PATTERNS IN THE AVOIDANCE OF MARKED SEGMENTAL CONFIGURATIONS IN JAPANESE LOANWORD PHONOLOGY

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1. Introduction

In this paper, I present the quantitative analysis of the patterns of repair strategies against marked segmental configurations in Japanese loanword phonology using a large-scale spontaneous speech corpus. I focus on the voiced obstruent geminates, and show how these marked configurations are resolved in spontaneous utterances. In the analysis, we have a closer look at the quantitative examination of the distribution of voiced geminates and repaired segments in terms of the chronological change and the phonological contexts. In doing so, I shed light on the properties of phonological factors that govern the distribution, such as Lyman's Law, that play crucial roles in Japanese phonology.

This paper is organized as follows. In Section 2, I introduce the background information concerning the research topic based on some seminal works on voiced geminates, and clarify the problems and the goals of this research. Section 3 presents the method of analysis. In Section 4, I summarize the data collected. Section 5 presents the analysis. Finally, in Section 6 I conclude with the discussion.

2. Background

2.1. Research Topic

This research focuses on the voiced obstruent geminates (hereafter voiced geminates) that occur in Japanese loanwords, such as [bb], [dd], and [gg] (Kuroda 1965, among others). When loanwords with word-final voiced obstruents are borrowed into Japanese, the original voiced singletons are altered and realized as voiced geminates followed by an epenthetic vowel. As exemplified in (1), *dog* is realized as *doggu*, and similarly *bed* is realized as *beddo*.

(1) a. dog => doggu 'dog'
    b. bed => beddo 'bed'

However, voiced geminates are traditionally prohibited in Japanese phonology. Therefore, although voiced singletons are borrowed as voiced geminates, these segments should be avoided and undergo some phonological processes to fit into the well-formed segmental configurations in Japanese. The most common phonological process involved is the devoicing, as shown in (2) *doggu* undergoes devoicing and is realized as *dokku*, and similarly *beddo* is realized as *betto* with the voiced geminates being devoiced (Vance 1979; Itô and Mester 1986; Nishimura 2003; Kawahara 2006b et seq.).

(2) a. doggu => dokku 'dog'
    b. beddo => betto 'bed'

During the past half century, there has been a large influx of loanwords, and consequently the items with voiced geminates are now widespread throughout the foreign stratum of Japanese lexicon (McCawley 1968; Vance 1987; Itô and Mester 1999), and thereby voiced geminates have diffused into Japanese phonology. Consequently, voiced geminates have become more likely to be regarded as a well-formed segment (Itô and Mester 1999). Still, voiced geminates are marked, and accordingly these segments are *optionally* repaired (change to less marked segments by phonological processes). This yields the variable phenomenon that consists of voiced geminates and repaired segments, as in [doggu]~[dokku], and [beddo]~[betto]. That is, the phonological processes as a repair strategy apply not categorically, but gradiently. Thus, the distribution of voiced geminates has to be characterized in terms of the probability.

2.2. Devoicing and Lyman's Law

The devoicing of voiced geminates has long been subject to studies of various frameworks, such as Optimality Theory (Itô and Mester 1999; Nishimura 2003; Kawahara 2006, 2008), Harmonic Grammar (Pater 2009), and Phonetics – auditory perception (Kawahara 2011a, b; 2012b). Here, I review the findings of some seminal works on the devoicing of voiced geminates, and illustrate the relationship between the properties of devoicing and Lyman's Law.

As mentioned above, devoicing is optionally applied as a repair strategy. The applicability of devoicing is partly predictable; in other words, there are patterns of devoicing. The most notable is Lyman's Law (Itô and Mester 1986; Vance 2005), that has long been subject to the phonological research in Japanese, such as the research on *rendaku* (Vance 1979, 1980; Itô and Mester 1986, among others). In short, Lyman's Law has the dissimilatory effects, and is regarded as a kind of OCP specific to the voice feature. That is, Lyman's Law bans multiple occurrences of [+voice] within certain domains.[1] Most of the examples of devoicing can be accounted for by Lyman's Law. However, there are some patterned exceptions; in other words, some specific cases are subject to Lyman's Law (Nishimura 2003).

(3) co-occurrence with other voiced obstruent(s) – devoicing
  a. /doggu/ => [dokku]
  b. /beddo/ => [betto]

(4) otherwise – no devoicing
  a. /eggu/ => [eggu] (*[ekku]) 'egg'
  b. /reddo/ => [reddo] (*[retto]) 'red'

(5) singleton – no devoicing
  a. /gibu/ => [gibu] (*[gipu]) 'give'
  b. /bagu/ => [bagu] (*[baku]) 'bug'

As shown in (3), if voiced geminates co-occur with other voiced obstruent(s), the devoicing applies as expected. For example, /doggu/ is realized as [dokku], and /beddo/ is realized as [betto]. However, if there is no other voiced obstruent, Lyman's Law does not come into play, and devoicing is not triggered. Consequently, /eggu/ is not realized as *[ekku], and /reddo/ is not realized as *[retto] in (4). Furthermore, the voiced obstruent singleton never devoices, even if it co-occurs with other voiced obstruent(s), as shown in (5). Based on these observed

[1] Deciding the domain of Lyman's Law is one of the important tasks in the research on *rendaku*, as it is directly linked to the applicability of Lyman's Law. The issue of domain is extensively discussed in Itô and Mester (2003).

patterns, Nishimura (2003) claims that neither voicing nor geminacy alone causes devoicing, but their combination can trigger the devoicing.

2.3. Problems and Goals

The previous studies on voiced geminates in Japanese loanwords have made substantial contributions to the phonological theory. Phonetic analysis has been conducted based on the empirical data, and the aspects of perception are being uncovered (Kawahara 2011a, b; 2012b). However, aspects of *production* are still understudied. In particular, the research using the spontaneous speech data has rarely been conducted. Furthermore, repair strategies other than devoicing have not been thoroughly studied. With this background in mind, the goals of this research are as follows. Primarily focusing on the *production* in spontaneous utterances, I shed light 1) on the gradient patterns manifested in the avoidance of voiced geminates, and 2) on the effects of phonological factors that govern the distributions of voiced geminates and repaired ones, such as Lyman's Law.

3. Method

Data was retrieved from the Corpus of Spontaneous Japanese (CSJ, Kokuritsu Kokugo Kenkyuujo 2008). The CSJ is a large-scale spontaneous speech corpus of common Japanese with rich annotation (Sano and Hibiya 2012). In terms of its size, CSJ consists of 3,302 speech samples, amounting to 662 hours of speech, and 7.5 million words. CSJ mainly consists of two types of speech samples: One type is APS, representing Academic Presentation Speech that is stylistically careful/formal; the other type is SPS, representing Simulated Public Speaking that is stylistically relaxed/casual. CSJ provides rich annotations concerning speaker attributes and characteristics of each speech, such as style, nervousness, and spontaneity. This feature makes it possible to analyze external factors in detail.

Every relevant utterance of potential voiced geminates in the CSJ was extracted (i.e. all voiced geminates and repaired segments). An exhaustive search for the CSJ brought forth a total of 1,666 tokens of voiced geminates and repaired segments. Segmentation is based on the annotated transcription in CSJ. The transcription of the CSJ consists of two formats, one type is *Kihonkei* that is the written form, and the other type is *Hatsuonkei* that represents the phonetic form. If the utterance undergoes a phonological process, then *Hatsuonkei* represents the underlying form and the surface form separately; if the utterance is realized faithfully, then the underlying form and the surface form are represented by a single notation. By referring to this system, we can infer the phonological processes involved. The factors I consider in the analysis include: birth-year of speakers, type of repairs, type of voiced geminates, preceding/following vowels, and Lyman's Law (specifically presence/absence of other voiced obstruent(s) within the same utterance). Many factors listed above are considered anew, because spontaneous utterances provide a detailed information about the actual usage, and enables to focus on the aspects that have been overlooked.

4. Data

This section presents the summary of the data. The extracted tokens were initially classified as one of two categories: either the segments are realized as voiced geminates, or the segments have undergone some sort of repair strategy. An example of the first category is an underlying /gg/ that is faithfully realized as [gg]. Two examples of the second category are an underlying /gg/ that undergoes devoicing and is realized as [kk], and an underlying /dd/ that undergoes degemination and is realized as [d]. This primary classification constitutes the basis of the following analysis. The probability of repair is calculated based on this variable.

Table 1 shows the overall distribution of voiced geminates and repaired segments.

Table 1. Distribution of voiced geminates and repaired segments

	frequency	*probability (%)*
voiced geminates	1,153	69.20
repaired segments	513	30.79
total	1,666	100

As shown in Table 1, the frequency as well as the probability of voiced geminates are higher than those of repaired ones. Specifically, about 70% of all tokens are realized as voiced geminates that are faithful to the underlying representations. In other words, repair strategies are applied only 30% of the time. The results show that although it is traditionally claimed that voiced geminates are infrequent in Japanese phonology, many voiced geminates appear faithfully in production, especially in spontaneous utterances, in support of the claim that voiced geminates have diffused into Japanese phonology and have become more likely to be regarded as a well-formed segment (Itô and Mester 1999).

5. Analysis

With the overall distribution in mind, this section presents the analysis considering the factors that can affect the distribution of voiced geminates and repaired segments.

5.1. Chronological Change

I firstly demonstrate the chronological change of voiced geminates and repaired segments. As mentioned above, voiced geminates have penetrated into the Japanese phonology due to the influx of loanwords. Consequently, it may be the case that voiced geminates are becoming less marked over time, resulting in the gradual increase in the production of these configurations. In this section, I examine this possibility. The CSJ provides the information about the birth-year of speakers. Using this information, I conducted an apparent-time analysis, in which the difference in speakers' birth-year corresponds to the apparent flow of time (see Bailey 2002 for apparent-time). I classified each token into six birth-year periods (grouped every 10 years): 1925-1934, 1935-1944, 1955-1964, 1965-1974, and 1975-1985. Based on this classification, I calculated the chronological transition of the probabilities of voiced geminates and repaired segments. Figure 1 illustrates the chronological changes in the probabilities of voiced geminates being repaired, according to the birth-year of speakers.

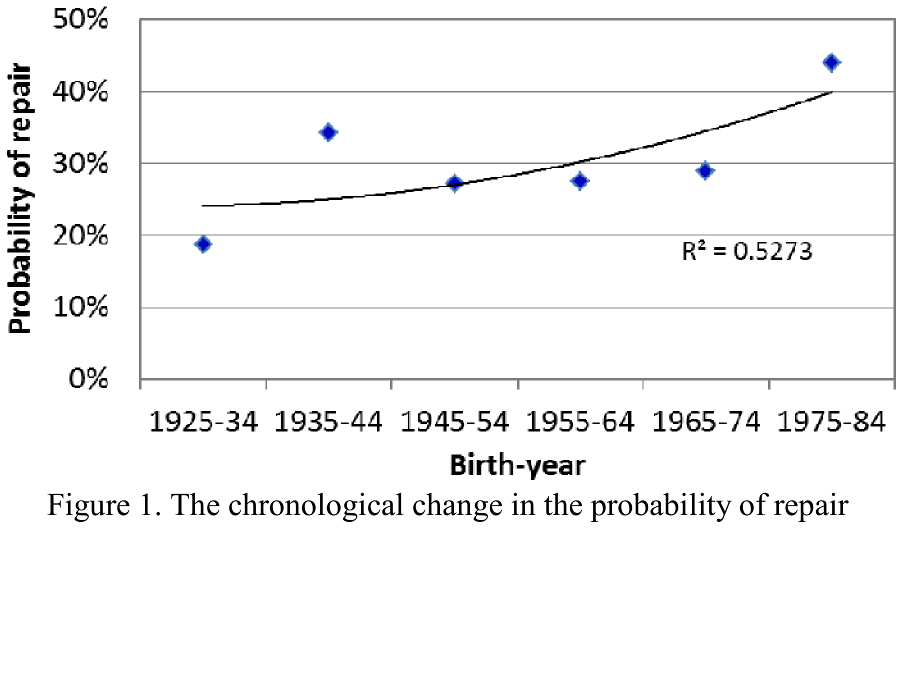


Figure 1. The chronological change in the probability of repair

As Figure 1 shows, the probability of repair rises as speakers' birth-year becomes more recent.[2] Itô and Mester (1999) claim that among the items in the Japanese lexicon, assimilated foreign items undergo devoicing (i.e., one of the repair strategies); on the other hand, unassimilated alien items remain intact without undergoing any repair. To interpret it broadly, the more the items are nativized into Japanese phonology, the more likely they are repaired. The increasing probability of repair in the present research suggests that the nativization of loanwords is developing over the years. Furthermore, given that the change proceeds not toward the acceptance of voiced geminates in Japanese phonology, but toward the alteration to fit into the Japanese template, we can argue that the voiced geminates still have the status of marked segments and are avoided.

5.2. Type of Repair

Next, I consider the distribution of repair strategies. As mentioned above, the most common phonological process involved in the avoidance of voiced geminates is the devoicing in the traditional characterization. However, repair strategies other than devoicing are also expected to apply. Here, we see what kinds of repair strategies are applied and the probabilities with which each repair is applied. Figure 2 shows the distribution of repair strategies.

Table 2. The distribution of repair strategies[3]

	frequency	probability (%)
devoicing	472	92.00
degemination	34	6.62
deletion	6	1.17
vowel lengthening	5	0.97
nasalization	3	0.58
rhotacization	1	0.19
total	521	100

As shown in Table 2, six types of repair strategies were observed. However, devoicing is predominant as it accounts for more than 90% of all repairs. The result supports the validity of the previous studies in the sense that the phonological process applied to the voiced geminates is predominantly devoicing. Furthermore, in most cases only a single repair strategy is applied, and only eight tokens show multiple repairs, such as the combination of devoicing and degemination.

I consider the uneven distribution of repair strategies in terms of economy. First, the predominance of devoicing may be associated with the least featural change (P-map hypothesis, Steriade 2001/2008). As exemplified in (6a), the featural change involved is limited to voice feature in devoicing; namely, [+voice] changes to [-voice] with place and manner features remaining intact. On the other hand, other repair strategies require a more broad change.

[2] Loanwords in Japanese show the tendency to increase. The frequency of loanwords in the present data (loanwords with underlying voiced geminates) is gradually increasing, 1925-1944: 165; 1945-1964: 649; 1965-1984: 850, although the amount of utterance differs according to the age group, and a comparison based on the frequency may not yield an absolute measure.

[3] In some cases, more than one repair strategy is applied in a single token. Therefore, the total frequency of repair strategies exceeds the number of tokens (513) where some kind of repair strategy is applied.

(6) a. devoicing: e.g. /beddo/ => [betto] (S00F0093)[4]
change in voice feature dd => tt
[+voice] [-voice]
b. degemination: e.g. /bagudaddo/ => [bagudaado] 'bagdad' (S09M0855)
change in timing slot addo => ado
xxx xx
compensatory lengthening ado => aado
xx xxx

Taking degemination in (6b) as an example among other strategies, degemination itself renders the change in the timing slot, as in /dd/ => [d]. This leads to the additional change such as the compensatory lengthening, as in /bagudaddo/ changes to [bagudaado] with the preceding vowel being lengthened. Deletion, vowel lengthening, nasalization and rhotacization are exemplified in (7).

(7) a. deletion: loss of whole segment(s)
e.g. handoreddo => handore_ 'hundred' (S04F0792)
b. vowel lengthening: copy of whole segment(s)
e.g. gaabeddʒi => gaabeedʒi 'garbage' (A01M0103) similar to (6b)
c. nasalization: change in multiple features
e.g. neebaahuddo => neebaahundo 'neighbourhood' (A01M0565)
d => *n*
[-sonorant] => [+sonorant]
[-nasal] => [+nasal]
[-delayed release] => ϕ
d. rhotacization: change in multiple features
e.g. disutoribyuuteddo => disutoribyuutoru[5] 'distributed' (A03M0018)
d => *r* ([ɾ])
[-sonorant] => [+sonorant]
[-continuant] => [+continuant]
[-delayed release] => ϕ
[-approximant] => [+approximant]
[-tap] => [+tap]

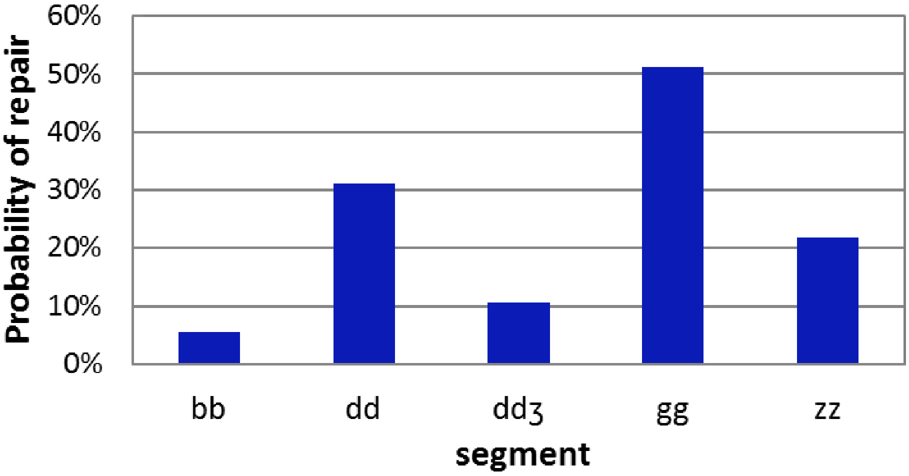
Thus, the uneven distribution of repair strategies, i.e., the predominance of devoicing can be explained by the economy of the repair processes.

Next, the low frequency of multiple repairs is also associated with the economy. As mentioned above, voicing or geminacy alone is not marked, but the combination of these two creates the marked segmental configurations and can trigger the repair. By applying either one of voicing or geminacy, the marked configurations can be resolved. Therefore, the application of additional process(es) violates the economy and tends to be avoided, as it does not further contribute to the segmental well-formedness (cf. Kawahara 2011a for perception).

[4] The alphanumeric character annotated to the end of each example (e.g. A04M0229) is the 'speech ID' that is used as the index of each speech. See Sano and Hibiya (2012) for more detail.
[5] In this example, the alternation of vowels and degemination are involved; however, I focus only on the change from *d* to *r*.

5.3. Type of Voiced Geminate

In this section, I examine the effects of the type of voiced geminates. In the present data, five types of (underlying) voiced geminates are observed. These segments are characterized according to the place and manner of articulation. With respect to the manner of articulation, three types are observed: stops (/bb/, /dd/, /gg/), fricatives (/zz/), and affricates (/ddʒ/). According to the place of articulation, stops are classified into three types: bilabial, coronal, and velar. Fricatives and affricates are exclusively coronal. I hypothesize that the differences in segmental properties affect the probability of repair. The probability of repair by segment type is shown in Figure 2.



$\chi^2(4) = 94.45$, $p<0.001$[6]

Figure 2. The probability of repair by segment type

As Figure 2 shows, velar stops /gg/ are repaired with the highest probability; other segments are repaired in the following descending order: coronal stop /dd/, coronal fricative /zz/, coronal affricate /ddʒ/, and bilabial stop /bb/.[7] Thus, in terms of the place of articulation the probability of repair shows a specific pattern. The pattern is summarized as the order in (8).

(8) /gg/	>	/dd/	>	/zz/	>	/ddʒ/	>	/bb/
velar				coronal				bilabial

Velar sounds show the highest probability of repair whereas bilabial sounds show the lowest probability of repair.[8] In comparison, coronal sounds show a probability that is intermediate between bilabial sounds and velar sounds. This suggests that the more back the place of articulation is, the more likely that the voiced geminates are repaired.

Next, I consider the geminate fricatives. Generally, geminate fricatives are perceptually non-prominent; and accordingly, singleton fricatives and geminate fricatives do not have the

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[6] The following distributions are tested by the chi-square test of independence using R (R Development Core Team 1993-2012). For the expository purposes, the distributions are illustrated by the probability although the statistical analysis was performed based on the frequency.

[7] The coronal stop shows the highest frequency both in voiced geminates (781/1153) and in repair (354/513), suggesting that the Japanese lexicon involve many foreign items with the geminate coronal stops compared with other voiced geminates.

[8] The geminate bilabial stops also show the lowest frequency (18). This is consistent with the claim of the previous study that the voiced geminate bilabial stop is rare in Japanese (Katayama 1998).

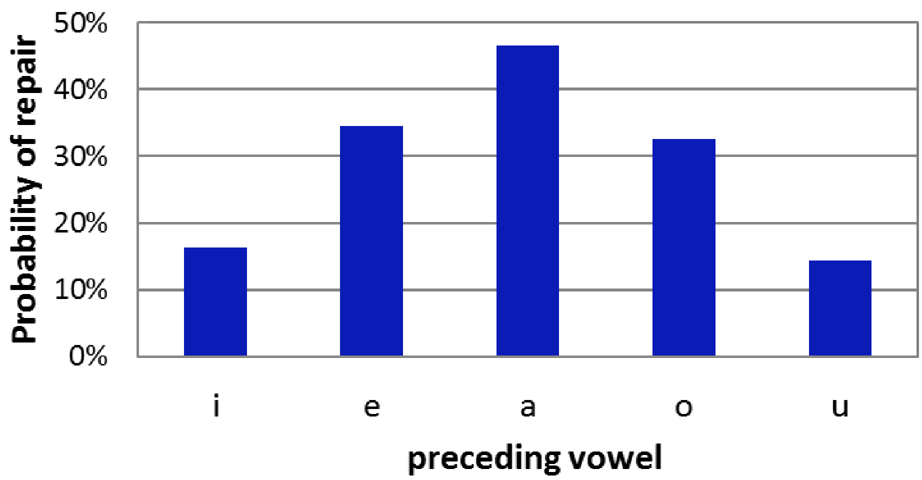
sufficient distance in their contrast, compared with other sounds like geminate stops. Therefore, geminate fricatives are marked and avoided (Blevins 2004; Kawahara 2006a). In the present data, when underlying geminate fricatives undergo some phonological processes, all of these sounds undergo the affrication in addition to the devoicing.

(9) devoicing and affrication: e.g. /guzzu/ => [guttsu] (*[gussu]) 'goods' (S07M0392)
devoicing zz => ss
affrication ss => tts

As exemplified in (9), the voiced geminate fricative is realized as voiceless geminate affricate, for example, /guzzu/ is realized as [guttsu], and not as *[gussu]. The devoicing resolves the marked combination of voicing and geminacy, and yields the voiceless geminate fricative.[9] However, the combination of geminacy and frication, that is also marked, still remains (see Ohala 1983; Lindblom and Maddieson 1988). Therefore, the additional process is called for, and in this case the affrication changes the fricative to the affricate. The second process appears to violate the economy principle if we only focus on the repair of the marked combination of voicing and geminacy; however, in order to avoid the marked geminate fricatives, the additional process is required.

5.4. Preceding Vowels

In this section, I examine the effects of vowels. First, I examine how the quality of preceding vowels affects the distribution of voiced geminates and repaired segments. In the present data, the voiced geminates and the repaired segments are observed in the environment of all five vowels of Japanese: /i/, /e/, /a/, /o/, and /u/.[10] I plot the probability of repair for each vowel in Figure 3.



$\chi^2(4) = 80.82, p<0.001$

Figure 3. The effect of preceding vowels on the applicability of repair

As Figure 3 shows, the low vowel /a/ shows the highest probability; the high vowels /u/ and /i/ show the lowest probability; the mid vowels /e/ and /o/ show the intermediate probability between high vowels and low vowels. The distribution in Figure 3 can be summarized as the order in (10).

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[9] The order of phonological processes is out of the scope of this research.

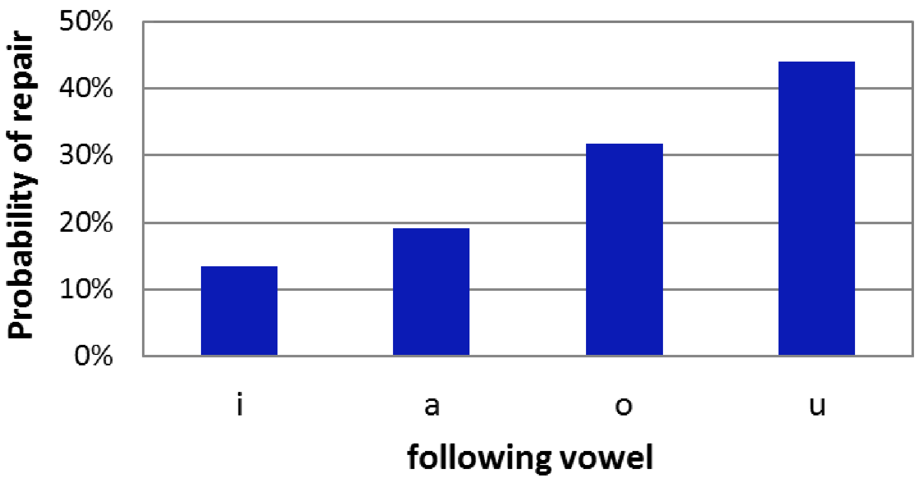
[10] In Japanese, the vowel /u/ is strictly /ɯ/ that is unrounded. However, I use the symbol *u*, as this difference does not relate to the purpose of the analysis.

(10) /a/ > /e/ > /o/ > /i/ > /u/
low mid high

As shown in (10), we can argue that the lower the preceding vowel, the higher the probability of repair. However, it is difficult to give a plausible phonetic account to this tendency, because in terms of aerodynamics the order of the probability of repair is the exact opposite of the difficulty in producing voiced geminates. The constriction of the vocal tract during the production of high vowels creates the greater air pressure in the oral cavity compared to other vowels, and this greater air pressure makes it difficult to produce voiced geminates (Ohala 1983; Hayes et al. 2004). Therefore, voiced geminates in the environment of high vowels should show the highest probability of repair. The reason why the lower preceding vowels induce more devoicing contrary to the aerodynamic consideration is an open question, and the examination of the effects of other factors that can contribute to the distribution here is also required. In any case, the result suggests that in the preceding context the application of repair is sensitive to height (or F1).

5.5. Following Vowels

Next, I examine how the quality of following vowel affects the distribution of voiced geminates and repaired segments. Among five vowels, only one token of voiced geminate with /e/ vowel that immediately follows the voiced geminate was observed, and no repaired counterpart was observed. Therefore, there can be a lexical gap here, and I removed the distribution in /e/ vowel from consideration. I plot the probability of repair for each vowel in Figure 4.



$\chi^2(3) = 63.95$, $p<0.001$

Figure 4. The effect of following vowels on the applicability of repair

As for the remaining vowels in Figure 4, the probability of repair rises from front vowel /i/ to back vowel /u/ as in (11).

(11) /u/ > /o/ > /a/ > /i/
back front

The result suggests that the more back the following vowels, the higher the probability. Therefore, we can argue that in the following context the application of repair is sensitive to backness (or F2).[11,12]

5.6. Lyman's Law

In the following sections, I consider the effects of Lyman's Law. Specifically, I examine the triggering factors of Lyman's Law. As mentioned above, Lyman's Law has the dissimilatory effects with respect to the voice feature, and bans multiple occurrences of [+voice] within certain domains. Therefore, if Lyman's Law is active in production, the probability of repair would be higher in contexts with violations of Lyman's Law (see Kawahara 2012b and references cited therein for perception). The items I consider are summarized in (12).

(12) a. Presence/absence of other voiced obstruent(s)
b. Locality: distance between voiced geminate and other voiced obstruent(s)
c. Number: the number of other voiced obstruents
d. Symmetry/asymmetry in preceding context/following context

Firstly in (12a), I confirm the overall effects of Lyman's Law by examining whether or not the presence or absence of voiced obstruents other than voiced geminates affects the probability of repair. Secondly in (12b), I examine whether or not the locality plays a role in determining the probability of repair. Specifically, I consider the distance between voiced geminate and other voiced obstruent(s). The distance is measured by intervening moras.[13] Thirdly in (12c), I examine whether or not the number of voiced obstruents other than voiced geminates plays a role in determining the probability of repair. Finally in (12d), I examine the symmetry or asymmetry in the preceding contexts and the following contexts, i.e., whether the Lyman's Law has the same/different effects on the preceding contexts and the following contexts. In the analysis, I compare the preceding contexts and the following contexts in terms of the effects of Lyman's Law. The analysis proceeds from the preceding contexts to the following contexts.[14]

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[11] There is also an alternative account; namely, most of the /i/ vowels are associated with affricates, producing *ddʒi*, for instance, *jaddʒi* 'judge.' Therefore, the distribution here can be biased, i.e., the distribution may be controlled by the place and manner features we examined in Section 5.3 other than vowels. If we ignore the distributions of /i/ and /e/ (recall that only one token of voiced geminate was observed preceding the vowel /e/ and no repair was observed.), then the remaining distributions is limited to the /a/, /o/, and /u/ vowels. The distributions that consists of these three vowels follows the pattern that is consistent with the aerodynamic consideration; namely, high vowels create the greater air pressure in the oral cavity, and the greater air pressure makes it difficult to produce voiced geminate, therefore, the probability of repair is highest in high vowels, and lowest in low vowels. The application of repair is sensitive to height (or F1); and contrary to the preceding vowels, we can give a straightforward phonetic account to this pattern.

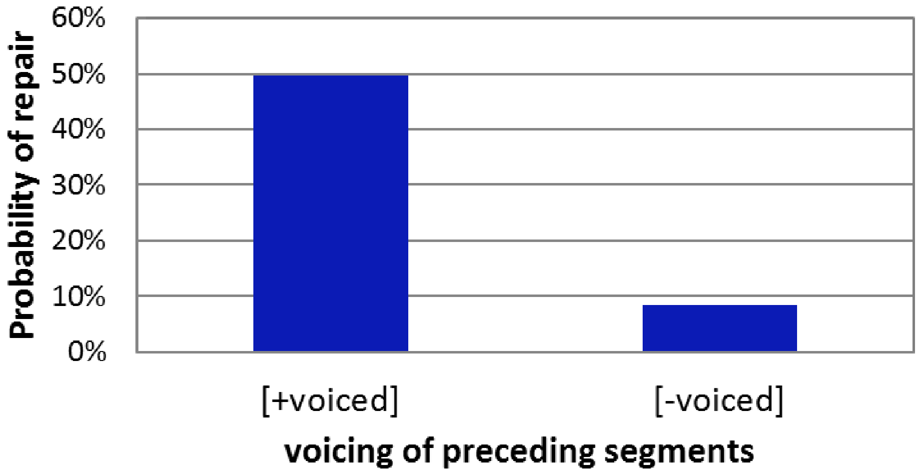
[12] Japanese has the open-syllable pattern (CV), and accordingly the voiced geminates are followed by vowels. Therefore, the voiced geminates and the following vowels are in the same syllable; on the other hand, the voiced geminates and the preceding vowels are in distinct syllables. This difference may be reflected in the direction and the degree of the effects of preceding/following vowels.

[13] I examined the preceding and the following six moras from voiced geminates, because most of the Lyman's Law-induced repair was caused by a trigger in adjacent moras (313/353=88.7%), and if the distance between voiced geminates and other voiced obstruent(s) exceeds two moras, the frequencies of both voiced geminates and repaired segments are significantly reduced. And in the distance of five moras, no repaired segment was observed.

[14] The examination of the Lyman's Law effects in the following contexts is presented in Section 5.6.4.

5.6.1. Presence/Absence of [+voice]

Lyman's Law was shown to be active in perception (Kawahara 2012b). In this section, I examine whether or not the Lyman's Law is also active in production. The effects can be tested by comparing the distributions with or without other voiced obstruent(s) than the voiced geminates. If Lyman's Law is active, the probability of repair would be higher in "presence" than in "absence" of other voiced obstruent(s). In the analysis, any instance of voiced obstruent is regarded as "presence," regardless of the locality and the number of voiced obstruents, since the purpose of the analysis here is to examine the overall effects of Lyman's Law. The probability of repair according to the presence/absence is shown in Figure 5.



$\chi^2(1) = 330.76$, $p<0.001$

Figure 5. The probability of repair by presence/absence of [+voice] (preceding context)

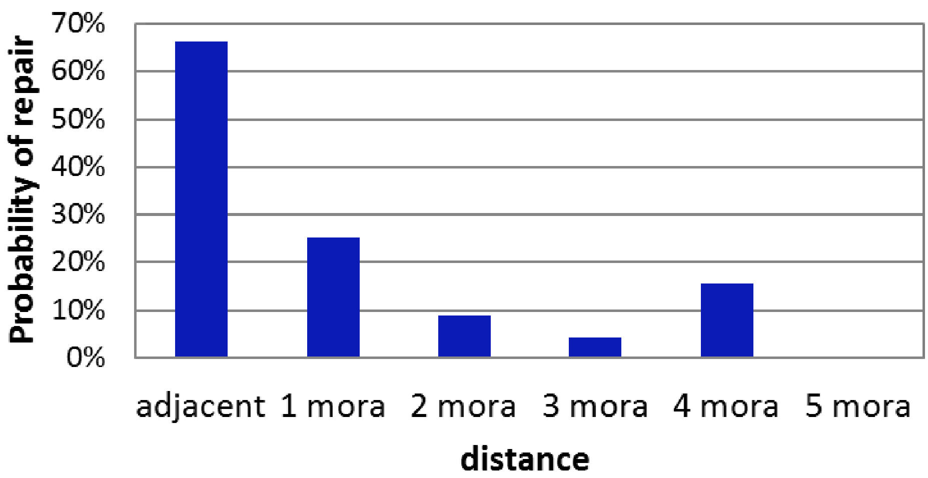
As shown in Figure 5, the probability of repair is significantly higher in presence ([+voice], 48.8%) than in absence ([-voice], 8.4%). The realization of voiced geminates tends to be blocked if there is other voiced obstruent(s). In other words, the presence of other voiced obstruent can induce the repair. Therefore, we can argue that Lyman's Law is active also in production.

5.6.2. Locality

In the previous studies, Lyman's Law was shown to be insensitive to the locality in perception (Kawahara 2012b). In this section, I examine the sensitivity of Lyman's Law to the locality in production. If Lyman's Law is sensitive to the locality, the probability of repair would be higher with voiced obstruents being closer to voiced geminates. In the analysis, I restrict our attention to the "presence" of other voiced obstruent(s), because the purpose of the examination is to see the effects of locality on the application of Lyman's Law, and the Lyman's Law does not play a role in the "absence." Furthermore, I removed all tokens that contained more than one voiced obstruent, as in such cases, which obstruent triggers the devoicing is unclear. For example, in *radifogiddo* 'Ladefoged' (A01M0936) with two voiced obstruents: one is adjacent to the voiced geminate, and the other is three moras away from the voiced geminate, the distance between the voiced obstruents and the voiced geminate cannot be uniformly determined.[15] The distance is based on the number of intervening moras, including the voiced obstruent as shown in (13).

(13) nee**ba**ahu**ddo** 'neighbourhood' (A01M0397)
voiced obstruent ⟷ voiced geminate
intervening 2 moras

The probability of repair by locality is shown in Figure 6.



$\chi^2(5) = 191.12$, $p<0.001$

Figure 6. The probability of repair by locality (preceding context)

As Figure 6 shows, the probability of repair is highest with the adjacent voiced obstruent, and it gradually declines as voiced obstruents move away from the voiced geminates. The result suggests that Lyman's Law is sensitive to the locality in production, and the closer the distance is, the more likely the repair strategy is applied. Lyman's Law is shown to have a stronger effect if the trigger and the target are closer together.

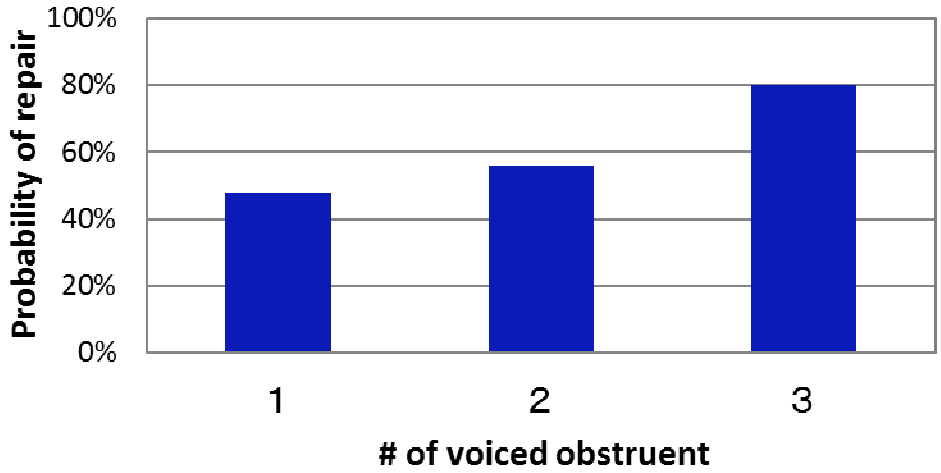
5.6.3. Number of voiced obstruents

In this section, I examine whether the Lyman's Law is sensitive to the number of voiced obstruents in production. If Lyman's Law is sensitive to the number, the probability of repair would be higher with more voiced obstruents. For the same reason in the previous discussion, I focused only on tokens that involve other voiced obstruent(s) than voiced geminates, where the Lyman's Law is active. Example tokens for each number of voiced obstruents are given in (14).

(14)	a. 1 voiced obstruent	sara**b**ureddo	'thoroughbred'	(S00F0131)
	b. 2 voiced obstruents	**b**aun**d**eddonesu	'boundedness'	(A02M0678)
	c. 3 voiced obstruents	**b**a**g**u**d**addo	'bagdad'	(S09M0855)

The distribution is summarized in Figure 7.

[15] The multiple occurrence of other voiced obstruents in voiced geminates accounts for 10% (52/453) and the one in repaired segments accounts for 15% (82/449) of the entire "presence." Therefore, the removal of the multiple occurrence does not significantly affect the result of the analysis.



$\chi^2(2) = 13.67$, $p<0.001$

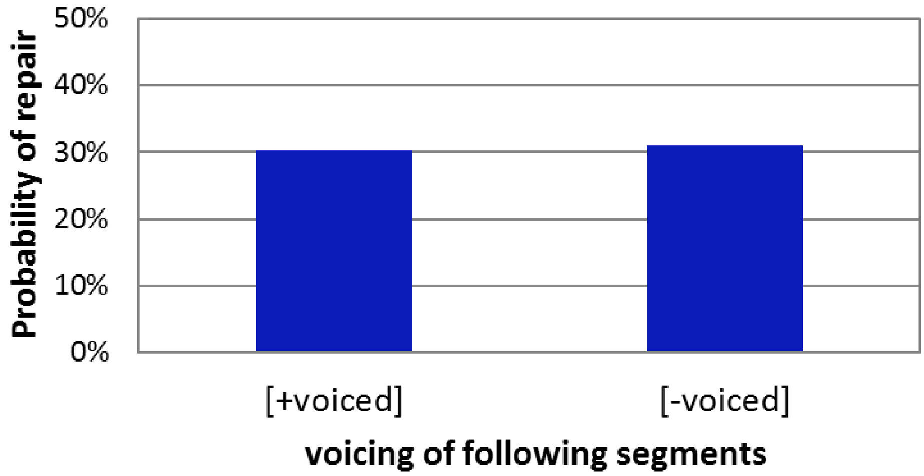
Figure 7. The probability of repair by number of triggers (preceding context)

As Figure 7 shows, the probability of repair gradually rises from one voiced obstruent to three voiced obstruents.[16] In other words, the more the number of voiced obstruents, the higher the probability of repair. The result suggests that the Lyman's Law is also sensitive to the number in production, and its effect is incremental. The Lyman's Law is shown to have a stronger effect if there are more triggers.

5.6.4. Symmetry/Asymmetry

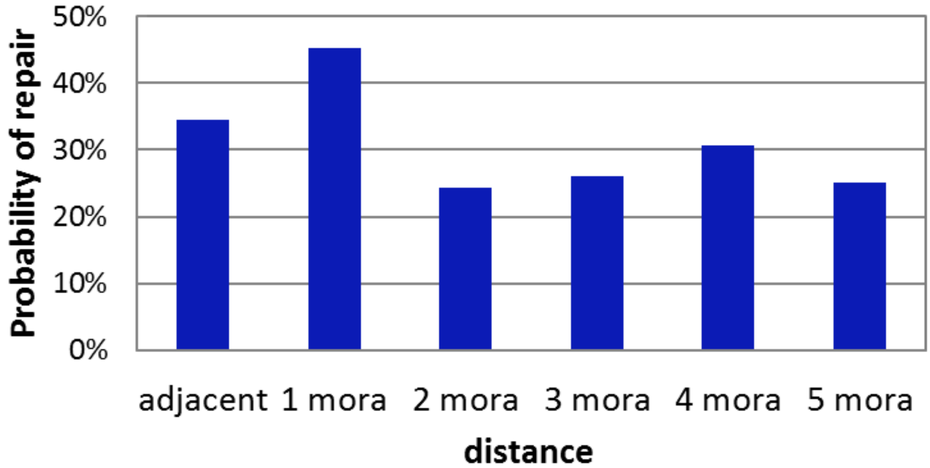
Finally, I examine the symmetry/asymmetry of the preceding and the following contexts. As we have seen, in the preceding contexts Lyman's Law was shown to be sensitive to all three items: the presence/absence, the locality, and the number of voiced obstruents. Here, I consider the relationship between the Lyman's Law and these three items in the following contexts. If Lyman's Law has the same effects on the preceding and the following contexts, then the distribution would be symmetric and there would be no difference between these two contexts; on the other hand, if Lyman's Law has different effects on the preceding and the following contexts, the distribution would be asymmetric and there would be differences according to the contexts. Figure 8 through Figure 10 I show the distributions for each item in the following contexts.

[16] Within six moras from voiced geminates, no token was observed where more than four voiced obstruents were involved.



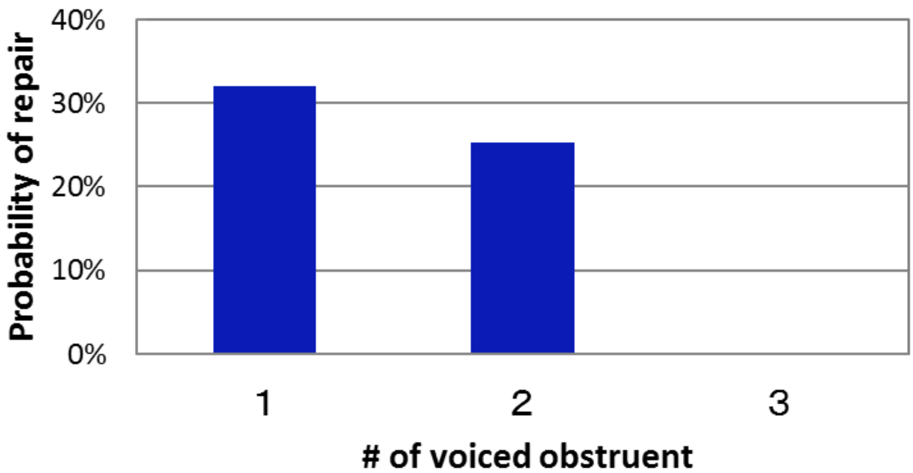
$\chi^2(1) = 0.06$, n.s.

Figure 8. The probability of repair by presence/absence of [+voice] (following context)



$\chi^2(5) = 8.09$, n.s.

Figure 9. The probability of repair by locality (following context)



$\chi^2(2) = 6.47$, $p<0.05$

Figure 10. The probability of repair by number of triggers (following context)

As Figure 8 shows, the probability of repair does not differ according to the presence or absence of other voiced obstruent(s). Similarly in terms of the locality in Figure 9, the distribution does not show a specific pattern. Only the number of voiced obstruents (Figure 10) shows a statistically significant pattern. The probability of repair is affected by the number of other voiced obstruent(s). Therefore, similar to the preceding contexts, the Lyman's Law is sensitive to the number of voiced obstruents in the following context as well as in the preceding context.

However, the direction of the effect is reversed; namely, the more voiced obstruents, the lower the probability of repair. The result suggests that in the following context the number of voiced obsrtuents has an anti-Lyman's Law effect. In summary, the preceding and the following contexts are under the asymmetric effects of Lyman's Law.

6. Conclusion

In this paper, I focused on the voiced geminates in Japanese loanword phonology and the manner by which these marked segmental configurations are avoided. I examined the patterns of avoidance focusing on the aspects of production, and the phonological factors that contribute to the patterns. The findings of this research are summarized as follows.

Firstly, repair strategies are becoming more likely to apply over the years. This suggests that the loanwords containing voiced obsrtuents are gradually being nativized. Secondly, among the repair strategies, devoicing is predominant. The choice of the strategies is dependent on the economy, such as the "least featural change" and the "minimal repair." Thirdly, in terms of the type of voiced geminates, the more back the place of articulation is, the higher the probability of repair is. The combination of the voicing and the geminacy is marked and avoided by the devoicing. The geminate fricative is also marked and avoided by the affrication. Finally, repair strategies are sensitive to the height (or F1) of the preceding vowel, but to the backness (or F2) of the following vowel. To take the results of the place of articulation of voiced geminates and in the following vowels together, we can argue that the likelihood of repair is dependent on the backness.

Lyman's Law is sensitive to the presence/absence of other voiced obstruent(s), the locality, and the number in the preceding contexts. Firstly, if other voiced obstruent exists, then voiced geminates are more likely to be repaired. Secondly, as for the locality, the closer the voiced obstruents, the higher the probability of repair. Thirdly, as for the number of voiced obstruents in the immediate vicinity, the more voiced obstruents there are, the higher the probability of repair is. In the following contexts, only the number of voiced obstruents plays a role in the following manner: the more voiced obstruents there are, the lower the probability of repair is. Thus, the effect of the preceding context and the following context is asymmetrical. Specifically, Lyman's Law is more sensitive to the preceding contexts. This suggests that in the flow of speech Lyman's Law looks ahead and has progressive effects.

I conclude by mentioning an issue to be addressed in the future. The explanation of some findings in this research is left open. The theoretical and/or empirical examination of the possible effects of factors as well as the interaction thereof that can contribute to the distribution of voiced geminate and repaired segments is required.

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