Sino-Japanese. In Itô and Mester's (1996, 2015a) analysis of Sino-Japanese items, the words in (1a-c) are all word compounds whereas those in (1d) are stem-stem or root-root compounds. The boundary in words in (1d) would have been called bound morpheme boundaries in Imai (2004) whereas those in (1a) and (1c) would have at least been her idea of a compound boundary. Second, there seem to be factors that have not been controlled, such as the preceding consonants and word length. Third, her results seem to suggest a potential interaction with accent. These factors were considered in Vance (1992), as well as the position of the devoiceable vowel in the word.

Vance (1992) found that HVD in Japanese is sensitive to morphological boundaries in that vowels at the boundary inhibit devoicing. However, a closer look at his data makes us wonder if it is really morphology that is at work. Vance looked at 24 compounds comprising two components, taken from the *HNK Pronunciation and Accent Dictionary* (1966).[5] Given that only one vowel is devoiced when there are two in consecutive devoicing environments, he examined words that have potential undergoers of HVD in two successive syllables, either both before the boundary, as in (2a) (underlining indicates the potential undergoers of devoicing), or across two parts of the compound, as in (2b).

(2) a. *enpitsu* ‘pencil’ + *kezuri* ‘sharpener’
b. *insatsu* ‘printing’ + *kikai* ‘machine’

After carefully controlling for the preceding consonant, accent, and position of the devoiceable vowel in the word, Vance found that in both types of words (2a) and (2b), the devoiceable vowels adjacent to the boundary do not undergo devoicing, whereas the others do. In Vance’s data, all except one include Sino-Japanese binoms. Thus, the morphological boundary in his study is similar to the compound boundary in the above discussed studies, at least in most data.

However, if we look closely at Vance’s (1992) data, it is unclear whether this boundary effect is morphological or phonological, as the morphological and phonological boundaries coincide, especially foot (and Prosodic Word) boundaries. For one, most words that he considers have four moras in the first noun. As Japanese feet have been argued to be canonically bimoraic (e.g., Kubozono 1999, Poser 1990, Tateishi 1989), if feet are formed within a morpheme and not formed across a morpheme boundary (e.g., Kubozono 2008), the morphological boundaries coincide with foot boundaries.

If we follow Itô and Mester’s (1996, 2015a) analysis of Sino-Japanese compounds (and assume that their proposed prosodic structure carries over in the post-lexical domain, where HVD occurs), the morphological boundaries in Vance’s words, of which all but five are Sino-Japanese, coincide both with Prosodic Word (PrWd) and foot boundaries. This is because, according to Itô and Mester (1996, 2015a), each Sino-Japanese morpheme (i.e., each *kanji*) constitutes a foot, and a compound comprising multiple *kanji* constitutes a PrWd. In all of Vance’s Sino-Japanese words, at least one of the components is a (Sino-Japanese) compound, so these components constitute PrWds. By definition all PrWd boundaries in Sino-Japanese words are also foot boundaries. Among the remaining five words, four have a Sino-Japanese compound (and therefore a PrWd) as a component.[6] If this is so, by the same token, the morphological boundaries coincide with PrWd and foot boundaries, that is, foot boundaries that are also PrWd boundaries. The only word that does not have a Sino-Japanese component is *higashi+kita* （東北） ‘northeast’, which comprises only Native words. It is not clear whether the morphological boundary (+) coincides with a PrWd boundary in this word, but it is likely to coincide with a foot boundary if we follow the foot formation that has been proposed for Japanese, that is, bimoraic within the domain of the morpheme (e.g., Kubozono 2008, 2011:2891): *higashi*)$_{\text{foot}}$(*kita*)$_{\text{foot}}$. Thus, the morphological effect of morphological boundaries claimed by Vance (1992) could well be the effect of phonological boundaries, especially foot boundary that is also at the PrWd boundary (perhaps with the exception of one word with respect to the PrWd boundary).[7]

To summarize the problem with the literature, although morphological effects have been reported on HVD with different types of morphological boundaries potentially having different effects, the possibility of the reported boundaries being phonological rather than morphological has not been addressed.

3. Testing the effect of morphological boundaries – Experiment 1

I disambiguate morphological and phonological information and test their effects on vowel devoicing. In this section and the next, I present two production experiments. The results suggest that with respect to the morphological boundary, there is no effect, at least not with the type of morphological boundary I consider here, although there is some interspeaker variation in some cases in experiment 2.

3.1 Experimental design – The wordlist

Following Vance (1992), I use words that have two potential undergoers of HVD in consecutive syllables. They are all nominals. To control for other factors that may affect devoicing, I use minimal pair groups. This allows consistency in terms of accentuation and segmental variation of the test words. There are three types. The first is nonsense monomorphemic words that consist of four light syllables (and thus four moras) and are of the shape CVC$\underline{V}$C$\underline{V}$*ka* (presented to the speakers in *katakana*), as shown in (3a). The second type comprises words that are segmentally identical to those in (3a), but bimorphemic: CVCVCV+*ka*, where *ka* (科) is a noun meaning ‘a subject of, a family of’, as in (3b). I use eight minimal pairs of these types (see the first two columns in Appendix 1 for the full list). If the morphological boundary has an effect, the second potential undergoers of devoicing would be affected differently in both groups. Those in (3b) are expected to devoice less often than those in (3a), as vowels in (3b) are at a boundary whereas those in (3a) are not.

(3) Test words (minimal pairs)

a. CVCVCV*ka*: Nonsense monomorphemic words
E.g., *nakisuka* (ナキスカ), *mapisuka* (マピスカ)

b. CVCVCV+*ka*: Bimorphemic compounds with *ka* (科) ‘a subject of, a family of’
E.g., *nakisu+ka* (ナキス科), *mapisu+ka* (マピス科)

The third type is constructed to consider the possible effect of the foot boundary. The test words, as given in (4), are a comparable group of words consisting of the same sequences of segments as the bimorphemic CVCVCV+*ka* discussed above, except that the words presented as compounds have an additional mora at the end (i.e., *gi* or *n*), resulting in bimorphemic compounds with two-mora second components, CVCVCV+*kagi* ‘key’ (鍵) and CVCVCV+*kan* ‘can’ (缶).

(4) CVCVCV+*kagi/kan*
E.g., *nakisu+kagi/kan* (ナキス鍵/缶), *mapisu+kagi/kan* (マピス鍵/缶)

If we compare these words with those in (3a), the first and second devoiceable vowels are footed differently. This is shown in (5).

(5) a. CV(CVCV)(*kagi/kan*)
b. (CVCV)(CV*ka*)

The first devoiceable vowel is not at the foot boundary in (5a), whereas it is in (5b). Here, I assume that Japanese feet are formed bimoraically from right to left within the domain of the morpheme (see, for example, Kubozono and Mester 1995, Poser 1990, and Tateishi 1989 on directionality). As the devoiceable vowels are footed differently in both groups of words, they may pattern differently with respect to HVD if the foot has a blocking effect. I prepared eight words for each morpheme -*kagi* and -*kan* (see Appendix 1, the last two columns, for the full list).

A note is in order about the CVCVCV+*ka* words used to test the effect of the morphological boundary (3b). They are not included to test the effect of the foot boundary because the footing of these words cannot be unambiguously determined. Recall from section 2 that Itô and Mester (1996) argued that each Sino-Japanese morpheme constitutes a foot. The *ka* in CVCVCV+*ka* is Sino-Japanese. Some scholars (e.g., Kubozono 2011:2891) have argued that Japanese feet do not cross morpheme boundaries. If we follow these analyses, CVCVCV+*ka* would be footed as CV(CVCV)+(*ka*) or (CV)(CVCV)+(*ka*). However, we do not know the footing at the post-lexical level. If morphological boundaries are ignored in constructing the feet at the post-lexical level, these words would be footed as (CVCV)(CV+*ka*). Post-lexical footing has not been studied for Japanese to the best of my knowledge, but post-lexical refooting has been argued as a possibility in other languages. For example, a foot-based explanation was proposed for Flapping in English (Carr 2020: 98–99), a post-lexical process discussed in section 1: Flapping applying across words (e.g., *hi*[ɾ] *it*, *see you* [ɾ]*omorrow*) and within words (e.g., *Be*[ɾ]*y*) are both argued to occur within a trochaic foot (ˈ*hit it*), (ˈ*see you to*)(ˈ*morrow*), (ˈ*Betty*) ([ˈ] indicates stress).[8] If we follow this foot-based analysis, footing across words means that feet are reconstructed in the post-lexical domain in English. Given the uncertainty around Japanese post-lexical footing, it is safe not to include CVCVCV+*ka* words in investigating the effect of the foot on HVD (but I will return to this in Section 3.4). The footing of CVCVCV+*kagi/kan* is CV(CVCV)+(*kagi/kan*) or (CV)(CVCV)+(*kagi/kan*) in either analysis. The size of the canonical foot (i.e., bimoraic) has been generally uncontroversial in the Japanese literature (e.g., Labrune 2012:170). As the second component *kagi/kan* has two moras in these words, they are within the same foot without crossing the morpheme boundary.

The third type of word in (4), CVCVCV+*kagi/kan*, has the second devoiceable vowel at the morpheme boundary. These words will be considered in the context of morpheme boundary effects. The morphological boundary in this experiment is one in bimorphemic compounds. The three types of words and relevant boundaries to investigate are summarized in Table 1.

Table 1 Test words in experiment 1 and boundary alignment of devoiceable vowels

	Word-internal boundary		Foot boundary	
	1st devoiceable vowel	2nd devoiceable vowel	1st devoiceable vowel	2nd devoiceable vowel
(CVCV)(CVCV)	No	No	Yes	No
CVCVCV+*ka*	No	Yes	NA	NA
CV(CVCV)+(*kagi/kan*)	No	Yes	No	Yes

The 32 test words were put in a carrier phrase *sore-wa* ___ *desu* 'that is ___'. I added ten distractor sentences, bringing the total up to 42.

3.2 Recording and acoustic analysis

A total of ten speakers from Tokyo and nearby areas (F: 6, M: 4) participated in the study.[9] I instructed them to read the words unaccented to avoid interacting with accentuation. Speakers sometimes pronounced CVCVCV*kagi* words as accented. This was expected, as compounds with *kagi* as the second component are generally often accented. In those cases, I asked the speakers to say the words again unaccented, and they were able to usually do so without a problem. A CVCV word that would make the compound unaccented would have been ideal (as other words all consisted of CV syllables), but I could not find one. Instead, I decided to add another bimoraic word, *kan*, which made the compound unaccented. Although *kagi* and *kan* are different in their syllable structures, as both groups of words did not pattern differently with respect to devoicing rates, I collapsed them together in the analysis, as presented in the next section.

Participants read the sentences at a natural speed as they appeared on the computer screen, one sentence at a time. They read the list (= all 42 sentences) five times, and each time, the sentences were randomized within the list. In the beginning, there was a short practice session, where they read words similar to the test words in the list. During the practice session, to secure the recognition of words in (3a) and (3b) as monomorphemic and bimorphemic, respectively, I explicitly asked them to treat words in (3a) as loanwords, which are typically written in *katakana* in Japanese, and words in (3b) as new words referring to a flower family, for example. The sessions were conducted in a room with sound-attenuated walls and recorded using a digital recorder (Marantz PMD 661), with the sampling rate set at 44.1 kHz and quantization at 24 bits, and a unidirectional dynamic microphone (headset) (SHURE SM10A, frequency response 50-15,000 Hz).

In the analysis, I removed the first repetition, which gave me four tokens per word for analysis. I judged the vowels as devoiced when (a) there was no voice bar or vertical striation in the spectrogram, (b) there was no vowel-like periodicity in the waveforms, and (c) there were no vowel-like sounds when I listened to the recording.

3.3 Results: No morphological boundary effect

The results showed 100% or near 100% devoicing on the second potential undergoers of HVD regardless of whether there was a morphological boundary following them or not. In CVC$\underline{\mathrm{V}}$C$\underline{\mathrm{V}}$+*ka* (N=320) and CVC$\underline{\mathrm{V}}$C$\underline{\mathrm{V}}$*ka* (N=320) words, the devoicing rates of the second devoiceable vowel were 100%. In CV(CVC$\underline{\mathrm{V}}$)(*kagi/kan*) words, the rate was 99.8%: vowels were devoiced 100% of the time in CV(CVC$\underline{\mathrm{V}}$)(*kagi*) words (N=320) and 99.7% of the time in CV(CVC$\underline{\mathrm{V}}$)(*kan*) words (N=317).[10] The word-internal boundary did not block the vowel from devoicing. It follows from this that there is no effect of the kind of morphological boundary considered here on HVD.

3.4 Results: No foot boundary effect

The prediction for the effect of foot boundary was that as the footing was different between (CVCV)(CVCV) and CV(CVCV)+(*kagi*)/(*kan*) items, the devoiceable vowels would be affected differently if the foot boundary affected the occurrence of vowel devoicing. The result of (almost) 100% of devoicing on the second devoiceable vowels (section 3.3) suggests that the foot boundary did not affect the HVD in the CVCVCV+*kagi/kan* items.

However, the first potential undergoers of HVD were not always devoiced, as shown in Table 2. They were devoiced 17.1% of the time in the (CVCV)(CVCV) items and 20.5% of the time in the CV(CVCV)+(*kagi/kan*) items.

Table 2 Devoicing rates of the first devoiceable vowel

	CVCVCVCV	CVCVCV+*ka*	CVCVCV+*kagi/kan*
Foot boundary	(CVCV)(CVCV)	NA	CV(CVCV)+(*kagi/kan*)
Devoicing rates of the first devoiceable vowel	17.1% (N=320)	19.3% (N=320)	20.5% (N=637)

The direction is as expected if the foot boundary had an effect: the vowel at the foot boundary was devoiced (17.1%) less often than that without the boundary (20.5%). To determine whether this difference is significant, I performed a mixed-effects logistic regression analysis with R (R Core Team, 2014) and the *lme4* package (Bates *et al.* 2014) of the relation between the devoicing rate and the presence/absence of the foot boundary. I included the speaker and item as random effects (random intercepts and random slopes for both speaker and item).[11] The result, shown in Table 3, suggests that the presence/absence of the foot boundary did not have a significant effect on the devoicing rate of the first devoiceable vowel (β = -6.572, p = 0.1357).

Table 3 Result of the mixed-effects logistic regression analysis

Factor	β-coefficient	z	p
Intercept	-4.653	-2.191	0.0285 *
Foot boundary yes (vs. no)	-6.572	-1.492	0.1357

Although the by-speaker variability is accounted for in the above models, I point out that there is some interspeaker variation when we look at individuals. Table 4 shows devoicing rates of the two potential undergoers of HVD in CVC$\underline{\text{V}}$C$\underline{\text{V}}$*ka* words and CVC$\underline{\text{V}}$C$\underline{\text{V}}$*kagi/kan* words, broken down by individual speakers. Two speakers, AO and SHO, have considerably higher rates of devoicing in the first devoiceable vowels in both CVC$\underline{\text{V}}$CV*ka* and CVC$\underline{\text{V}}$CV*kagi/kan* words, whereas the rest of the speakers hardly devoice these vowels. Speakers AO and SHO devoice both vowels at high rates. Vowel devoicing in two adjacent syllables is not a dominant pattern in the literature. The pattern that most speakers have in this study is in line with the literature: when there are two devoiceable vowels in successive syllables, one is usually devoiced and the other is voiced. However, devoicing two vowels in consecutive devoicing environments is not unattested (e.g., Maekawa and Kikuchi 2005). The devoicing rates for Speaker AO do not seem to be affected by the presence or absence of the foot boundary as this speaker devoices the vowel at high rates whether it is at the boundary (96% of the time) or not (100%). Speaker SHO may show a little larger difference (75% vs. 90%). However, this may be explained by the preceding sound rather than the foot boundary: when he does not devoice the first devoiceable vowel, the vowel is usually preceded by a [p], as opposed to [k]. In conclusion, there does not seem to be an obvious effect of the foot boundary.

Table 4 Devoicing rates (%) for individual speakers

	CVC$\underline{V}$CV*ka*	CVCVC$\underline{V}$*ka*	Ns	CVC$\underline{V}$CV *kagi/kan*	CVCVC$\underline{V}$ *kagi/kan*	Ns
AK	0	100	32	0	100	63
TS	0	100	32	0	100	63
W	0	100	32	0	100	64
K	0	100	32	1	100	64
M	0	100	32	1	100	64
R	0	100	32	3	100	64
SH	0	100	32	1	100	63
TO	0	100	32	6	100	64
AO	96	100	32	100	100	64
SHO	75	100	32	90	98	64
Total	17	100	320	20	99	637

3.5 Discussion

To summarize the production experiment, it was found that HVD was not sensitive to morphological boundaries in bimorphemic compounds (i.e., CVCVCV+*ka* 科, CVCVCV+*kagi* 鍵, CVCVCV+*kan* 缶). It was also found that there was not a statistically significant effect of the foot boundary. One may argue that Japanese feet are aligned at the left edge (e.g., Ito and Mester 2015b, 2016) and that thus, the foot structure of CVC$\underline{V}$C$\underline{V}$+*kagi/kan* should be (CVC$\underline{V}$)(C$\underline{V}$)+(*kagi/kan*) rather than CV(C$\underline{V}$C$\underline{V}$)+(*kagi/kan*) or (CV)(C$\underline{V}$C$\underline{V}$)+(*kagi/kan*). If so, the fact that the second devoiceable vowel is almost always devoiced but the devoicing rate was far lower in the first devoiceable vowel in both (CVC$\underline{V}$)(C$\underline{V}$*ka*) and (CVC$\underline{V}$)(C$\underline{V}$)+(*kagi/kan*) could be attributed to the foot boundary at the first devoiceable vowel. In that case, the results suggest that the foot boundary has an effect whereas the morphological boundary does not.

A few points must be considered. First, I used certain segments before the devoiceable vowels: stops before the first devoiceable vowel and fricatives before the second one (CVC$_{[stop]}$VC$_{[fric.]}$V*k*…). I made this choice to avoid the interaction between the segmental and potential morphological effects. Vowels are less likely to devoice after a stop than after a fricative in consecutive devoicing environments (e.g., Maekawa and Kikuchi 2005, Tsuchida 1997). Therefore, if the second devoiceable vowel, which is after a fricative, has an inhibitory effect, the inhibition would be less likely to be the result of the preceding consonant, as the fricative would not inhibit the vowel to undergo devoicing in competition with the stop. However, one may argue that this segmental effect was stronger than the potential morphological boundary effect, causing a ceiling effect, and the vowel would have been devoiced with or without the adjacent boundary. To avoid this interpretation, I should look at the same sequences of segments (e.g., …*kukuka*…, …*chichika*…). This would allow me to see the effect more clearly as it may appear stronger if the investigation was pursued with more variability.

Second, in looking at the effect of morphological boundaries, the effect of a longer second morpheme should be investigated. A short word like *ka* 科 may not invoke a strong boundary and behave like a clitic. A longer word (e.g., a three-mora word) may produce a different result.

Third, in looking at the effect of foot boundaries, it would be good to have words of the same length in both groups of words to avoid a length effect. In this experiment, one group of words was five moras long (CV.CV.CV.ka.gi/ka.n, where periods indicate mora boundaries) whereas the other was four moras long (CV.CV.CV.(+)ka). An additional mora in words in the second group, e.g., ma.CV.CV.CV.ka, would control for the length of the words, and the two potential undergoers of HVD would still be footed differently.

4. Experiment 2: A follow-up study

To overcome the shortcomings concerning the first experiment discussed in Section 3.5, a follow-up experiment was conducted.

4.1 Methodology

Among the three points of concern raised in Section 3.5, the first aspect was the ceiling effect. To avoid this segmental effect, I use the same sequence of CVs, particularly, *kiki* and *chichi*, in the follow-up experiment. Second, the second morpheme may have been too short to test the effect of morpheme boundaries on devoicing, consisting of one mora, *ka*. In the follow-up experiment, I use a longer second element, with a three-mora word, *kamoku* 科目 'subject,' as well as one of the words from the first experiment, i.e., *kan* 缶 'can.' *Kamoku* is Sino-Japanese and bimorphemic *ka-moku*, whereas *kan* is monomorphemic. Third, to control for the word lengths, I prepare pairs of words with the same number of mora, with a *chichi* sequence footed differently.

The test words are given in (6). (6a) and (6b) have identical segmental structures, but (6a) is a nonsense, and I assume monomorphemic, word, *nakikikamoku*, whereas (6b) is a compound noun, *nakiki+ka'moku* 'the subject *nakiki*,' with the second component *kamoku* 科目 meaning 'a subject of' and the first part being a nonsense word. Similarly, (6c) is monomorphemic whereas (6d) is bimorphemic. Note that there are two high vowels in consecutive devoicing syllables, *kiki* and *chichi*, with the second devoiceable vowels at the morpheme boundary in (6b, d) but not in (6a, c). Thus, if the morpheme boundary affects the HVD, these vowels would be devoiced at significantly different rates: if the presence of the boundary has an inhibitory effect on HVD, the devoicing rate of the second *i* would be significantly lower in (6b, d) than in (6a, c).

(6) Test words
(a) *nakikikamoku* ナキキカモク (nonsense word)
(b) *nakiki+ka'moku* ナキキ科目 (*nakiki*: a nonsense word, *kamoku* 科目 'a subject of')
(c) *manachichika* マナチチカ (nonsense word)
(d) *nachichi+kan* ナチチ缶 (*nachichi*: a nonsense word, *kan* 缶 'can')

In terms of footing, in (6a) and (6b), the two devoiceable vowels in *kiki* are footed differently: (*naki*)(*kika*)(*moku*) and *na*(*kiki*)+*ka'moku*. Similarly, the two devoiceable vowels in *chichi* are footed differently in (6c) and (6d): *ma*(*nachi*)(*chika*) and *na*(*chichi*)+(*kan*). Table 5 summarizes the status of the devoiceable vowels with respect to the word-internal and foot boundaries.

Table 5 Boundary alignment of devoiceable vowels in experiment 2

	Morpheme boundary		Foot boundary	
	1st devoiceable vowel	2nd devoiceable vowel	1st devoiceable vowel	2nd devoiceable vowel
(naki)(kika)(moku)	No	No	Yes	No
na(kiki)+ka'moku	No	Yes	No	Yes
ma(nachi)(chika)	No	No	Yes	No
na(chichi)+(kan)	No	Yes	No	Yes

These four words were put in a carrier phrase *sore-wa* ___ *desu* 'that is ___' and randomized together with three distractor sentences. Six speakers from Tokyo or nearby areas repeated the list eight times. One speaker was recorded in a quiet room (sampling rate at 44.1k Hz, 16-bit quantization) and the rest were recorded in a room with sound-attenuated walls (sampling rate at 44.1k Hz, 24-bit quantization). In both recordings, the same recorder and microphone were used as those in experiment 1 (Section 3.2).

A note is in order about the instructions that the participants received. In the list, the monomorphemic words *nakikikamoku* and *manachichika* were written in *katakana* (ナキキカモク, マナチチカ), whereas the compounds *nakiki+ka'moku* and *nachichi+kan* were written with *nakiki* and *nachichi* in *katakana* and *kamoku* and *kan* in *kanji* (ナキキ科目, ナチチ缶). Participants were asked to treat the monomorphemic words as single words and the compounds as though they were a subject called *nakiki* for *nakiki+kamoku* and a type of can for *nachichi+kan*. The accent was also included in the instructions. I asked them to put the accent on the syllable *ka* in *nakiki+ka'moku,* which was expected for compounds with *kamoku* in the second element. I asked them to use unaccented accent patterns for the other three words. This accentuation was not a problem for *manachichika* and *nachichi+kan.* For *nachichi+kan*, I gave them an actual unaccented word, *doramu+kan* 'drum can,' with the same *kan* 'can' in the second element and asked them to use the same accent pattern. The unaccented pattern may have felt unnatural for *nakikikamoku* as it may have been an exceptional pattern for a long loanword, which was the category that this nonsense word was intended to be in (recall that I used *katakana* for it, which is the orthography usually used for loanwords and mimetics in Japanese). I gave them *karifo-runia* 'California,' as a comparable word to follow the accent. *Kariforunia* is an example of an actual unaccented loanword that has the same syllable structure as *kakikikamoku*, i.e., six moras in all light syllables. Even if this was not the most natural accentuation for the test word *nakikikamoku*, this was the optimal design to induce the monomorphemic reading of the word. If it were accented, the accent would have probably fallen on the *ka*, that is, on the syllable that contains the third mora from the end, following loanword accentuation (McCawley 1968, 1978). If there is an accent in this type of long word, the word may be interpreted as having a pseudo-morpheme boundary before *ka* if we follow Ogawa and Kubozono's (2005) analysis. If this is so, the word cannot represent a monomorphemic word. If the word is pronounced unaccented, however, the possibility of it being treated potentially as a complex word is reduced. Therefore, given that the second morpheme in the complex word needed to be long and I needed a corresponding monomorphemic item, unaccented accentuation was optimal to use.

The devoicing judgments were done with the same criteria as in the first experiment, using the waveform, spectrogram, and my perception (section 3.2). The two CVs *kiki* were sometimes pronounced without explicit closure of the second *k*. When this happened and there was no voicing until the second *k*, the first vowel was treated as devoiced in these tokens.

4.2 Results

The devoicing rates of the second devoiceable vowels are given in Table 6. They were not always devoiced. When they were at the word-internal boundary, they were devoiced at about 37.5% of the time in *nakiki+ka'moku* and 79.1% of the time in *nachichi+kan*. The average devoicing rate for these two items together is about 58.3%. On the other hand, the second devoiceable vowels were devoiced 68.75% of the time on average in the monomorphemic items. The rates were about 52.0% for *nakikikamoku* and 85.4% for *manachichika*. Thus, on average, the devoicing rate is lower when the vowel is at the morpheme boundary (58.3%) than when it is not (68.75%) by about 10.4 percentage points.

Table 6 Devoicing rates of the second devoiceable vowels

	2nd devoiceable vowel at morpheme boundary	Devoicing rate of 2nd devoiceable vowel (%)	N
(naki)(kika)(moku)	No	52.0	48
na(kiki)+ka'moku	Yes	37.5	48
ma(nachi)(chika)	No	85.4	48
na(chichi)+(kan)	Yes	79.1	48

However, the result of a mixed-effects logistic regression analysis (R ver. 3.1.2, with the *lme4* package) suggests that the word-internal boundary does not have a significant effect on the rate of vowel devoicing. The main effect terms included in the model were the morphological boundary and preceding consonant. The interaction of the morphological boundary with the preceding segment was also included as a predictor. The speaker and item were included as random effects (random intercepts and random slopes for both). The result, given in Table 7, shows that the main effect of the morphological boundary does not reach significance. (p = 0.339021).[12]

Table 7 Result of the mixed-effects logistic regression analysis: morpheme boundary

Factor	β-coefficient	z	p
Intercept	2.4955	2.973	0.002951 **
Morpheme boundary yes (vs. no)	-0.9507	-0.956	0.339021
Preceding segment *k* (vs. *ch*)	-2.4025	-3.625	0.000289 ***
Morpheme boundary: Preceding segment	0.2489	0.292	0.770089

The examination of individual speakers revealed interspeaker variations. If we look at the directions in pairs (*nakikikamoku* vs. *nakiki+kamoku*, *manachichika* vs. *nachichi+kan*) in Table 8, only Speaker S follows the overall pattern in both pairs (i.e., lower devoicing rates for the vowel at the boundary). Speakers A and F consistently go against this pattern in both pairs. Speaker K shows different directions between the pairs (i.e., *nakikikamoku* > *nakiki+kamoku* but *manachichika* < *nachichi+kan*). The rest of the speakers (M and W) follow the overall pattern in the *nakikikamoku* vs. *nakiki+kamoku* pair but have 100% devoicing in items in the other pair. Most speakers (K, M, S, and W) follow the overall pattern in the *nakikikamoku* vs. *nakiki+kamoku* pair, with only one speaker (S) following the pattern in the other pair. The statistical results discussed above are reasonable, given that the two pairs show inconsistent patterns. It is noteworthy that the overall pattern is found among two-thirds of the speakers in the pair involving the bimorphemic Sino-Japanese compound *nakiki+ka-moku*. This word involves the boundary (+) that is argued to have an inhibitory effect in the literature (Section 2). I will return to this point in section 5.

Table 8 Individual devoicing percentages of the second devoiceable vowels

	Item, morpheme boundary parameter			
	(naki)(kika)(moku)	na(kiki)+ka'moku	ma(nachi)(chika)	na(chichi)+(kan)
Speaker	No	Yes	No	Yes
A	25.0	50.0	87.5	100.0
F	12.5	37.5	37.5	62.5
K	37.5	0.0	87.5	100.0
M	62.5	37.5	100.0	100.0
S	87.5	37.5	100.0	12.5
W	87.5	62.5	100.0	100.0
Mean	52.0	37.5	85.4	79.1

Next, the effect of the foot boundary is examined. The first devoiceable vowels are used here, the second devoiceable vowels have the same settings for foot boundary as the morphological boundary parameters (see Table 5). The devoicing rates of the first devoiceable vowels in the four items are given in Table 9. If we compare the relevant vowels between (*naki*)(*kika*)(*moku*) and *na*(*kiki*)+*ka'moku* and between *ma*(*nachi*)(*chika*) and *na*(*chichi*)+(*kan*), the vowel at the foot boundary devoices less often (52.0%) than the vowel that is not at the boundary (56.25%) in the first pair, whereas the direction is the opposite (77% vs 70.8%) in the other pair. The first pair goes along with the prediction that the foot boundary has an inhibitory effect, but the second pair goes against it. If we combine the four items, the devoicing rates between the two conditions are almost the same: it is about 64.5% if the first devoiceable vowels are at the foot boundary ((*naki*)(*kika*)(*moku*) and *ma*(*nachi*)(*chika*)), whereas it is 63.5% when the vowel is not at the boundary (*na*(*kiki*)+*ka'moku* and *na*(*chichi*)+(*kan*)).

Table 9　Devoicing rates of the first devoiceable vowels

	1st devoiceable vowel at foot boundary	Devoicing rate of 1st devoiceable vowel (%)	N
(naki̱)(ki̱ka)(moku)	Yes	52.0	48
na(ki̱ki̱)+ka'moku	No	56.25	48
ma(nachi̱)(chi̱ka)	Yes	77.0	48
na(chi̱chi̱)+(kan)	No	70.8	48

The difference is not statistically significant. A mixed-effects logistic regression analysis was performed (with R ver. 3.1.2 and *lme4* package) with the main effect terms of the foot boundary and preceding segments (*k* vs. *ch*), and the interaction of the boundary with the preceding segment. The speaker and item were included as random effects (random intercepts and random slopes for both). Table 10 presents the results. Both the main effect of the foot boundary (β = 0.4934, p = 0.5864) and other factors did not reach significance. This suggests that the foot boundary does not have a significant effect on the rate of vowel devoicing.

Table 10　Result of the mixed-effects logistic regression analysis: foot boundary

Factor	β-coefficient	z	p
Intercept	2.2702	1.590	0.1117
Foot boundary yes (vs. no)	0.4934	0.544	0.5864
Preceding segment *k* (vs. *ch*)	-1.1409	-1.947	0.0516
Foot boundary: Preceding segment	-0.8639	-0.989	0.3227

Individuals presented great variations again. Table 11 presents the devoicing rates. Only Speaker F follows the overall patterns in both pairs (i.e., *nakikikamoku* < *nakiki+kamoku*, *manachichika* > *nachichi+kan*).

Speaker S follows the tendency in one pair (*nakikikamoku* < *nakiki+kamoku*) but not in the other. Speaker K does not follow it in the *nakikikamoku* vs. *nakiki+kamoku* pair and is the ceiling in the other. Speakers A and M show 100% devoicing in both pairs, whereas Speaker W has low rates across all words. There was not a strong tendency between the pairs: the pairs only have two speakers each (two different speakers) who follow the average patterns.

Table 11 Individual devoicing percentages of the first devoiceable vowels

	Item, foot boundary parameter			
	(naki)(kika)(moku)	na(kiki)+ka'moku	ma(nachi)(chika)	na(chichi)+(kan)
Speaker	Yes	No	Yes	No
A	100.0	100.0	100.0	100.0
F	37.5	62.5	100.0	75.0
K	37.5	12.5	100.0	100.0
M	100.0	100.0	100.0	100.0
S	37.5	62.5	12.5	37.5
W	0.0	0.0	50.0	12.5
Mean	52.0	56.3	77.0	70.8

4.3 Discussion

The follow-up study suggested that there is not significant effect of either the word-internal or foot boundary on the rate of vowel devoicing, despite the fact that the direction follows the predictions for the morphological boundary. In particular, in the pair involving the Sino-Japanese binom *ka-moku*, over half (i.e., four of six) of the speakers showed the patterns expected if the morpheme boundary had an effect.

One may criticize the assumptions around Japanese foot formation that this study employed. If the feet are aligned at the left rather than the right edge (Ito and Mester 2016), as shown in Table 12, the pair that can be used for the investigation of the effect of foot boundary with respect to the first devoiceable vowel is the *(mana)(chichi)(ka) vs. (nachi)(chi)+kan* pair, and the direction is as expected as the vowel at the boundary devoices less often (70.8%) than the one without the boundary (77.0%).

Table 12 Devoicing rates of the first devoiceable vowels: foot aligned at left edge

	1st devoiceable vowel at foot boundary	Devoicing rate of 1st devoiceable vowel (%)	N
(naki)(kika)(moku)	Yes	52.0	48
(naki)(ki)+ka'moku	Yes	56.25	48
(mana)(chichi)(ka)	No	77.0	48
(nachi)(chi)+kan	Yes	70.8	48

5. General discussion: Word-internal boundary and HVD

I discuss the types of word-internal boundaries and their effects on HVD. The findings in this study are summarized in Table 13. The two production experiments suggest that in consecutive devoicing environments, HVD was not affected by the presence of a word-internal boundary of the kind investigated. However, there were interspeaker variations in experiment 2 and four of the six speakers followed the direction as though the morphological boundary had an effect in the *nakikikamoku* vs. *nakiki+kamoku* pair, whereas this was not the case in the other, *manachichika* vs. *nachichi+kan*, pair.

Table 13 Summary of results in this study, morphological boundary

	Experiment 1	Experiment 2
Effect of morphological boundary	No (devoicing ceiling)	No (interspeaker variation in *nakiki(+)kamoku* pair)
Compounds used in experiment	⋯+*ka*, ⋯+*kagi*, ⋯+*kan*	⋯+*ka-moku*, ⋯+*kan*

There was a consistent effect of certain segmental factors: in the second production experiment discussed in Section 4.2 (Table 7), the preceding segment had a significant effect. In experiment 2, if the feet were aligned at the left edge, the effect of a foot boundary was suggested, although this should be examined further in a better-designed experiment. These findings are not surprising given that HVD is a post-lexical process. In the post-lexical domain, the visibility of phonological information is expected in the application of a phonological process. The effect may be prosodic: Kilbourn-Ceron (2014) and Kilbourn-Ceron and Sonderegger (2018), looking at the prosodic boundaries of levels higher than the foot, found that these boundaries affect the probability of HVD and that the magnitude of the effect depends on the level.[13]

If we examine the types of compounds used in this study more closely, a clearer picture emerges regarding possible morphological effects. Recall that among the four compounds used in my experiments, one (*nakiki+ka'moku*) has a complex second element, i.e., Sino-Japanese binom (bimorphemic), whereas the other compounds are bimorphemic as a whole. It is this compound that showed a consistent pattern in the direction of the presence of the morpheme boundary effect in more than half of the participants. As mentioned in Section 2, Imai (2004), Kondo (1997), and Yoshida recognized different kinds of morphological boundaries with different effects in HVD rates.

These may suggest that it may not be individual morphemes that are visible in HVD inhibition. We cannot reduce the effect to the morphological boundary because the boundaries in bimorphemic compounds (i.e., …+*ka*, …+*kagi*, and …+*kan*) do not seem to affect HVD rates. Rather, it seems that the word-internal boundary in compounds that have a bimorphemic word as a component does affect it among some speakers. This generalization seems, by and large, to conform to the patterns reported in the abovementioned literature. There does not seem to be a single morphological unit that can capture this bimorphemic unit other than the innermost compound. For example, in Sino-Japanese vocabulary, these are root-root compounds as the morphemes are often bound, but in Yamato, they are often free morphemes and are thus word compounds.

In phonological terms, the bimorphemic (M-M) unit can arguably be captured as the Prosodic Word (PrWd), at least with words used in this study. In Sino-Japanese vocabulary, where each morpheme is either one or two moras long, this unit coincides with the PrWd. According to Ito and Mester (2015a, 2015b), these root-root compounds constitute single PrWds and morphemes in M-M are not PrWds on their own. Any attachment of other morphemes to them (either Sino-Japanese or any other type) recursively creates larger PrWds. Therefore, in one of the compounds used in my experiments, *nakiki+ka-moku*, the + boundary coincides with a PrWd boundary as *ka-moku* is a Sino-Japanese binom, whereas the – boundary does not, i.e., $[nakiki+[ka\text{-}moku]_{\omega}]_{\omega}$ (ω denotes Prosodic Word).

Other compounds used in this study (CVCVCV-*ka*, CVCVCV-*kagi,* CVCVCV-*kan*) are all bimorphemic (M-M) but they involve non-Sino-Japanese morphemes. The first element CVCVCV is nonsense and the second is either a monomorphemic Sino-Japanese (*-ka, -kan*) or a monomorphemic Yamato (*-kagi*). The unit M-M that comprised non-Sino-Japanese morphemes like these is not as clear.

Yamato compounds of this shape, in particular four-mora compounds consisting of two bimoraic morphemes (e.g., *nora-neko* 'stray cat' (Kubozono and Fujiura 2004, (6b), p. 11)), can be analyzed as single PrWds based on their accentuation patterns, even though the components are morphological words individually (Kubozono and Fujiura 2004, Mester 2018). Furthermore, Ito and Mester (2019) argued that in general, if both the first and second elements are short, being monomoraic or bimoraic, the compounds are single PrWds and the unaccented pattern is the default if both elements are bimoraic.

Compounds used in this study have a short second element (E2) (*-ka*, *-kagi*, *-kan*), but the first element (E1) is three, and not one or two, moras long (CVCVCV). Ito and Mester (2018) dealt with cases similar to these (e.g., *bizinesu'+shoo* 'business show', *perusha+ne'ko* 'Persian cat') and analyzed the E1 as projecting a PrWd and the E2 as projecting: (a) a foot but not a PrWd on its own if the compound is accented on the last syllable of E1 (*bizinesu'+shoo*), which is the regular pattern, and (b) a foot that also projects a PrWd if the accent is on the first syllable of E2, retaining the original accent of the E2 (*perusha+ne'ko*). However, these crucially involve cases where the compound is accented, whereas the compounds used in this study are unaccented (although somewhat artificially in the CVCVCV+*kagi* compound).

I propose that as the presence of an accent is expected in (nominal) compounds comprising CVCVCV E1 and short E2 (especially on the last syllable of E1 as the regular pattern), unaccented compounds with relatively short components as those in this study may behave like those with short E1 and E2, constituting single PrWds, especially when their compositional nature is opaque. Labrune (2012: 216) pointed out that in compound accentuation, compounds that are semantically opaque are not likely to be treated in the same way as those whose compositional nature is transparent. Her statement was for four-mora compounds, but there are bimorphemic ones that can be analyzed as being semantically opaque regardless of the length of the words. For example, *minami+kaze* 'south wind' and *higashi+kaze* 'east wind' can be lexicalized as simple words just like *kita+kaze* 'north wind' at least for some speakers, as they are relatively short (five moras long) and unaccentedness can signal to the speaker that they are not typical compounds in terms of accentuation. If this is so, they can be analyzed as single PrWds for those speakers phonologically, although morphologically, they are compounds.

Given this analysis, the results of the experiments discussed above are consistent in suggesting that a phonological boundary, the PrWd boundary, has an effect, albeit limited, in that it yields interspeaker variation. The words used in the experiments may have the Prosodic Word structure presented in Table 14. Monomorphemic words and all compounds except *nakiki+kamoku* are single PrWds whereas *nakiki+kamoku* has a PrWd boundary in it. It can be concluded that the PrWd boundary has a (limited) inhibitory effect on HVD.

Table 14 Prosodic Word structure of words used in this study based on analysis proposed

	Experiment 1	Experiment 2
Monomorphemic words	$[\mathrm{CVCVCVCV}]_{\omega}$	$[nakikikamoku]_{\omega}$, $[manachichika]_{\omega}$
Compounds	$[\mathrm{CVCVCV}{+}ka]_{\omega}$, $[\mathrm{CVCVCV}{+}kagi]_{\omega}$, $[\mathrm{CVCVCV}{+}kan]_{\omega}$	$[nakiki{+}[kamoku]_{\omega}]_{\omega}$, $[nachichi{+}kan]_{\omega}$

In sum, it first appears that morphological boundaries must be visible to explain variability in the process of HVD. However, when these morphological boundaries are examined more closely, it appears that they do not always explain the results and an appeal to PrWd boundaries presents a more plausible analysis, consistent with the observation that HVD is post-lexical, referring to phonological information.

6. Conclusion

This paper was concerned with morphological visibility in HVD, a post-lexical process in Japanese. The motivation behind the investigation emerged from the body of literature on HVD, which argued for the effect of word-internal boundary as a blocking factor. The visibility of morphological information is a surprise as post-lexical rules have long been assumed to have access to phonological information only and not to morphological information.

The production experiments investigated whether the word-internal morpheme boundary can affect devoicing rates. The effect of the foot boundary was also investigated. The results statistically suggested that neither boundary had any effects. However, there was an interspeaker variation in one pair of words with respect to the morphological effect. Foot boundary may have had an effect if the feet were aligned at the left edge.

The question was then raised as to whether the effect that appeared morphological was really so, or the structure relevant in what morphology is seemingly referred to in HVD may be phonological instead. When the kinds of morphological boundaries used in the experiments were examined, it was proposed that what is referred to in HVD may not be morphological but phonological, and prosodic, in particular, the PrWd boundary. It is possible that a reference to morphological structure plays no role in HVD.

Further research is necessary. First, the level of foot should be examined in detail. There has been no study on HVD that has looked solely at the effect at this level, to the best of my knowledge. A source of difficulty in investigating the level of foot in relation to HVD lies in the fact that there are different proposals in the Japanese literature in terms of the directionality of foot formation. Furthermore, foot construction in the post-lexical domain has not been discussed much. For example, the assumption that the foot constructed at the lexical level be carried over in the post-lexical foot structure should be researched. As mentioned in Section 3.1, when English Flapping is analyzed based on the foot (Carr 2020), the feet are constructed across words. For this to hold, feet must be reconstructed at the post-lexical level. A study focusing on the foot in HVD promises to provide further insights on post-lexical foot structure, especially as higher prosodic levels have been found to be important in explaining variability in HVD in the single devoicing environment (e.g., Kilbourn-Cereon and Sonderegger 2018).

Second, accentuation should be carefully controlled for. In this study, *nakikikamoku* without accent was probably unnatural for the speakers. There was a good reason behind asking them to read it unaccented as discussed in section 4.1. However, forcing unnatural reading is not good. A design free of this concern would be ideal.

Third, the potential role of morphological information in the post-lexical domain should be explored in other phonological processes and languages. This should be studied carefully because as in the case of HVD discussed in this paper, even if morphological information appears available in a phonological process, we still do not know whether it involves direct access to morphology or access via phonological constituents as proposed by, for instance, Nespor and Vogel (1986, 2007).

* The results of experiments discussed in this paper were orally presented in Hirayama (2013, 2015). I thank Haruo Kubozono, Keren Rice, Jessamyn Schertz, participants in the PAIK meeting (March 16, 2013), Phonology Group meeting (Dept. of Linguistics at the University of Toronto, Sept. 6, 2013), the 3rd ICPP (Dec. 20-22, 2013), the Conference of the Phonology-Morphology Circle of Korea (December 19, 2015) for their comments as well as help with the experimental design and other technical issues. Errors are mine.

1 In this paper, I use Hepburn Romanization in italics for the phonemic/lexical transcription. Apostrophes indicate lexical accent on the syllable to the left.

2 Yoshida's words and their devoicing percentages are as follows. Transcriptions and glosses are his. /yuuki#kagaku/ 'organic chemistry' (100%), /sinzoku#kaigi/ 'family council' (80.0%), /zyusi#kakoo/ 'resinate [MH_resin processing]' (72.7%), /muketu#kakumee/ 'bloodless revolution' (100%), /kagaku#sayoo/ 'chemical action' (100%), /kagaku#seNi/ 'synthetic fiber' (100%), /ziti#seesiN/ 'self-government'+'attitude' (54.5%), /dokuritu#sensoo/ 'war of independence' (100%), /taisyoku#teate/ 'retirement allowance' (54.5%), /kenryoku#toosoo/ 'power struggle (100%), /dokuritu#toosi/ 'investment in self-supporting accounting system' (90.9%).

3 See, for instance, Nielsen (2015) and Tsuchida (1997, 2001) for general discussion and phonological factors conditioning vowel devoicing in consecutive environments.

4 Note that words in (1) do not always have vowels in the consecutive devoicing environments; I took these from Kondo's discussion of her experiment design in general, where words from the single and consecutive devoicing environments are discussed together.

5 All but one are nominal compounds. The one exception is *shinki+kusai* （辛気くさい） 'depressed', which is an adjective.

6 The following are Sino-Japanese+Native compounds: *enpitsu+kezuri* （鉛筆削り）, *isanshiki+sumire* （三色すみれ）, *shinki+kusai* （辛気くさい）, and *taikutsu+shinogi* (退屈しのぎ).

7 Poser (1990, fn. 4) mentions the relevance of foot in HVD, suggesting further research on the issue.

8 Examples *hit it* and *Betty* are from Carr (2020), while *see you tomorrow* is mine, which is footed according to foot formation proposed in Carr, i.e., trochaic, assuming stress on *see* and *mo*.

9 Four of the speakers (M, R, SH, and SHO) were living in the Kansai region at the time of recording, but their results did not show a distinguishing pattern from the rest of the speakers.

10 The total number of tokens is not the expected 320 but rather 317, because there were two speakers who pronounced a word incorrectly and one speaker who had an unnatural pronunciation in one token; these tokens were excluded from the analysis.

11 glmer(DevoicingV2 ~ FootAtV2 + (1+FootAtV2|Speaker) + (1+FootAtV2|ItemNumber), data = Exp1, family = binomial, control=glmer-Control(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

12 glmer(DevoicingV2 ~ MorphAtV2 + PrecedingSegment + MorphAtV2 * PrecedingSegment + (1+MorphAtV2|Speaker) + (1+MorphAtV2|Item), data = Exp2, family = binomial, control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=2e5)))

The result is the same when the preceding segment and the interaction terms are removed from the model in that the factor of the morphological boundary does not reach significance (β = -0.8228, p = 0.575).

13 This is in line with other studies that suggest that the higher the prosodic level in the hierarchy, the stronger the effects (e.g., Fougeron 2001).

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Appendix 1: Wordlist for experiment 1

	CVCVCVka (monomorphemic)		CVCVCV+ka ‘subject’		CVCVCV+kagi ‘key’	CVCVCV+kan ‘can’
1	nakishika	ナキシカ	nakishi+ka	ナキシ科	ナキシ鍵	ナキシ缶
2	nakisuka	ナキスカ	nakisu+ka	ナキス科	ナキス鍵	ナキス缶
3	makushika	マクシカ	makushi+ka	マクシ科	マクシ鍵	マクシ缶
4	makusuka	マクスカ	makusu+ka	マクス科	マクス鍵	マクス缶
5	mapushika	マピシカ	mapushi+ka	マピシ科	マピシ鍵	マピシ缶
6	mapisuka	マピスカ	mapisu+ka	マピス科	マピス鍵	マピス缶
7	napushika	ナプシカ	mapushi+ka	ナプシ科	ナプシ鍵	ナプシ缶
8	napusuka	ナプスカ	mapusu+ka	ナプス科	ナプス鍵	ナプス缶

Appendix 2: Wordlist for experiment 2

nakikikamoku	ナキキカモク	manachichika	マナチチカ
nakiki+kamoku	ナキキ科目	nachichi+kan	ナチチ缶