Geminate devoicing in Japanese loanwords: Theoretical and experimental investigations

Abstract

This paper provides an overview of theoretical and experimental investigations of voiced geminates in Japanese. Active discussion was initiated by Nishimura's (2003) discovery that in Japanese loanword phonology, voiced geminates can be devoiced, when they co-occur with another voiced obstruent (e.g. /doggu/ → /dokku/). This context-sensitive devoicing of geminates has received much theoretical attention since then, and has been analyzed within several different theoretical frameworks. Subsequently, the phonetic and psycholinguistic natures of voiced geminates have also been explored, in tandem with corpus-based analyses and computational modeling. It thus seems safe to say that this devoicing pattern of voiced geminates in Japanese has had some substantial impacts in the recent theoretical literature and related field. The empirical focus of this paper is on one simple devoicing phenomenon in Japanese, but implications for general linguistic theories are discussed throughout.

1 The basic patterns

1.1 Prohibition of voiced geminates in native phonology

In Japanese, voiced obstruent geminates (/bb, dd, gg/) are not allowed in the native phonology (Ito & Mester, 1999).[1] Not only do they not make lexical contrasts, some evidence from phonological alternations shows that voiced geminates are actively avoided. For example, the suffix /-ri/, when attached to mimetic roots, causes gemination of root final consonants, as in (1). However, when the root-final consonants are voiced obstruents, gemination is blocked, and a nasal is inserted instead, as in (2) (Ito & Mester, 1999).

(1) Gemination caused by /-ri/

a. /u**k**a+ri/ → /u**kk**ari/ 'absent-mindedly'

[1] This paper uses phonemic transcription (Vance, 2008) rather than IPA transcriptions except where phonetic details are relevant.

b. /bi**k**u+ri/ → /bi**kk**uri/ ‘surprised’

(2) Gemination does not target voiced obstruents

a. /syo**b**o+ri/ → /sy**mb**ori/ ‘disappointed’

b. /u**z**a+ri/ → /u**nz**ari/ ‘sick of something’

For other pieces of evidence for the avoidance of voiced geminates from alternation, see the Sino-Japanese root fusion pattern (Ito & Mester, 1996), the mimetic gemination pattern (Nasu, 1999), and rendaku (Sano, 2014).

1.2 Voiced geminates in loanwords

Despite the lack of voiced geminates in native phonology, voiced geminates do appear in loanwords. Word-final consonants preceded by a lax vowel in source languages are often borrowed as geminates, as shown in (3) (Kubozono, to appear). This adaptation process created voiced geminates in the loanword sector of the Japanese lexicon (Ito & Mester, 1999).

(3) Gemination of word-final consonants in loanword adaptation

a. ca**t** → /kya**tt**o/

b. pa**ck** → /pa**kk**u/

c. re**d** → /re**dd**o/

d. bi**g** → /bi**gg**u/

1.3 Devoicing of voiced geminates

Although a voicing contrast became contrastive in geminates in Japanese loanword phonology, it was still observed that some voiced geminates can be pronounced as devoiced (Ito & Mester, 1999; Quakenbusch, 1989; Vance, 1987). One big puzzle, however, was that not all voiced geminates seem to have been devoicable. Ito & Mester (1999) proposed to treat devoicable geminates as contained in “assimilated foreign items” and non-devoiceable geminates as contained in “unassimilated foreign items”. This quasi-etymological distinction was a bit ad hoc, given that the distinction was not independently motivated, and also given that there was no measure to quantify “the degree of assimilatedness”.

In 2003, Nishimura has identified a *phonological* condition which makes devoicing of geminates possible. Concretely, he points out that the devoicing of geminates occurs only when there is another voiced obstruent within the same morpheme, as in (4). In other words, devoicing of geminate is caused by a restriction against two voiced obstruents within the same stem, which is independently known as the OCP(voice) (henceforth the OCP), or Lyman’s Law in the native phonology of Japanese (Ito & Mester, 1986, 2003).

(4) Devoicing of OCP-violating geminates

a. /ba**dd**o/ → /ba**tt**o/ ‘bad’

b. /ba**gg**u/ → /ba**kk**u/ ‘bag’

c. /do**gg**u/ → /do**kk**u/ ‘dog’

Nishimura (2003) contrasts OCP-violating geminates with non-OCP-violating geminates as in (5), and OCP-violating singletons as in (6). For these, devoicing seems impossible.

(5) Non-OCP-violating geminates

a. /suno**bb**u/ → */suno**pp**u/ ‘snob’

b. /re**dd**o/ → */re**tt**o/ ‘red’

c. /e**gg**u/ → */e**kk**u/ ‘egg’

(6) OCP-violating singletons

a. /gi**b**u/ → */gi**p**u/ ‘give’

b. /ba**g**u/ → */ba**k**u/ ‘bug’

c. /da**g**u/ → */da**k**u/ ‘Doug’

The patterns illustrated in (4)-(6) initiated extensive theoretical debate, which is reviewed in the next section.

Before moving on, one remark is in order: we need to distinguish between loanword adaptation (=(3)) and loanword phonology (=(4)). The former is the phase when Japanese speakers borrow these words from the source languages; the latter is about what happens to these words after the adaptation. This distinction is important, because Kaneko & Iverson (2009) show that voiced geminates are not necessarily borrowed as voiceless in the presence of another voiced obstruent. Thus the devoicing of geminates in (4) occurs in loanword phonology rather than in loanword adaptation.

2 Phonological analyses

This section provides an overview of different theoretical analyses of the data set in (4)-(6) in a chronological order. As stated above, devoicing of OCP-violating geminates is optional, but the following analysis abstracts away from this optionality, except for the Maxent analysis, which intrinsically predicts optionality. See section 6 for more on the optionality.

2.1 A local conjunction analysis: Nishimura (2003)

The devoicing pattern instantiates a case of "a gang effect" in that neither being a geminate nor violating the OCP(voice) alone suffices to cause devoicing. In other words, two conditions (violating OCP and being a geminate) have to be met to cause devoicing. This observation is challenging for Optimality Theory (Prince & Smolensky, 1993/2004), since Optimality Theory, in its standard form, does not predict this sort of effect, because of strict domination—a violation of a constraint that is ranked higher takes priority over any amount of violations of lower ranked constraints.

To illustrate this problem, let us consider three basic constraints, shown in (7):

(7) Three constraints posited by Nishimura and subsequent work

a. FAITH(VOICE): Devoicing is not allowed.

b. OCP: A morpheme cannot contain two voiced obstruents (=Lyman's Law).

c. *VOIOBSGEM: A voiced obstruent geminate is prohibited.

The first faithfulness constraint is necessary because a voicing contrast is contrastive in Japanese phonology in general. The second constraint, OCP, is theoretical instantiation of Lyman's Law, which is independently motivated in Japanese phonology. The final constraint, *VOIOBSGEM, captures the prohibition against voiced geminates in the native phonology. Given these constraints, in the loanword phonology, the faithfulness constraint must dominate the two markedness constraint, as the tableaux in (8) and (9) show.

(8) FAITH(VOICE) $\gg$ OCP: no devoicing of singletons

/**d**agu/	FAITH(VOICE)	OCP	*VOIOBSGEM
→ /**d**agu/		*	
/**d**aku/	*!		

(9) FAITH(VOICE) $\gg$ *VOIOBSGEM: no devoicing of voiced geminates

/e**gg**u/	FAITH(VOICE)	OCP	*VOIOBSGEM
→ /e**gg**u/			*
/ekku/	*!		

In other words, since devoicing does not occur either with OCP-violating singletons (=(6)) or non-OCP-violating geminates (=(5)), FAITH(VOICE) must be ranked at the top. However, this top-ranking of the faithfulness constraint blocks the devoicing of geminates, even when the geminates violate OCP as well, as illustrated in (10):

(10) The top ranking of FAITH(VOICE) prevents devoicing of geminates

/**d**o**gg**u/	FAITH(VOICE)	OCP	*VOIOBSGEM
→ /**d**o**gg**u/		*	*
/**d**okku/	*!		

To solve this problem, Nishimura (2003) proposed to deploy the mechanism of local conjunction (Smolensky 1993 *et seq.*). By conjoining OCP and *VOIOBSGEM within the domain of stem (=$\{$OCP&*VOIGEM$\}_{stem}$), and ranking it above FAITH(VOICE), we obtain the right outcome, as in (11).

(11) The function of $\{$OCP&*VOIGEM$\}_{stem}$

/**d**o**gg**u/	$\{$OCP&*VOIGEM$\}_{stem}$	FAITH(VOICE)	OCP	*VOIOBSGEM
/**d**o**gg**u/	*!		*	*
→ /**d**okku/		*		

2.2 A split-faithflulness analysis: Kawahara (2006)

Kawahara (2006) argues that the local conjunction analysis of Nishimura (2003) is too powerful in the sense that two seemingly irrelevant constraints are conjoined in a domain as large as a stem (see also McCarthy 1999, 2003, and Padgett 2002 for related discussion). Instead, Kawahara (2006) proposed that faithfulness constraints for voicing should be split in such a way that singletons and geminates are subject to different faithfulness constraints. Once we posit two faithfulness constraints, we can do away with the local conjunction constraint.

To illustrate, FAITH-SING is ranked above OCP, which in turn dominates FAITH-GEM. This ranking allows OCP to devoice geminates, but not singletons, as shown in (12)-(13):

(12) FAITH-SING ≫ OCP: No devoicing of singletons

/**b**a**g**u/	FAITH-SING	OCP	FAITH-GEM
→ /**b**a**g**u/		*	
/**b**aku /	*!		

(13) OCP ≫ FAITH-GEM: Devoicing of geminates

/**d**o**gg**u/	FAITH-SING	OCP	FAITH-GEM
/**d**o**gg**u/		*!	
→ /**d**okku/			*

Though ranked below OCP, FAITH-GEM dominates *VOIOBSGEM to prevent context-free devoicing of geminates, as in (14):

(14) FAITH-GEM ≫ *VOIOBSGEM: No context-free devoicing of geminates

/e**gg**u/	FAITH-SING	OCP	FAITH-GEM	*VOIOBSGEM
→ /e**gg**u/				*
/ekku/			*!	

This split-faitfhfulness approach thus can model the devoicing patterns without resorting to the complex locally-conjoined constraint, $\{\text{OCP\&*VOIGEM}\}_{stem}$. Furthermore, as we will discuss more in section 3, the splitting of faithfulness constraints can be considered to be grounded in the perceptibility differences of voicing contrasts in singletons and geminates.

2.3 An approach from the theory of contrast: Rice (2006)

Rice (2006), as a reply to Kawahara (2006), offers a different interpretation of why singletons and geminates behave in different ways with respect to OCP. As discussed more fully in section 3, Kawahara (2006) derives the phonological difference between singletons and geminates from their phonetic differences.

On the other hand, within the framework of the theory of contrast and markedness (Dresher, 2010), Rice (2006) attempts to derive a difference between singletons and geminates from the contrastiveness in the native phonology. A voicing difference is contrastive only in singletons in the native phonology (Ito & Mester, 1999); as a result, the [voice] feature is projected only for singletons (and hence more stable). Rice (2006) thus shares the same spirit with Kawahara (2006) in that they both capitalize on the phonological "devoicability" difference between singletons and geminates—Kawahara (2006) tried to find its root in phonetics; Rice (2006) instead resorted to the contrastiveness in the native phonology.

2.4 A Harmonic Grammar analysis: Pater (2009)

Pater (2009) presents a reanalysis of the devoicing phenomenon within the framework of Harmonic Grammar, in which constraints are weighted instead of ranked. Harmonic Grammar is similar to the standard Optimality Theory, but instead of ranked constraints, it uses a set of weighted constraints. Based on the weights assigned for each constraint, a harmonic score of each candidate is calculated as follows: $H(cand_j) = \Sigma w_i * c_i(cand_j)$, where w_i represents weight assigned to $constraint_i$ and $c_i(cand_j)$ violation profiles of a particular $candidate_j$ with respect to $constraint_i$. In short, harmonic scores are weighted sums of all constraint violations. The candidate with the highest harmonic score wins.

Pater (2009) uses the set of constraints posited in (7). In this analysis, FAITH should have a higher weight than OCP and *VOIOBSGEM; say, 1.5 vs. 1 and 1. These weighting relations would prevent devoicing of OCP-violating singletons or context-free devoicing of geminates, as in (15)-(16).

(15) $w(\text{FAITH}) > w(\text{OCP})$: no devoicing of OCP-violating singletons

/**d**agu/	FAITH (1.5)	OCP (1)	*VOIOBSGEM (1)	H-Score
→ **d**agu		-1		-1
daku	-1			-1.5

(16) $w(\text{FAITH}) > w(\text{*VOIOBSGEM})$: no context-free devoicing of geminates

/e**gg**u/	FAITH (1.5)	OCP (1)	*VOIOBSGEM (1)	H-Score
→ e**gg**u			-1	-1
ekku	-1			-1.5

However, as long as the sum of the weight of OCP and that of *VOIOBSGEM is higher than that of FAITH (e.g. $1 + 1 > 1.5$), devoicing occurs to satisfy both OCP and *VOIOBSGEM, as in (17). A gang-effect occurs because one violation of FAITH simultaneously satisfies the two lower-weighted markedness constraint.

(17) The gang effect in Harmonic Grammar

/**d**o**gg**u/	FAITH (1.5)	OCP (1)	*VOIOBSGEM (1)	H-Score
do**gg**u		-1	-1	-2
→ **d**okku	-1			-1.5

This analysis is appealing in that it analyzes the patterns of loanword devoicing using only the three basic constraints in (7), without additional theoretical machineries such as local conjunction or splitting of faithfulness constraints. See, however, Tesar (2007) for a critical reply to Pater et al. (2007), a manuscript upon which Pater (2009) is based.

2.5 A Maxent Harmonic Grammar analysis: Coetzee and Pater (2009)

Coetzee & Pater (2011) also briefly mention an analysis based on Max-Entropy Harmonic Grammar (Hayes & Wilson, 2008), in which the probability of a candidate being selected is proportional to its Maxent value, which is $P * (cand_i) = e^{-H(cand_i)}$. This theory deploys positive weights, and since $e^{-H} = \frac{1}{e^H}$, higher $H(cand_i)$ would result in lower probability of $candidate_i$ being selected.

Since this theory, like Harmonic Grammar, uses weighted constraints, the gang effect is accounted for (Coetzee & Pater, 2011). Another important aspect of this theory is that every candidate is assigned some probability, and therefore, it inherently predicts variation; i.e. multiple outputs for each input form. This model therefore is suited to account for the optionality of devoicing of OCP-violating geminates.

2.6 Interim conclusion

In summary, the loanword geminate devoicing pattern has been analyzed using several theoretical mechanisms: (i) local conjunction, (ii) split faithfulness constraints, (iii) projection of features based on contrastivity, (iv) Harmonic Grammar, and (v) Maxent grammar. As far as I know, there has not been a knock-out argument for one theory over the others. McCarthy (2008) in his textbook uses the Japanese devoicing case as an exercise to illustrate local conjunction. Pater (to appear) still uses it as a show-case support for Harmonic Grammar. Flemming (2013) uses it to illustrate a Maxent grammar.

Before completing this section, the devoicing of OCP-violating geminates has been discussed in yet another theoretical context: theories of lexical stratification. The OCP is active in the native phonology (Ito & Mester, 1986, 2003), and the OCP-driven devoicing of geminates shows that the OCP produces an emergent phonological pattern in the loanword phonology. This connection demonstrates how loanword phonology patterns can arise from those in native phonology (Ito & Mester, 2003, 2008; Tateishi, 2002).

3 Phonetics of voiced geminates

3.1 Acoustics

The split-faithfulness analysis presented by Kawahara (2006) (reviewed in section 2.2) triggered interests in the phonetics of voiced geminates. The question raised in that work was why there are different faithfulness constraints for singletons and geminates. Descriptively speaking, Japanese speakers devoice only OCP-violating geminates, not OCP-violating singletons. To explain this observation, Kawahara (2006) used the P-Map theory (Steriade, 2001/2008), which posits that a phonological change that causes a larger perceptual change is considered to be worse by the speakers. In this view, for the case of Japanese, speakers neutralize a voicing contrast in geminates because it is not perceptually salient, whereas devoicing singleton is perceptually too conspicuous.

The specific prediction is thus that a voicing contrast is less perceptible in geminates than in singletons. To test this prediction, Kawahara (2006) conducted an acoustic study, which found that Japanese voiced geminates are semi-devoiced, as shown in Figure 1. For a singleton [d], voicing vibration continues throughout the closure—the continuation of voicing is observed both on the waveform as well as the voice bar in the spectrogram. On the other hand, voicing in geminates is ceased at an early phase of closure for a geminate [dd].

This semi-devoicing of geminates has a well-known aerodynamic root (Hayes & Steriade, 2004; Ohala, 1983). In order to maintain vibration of the glottis, the intraoral airepressure (P_o) must be lower than the subglottal airpressure (P_s). However, P_o automatically rises as the air

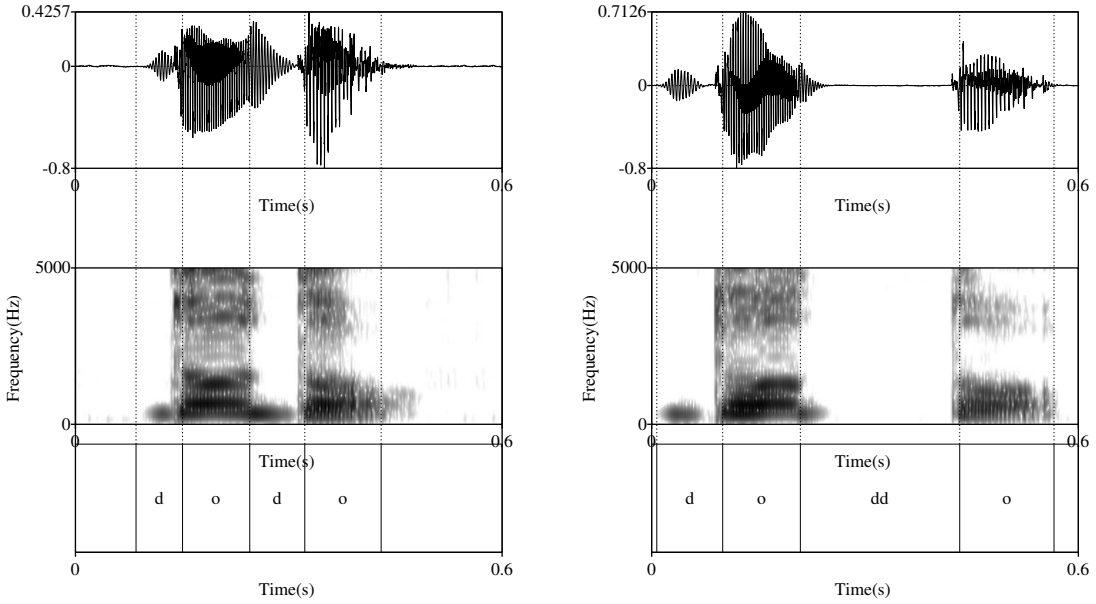

Figure 1: Sample waveforms and spectrograms. A left figure shows a singleton [d]; the right figure shows a geminate [dd]. Tokens based on Kawahara (2013).

goes into the oral cavity. As a result, it becomes increasingly hard to maintain voicing during stop closure. Japanese speakers therefore give up on keeping voicing during geminate closure.[2]

The overall results of Kawahara (2006), based on the production of the three speakers, show almost 100% of closure voicing during singleton stops. On the other hand, voiced geminates show only 40% of closure voicing. Since voicing during closure is an important perceptual cue for voicing (Lisker, 1978; Ohala, 1981; Raphael, 1981), we expect that voiced geminates are perceptually less voiced than voiced singletons.

3.2 Perception

Kawahara (2006) also conducted a perception experiment to address the prediction by the P-map more directly. The stimuli were covered by mulit-layered cocktail party noise to avoid ceiling effects. Native speakers of Japanese judged the voicing quality of intervocalic consonants. d'-values were calculated (Macmillan & Creelman, 2005), which represents a perceptual distance for each type of voicing contrast, one in the singleton pair and one in the geminate pair. The result shows that the average d' is 3.79 in the singleton pair and .71 in the geminate pair. The perception experiment thus shows that a voicing contrast is less perceptible in geminates than in singletons.

[2]Kawahara (2006) stimulated phonetic research on voiced geminates in non-standard dialects of Japanese, which shows that some of Japanese dialects show full voicing during geminates (Matsuura, 2012; Takada, 2013).

To summarize, the phonological observation is that a voicing contrast is more likely to neutralize in geminates than in singletons, and the perception experiment shows that the contrast is less perceptible in geminates. Taken together, there is a correlation between phonetic perceptibilitiy and phonological devoicability: the smaller the perceptual change that a phonological change causes, the more likely it occurs (Steriade, 2001/2008). To the extent that this correlation is real, devoicing of geminate is phonetically natural.

One complication about this conclusion is that, while the devoicability difference between singletons and geminates may be phonetically natural, the cause of devoicing, OCP(voice), may not be phonetically natural (Kawahara, 2008; Ohala, 1981). OCP(voice), or more descriptively speaking, dissimilation in voicing, is cross-linguistically rare, and always historically arose from dissimilation of other contrasts, such as aspiration or prenasalization (Ohala, 1981). These observations are accounted under Ohala's theory of dissimilation, in which dissimilation arises from misperception of a phonological contrast whose phonetic cues are spread out over several segments. Dissimilation in voicing is unexpected—or unnatural—from this perspective, because cues for voicing contrasts are localized, and not spread-out (see Kawahara 2008 for discussion).

Dissimilation in voicing thus can only historically arise from dissimilation in other features, prenasalization in the case of Japanese (Unger, 1975; Vance, 2005). To the extent that dissimilation in voicing does not make phonetic sense, it means that the trigger of the devoicing of geminates in Japanese is phonetically unnatural. Kawahara (2008) thus advances a view that phonetic naturalness and unnaturalness can coexist within a single phonological system (Hayes et al., 2009).

4 Psycholinguistics: Judgment experiments

All the theoretical work after Nishimura (2003) took it for granted that the data in (4)-(6) were correct. However, the examples were based on the intuitions of Nishimura (2003) and Kawahara (2006), the authors of the papers themselves. Kawahara (2011b) raised the question of whether the data in (4)-(6) can be supported by some more objective methods.

The issue of the quality of intuition-based data has recently been much discussed especially in the area of syntax, but also in the domain of phonology (see Kawahara 2011b for an overview). To briefly summarize the potential concerns, first, some "phonological patterns" have been shown to be non-productive with experiments using nonce words (Ohala, 1974; Sanders, 2003; Vance, 1987). Second, it is questionable whether the data based on the author's intuition can be generalized to the general population of Japanese speakers.[3] Third, the inner sensation of Nishimura

[3]For generative linguistics, it may not perhaps matter whether a pattern generalizes to the whole speech community or not, as long as there is a single individual that instantiates a particular pattern, because every individual grammar must have arisen from Universal Grammar. While this logic itself seems sound, I find it worrisome when the whole theory is built on data from a single individual (cf. Kelkar's Hindi: Kelkar 1968, cited and discussed by Hayes 1995,

(2003) and Kawahara (2006) cannot be observed from outside; i.e. cannot be replicated. Fourth, linguists may unconcsiouly feel tempted to oversimplify the pattern when they report the data based on their own intuition: it is not clear whether the reality is as simple as "only OCP-violating geminates can devoice". Finally, it is not clear whether Nishimura (2003) and Kawahara (2006) can be completely unbiased when they provided the data (Gibson & Fedorenko, 2010).

To address these concerns, a series of judgement studies have been run using naive native speakers (Kawahara, 2011a,b, 2013). To take Kawahara (2011a) as an example for illustration, the experiment asked the naturalness of devoicing in four contexts: (1) OCP-violating geminates, (2) non-OCP-violating geminates, (3) OCP-violating singletons, and (4) non-OCP-violating singletons. The participants were given one form (e.g. /doggu/) and the other variant form with devoicing (i.e. /dokku/) and were asked how natural that second form is as a pronunciation of the first form. The experiment was thus a naturalness judgment experiment on a phonological process. The study used a 5-point naturalness scale from "very natural" to "very unnatural".

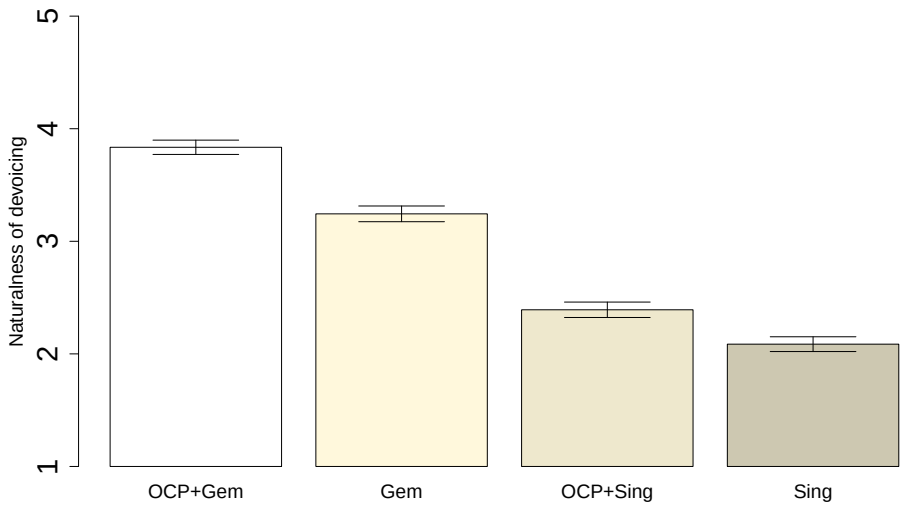

Figure 2: The naturalness ratings of the devoicing of the four conditions. Taken from Kawahara (2011a).

Figure 2 shows that results of the rating study by Kawahara (2011a). Japanese speakers did find devoicing of OCP-violating geminates most natural (the leftmost bar), which shows that the intuitions provided by Nishimura (2003) and Kawahara (2006) were not ungrounded. However, the story did not seem as simple as that. First, the Japanese speakers found devoicing of non-OCP-violating geminates more natural than that of OCP-violating singletons (2nd vs. 3rd bar). Second,

pp.276-278 and Prince & Smolensky 1993/2004, pp.47-50, especially footnote 22).

OCP made devoicing of singletons natural too (3rd vs. 4th bar). Overall, there was no clear line that divides the continuum into two categories, "grammatical devoicing" and "ungrammatical devoicing", contra what Nishimura (2003) and Kawahara (2006) claimed. This non-dichotomous distinction among the four conditions is observed even when the participants used a binary yes/no response format in a follow-up experiment (Kawahara, 2013).

It thus turned out that native speakers' judgment patterns are more gradient than the assumed "grammatical" vs. "ungrammatical" dichotomy. This beyond-binary distinction in judgment pattern is in fact well-attested cross-linguistically in phonotactic judgment patterns (see e.g. Pierrehumbert 2001). The results of the judgment studies show that this gradient nature of judgment patterns hold for judgment patterns of the phonological process in Japanese.

In addition, the experiment revealed that various linguistic factors other than OCP and geminacy impact naturalness of devoicing. For example, multiple triggers (e.g. **/b**a**gu**d**a**dd**o/** 'Bagdad/) made devoicing more natural. Second, speakers's ratings were lower when devoicing resulted in merger of two lexical items; e.g. /baggu/ 'bag' and /bakku/ 'back'. Third, speakers rated the devoicing of more frequent items more natural, as shown in Figure 3. This aspect of devoicing is more fully addressed in section 6.

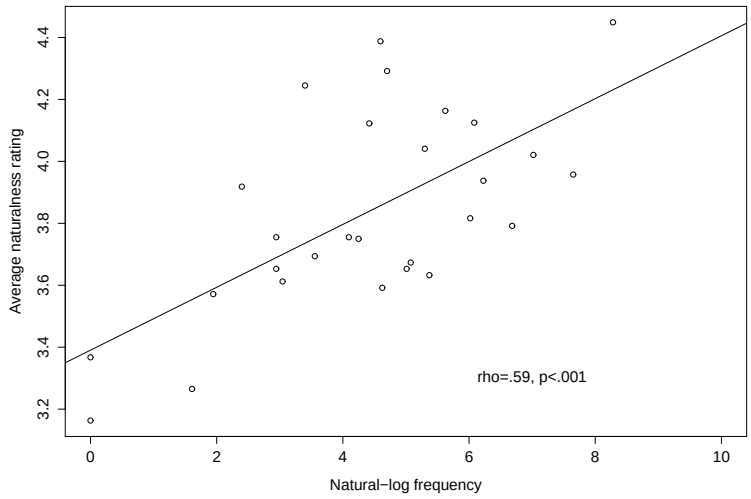

Figure 3: The correlation between average naturalness ratings and lexical frequency. Taken from Kawahara (2011a).

All of these results show that characterization of the devoicing described by Nishimura (2003) and Kawahara (2006) involved oversimplification, which in turn highlights the importance of experimentation in phonological research.

5 Corpus studies

All the judgment experiments show that Japanese speakers judge OCP-violating geminates most natural. The results of the judgment experiments lend some credibility to the original data presented in Nishimura (2003) and Kawahara (2006). Nevertheless, some concern still remains because speakers' intuition and their actual speech behavior do not sometimes match (Labov, 1996). Sano (2013) took up on this issue, which is further developed by Kawahara & Sano (2013) and Sano & Kawahara (2013), who explored the behavior voiced geminates in actual utterances.

These studies used the Corpus of Spontaneous Japanese (the CSJ) (NINJAL, 2008). This database is a large database of spoken Japanese and comes with a rich annotation system. It provides both underlying forms and surface forms, which allows us to assess whether voiced geminates are devoiced or not. The corpus studies confirm that OCP-violating geminates appear more as devoiced (about 40%) than non-OCP violating geminates (about 5%). They also (more or less) confirmed the frequency effect found by Kawahara (2011a) (see Figure 3).

Sano (2013) and Kawahara & Sano (2013) also find an effect of place of articulation on the devoicability of geminates as well: the backer the place, the more likely the geminates devoice. This patterning reflects a well-known aerodynamic difficulty hierarchy of voiced stops (Hayes & Steriade, 2004; Ohala, 1983). The backer the place, the smaller and less inflexible the oral cavity behind the constriction is, the harder it is to obtain sufficient transglottal air pressure drop to maintain voicing.

In addition to these grammatical factors, Sano & Kawahara (2013) found that non-grammatical factors impact the likelihood of devoicing as well. For example, female speakers were found to devoice geminates more often than male speakers.[4] Other non-grammatical factors that are found to impact the devoicability of geminates include age (younger speakers devoice more), speech style (devoicing is more likely in informal speech), education level (people with higher education devoice less), and others. Sano & Kawahara (2013) present analyses of geminate devoicing from the perspective of sociolignuistics.

To summarize, corpus analyses reveal that several factors affect the devoicability of geminates, both grammar-internal and grammar-external. As with the grammaticality judgment experiments summarized in section 4, the corpus-based studies show that devoicing of voiced geminates is not as monolithic as it was once thought of as.

[4]If we regard the devoicing of geminates as an on-going sound change, this observation is compatible with the sociolinguistic observation of a gender effect on sound changes—female speakers are known to initiate sound changes (Sano & Kawahara, 2013).

6 Modeling: Lexical frequency effects on phonology

Finally, Coetzee & Kawahara (2013) applied a model proposed in Coetzee (2009) to makes one step forward toward incorporating such complications of actual phonological patterns in linguistic theorization. Recall that there is a correlation between devoicing and lexical frequency, both in the judgment patterns as well as in the patterning in the corpus. This correlation is actually an old observation that is pervasive in phonology (Bybee, 2006), but one gap that generative phonological models were not good at dealing with; phonological theories have often set aside this observation, sometimes under the name of "idealization", or sometimes by relegating it to the "matter of performance".

Coetzee & Kawahara (2013) proposed a computational model in which the weights of faithfulness constraints are scaled for each lexical item using β-distributions. This system assigns higher weights to non-frequent items and lower weights to frequent items. As a result, more frequent items are more likely to undergo phonological processes. Coetzee & Kawahara (2013) show that the model shows a significantly better fit with actual data, once frequency effects are incorporated into grammar.

This proposal shows that generative grammatical models can incorporate the effect of lexical frequencies on phonological patterns. It demonstrates that maybe generative phonology is now at a point where we can broaden our empirical coverage, without relying too much on "idealization" or relegating the frequency effects as the "matter of performance" (Coetzee, 2009; Coetzee & Kawahara, 2013).

7 A remaining challenge: /p/ causes devoicing

One remaining challenge about the research on geminate devoicing is the behavior of /p/. All the studies so far assumed that it is only voiced obstruent that triggers devoicing of geminates. However, recent studies point out that /p/ can trigger devoicing as well. Some examples are shown in (18).

(18) /p/-deriven devoicing

a. /kyuupi**dd**o/ → /kyuupi**tt**o/ 'cupid'

b. /pirami**dd**o/ → /pirami**tt**o/ 'piramid'

c. /aipa**dd**o/ → /aipa**tt**o/ 'i-pad'

Fukazawa et al. (2014) show that /p/ indeed causes devoicing of geminates, using a judgment experiment and a corpus study. The challenge is that none of the theoretical analyses reviewed in section 2 predicts it: this is because all the analyses in some way or another assume that the trigger

of devoicing is OCP(voice), but the co-occurence of /p/ and voiced geminates should not violate OCP(voice).

Fukazawa et al. (2014) show based on the lexical search of Amano & Kondo (1999) that /p/ and voiced geminates are the two most infrequent sounds in the whole Japanese lexicon, presumably because these sounds are only allowed in loanwords (Ito & Mester, 1999). They argue that there may be another type of OCP constraint, independent of OCP(voice), which prohibits the occurrence of two unfamiliar segments within a word.

Kawahara (2015) entertains an alternative analysis based on Japanese orthography: voiced obstruents and [p] are shown with diacritic marks, the former with *dakuten* and the latter with *han-dakuten*. Therefore all of /p/, voiced obstruent, and voiced geminates are written with an orthographic diacritic. OCP(voice) may then actually be OCP(diacritic), which accounts for both devoicing driven by /p/ and devoicing driven by a voiced obstruent. This analysis is radical in that it (partly) shifts the burden of explanation from sounds to letters. This /p/-driven devoicing of geminates is at any rate a challenge to any phonological analysis of geminate devoicing.

8 Conclusion

This paper has reviewed how the phonology of voiced geminates in Japanese loanwords has been analyzed from different perspectives. This review has shown that we can take one phonological phenomenon, and tackle it from various perspectives: theoretical, experimental, corpus-based, and computational. These approaches can reveal how phonology interacts with other factors (phonetics, lexical, and sociolinguistic), having ramifications in phonological theorization as well as in related fields.

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