J East Asian Linguist (2011) 20:169–194
DOI 10.1007/s10831-011-9074-3

Aspects of Japanese loanword devoicing

Shigeto Kawahara

Received: 19 June 2010 / Accepted: 17 February 2011 / Published online: 12 April 2011

Abstract Nishimura (M.A. thesis, 2003) first pointed out that in Japanese loan words, voiced geminates devoice optionally when they co-occur with another voiced obstruent, i.e., when they violate OCP(voice) (e.g., /baggu/ → [bakku] 'bag'). This devoicing of geminates has been used to make several theoretical claims in the recent phonological literature. However, these claims have so far largely been based on intuition-based data provided by Nishimura (M.A. thesis, 2003) and Kawahara (Language 82(3):536–574, 2006). Kawahara (Nat Lang Linguist Theory, 2011a) addressed this problem by conducting a rating study. The first aim of this study, building on Kawahara (Nat Lang Linguist Theory, 2011a), is to further support the empirical foundation of these theoretical claims by way of a large-scale rating study. The current study shows that (i) the OCP and geminacy each affect naturalness rating of devoicing, and (ii) there is nevertheless something special about the combination of the OCP and geminacy. The second aim is to test an assumption behind the recent literature on this phenomenon. The assumption is that this devoicing pattern is monolithic—i.e., all voiced geminates uniformly undergo devoicing in a certain phonological environment. The current experiment shows that this assumption is too simplistic. In particular it shows (i) speakers rate the devoicing of affricates as natural as that of stops, (ii) speakers find devoicing of items that merge with other lexical items less natural, (iii) speakers rate devoicing as more natural when there are multiple triggers, (iv) speakers find devoicing of [dd] more natural than that of [gg], and (v) speakers find devoicing of more frequent items more natural.

Keywords Japanese · Devoicing · OCP · Geminates · Homophony avoidance · Lexical frequency · Experimental phonology · Phonological judgment

S. Kawahara (✉)
Department of Linguistics, Rutgers University, 18 Seminary Place,
New Brunswick, NJ 08901, USA
e-mail: kawahara@rci.rutgers.edu

1 Introduction

1.1 The phenomenon

Nishimura (2003) first pointed out that in Japanese loanword phonology, voiced geminates optionally devoice when they occur with another voiced obstruent, as in (1).[1] This devoicing of geminates is caused by a restriction against two voiced obstruents within the same stem, which is known as the OCP(voice) (henceforth the OCP) (for the OCP in Japanese, see Itô and Mester 1986, 2003 as well as discussion below). Nishimura (2003) and Kawahara (2006) contrast OCP-violating geminates with voiced consonants in two other contexts: non-OCP-violating voiced geminates and OCP-violating singletons, which are claimed not to undergo devoicing, as in (2)–(3).

(1) Geminates can optionally devoice if they co-occur with another voiced obstruent
   a. ba**dd**o → ba**tt**o 'bad'
   b. dore**dd**o → dore**tt**o 'dread'
   c. deibi**dd**o → deibi**tt**o 'David'
   d. ba**gg**u → ba**kk**u 'bag'
   e. do**gg**u → do**kk**u 'dog'

(2) Geminates do not devoice otherwise
   a. suno**bb**u → *suno**pp**u 'snob'
   b. re**dd**o → *re**tt**o 'red'
   c. e**gg**u → *e**kk**u 'egg'

(3) Singletons do not devoice when they violate the OCP
   a. gi**b**u → *gi**p**u 'give'
   b. ba**g**u → *ba**k**u 'bug'
   c. da**g**u → *da**k**u 'Doug'

Since Nishimura (2003), the patterns in (1)–(3) have received much attention in the theoretical literature (Coetzee and Pater, to appear; Crawford 2009; Farris-Trimble 2008; Haraguchi 2006; Hayes 2009; Itô and Mester 2008; Kaneko and Iverson 2009; Kawahara 2005, 2006, 2008; McCarthy 2008; Nishimura 2006; Pater 2009; Pycha et al., 2006; Rice 2006; Steriade 2004; Tanaka 2010; Tateishi 2002; Tesar 2007). To briefly summarize the debates concerning (1)–(3), one debate addresses how the difference between singletons and geminates arises. Kawahara (2005, 2006) demonstrates through an acoustic experiment that Japanese voiced geminates are phonetically half devoiced. The follow-up perception experiment

[1] In an online adaptation experiment reported in Kaneko and Iverson (2009), Japanese speakers did not show evidence for this OCP-induced devoicing when they adapted new loanwords. Their finding shows that this devoicing occurs in loanword phonology, not in the process of loanword adaptation (Kaneko and Iverson 2009; Kawahara 2006, 2008, 2011a). In other words, devoicing does not happen *when* Japanese speakers borrow these loanwords, but it does *after* they borrow them.

further demonstrates that a voicing contrast is perceptually less salient in geminates than in singletons. Kawahara (2005, 2006, 2008) argues based on these results that this low perceptibility is the source of the higher neutralizability of geminates. Rice (2006) on the other hand argues that a voicing contrast in geminates is more neutralizable than the one in singletons because the former is not contrastive in Japanese native phonology. These studies argue therefore that a difference in phonological neutralizability arises from either a difference in phonetic perceptibility (Steriade 2001/2008) or contrastiveness elsewhere in the phonology (Dresher 2010).

The second debate focuses on the cumulative behavior of devoicing in (1), which is also known as a "gang effect". Nishimura (2003) and Kawahara (2006) claim that neither geminacy nor the OCP alone can cause devoicing, as in (2) and (3), but that when both factors are relevant devoicing can take place. This gang effect may bear on a general debate about how to model constraint interaction (Coetzee and Pater, to appear; Farris-Trimble 2008; Hayes 2009; Nishimura 2003; Pater 2009; Tesar 2007). This sort of gang effect cannot be modeled in a ranking-based theory of constraint interaction, such as Optimality Theory (Prince and Smolensky 1993/2004), without additional mechanisms.[2] However, a theory with weighted constraints can model the cumulative pattern without extra mechanisms (Pater 2009).

The final debate is about how the emergence of the loanword devoicing in (1) bears on a theory of lexical stratification. The OCP is active in native Japanese phonology (Itô and Mester 1986), and the data in (1) show that the OCP produces an emergent phonological pattern in loanword phonology. This connection may shed light on how loanword phonology derives from native phonology (Crawford 2009; Itô and Mester 2008; Tateishi 2002).

In summary, the patterns in (1)–(3) have evoked many theoretical debates. However, one problem identified by Kawahara (2011a) is that these theoretical claims have been primarily based on the intuitions of Nishimura (2003) and Kawahara (2006). Several studies have shown potential pitfalls of an approach relying purely on authors' introspections (see, among others, Alderete and Kochetov 2009; Dabrowska 2010; Gibson and Fedorenko 2010; Griner 2001; Kawahara 2011a; Labov 1975, 1996; Myers 2009; Ohala 1974, 1986; Schütze 1996; Vance 1980 and references cited therein). Since several important theoretical claims have been made based on the Japanese devoicing data, their empirical foundation should ideally be supported by systematic experimentation with a number of theoretically-unbiased native speakers. To address this problem, Kawahara (2011a) conducted a rating experiment with a number of native Japanese speakers. The experiment indeed showed that Japanese speakers generally find devoicing of OCP-violating geminates more natural than devoicing in other environments. Kawahara (2011a) thus succeeds in securing the empirical basis of the claims made based on the patterns in (1)–(3).

However, Kawahara (2011a) found two aspects which go beyond what Nishimura (2003) and Kawahara (2006) report based on their intuitions. First,

[2] Two solutions have been proposed: (i) to posit a complex locally-conjoined (Smolensky 1995) markedness constraint that is violated only when both the OCP and a constraint against voiced geminates are violated (Nishimura 2003, 2006), or (ii) to posit different faithfulness constraints for singletons and geminates (Kawahara 2006, 2008).

Japanese speakers distinguish the grammaticality of two processes that were both judged to be "ungrammatical" by Nishimura (2003) and Kawahara (2006): devoicing of non-OCP violating geminates and devoicing of OCP-violating singletons. Given that there is a three way distinction in acceptability between OCP-violating geminates, non-OCP-violating geminates, and OCP-violating singletons, Kawahara (2011a) contends that it is difficult to draw an objective line between grammatical processes and ungrammatical processes. One of the aims of this paper is to test whether this fine-grained grammatical distinction holds in a wider set of data than considered in Kawahara (2011a).

Second, Kawahara (2011a) found that the devoicing of OCP-violating geminates may not be as monolithic as previous studies have assumed. In other words, the experiment found that there are specific types of words with certain properties—phonological and otherwise—which showed higher/lower ratings than other items. The results thus cast doubt on the assumption that the devoicing of OCP-violating geminates is a uniform, monolithic phonological pattern, as Nishimura (2003) (and subsequent studies) have assumed.[3] Rather, various factors may contribute to the naturalness of devoicing of OCP-violating geminates. This paper therefore reports a follow-up experiment to address questions that are raised—and remained unanswered—in Kawahara (2011a) (and beyond).

1.2 Seven hypotheses tested

The specific hypotheses about Japanese devoicing that this paper addresses are listed in (4).

(4) Hypotheses tested
   a. Singletons: Does the OCP affect naturalness of devoicing of singletons? If so, does it uniformly affect singletons and geminates?
   b. Affricates: Do Japanese speakers find devoicing of voiced affricates as natural as that of voiced stops?
   c. Merger: Do Japanese speakers rate devoicing less natural if devoicing would result in merger with another lexical item?
   d. Locality: Does the distance between the trigger and the voiced consonants affect naturalness of devoicing?
   e. Multiple trigger: Do the numbers of the triggers affect naturalness of devoicing?
   f. Place effects: Does place of articulation affect naturalness of devoicing?
   g. Lexical frequency effects: Do the lexical frequencies of the words affect naturalness of devoicing?

First, Kawahara (2011a) found that the OCP does make the devoicing of geminates more natural, but that study did not test whether the OCP makes

[3] This paper is not meant to undermine the value of the discovery by Nishimura (2003). Idealization is a standard methodology in linguistics (and other fields). This paper attempts to reveal a more realistic nature of devoicing in Japanese loanwords. "[I]dealization is only the *starting point* of inquiry, not its goal" (Riemer 2009, p. 626, emphasis in original).

devoicing of singletons more natural. The assumption was that devoicing of OCP-violating singletons was already "bad enough;" i.e., devoicing of singletons would be ungrammatical regardless of whether they violate the OCP or not. However, Kawahara (2011a) found that Japanese speakers distinguish between two "ungrammatical processes" (e.g., devoicing of non-OCP-violating geminates and devoicing of OCP-violating singletons), and therefore, it is of some interest whether Japanese speakers would treat devoicing of singletons differently depending on whether the words under question violate the OCP or not. A related question, to the extent that the OCP does influence the naturalness of devoicing of singletons, is whether the OCP affects singletons and geminates to the same degree.

Second, the status of devoicing of affricates has not been explicitly tested.[4] Neither Nishimura (2003) nor Kawahara (2006) report their intuitions about affricates. Haraguchi (2006) treats some intervocalic affricates as fricatives (which allophonically do alternate in this position; see footnote 4), and judges their devoicing to be "?*". Nishimura (2006) treats affricates on a par with voiced stops. Kawahara (2011a) did not include affricates in the stimuli. Therefore, whether affricates and stops pattern in the same way or not is an open question.

Third, some items can result in merger with already-existing lexical items ([baggu] 'bag' vs. [bakku] 'back'). Ichimura (2006) argues that (Japanese) speakers avoid such mergers of existing lexical items. More generally, such anti-merger constraints have been proposed by many researchers for various languages (Blevins 2005; Crosswhite 1999; Itô and Mester 2004; Kaplan 2010; Lubowicz 2007; Padgett 2002; Urbanczyk 2005), especially within the context of Optimality-Theoretic (Prince and Smolensky 1993/2004) Dispersion Theory (Flemming 1995). Kawahara (2011a) found a non-significant tendency toward the expected direction, and a follow-up study with more relevant lexical items was claimed to be necessary.

Fourth, there are items in which the trigger of devoicing is distant from the devoicing geminates (e.g. [doreddo] 'dread'). Dissimilatory force is cross-linguiatically known to be stronger between two closer elements, i.e., with less fewer intervening segments (Frisch et al. 2004; Itô and Mester 2003; Suzuki 1998; Tanaka 2007). In fact, there is evidence within Japanese that locality may matter: In a phenomenon known as Rendaku, the initial consonant of the second member of a compound becomes voiced (e.g. /nise+tanuki/ → [nise-danuki] 'fake raccoon'); however, if there is already a voiced obstruent in the second member, this voicing is blocked (i.e., Lyman's Law) (e.g. /nise+tokage/ → [nise-tokage] 'fake lizard') (Itô and Mester 1986, 2003; Lyman 1894). Vance (1980) found in a nonce-word experiment that the closer the blocker consonant, the less likely that Rendaku occurs. Therefore, we expect that in words in which the trigger and the geminates are non-local, speakers may find devoicing of OCP-violating geminates less natural. Kawahara (2011a) in fact found such a tendency, although it did not reach statistical significance. However, the stimuli contained only two relevant items ([doreddo] 'dread' and

[4] Voiced affricates in Japanese alternate with fricatives intervocalically. Whether this alternation is free-variation or allophonic alternation is controversial (Maekawa 2009, 2010; Vance 1987); for the sake of exposition, I treat them as affricates in this paper. See Maekawa (2009, 2010) for phonetic factors that influence this alternation.

[doraggu] 'drug'), leaving the possibility that that experiment did not have enough statistical power.

Fifth, there are items that contain two triggers of devoicing (e.g. [deibiddo] 'David'). Tesar (2007) points out that in such words, devoicing of geminates would still violate the OCP (e.g., [deibitto]). It is possible that the OCP militates against each pair of voiced obstruents, and therefore devoicing of geminates does ameliorate the violation of the OCP (Kawahara 2008; Tesar 2007). For example, [deibiddo] incurs three violations ([d]–[b], [d]–[dd], [b]–[dd]) whereas [deibitto] incurs only one ([d]–[b]). Nevertheless, it is also possible that speakers may find devoicing of geminates less natural in this kind of word, because of the remaining violation(s) of the OCP. Kawahara (2011a) found a non-statistical tendency toward this direction; however, the stimuli contained only two relevant items ([deibiddo] 'David' and [deddobooru] 'deadball'), again leaving the possibility that the experiment lacked enough statistical power to reveal a real difference.

Sixth, according to the data in Nishimura (2003), [gg] is more likely to devoice than [dd] (Kawahara 2006). In terms of the aerodynamic difficulty that voiced geminates present, this observation makes sense (Hayes and Steriade 2004; Jaeger 1978; Ohala 1983; Ohala and Riordan 1979; Westbury 1979). To maintain voicing, it is necessary to keep intraoral air pressure lower than subglottal air pressure. However, with stop closure, airflow required to maintain voicing increases the intraoral air pressure. The rise in intraoral air pressure occurs more quickly for [gg] than for [dd] because the intraoral cavity behind the constriction is smaller and less flexible to expand for [gg]. Transglottal air pressure drop necessary to sustain voicing should then decease more quickly for [gg] than for [dd] (see the references cited above). On the other hand, Kawahara (2011a) did not find this asymmetry in the judgment patterns; in fact, the experiment found a non-significant tendency toward Japanese speakers rating the devoicing of [dd] more natural than that of [gg]. This follow-up experiment is designed to address this conflict by including more relevant items.

Finally, Kawahara (2011a) found that lexical frequencies of the target items affect the naturalness of devoicing in that devoicing of more frequent words was judged to be more natural. Moreover, this positive correlation was found only in certain grammatical contexts (OCP-violating geminates and word-internal OCP-violating singletons) but not in other contexts (non-OCP-violating geminates and word-initial OCP-violating singletons). However, this limited effect of lexical frequencies on naturalness rating should be taken with caution because some conditions had only nine items in Kawahara (2011a). The current study is thus designed to confirm the limited effect of lexical frequencies with a larger set of data. This question is in part motivated by a growing body of interest in to what extent lexical frequency affects phonological regularity (for different proposals on this issue, see e.g. Boersma and Hayes 2001; Bybee 1999, 2001; Coetzee 2009b; Coetzee and Kawahara 2010; Coleman and Pierrehumbert 1997; Frisch et al. 2000; Hay et al. 2003; Hayes and Londe 2006).

These are the seven questions that the current experiment aims to address. To summarize, Kawahara (2011a) aimed to make a general comparison between OCP-violating geminates and other consonants, and it indeed showed that Japanese

speakers treat OCP-violating geminates differently from other consonants. It also found hints of interesting variations within OCP-violating geminates. However, the study was limited in its power because it did not have enough lexical items. The current experiment thus follows up on Kawahara (2011a) to address these remaining questions. The current experiment therefore includes many more lexical items to guarantee sufficient statistical power.

2 Method

2.1 Stimuli

Table 1 lists the entire stimuli. (In this paper I use romanized representation of Japanese except for the affricate [ʤ].) To address the questions reviewed in Sect. 1.2, the stimuli were constructed as follows. The design had four conditions: OCP-violating geminates, non-OCP-violating geminates, OCP-violating singletons, and non-OCP-violating singletons. The current experiment included many relevant lexical items because, for some hypotheses discussed above, Kawahara (2011a) considered only a few relevant items. To that end, first, many words containing OCP-violating geminates were collected, partly based on three previous studies (Kawahara 2011a; Nishimura 2003, 2006), which resulted in 28 items. Within these items, one item contained [bb], 16 items contained [dd], six items contained [gg], and five items contained affricates. There is only one item containing [bb], because [bb] barely appears in Japanese loanwords in the first place; on the other hand, there are many words containing [dd], because [dd] is most commonly found (Kaneko and Iverson 2009; Katayama 1998; Shirai 2002). After collecting items for the OCP-violating gemination condition, for the other three conditions, 28 items were collected with the same numbers of items with matching place of articulation. This resulted in 112 items in total (cf. Kawahara 2011a had 33 items).

The items in which the target consonants come after nasal consonants were avoided because nasals encourage voicing—and may hinder devoicing—in the following consonants (Hayes and Stivers 1995; Pater 1999). Since the OCP-violating geminates generally appear in word-final syllable, the target consonants in the other conditions were placed in word-final syllables as much as possible. In the OCP-violating geminate condition, those that have non-local triggers are [buraddo], [bureddo], [doreddo], [guriddo], [haiburiddo], [madoriddo], [saraburedddo], [doraggu], [biredʤi], [buridʤi], and [kemburidʤi]. Those that have multiple triggers are [bagudaddo], [deibiddo], [sindobaddo], and [debaggu]. Those that would result in merger with other existing lexical loanword items are [baddo] vs. [batto] 'bat', [daddo] vs. [datto] 'DAT', [baggu] vs. [bakku] 'back', and [doggu] vs. [dokku] 'dock'.[5]

[5] Since the instructions of the experiment made it clear that the experiment was about loanwords, merger with non-loanwords was not considered to be merging. For OCP-violating geminates, there were two such items: [budda] and [guddo] could be considered as merging with phrases [but-ta] 'hit (past)' and [gut-to] 'patiently' (the latter with an accentual difference).

Table 1 The list of the stimuli

OCP-violating geminates		Non-OCP-violating geminates		OCP-violating singletons		Non-OCP-violating singletons	
gebberusu	'Göbbels'	habburu	'Hubble'	ʤdobu	'job'	ibu	'eve'
baddo	'bad'	hariuddo	'Hollywood'	baado	'bird'	haado	'hard'
bagudaddo	'Bagdad'	huddo	'hood'	bado	'badminton'	haido	'hide'
budda	'Buddha'	heddo	'head'	baraado	'ballad'	huudo	'food'
buraddo	'blood'	kiddo	'kid'	barikeedo	'barricade'	kaado	'card'
bureddo	'bread'	maddo	'mad'	bideo	'video'	koodo	'cord'
daddo	'dad'	mesoddo	'method'	biriyaado	'billiard'	moodo	'mode'
deddo	'dead'	middo	'mid'	biroodo	'velvet'	muudo	'mood'
deibiddo	'David'	reddo	'red'	boodaa	'border'	niido	'need'
doreddo	'dread'	rikiddo	'liquid'	boodo	'board'	nuudo	'naked'
goddo	'god'	roddo	'rod'	daioodo	'dyode'	raado	'lard'
guddo	'good'	shureddaa	'shredder'	gaaden	'garden'	raidaa	'rider'
guriddo	'grid'	sureddo	'thread'	gaado	'guard'	waado	'word'
haiburiddo	'hybrid'	teddo	'Ted'	gaido	'guide'	roodo	'rode'
madoriddo	'Madrid'	uddo	'wood'	goorudo	'gold'	saido	'side'
sarabureddo	'thoroughbred'	yunaiteddo	'United'	gureedo	'grade'	siido	'seed'
sindobaddo	'Sindbad'	piramiddo	'pyramid'	zoido	(common name)	saado	'third'
baggu	'bag'	eggu	'egg'	bagu	'bug'	hagu	'hug'
biggu	'big'	furaggu	'flag'	ʤogu	'jog'	riigu	'league'
debaggu	'debug'	furoggu	'frog'	burogu	'blog'	magu	'mug'
doggu	'dog'	reggu	'leg'	giga	'giga'	ragu	'rag'
doraggu	'drag'	sumoggu	'smog'	tagarogu	'Tagalog'	tagu	'tag'
baddʒi	'badge'	maridʤi	'marriage'	dameeʤi	'damage'	keeʤi	'cage'
bireddʒi	'village'	heddʒi	'hedge'	engeeʤi	'engage'	peeʤi	'page'
buriddʒi	'bridge'	roddʒi	'lodge'	gareeʤi	'garage'	raaʤi	'large'
ʤaddʒi	'judge'	eddʒi	'edge'	geeʤi	'gauge'	imeeʤi	'image'
kemburidʤi	'Cambridge'	kareddʒi	'college'	ʤooʤi	'George'	chaaʤi	'charge'
gudzzu	'goods'	kidzzu	'kids'	ʤazu	'jazz'	ruuzu	'loose'

2.2 Task

In this experiment Japanese speakers rated the naturalness of devoicing in four grammatical conditions. The instructions explained that the questionnaire was about the naturalness of devoicing in Japanese loanwords. For each question, the participants were presented with one stimulus, and were asked to judge the naturalness of the form that undergoes devoicing of word-internal consonants (e.g., given [baddo], how natural would you find it to pronounce it as [batto]?). For stimuli with two singleton voiced consonants, the devoiced forms were those that devoice the second voiced consonant. The target stimuli as well as their devoiced forms were all presented in Japanese *katakana* orthography. (See Kawahara 2011b for a comparison between orthography-based rating and audio-based rating of the devoicing patterns under discussion.)

Following Kawahara (2011a), the speakers judged the naturalness of devoicing on a 5-point scale: A "very natural," B "somewhat natural," C "neither natural nor unnatural," D "somewhat unnatural," and E "very unnatural." (The software used to present the stimuli (sakai; see below) could not present the scale numerically, so the responses were converted to a numerical scale later). The speakers were asked to read the stimuli before answering each question, and to base their decision on their auditory impression rather than on orthography. The devoiced form of affricates—although they can alternate with fricatives intervocalically (see footnote 4)—were represented as voiceless affricates, rather than voiceless fricatives, following Nishimura (2006).

2.3 Procedure

Sakai (https://sakai.rutgers.edu/portal) was used to run the online experiment (see Reips 2002 for general discussion on online experimentation). The first page of the experimental website presented a consent form for a human subject experiment, and then they were forwarded to a testing site. After that, each page presented one stimulus. The instructions and the options were provided in Japanese orthography. Sakai randomized the order of the stimuli. At the end of the experiment, participants were asked if they knew the devoicing of OCP-violating geminates discussed in Kawahara's work; data from those who answered positively to this question were excluded from the following analysis, in order to prevent the results from being affected by the participants' theoretical orientation.

2.4 Participants

To obtain enough statistical power, the experiment was run until 52 native speakers of Japanese completed the study. Three speakers were familiar with the devoicing phenomenon and therefore were excluded from the following analysis.

2.5 Frequency measures

The frequencies of the stimuli were taken from a Japanese lexical corpus, Amano and Kondo (2000). Following the standards of psycholinguistic studies (Rubin 1976;

Smith and Dixon 1971), the natural log frequencies of these values were calculated (ln(0) was replaced with 0). The mean log-frequencies of the four grammatical conditions were as follows: OCP-violating geminates: 4.39; non-OCP-violating geminates: 4.01; OCP-violating singletons: 4.51; non-OCP-violating singletons: 5.51.

2.6 Statistics

The responses were first converted to numerical values in the following way: "very natural" = 5; "somewhat natural" = 4; "neither natural nor unnatural" = 3; "somewhat unnatural" = 2; "very unnatural" = 1. For statistical analyses, first, a general linear mixed model was run (Baayen et al. 2008; Baayen 2008; Bates 2005; Jaeger 2008) using R (R Development Core Team 1993–2011) with the `lme4` package (Douglas et al. 2011).

The first analysis included all the data points. Rating scores were regressed against a general model in which OCP, geminacy, affricacy (i.e., affricates vs. stops), the possibility of merger, and lexical frequency were fixed factors, and speakers and items were random factors. Two other factors—the number of intervening syllables and the number of triggers—were not included in this general model, because they concern only OCP-violating words. Place was not coded for affricates—hence not included in this general model either—because the place of affricates was largely predictable. This general model included many fixed factors, partly to test whether two grammatical factors—OCP and geminacy—would have effects on naturalness rating beyond the other factors. The general model also included the interaction term between the OCP and geminacy. A significant interaction would mean that there is something special about the combination between the OCP and geminacy, i.e., there is something special about OCP-violating geminates, as Nishimura (2003) and Kawahara (2006) claim.

The second analysis only analyzed OCP-violating geminates, the grammatical condition that is of most interest to us. This model included the possibility of merger, the multiplicity of triggers, the number of intervening syllables, and lexical frequency as fixed factors. Affricacy was not included in this model, because it correlated highly with lexical frequency ($r = 0.37$), and the inclusion of affricacy would have resulted in a multicollinearity problem. More specific hypotheses that were not covered by these general linear mixed models were addressed by simple t-test based contrast analyses. The alpha level was not adjusted because different tests test different, independent pre-planned hypotheses.

The `lme4` package does not automatically compute p-values because the exact procedure to calculate degrees of freedom is not known for linear mixed model analyses. Therefore, they were instead calculated by the Markov chain Monte Carlo method using the `pval.func()` function of the `languageR` package (Baayen 2009). Finally, the correlation between the ratings and the frequencies was tested by a Spearman correlation test using R.

3 Results

3.1 The four grammatical conditions

Figure 1 illustrates the average ratings of the four grammatical conditions (OCP-violating geminates: /baddo/ → [batto], non-OCP-violating geminates: /heddo/ → [hetto], OCP-violating singletons: /baado/ → [baato], and non-OCP-violating singletons: /haado/ → [haato]). Here and throughout, the error bars represent 95% confidence intervals based on the variability across all relevant items and speakers and a *t*-distribution.

Japanese speakers find the devoicing of OCP-violating geminates most natural (average = 3.84), more natural than devoicing of non-OCP-violating geminates (average = 3.24). They also rate the devoicing of non-OCP-violating geminates more natural than that of OCP-violating singletons (the average = 2.39). The comparisons among the first three cases replicate the results of Kawahara (2011a). Moreover, the speakers judged devoicing more natural when singletons violate the OCP (averages = 2.39 vs. 2.08).

Table 2 shows the results of the general linear mixed model. The effects of the OCP and geminacy are both significant, each contributing to the naturalness judgments. Their interaction term is significant, which shows that the OCP affects ratings significantly more in the geminate condition than in the singleton condition (the difference in the geminate conditions = 0.60 (3.84−3.24) vs. the difference in the singleton condition = 0.31 (2.39−2.08)). Affricacy and lexical frequency have an effect on overall naturalness ratings. The possibility of merger does not have a significant impact in this general model.

Table 3 illustrates the linear mixed model analysis only on OCP-violating geminates. In this analysis, multiplicity of trigger and lexical frequency have a significant effect. In the following sections, we look at the specific hypotheses that were reviewed in Sect. 1.2.

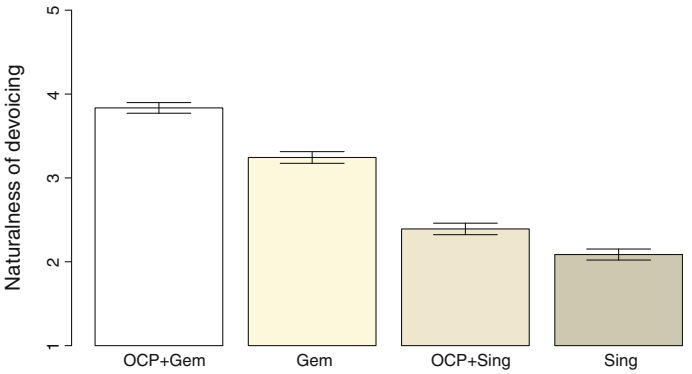

Fig. 1 The average naturalness ratings of OCP-violating geminates, non-OCP-violating geminates, OCP-violating singletons, and non-OCP-violating singletons. The *error bars* represent 95% confidence intervals

Table 2 The results of the genearl linear mixed model

	Coefficients	*t*-value	Significance
OCP	0.324596	7.358	<0.001
Gem	1.191316	27.492	<0.001
OCP:Gem	0.254924	4.240	<0.001
Affricacy	−0.094928	−2.398	<0.05
Merger	−0.022312	−0.558	n.s.
Frequency	0.026240	3.659	<0.001

Table 3 The results of the linear mixed model on OCP-violating geminates

	Coefficients	*t*-value	Significance
Merger	−0.116150	−1.314	n.s.
Multiplicity of trigger	0.233651	2.312	<0.05
Number of intervening syllables	−0.001614	−0.020	n.s.
Frequency	0.122237	8.615	<0.001

3.2 Affricates

Figure 2 compares naturalness ratings between stops and affricates. The difference between stops and affricates is small (stops 2.91 vs. affricates 2.79) but significant overall ($t = -2.398, p < 0.05$). Within OCP-violating geminates, speakers rate the devoicing of affricates slightly more natural than the devoicing of stops. However, the difference is very small (stop 3.83 vs. affricate 3.86) and non-significant according to a post-hoc test comparing the rating scores of OCP-violating geminate stops and those of OCP-violating geminate affricates ($t(1362) = 0.387$, n.s.). This result is consistent with Nishimura's (2006) treatments of voiced affricates in that Japanese speakers treat devoicing of affricates at least as natural as that of stops (cf. Haraguchi 2006).

3.3 An anti-merger effect

Figure 3 compares the naturalness ratings of items that result in merger and those that do not. Speakers in general disfavor devoicing that would result in merger (averages: 2.79 vs. 2.91), but the overall effect does not reach significance ($t = -0.558$, n.s.). A liner mixed model on OCP-violating geminates does not reveal a significant different either (averages: 3.65 vs. 3.87: $t = -1.314$, n.s.). However, given the non-overlapping error bars in Fig. 3, a post-hoc test was run to compare OCP-violating geminates that would result in merger and those that would not. This analysis revealed a significant difference ($t(1362) = -2.286, p < 0.05$).

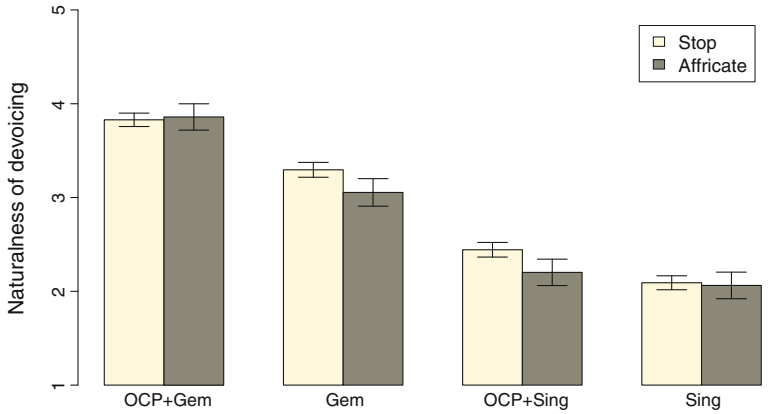

Fig. 2 A comparison between affricates and stops in terms of naturalness ratings

At least within OCP-violating geminates, therefore, speakers find devoicing that results in merger less natural than those that do not.

3.4 Locality

Figure 4 illustrates, for OCP-violating singletons and OCP-violating geminates, the effect of intervening syllables on the naturalness ratings of devoicing; each bar represents cases with a different number of intervening syllables.

For OCP-violating geminates, the number of intervening syllables does not have any effects (3.83 vs. 3.84: $t = -0.020$, n.s.). For OCP-violating singletons, surprisingly, the more intervening syllables exist, the more natural the devoicing is rated. Post-hoc analyses show that devoicing of singletons is rated more natural

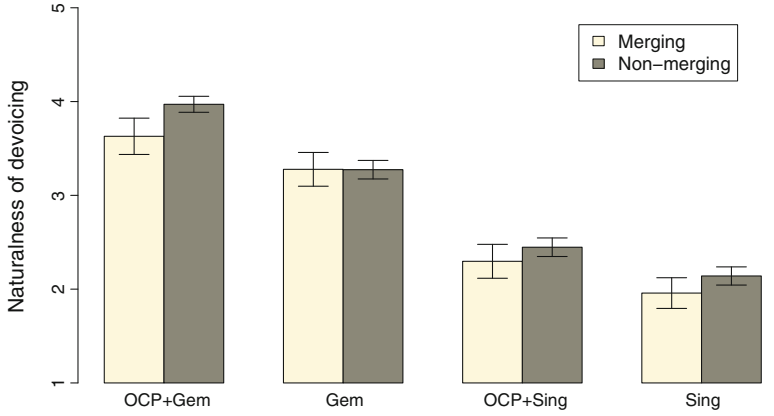

Fig. 3 A comparison between items that would result in merger and those that would not

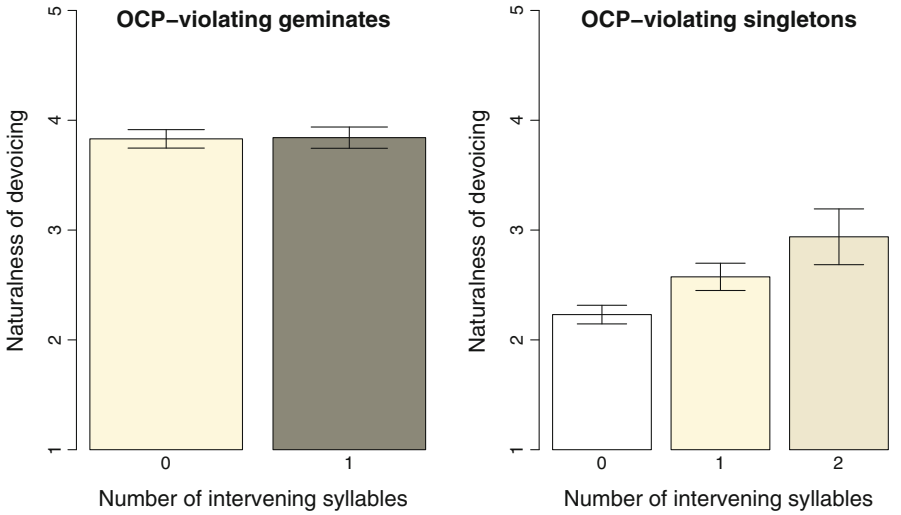

Fig. 4 The average naturalness ratings according to the numbers of intervening syllables. *Left figure* OCP-violating geminates; *right figure* OCP-violating singletons

when there is one intervening syllable than when there is none (2.57 vs. 2.23: $t(1266) = -4.575, p < 0.001$); the comparison between 1 syllable and 2 syllables is also significant (2.57 vs. 2.94: $t(535) = -2.486, p < 0.05$).

3.5 Words with multiple triggers

Figure 5 illustrates, for OCP-violating geminates, the effects of the numbers of trigger on naturalness ratings (in the current stimuli, there are no items for the OCP-violating singleton condition in which there are multiple triggers). Speakers rate devoicing more natural when there are multiple triggers than when there is only one trigger (4.05 vs. 3.80: $t = 2.312, p < 0.05$).

3.6 Place effects

Figure 6 illustrates the effect of place on naturalness ratings for stops. The Japanese speakers rate devoicing of coronal stops more natural than devoicing of dorsal stops, and rate devoicing of labials lower than that of dorsals (labial 2.38, coronal 3.01, dorsal 2.73). Place shows a significant impact on naturalness rating overall ($t = 7.187, p < 0.001$). Post-hoc analyses show that within OCP-violating geminates, speakers rate devoicing of [dd] higher than that of [gg] (3.91 vs. 3.67: $t(1022) = 2.462, p < 0.05$). The difference between [bb] and [gg] is also significant (3.16 vs. 3.67: $t(288) = 2.764$, $p < 0.01$); however, there is only one item containing [bb] in each condition, and therefore it is difficult to make any conclusive generalizations about the labial vs. dorsal comparison.

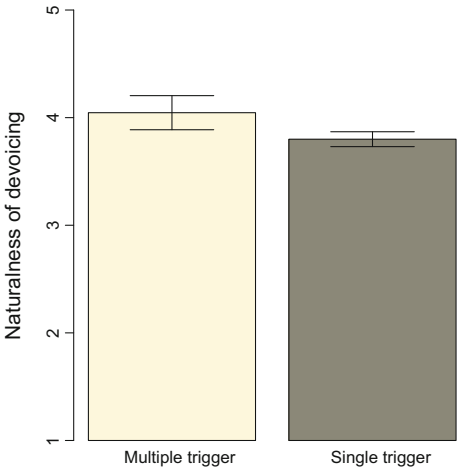

Fig. 5 The effect of the numbers of triggers on naturalness ratings (OCP-violating geminates only)

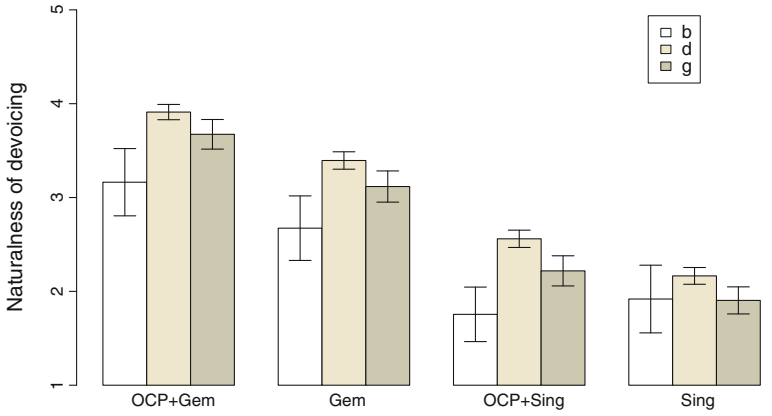

Fig. 6 The average naturalness ratings by place of articulation

3.7 Lexical frequency effects

Finally, the scatterplots in Fig. 7 illustrate the effect of lexical frequencies on naturalness ratings in the four grammatical conditions. Each scatterplot plots, for each lexical item, its average naturalness rating on the *y*-axis against its natural-log frequency on the *x*-axis (the *y*-axis scales are different in different scatterplots). In OCP-violating geminates, naturalness ratings positively correlate with lexical frequencies ($\rho = 0.59, p < 0.001$): Japanese speakers rate devoicing more natural when the word in question is more frequent.[6] On the other hand, lexical fre-

[6] See Coetzee and Kawahara (2010) for an attempt to model this frequency effect.

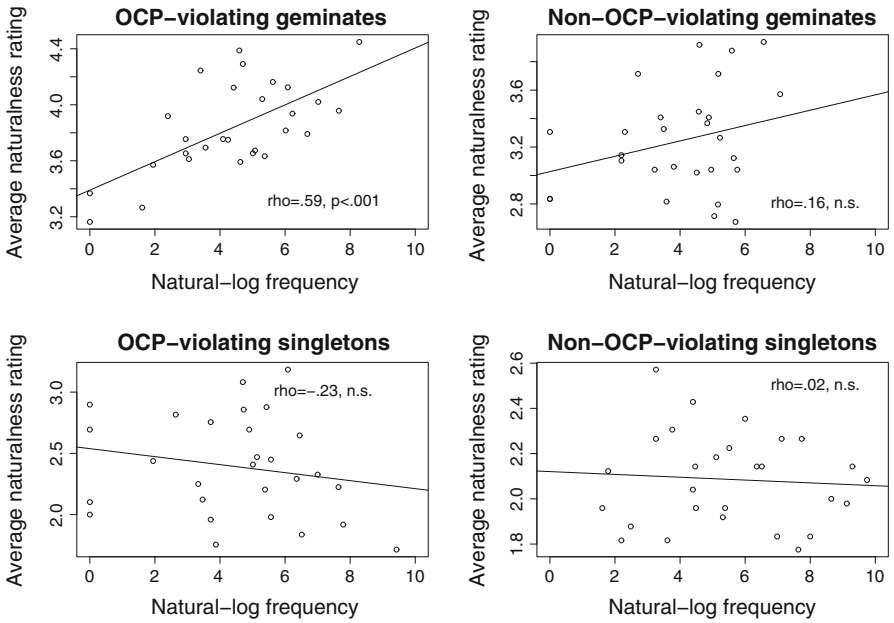

Fig. 7 The effects of lexical frequency on naturalness ratings in the four grammatical conditions: OCP-violating geminates, non-OCP-violating geminates, OCP-violating singletons, non-OCP-violating geminates. Each *dot* represents one lexical item. The *y*-axis scales are different in different sub-figures

quencies do not show any significant effects on naturalness ratings in the other three conditions (non-OCP-violating geminates: $\rho = 0.16$, n.s.; OCP-violating singletons: $\rho = -0.23$. n.s; non-the OCP violating singletons: $\rho = 0.02$, n.s.).

4 Discussion

4.1 The OCP and geminacy

The current rating study first of all has shown that the OCP and geminacy each contribute to the naturalness ratings of devoicing for Japanese speakers. Moreover, the OCP and geminacy interact to a statistically significant degree, indicating that the effect of the OCP is stronger on geminates than on singletons, i.e., the effects of the OCP and geminacy are not additive. This significant interaction is perhaps what underlines the intuition of Nishimura (2003) and Kawahara (2006) that devoicing is only "possible" in OCP-violating geminates (though see Sect. 4.2).

This significant interaction can present a challenge to an analysis of the patterns in (1)–(3) using weighted constraints (Pater 2009). In this analysis, two simple markedness constraints—the OCP and a constraint against voiced geminates—have lower weights than a faithfulness constraint that prevents devoicing. However, the weights of these markedness constraints add up to coerce devoicing of OCP-violating geminates. The analysis derives devoicing of OCP-violating geminates

from addition of violations of two lower-weighted constraints. However, the current rating results show that the effects of the OCP and geminacy are not additive.

4.2 Gradiency: beyond a grammatical/ungrammatical dichotomy

The rating patterns of the four grammatical conditions show that grammatical ratings follow a gradient pattern, as Kawahara (2011a) contends. Nishimura (2003) and the following studies have assumed that only devoicing of OCP-violating geminates is grammatical, while context-free devoicing of geminates and OCP-induced devoicing of singletons are ungrammatical, as in (2)–(3). In other words, a grammatical/ungrammatical dichotomy was assumed to exist.

However, the current results show that there is a distinction among "ungrammatical processes:" (i) speakers find context-free devoicing of geminates better than OCP-induced devoicing of singletons, and (ii) speakers find devoicing of singletons more natural when they violate the OCP. Given this result, it is hard to draw a line between "grammatical" devoicing and "ungrammatical" devoicing. These results therefore demonstrate that judgments do not operate as a grammatical/ungrammatical diachotomy, but instead follow a more fine-grained gradient pattern. (For relevant discussion, see among others Albright 2009; Berent et al. 2007; Coetzee 2008, 2009a; Goldrick to appear; Hayes 2000, 2009; Pertz and Bever 1975; Pierrehumbert 2001; see Adli 2010; Chomsky 1965; Myers 2009; Schütze 1996; Sorace and Keller 2005 for a similar observation in syntactic judgments.)[7]

One may argue that the current experiment resulted in a gradient rating pattern because the scale used in the current experiment was gradient. To address this question, Kawahara (2011b) ran a series of follow-up experiments on the same devoicing patterns in Japanese. One experimental variable tested in the study was a mode of judgment, comparing a judgment pattern using a scale, as in the current experiment, and a judgment pattern using a binary forced-choice paradigm. In the latter mode, the participants were asked to judge whether devoicing was possible or impossible in various phonological environments. The results show that the four-way grammatical distinction we observed in the current experiment still holds even with a binary forced-choice task. The results in Kawahara (2011b) thus demonstrate that the four-way grammatical distinction found in the current experiment is not an artifact of an experimental task.

To the extent that acceptability patterns show a four-way distinction, a further question arises: why Japanese speakers make the two distinctions other than the one identified by Nishimura (2003) ((i) context-free devoicing of geminates is better than OCP-induced devoicing of singletons, and (ii) devoicing of singletons is more natural when they violate the OCP). The second case makes sense because Japanese native phonology does avoid words containing OCP-violating singletons (Itô and Mester 1986, 1995, 1999), and this avoidance may have led to the higher naturalness of devoicing of OCP-violating singletons even in loanwords.

[7] An interesting question that arises given this result is how this four-way grammatical judgment distinction is reflected in actual production patterns. A systematic production experiment is called for to address this question.

The first distinction is less straightforward to explain. It may be that, since Japanese voiced geminates are semi-devoiced phonetically and since they are perceptually more similar to voiceless counterparts than singleton voiced consonants are (Kawahara 2005, 2006), Japanese speakers may prefer devoicing of geminates in general to devoicing of singletons. An alternative would be to say that voiced geminates are "more marked" than OCP-violating singletons, although there is no evidence for this postulation in Japanese phonology: They are both prohibited in native phonology, and they are both permitted in loanword phonology (Itô and Mester 1995, 1999).

4.3 A summary of other effects

In addition to revealing the nature of the contributions of the OCP and geminacy on naturalness ratings, the current experiment reveals several aspects of devoicing of OCP-violating geminates: (i) speakers rate the devoicing of affricates as natural as that of stops, (ii) speakers rate devoicing more natural when it does not result in merger with other lexical items, (iii) speakers rate devoicing of voiced geminates more natural when there is more than one trigger, (iv) speakers rate devoicing [dd] more natural than [gg], and (v) speakers rate devoicing of more frequent lexical items more natural.[8]

4.4 Locality of OCP

The current experiment does not find an effect of intervening syllables on the naturalness of devoicing in OCP-violating geminates, although cross-linguistically dissimilatory forces are known to be stronger between two closer elements (Frisch et al. 2004; Itô and Mester 2003; Suzuki 1998; Tanaka 2007). The results may imply, at least in the case of devoicing of OCP-violating geminates in Japanese, that the domain of the OCP is unbounded—as long as two voiced obstruents are within the same domain, an equal amount of force applies (though see below for a potential confound). This conclusion may not come as a surprise, given that blockage of Rendaku due to the OCP occurs across intervening syllables (e.g., /nise+tokage/ → [nisetokage] 'fake lizard', Itô and Mester 1986, 2003). This non-local nature of the Japanese OCP constraint, however, is not what is predicted from the results of Vance's (1980) nonce-word study in which blockage of Rendaku occurred more

[8] Kazu Kurisu and Gunnar Hanson (p.c.) independently asked if accents can affect the naturalness of devoicing. If accented syllables are phonologically strong (Beckman 1997) (although such evidence is scarce in Japanese accented syllables), then speakers may disfavor devoicing in accented syllables. However, since heavy syllables attract accents in Japanese loanwords (Kubozono 2006), in the OCP-violating geminate condition, voiced geminates are generally in the syllable coda of accented syllables; e.g. [bággu] 'bag' and [dorággu] 'drag'. Three exceptions are [déibiddo] 'David', [baddʒi] 'badge', and [bíreddʒi] 'village'. The averages confirm the expectation that devoicing is less natural in accented syllables: 3.83 (accented syllable) vs. 3.91 (non-accented syllable). However, a more systematic study with auditory stimuli is necessary to address this question more carefully, because some loanwords can be pronounced without an accent when they become familiar, especially in a particular group of people (Inoue, 1998) (e.g., [debaggu] 'debug' can be pronounced without an accent when used by computer experts), and there is no way of knowing if/when this deaccenting occurred for particular items for particular speakers.

frequently when the blocker consonant is closer to the consonants that would undergo Rendaku.

Recall next that speakers rate devoicing of singletons more natural when there are intervening syllables. Andries Coetzee (p.c.) pointed out that there could be an assimilative effect in voicing between consonants across vowels (see Hansson 2004; Rose and Walker 2004 for some cases of long-distance voicing assimilation). If that were the case, then it would disfavor devoicing when two voiced consonants appear close to each other. This is an interesting hypothesis that is worth testing in future research, although no evidence is known for this sort of long-distance assimilative effect in Japanese phonology.

Another possibility, raised by Kyoko Yamaguchi (p.c.), is to resort to an idea of positional faithfulness (Beckman 1997). Words with OCP-violating singletons with intervening syllables are, by virtue of having intervening syllables, long (longer than two syllables) (e.g. [baraado] 'ballad', [barikeedo] 'barricade', and [biriyaado] 'billiard'). It may be that in general speakers may allow neutralizing a contrast in late syllables in long words, because preceding syllables provide enough cues for lexical access (as predicted by, for example, a cohort model of lexical access: Marslen-Wilson 1975; Marslen-Wilson and Welsh 1978). Put in phonological terms, later syllables in long words are positionally weak, so that they are more likely to undergo phonological alternations (see Becker and Nevins 2010 for a similar observation about the correlation between word-length and neutralizability in Turkish, and its positional-faithfulness based explanation; see Kawahara and Shinohara 2011 for evidence for the positional strength of initial syllables in Japanese).

4.5 The effect of multiple triggers

The initial hypothesis about words containing multiple triggers was that their devoicing would be rated less natural than that of words that contain only one trigger, because words with multiple triggers would still incur violation(s) of the OCP after they undergo devoicing (Kawahara 2008; Tesar 2007). However, the actual results go in the opposite direction. Devoicing in words with multiple triggers is considered to be more natural.

The higher rating of words with multiple triggers may stem from the fact that there are multiple forces that coerce dissimilation. Suppose the OCP constraint assesses its violation by pairs of two voiced obstruents (Kawahara 2008; Tesar 2007). Then words with two triggers have three violations (e.g., [deibiddo] has three violations: [d]–[b], [d]–[dd], [b]–[dd]), and devoicing the geminates reduces the violations by two (e.g., [deibitto] has one violation: [d]–[b]). On the other hand, words with one trigger have one violation (e.g., [baddo] has one violation: [b]–[dd]) and devoicing would resolve that violation. The former case therefore ends up resolving more of the OCP violations, and hence it could be judged more natural.

This scenario predicts that there can be a case in which dissimilation is coerced only when there are two triggers—Itô and Mester (2003) deny that such a pattern is possible (p. 265, endnote 23) (see also Tanaka 2007; Tesar 2007). However, there are patterns of vowel harmony that are triggered only when there is more than one trigger: e.g., Classical Manchu (Dresher 2010; Walker 2001; Zhang 1996). In

Hungarian, moreover, harmony strength is stronger when there are multiple triggers (Hayes and Londe 2006; Hayes et al. 2009). The result may show that the same tendency holds in dissimilation, although this hypothesis needs to be examined more extensively in light of cross-linguistic patterns of dissimilation.

4.6 Place effects

This study replicated Kawahara (2011a) in that Japanese speakers find the devoicing of [dd] more natural than that of [gg]. This pattern, however, goes counter to the direction that is expected from the aerodynamic challenge imposed on voiced stops (see Sect. 1.2). One possibility is the difference actually comes from the following vowel: In Japanese loanwords, word-final [d] in source words is followed by [o] and [g] is followed by [u] (Katayama 1998). Moreover, word-final high vowels preceded by voiceless consonants are devoiced (Tsuchida 1997). Therefore, devoicing of [gg] word-finally would feed the devoicing of the following [u], whereas devoicing of [d] does not, because the vowel is non-high. As a consequence, Japanese speakers may disfavor devoicing of [gg] compared to devoicing [dd] because devoicing of [gg] would cause a further phonological change. A problem of this explanation is that the previous study by Kawahara (2011a) did not find the effect with devoicability of the following vowel in naturalness rating. Another problem with this explanation, which was raised by an anonymous reviewer, is the fact that the devoicing of [bb] was rated lower than that of [gg], despite the fact that the following vowel is not devoicable in the geminate conditions ([gebberusu] 'Göbbels' and [habburu] 'Hubble'). (Recall however that we should take this pattern with caution because there is only one lexical item with a labial stop per each condition.)

An alternative explanation is that words containing [dd] are more frequent than those that contain [gg] (average log frequencies: 4.72 vs 3.44). However, this frequency-based explanation does not hold for OCP-violating geminates ([dd]: 3.99 vs. [gg]: 4.79). Another potential factor is that [dd] is more frequent as a sound than [gg] in Japanese loanword phonology in general (i.e., it has a high phoneme frequency). Kawahara (2005) finds, based on Amano and Kondo (2000), that [dd] appears 22,896 times (10.04 in log), whereas [gg] appears 1,201 times (7.09 in log). This higher phoneme frequency of [dd] may be a reason for why Japanese speakers judged the devoicing of [dd] to be more natural. To the extent that this explanation is on the right track, the frequencies of sounds in general—rather than the frequencies of the words *per se*—may affect the naturalness ratings, although this hypothesis needs to be tested in future experimentation.

4.7 Lexical frequency effects

Finally, the current study has found that lexical frequencies affect grammatical judgments only in a limited grammatical condition, replicating Kawahara (2011a) with a much larger pool of stimuli. The results show that it is not the case that lexical frequencies govern judgment patterns entirely; only in limited grammatical environments can lexical frequencies exert their effects.

Modeling the limited effect of frequency provides a challenging and interesting task for future research. Jason Shaw (p.c.) raised the following possibility: Since the type frequency of words containing OCP-violating geminates is smaller than the type frequencies of other kinds of words, the devoicing pattern is less regularized for OCP-violating geminates. In other words, in the three environments other than words with OCP-violating consonants, there are sufficient number of words so that their phonological properties are stabilized, resulting in less phonological variation. On the other hand, since words containing OCP-violating geminates are still small in number (this study contained "only" 28 words with OCP-violating geminates), its phonological property as a group is yet to be stabilized, leaving room for lexical frequencies to affect the phonological variation (see Albright and Hayes 2003; Bybee 2001; Bybee and Pardo 1981; Pierrehumbert 2001 for a relevant discussion). This hypothesis provides an interesting line of approach for modeling the limited influence of lexical frequencies on the naturalness judgement pattern, but verifying the hypothesis is left for future research.

4.8 Overall summary

The current experiment shows that the OCP and geminacy each affect naturalness rating of devoicing in Japanese. It moreover reveals a significant interaction between these two factors, suggesting that the OCP affects rating more in geminate consonants, supporting the original observation of Nishimura (2003). In addition, this study reveals that various factors—the possibility of merger, place of articulation, and the lexical frequencies of the words—affect naturalness ratings of devoicing. The current study shows that devoicing of OCP-violating geminates is not as monolithic as previous phonological studies have assumed, and in this regard, it highlights the importance of an experimental approach to theoretical linguistics.

One final remaining question that arises given the current results is which factors are due to grammar and which factors are due to task effects. It seems safe to conclude that the influence of the OCP, geminacy, affricacy, and place, are due to grammatical factors, because these are notions intrinsic to phonology (i.e., any phonological system must encode these notions in the grammar). Some other cases are not so clear-cut. The anti-merger effect, for example, may be due to the fact that Japanese speakers are consciously avoiding lexical mergers, not necessarily that this effect is encoded in the grammar. The length effect we observed in Sect. 4.4 can also be interpreted as speakers "consciously not caring" about neutralizing a contrast in late syllables in long words, without this effect being grammaticalized. Teasing apart grammatical effects from non-grammatical ones is not always an easy task (e.g., Berent et al. 2007; Featherson 2005; Goldrick to appear; Schütze 1996), and the decision often depends on the entire architectural structure of grammar. Addressing this question is thus an important issue in future linguistic research.

Acknowledgements My thanks first of all go to the participants of this experiment, without whom this paper would not have existed. Particularly, I am grateful to Toshio Matsuura for encouraging his students to participate in the experiment. I am also grateful to Kazuko Shinohara for her help in constructing the stimuli and to Sophia Kao for her help in setting up the online experiment. For their comments on earlier versions of this paper, I would like to thank the following people: Michael Becker, Andries Coetzee,

Bruce Hayes, Kazu Kurisu, Shanna Lichtman, Toshio Matsuura, Jason Shaw, Kyoko Yamaguchi, three anonymous reviewers for *JEAL*, and the audiences at the University of British Columbia, especially Bryan Gick and Gunnar Hanson. All remaining errors are mine.

References

Adli, Aria. 2010. Constraint cumulativity and gradience: Wh-scrambling in Persian. *Lingua* 120 (9): 2259–2294.

Albright, Adam. 2009. Feature-based generalisation as a source of gradient acceptability. *Phonology* 26 (1): 9–41.

Albright, Adam, and Bruce Hayes. 2003. Rules vs. analogy in English past tenses: A computational/experimental study. *Cognition* 90: 119–161.

Alderete, John, and Alexei Kochetov. 2009. Japanese mimetic palatalization revisited: Implications for conflicting directionality. *Phonology* 26 (3): 369–388.

Amano, Shigeaki, and Tadahisa Kondo. 2000. *NTT database series: Lexical properties of Japanese, 2nd release*. Tokyo: Sanseido.

Baayen, Harald R. 2008. *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge: Cambridge University Press.

Baayen, Harald R. 2009. LanguageR. R package. http://cran.r-project.org/web/packages/languageR/index.html.

Baayen, Harald R., Doug J. Davidson, and Douglas M. Bates. 2008. Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language* 59: 390–412.

Bates, Douglas M. 2005. Fitting linear mixed models in R. *R News* 5: 27–30.

Bates, Douglas, Maechler, Martin, and Bolker Ben. 2011. Linear mixed-effects models using S4 classes. R Package. http://cran.r-project.org/web/packages/lme4/index.html.

Becker, Michael, and Andrew Nevins. 2010. Initial-syllable faithfulness as the best model of wordsize effects in alternations. Paper presented at the 84th meeting of LSA, Baltimore.

Beckman, Jill. 1997. Positional faithfulness, positional neutralization, and Shona vowel harmony. *Phonology* 14 (1): 1–46.

Berent, Iris, Donca Steriade, Tracy Lennertz, and Vered Vaknin. 2007. What we know about what we have never heard: Evidence from perceptual illusions. *Cognition* 104: 591–630.

Blevins, Juliette. 2005. Understanding antigemination: Natural or unnatural history. In *Linguistic diversity and language theories*, ed. Zygmunt Frajzyngier, David Rood, and Adam Hodges, 203–234. Amsterdam: Benjamins.

Boersma, Paul, and Bruce Hayes. 2001. Empirical tests of the Gradual Learning Algorithm. *Linguistic Inquiry* 32: 45–86.

Bybee, Joan. 1999. Usage-based phonology. In Functionalism and formalism in linguistics, ed. Michael Darnell, Edith Moravscik, Michael Noonan, Frederick Newmeyer, and Kathleen Wheatly, 211–242. Amsterdam: Benjamins.

Bybee, Joan. 2001. *Phonology and language use*. Cambridge: Cambridge University Press.

Bybee, Joan, and Elly Pardo. 1981. On lexical and morphological conditioning of rules: A nonce-probe experiment with Spanish verbs. *Linguistics* 19: 937–968.

Chomsky, Noam. 1965. *Aspects of the theory of syntax*. Cambridge: MIT Press.

Coetzee, Andries W. 2008. Grammaticality and ungrammaticality in phonology. *Language* 84 (2): 218–257.

Coetzee, Andries W. 2009a. Grammar is both categorical and gradient. In *Phonological Argumentation: Essays on evidence and motivation*, ed. Steve Parker, 9–42. London: Equinox.

Coetzee, Andries W. 2009b. Phonological variation and lexical frequency. In *Proceedings of North East Linguistic Society 38,* ed. Anisa Schardl, Martin Walkow, and Muhammad Abdurrahman, 189–202. Amherst: GLSA Publications.

Coetzee, Andries W., and Shigeto Kawahara. 2010. Frequency and other biases in phonological variation. Ms., Michigan University and Rutgers University (submitted for publication in Natural Language and Linguistic Theory).

Coetzee, Andries W., and Joe Pater. to appear. The place of variation in phonological theory. In *The handbook of phonological theory,* 2nd edn, ed. John A. Goldsmith, Jason Riggle, and Alan Yu. Oxford: Blackwell-Wiley.

Coleman, John, and Janet Pierrehumbert. 1997. Stochastic phonological grammars and acceptability. In *Computational phonology: Third meeting of the ACL special interest group in computational phonology*, 49–56. Somerset: Association for Computational Linguistics.
Crawford, J. Clifford. 2009. Adaptation and transmission in Japanese loanword phonology. Ph.D. dissertation, Cornell University.
Crosswhite, Katherine. 1999. Intra-paradigmatic homophony avoidance in dialects of Slavic. In *UCLA working papers in linguistics: Papers in phonology 2*, ed. Matthew K. Gordon, 48–67.
Dabrowska, Ewa. 2010. Naive vs. expert intuitions: An empirical study of acceptability judgments. *The Linguistic Review* 27 (1): 1–23.
Dresher, B. Elan. 2010. *The contrastive hierarchy in phonology*. Cambridge: Cambridge University Press.
Farris-Trimble, Ashley. 2008. Cumulative faithfulness effects in phonology. Ph.D. dissertation, Indiana University.
Featherson, Sam. 2005. Universals and grammaticality: Wh-constraints in German and English. *Linguistics* 43: 667–711.
Flemming, Edward. 1995. Auditory representations in phonology. Ph.D. dissertation, University of California Los Angeles.
Frisch, Stefan, Nathan Large, and David Pisoni. 2000. Perception of wordlikeness: Effects of segment probability and length of the processing of nonwords. *Journal of Memory and Language* 42: 481–496.
Frisch, Stephan, Janet Pierrehumbert, and Michael Broe. 2004. Similarity avoidance and the OCP. *Natural Language and Linguistic Theory* 22: 179–228.
Gibson, Edward, and Evelina Fedorenko. 2010. Weak quantitative standards in linguistics research. *Trends in Cognitive Sciences* 14 (6): 233–234.
Goldrick, Matthew. to appear. Utilizing psychological realism to advance phonological theory. In *The handbook of phonological theory II*, ed. John A. Goldsmith, Jason Riggle, and Alan Yu. Oxford: Blackwell-Wiley.
Griner, Barry. 2001. Productivity of Japanese verb tense inflection: A case study. MA thesis, University of California, Los Angeles.
Hansson, Gunnar Olafur. 2004. Long-distance voicing agreement: An evolutionary perspective. In *Proceedings of Berkeley Linguistic Society 30*, ed. M. Fleischer Ettlinger and M. Park-Doob, 130–141. Berkeley: Berkeley Linguistic Society.
Haraguchi, Shosuke. 2006. A theory of voicing. ms., Meikai University. http://www.let.leidenuniv.nl/ulcl/faculty/vdweijer/jvoice/haraguchi.pdf.
Hay, Jennifer, Janet Pierrehumbert, and Mary Beckman. 2003. Speech perception, wellformedness, and the statistics of the lexicon. In *Papers in laboratory phonology VI: Phonetic interpretation*, ed. John Local, Richard Ogden, and Rosalind Temple, 58–74. Cambridge: Cambridge University Press.
Hayes, Bruce. 2000. Gradient well-formedness in Optimality Theory. In *Optimality Theory: Phonology, syntax, and acquisition*, ed. Joost Dekkers, Frank Van der Leeuw, and Jeroen Van de Weijer, 88-120. Oxford: Oxford University Press.
Hayes, Bruce. 2009. Embedding grammar in a quantitative framework: Case studies from phonology and metrics. Handout for a minicourse at Brown University.
Hayes, Bruce, and Zsuzsa Londe. 2006. Stochastic phonological knowledge: The case of Hungarian vowel harmony. *Phonology* 23: 59–104.
Hayes, Bruce, and Donca Steriade. 2004. Introduction: The phonetic bases of phonological markedness. In *Phonetically based phonology*, ed. B. Hayes, R. Kirchner, and D. Steriade, 1–33. Cambridge: Cambridge University Press.
Hayes, Bruce, and Tanya Stivers. 1995. Postnasal voicing. ms., University of California, Los Angeles. http://www.linguistics.ucla.edu/people/hayes/phonet/ncphonet.pdf.
Hayes, Bruce, Kie Zuraw, Péter Siptár, and Zsuzsa Londe. 2009. Natural and unnatural constraints in Hungarian vowel harmony. *Language* 85 (4): 822–863.
Ichimura, Larry. 2006. Anti-homophony blocking and its productivity in transparadigmatic relations. Ph.D. dissertation, Boston University.
Inoue, Humio. 1998. *Nihongo wocchingu [Watching Japanese]*. Tokyo: Iwanami.
Itô, Junko, and Armin Mester. 1986. The phonology of voicing in Japanese: Theoretical consequences for morphological accessibility. *Linguistic Inquiry* 17: 49–73.
Itô, Junko, and Armin Mester. 1995. Japanese phonology. In *The handbook of phonological theory*, ed. John Goldsmith, 817–838. Oxford: Blackwell.
Itô, Junko, and Armin Mester. 1999. The phonological lexicon. In *The handbook of Japanese linguistics*, ed. Natsuko Tsujimura, 62–100. Oxford: Blackwell.

Itô, Junko, and Armin Mester. 2003. *Japanese morphophonemics*. Cambridge: MIT Press.
Itô, Junko, and Armin Mester. 2004. Morphological contrast and merger: Ranuki in Japanese. *Journal of Japanese Linguistics* 20: 1–19.
Itô, Junko, and Armin Mester. 2008. Lexical classes in phonology. In *The Oxford handbook of Japanese linguistics*, ed. S. Miyagawa and M. Saito, 84–106. Oxford: Oxford University Press.
Jaeger, Florian T. 2008. Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language* 59: 434–446.
Jaeger, Jeri J. 1978. Speech aerodynamics and phonological universals. In *Proceedings of Berkeley Linguistic Society 4*, ed. Jeri Jaeger, Anthony Woodbury, Farrel Ackerman, Christine Chiavello, Orin Gensler, John Kingston, Eve Sweetner, Henry Chompson, and Kenneth Whistler, 311–325. Berkeley: Berkeley Linguistics Society.
Kaneko, Emiko, and Gregory Iverson. 2009. Phonetic and other factors in Japanese on-line adaptation of English final consonants. In *Studies in language sciences 8: Papers from the eighth annual conference of the Japanese Society for Language Science*, ed. Shunji Inagaki and Makiko Hirakawa. Tokyo: Kuroshio Publications.
Kaplan, Abby. 2010. How much homophony is normal? Paper presented at CUNY Conference on the Word in Phonology, CUNY.
Katayama, Motoko. 1998. Optimality Theory and Japanese loanword phonology. Ph.D. dissertation, University of California, Santa Cruz.
Kawahara, Shigeto. 2005. Voicing and geminacy in Japanese: An acoustic and perceptual study. In *University of Massachusetts occasional papers in linguistics 31*, ed. Kathryn Flack and Shigeto Kawahara, 87–120. Amherst: GLSA.
Kawahara, Shigeto. 2006. A faithfulness ranking projected from a perceptibility scale: The case of voicing in Japanese. *Language* 82 (3): 536–574.
Kawahara, Shigeto. 2008. Phonetic naturalness and unnaturalness in Japanese loanword phonology. *Journal of East Asian Linguistics* 18 (4): 317–330.
Kawahara, Shigeto. 2011a. Japanese loanword devoicing revisited: A rating study. *Natural language and Linguistic Theory* 29.
Kawahara, Shigeto. 2011b. Modes of phonological judgments. ms., Rutgers University.
Kawahara, Shigeto, and Kazuko Shinohara. 2011. Phonetic and psycholinguistic prominences in pun formation: Experimental evidence for positional faithfulness. In *Japanese/Korean linguistics 18*, ed. W. McClure and M. den Dikken, 177–188. Stanford: CSLI.
Kubozono, Haruo. 2006. Where does loanword prosody come from?: A case study of Japanese loanword accent. *Lingua* 116: 1140–1170.
Labov, William. 1975. What is a linguistic fact? In Empirical foundations of linguistic theory: The scope of American linguistics, ed. Robert Austerlitz, 77–113. Lisse: The Peter de Ridder Press.
Labov, William. 1996. When intuitions fail. In *Papers from the 32nd regional meeting of Chicago Linguistic Society: Papers from the parasession on theory and data in linguistics*, ed. Lisa McNair, Kora Singer, Lise, Dolbrin, and Michelle Aucon, 77–106. Chicago: Chicago Linguistics Society.
Lubowicz, Anna. 2007. Paradigmatic contrast in Polish. *Journal of Slavic linguistics* 2: 229–262.
Lyman, Benjamin S. 1894. Change from surd to sonant in Japanese compounds. *Oriental Studies of the Oriental Club of Philadelphia*, 1–17.
Maekawa, Kikuo. 2009. Nihongo za-gyo-no choo-on yooshiki-no hen-i-ni tsuite [On the articulatory variability of /z/ in Japanese]. *Dai 23kai Nihon Onsei Gakkai Zenkoku Taikai Yokoushuu*, 169–174.
Maekawa, Kikuo. 2010. Coarticulatory reinterpretation of allophonic variation: Corpus-based analysis of /z/ in spontaneous Japanese. *Journal of Phonetics* 38 (3): 360–374.
Marslen-Wilson, William. 1975. Sentence perception as an interactive parallel process. *Science* 189: 226-228.
Marslen-Wilson, William, and Alan Welsh. 1978. Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology* 10: 29–63.
McCarthy, John J. 2008. *Doing Optimality Theory*. Oxford: Blackwell-Wiley.
Myers, James. 2009. Syntactic judgment experiments. *Language and Linguistic Compass* 3 (1): 406–423.
Nishimura, Kohei. 2003. Lyman's Law in loanwords. M.A. thesis, Nagoya University.
Nishimura, Kohei. 2006. Lyman's Law in loanwords. *Phonological Studies [Onin Kenkyuu]* 9: 83–90.
Ohala, John J. 1974. Experimental historical phonology. In *Historical linguistics II: Theory and description in phonology. Proceedings of the first international linguistic conference on historical linguistics*, ed. J.M. Naderson and Charles Jones, 353–389. New York: Elsevier.
Ohala, John J. 1983. The origin of sound patterns in vocal tract constraints. In *The production of speech*, ed. Peter MacNeilage, 189–216. New York: Springer.

Ohala, John J. 1986. Consumer's guide to evidence in phonology. *Phonology* 3: 3–26.
Ohala, John J., and C. J. Riordan. 1979. Passive vocal tract enlargement during voiced stops. In *Speech communication papers*, ed. J.J. Wolf and D.H. Klatt, 89–92. New York: Acoustical Society of America.
Padgett, Jaye. 2002. Contrast and postvelar fronting in Russian. *Natural Language and Linguistic Theory* 21: 39–87.
Pater, Joe. 1999. Austronesian nasal substitution and other NC effects. In *The prosody-morphology interface*, ed. Rene Kager, Harry van der Hulst, and Wim Zonneveld, 310–343. Cambridge: Cambridge University Press.
Pater, Joe. 2009. Weighted constraints in generative linguistics. *Cognitive Science* 33: 999–1035.
Pertz, D.L., and T.G. Bever. 1975. Sensitivity to phonological universals in children and adolescents. *Language* 51: 149–162.
Pierrehumbert, Janet B. 2001. Stochastic phonology. *GLOT* 5: 1–13.
Prince, Alan, and Paul Smolensky. 1993/2004. *Optimality Theory: Constraint interaction in generative grammar*. Malden: Blackwell.
Pycha, Anne, Eurie Shin, and Rhan Shosted. 2006. Directionality of assimilation in consonant clusters: An experimental approach. *UC Berkeley Phonology Lab Annual Report*.
R Development Core Team. 1993–2011. R: *A language and environment for statistical computing*. Vienna, Austria. R Foundation for Statistical Computing. Software. http://www.R-project.org.
Reips, Ulf-Dietrich. 2002. Standards for internet-based experimenting. *Experimental Psychology* 49 (4): 243–256.
Rice, Keren. 2006. On the patterning of voiced stops in loanwords in Japanese. *Toronto Working Papers in Linguistics* 26: 11–22.
Riemer, Nicholas. 2009. Grammaticality as evidence and as prediction in a Galilean linguistics. *Language Sciences* 31: 612–633.
Rose, Sharon, and Rachel Walker. 2004. A typology of consonant agreement as correspondence. *Language* 80 (3): 475–532.
Rubin, David. 1976. Frequency of occurrence as a psychophysical continuum: Weber's fraction, Ekman's fraction, range effects, and the phi-gamma hypothesis. *Perception & Psychophysics* 20: 327–330.
Schütze, Carlson. 1996. *The empirical base of linguistics: Grammaticality judgments and linguistic methodology*. Chicago: University of Chicago Press.
Shirai, Setsuko. 2002. Gemination in loans from English to Japanese. M.A. thesis, University of Washington.
Smith, Roger, and Theodore Dixon. 1971. Frequency and judged familiarity of meaningful words. *Journal of Experimental Psychology* 88: 279–281.
Smolensky, Paul. 1995. On the internal structure of the constraint component CON of UG. Paper presented at the University of California, Los Angeles.
Sorace, Antonella, and Frank Keller. 2005. Gradience in linguistic data. *Lingua* 115 (11): 1497–1524.
Steriade, Donca. 2001/2008. The phonology of perceptibility effects: The P-map and its consequences for constraint organization. In *The nature of the word*, ed. Kristin Hanson and Sharon Inkelas, 151–179. Cambridge: MIT Press (Originally circulated in 2001).
Steriade, Donca. 2004. Projecting non-lexical phonology from phonetic knowledge. Paper presented at Symposium on phonological theory: Representations and architectures, the City University of New York.
Suzuki, Keiichiro. 1998. A typological investigation of dissimilation. Ph.D. dissertation, University of Arizona.
Tanaka, Shin-Ichi. 2007. On the nature of typology of dissimilation. *English Linguistics* 24 (1): 279–313.
Tanaka, Shin-Ichi. 2010. The eurhythmics of segmental melody. *Journal of the Phonetic Society of Japan* 13 (3): 44–52.
Tateishi, Koichi. 2002. Bunpoo no ichibutoshite no goisoo no zehi [Lexical strata as a part of grammar]. *Journal of the Phonetic Society of Japan* 6 (1): 34–43.
Tesar, Bruce. 2007. A comparison of lexicographic and linear numeric optimization using violation difference ratios. ms., Rutgers University.
Tsuchida, Ayako. 1997. Phonetics and phonology of Japanese vowel devoicing. Ph.D. dissertation, Cornell University.
Urbanczyk, Suzanne. 2005. Enhancing contrast in reduplication. In *Studies on reduplication*, ed. B. Hurch, 431–454. Mouton: de Gruyter.
Vance, Timothy J. 1980. The psychological status of a constraint on Japanese consonant alternation. *Linguistics* 18: 245–267.

Vance, Timothy J. 1987. *An introduction to Japanese phonology*. New York: SUNY Press.
Walker, Rachel. 2001. Round licensing, harmony, and bisyllabic triggers in Altaic. Natural Language and Linguistic Theory 19: 827–878.
Westbury, John R. 1979. Aspects of the temporal control of voicing in consonant clusters in English. Ph.D. dissertation, University of Texas, Austin.
Zhang, Xi. 1996. Vowel systems of the Manchu-Tungus languages of China. Ph.D. dissertation, University of Toronto.