

Phonology and orthography: The orthographic characterization of rendaku and Lyman’s Law*

Abstract

This paper argues that phonology and orthography go in tandem with each other to shape our phonological behavior. More concretely, phonological operations are non-trivially affected by orthography, and phonological constraints can refer to them. The specific case study comes from a morphophonological alternation in Japanese, *rendaku*. *Rendaku* is a process by which the first consonant of the second member of a compound becomes voiced (e.g., /oo/ + /tako/ → [oo+**d**ako] ‘big octopus’). Lyman’s Law blocks *rendaku* when the second member already contains a voiced obstruent (/oo/ + /tokage/ → *[oo+**d**okage], [oo+**t**okage] ‘big lizard’). Lyman’s Law, as a constraint which prohibits a morpheme with two voiced obstruents, is also known to trigger devoicing of geminates in loanwords (e.g. /beddo/ → [**b**etto] ‘bed’). *Rendaku* and Lyman’s Law have been extensively studied in the past phonological literature. Inspired by recent work that shows the interplay between orthographic factors and grammatical factors in shaping our phonological behaviors, this paper proposes that *rendaku* and Lyman’s Law actually operate on Japanese orthography. *Rendaku* is a process that assigns *dakuten* diacritics, and Lyman’s Law prohibits morphemes with two diacritics. The paper shows that a set of properties of *rendaku* and Lyman’s Law follow from this proposal. However, since some aspects of *rendaku* and Lyman’s Law are undoubtedly phonological, the ultimate conclusion is that it is most fruitful to recognize a model of phonology in which it has access to orthographic information.

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1 Introduction

1.1 Theoretical context

In the traditional view, phonology is strictly about sounds, and orthography has been considered to have nothing to do with phonological theory, or phonological knowledge. This has been the case since linguistics distinguished itself from philology, under the influence of landmark studies like Saussure (1916/1972). However, there are a few recent proposals and observations in the phonological literature that cast doubts on traditional, strictly orthographic-free versions of phonological theory. For simple illustration, take an English minimal pair like *latter* vs. *ladder*. Without orthographic information, there is no way for English speakers to know that the first word contains word-medial /t/, whereas the latter word contains word-medial /d/. (Adult) English speakers presumably know the difference between the two words, because when they hyper-articulate, their underlying /t/ and /d/, which would otherwise be neutralized as a flap, can be pronounced as such. However, from their surface sounds alone, it is very difficult to learn that *latter* contains /t/ and *ladder* contains /d/ in their underlying representation.*¹ This simple example illustrates the fact that we cannot disregard orthography entirely, when addressing the nature of our phonological knowledge.

Ito et al. (1996) offer an illustrative—and probably more illuminating—example. In a Japanese argot language game, known as *zuujā-go*, reversing occurs based on bimoraic feet: e.g. /(**ba**tsu)+(gUN)/ → [(gum)+(ba**tsu**)] ‘exquisite’. When the first syllable contains a geminate, the reserved segment, which corresponds to a geminate marker in the original word, appears as [tsu]; e.g. /(**bi**k)+(kuri)/ → [(kuri)+(bi**tsu**)] ‘surprised’. Why does [tsu] appear in place of coda /k/ in /bik/? The most reasonable conjecture about this conversion of a coda /k/ to [tsu], according to Ito et al. (1996), is because the gemination is marked with a smaller version of the letter for /tsu/ (っ) in Japanese orthography. Thus, in terms of orthography, this argot can be expressed as びっくり → くりびっ, in which the gemination marker っ is realized as the full-size version of the letter っ after the reversal (っ cannot stay small after the reversal, because っ needs a following segment to express its gemination). This is an example

*¹ One may quibble that the difference between *latter* vs. *ladder* can be learned without orthographic information, because the post-tonic neutralization of /t/ and /d/ is phonetically “incomplete” (Herd et al., 2010); however, it is shown that the magnitude of the difference between /t/-flap and /d/-flap is tiny, and that such minimal pairs are not perceptually distinguishable (Braver, 2014).

in which orthography offers a straightforward explanation for the sound pattern under question. This conclusion does not mean, however, that the Japanese argot pattern is entirely dictated by orthography. Ito et al. (1996) show that various prosodic factors affect the formation of the argot—after all, the pattern is based on a bimoraic foot (see Poser 1990 *et seq.*), which is very phonological. It therefore seems that both phonological and orthographic factors together shape the Japanese argot pattern.

More recently, Nagano & Shimada (2014) proposed that Japanese *kanji*—Chinese characters used in the current Japanese orthography system—should be used as a representation of lexemes in the Japanese lexicon. More often than not, one *kanji* in Japanese has two readings: for example, 繁 can be read as /ɕige/ or /han/, both meaning “prosperous” (see Nagano & Shimada 2014 for extended exemplification). This dual reading creates apparently extremely complex suppletive morphological patterns, which can be modeled very simply if *kanji* is a part of linguistic knowledge of Japanese speakers, over which morphological representations can operate.

Relatedly, Poser (1990) points out one hypocoristic formation in Japanese which makes sense only in terms of orthography. For example, a person named 丘 (/takaçi/) can be called /kjuu/, because /takaçi/ and /kjuu/ are two readings of the same kanji 丘. Likewise, a girl with the name 恵 (/megumi/) can be called /kei/, because 恵 has these two readings. It is unlikely that phonology alone converts /takaçi/ to [kjuu] or /megumi/ to [kei]. This hypocoristic formation is instead mediated by the *kanji* characters. At the same time though, this hypocoristic formation is based on a bimoraic foot in that the outcome of the conversion is bimoraic (Poser, 1990), as is the case with the argot pattern discussed by Ito et al. (1996).

Shaw et al. (2014) found something essentially similar in Chinese: in order to account for compound truncation patterns in Chinese, it is crucial to consider Chinese characters as part of lexical representations. Shaw et al. (2014) demonstrates that what survives in truncation is affected by the predictability of each compound member, and that “predictability” is arguably a crucial part of our linguistic knowledge (Hall et al. 2016 for a recent overview). Shaw et al. (2014), moreover, showed that the frequencies of Chinese characters are a good measure for quantifying their predictability, again suggesting that Chinese characters are an important part of the linguistic knowledge of Chinese speakers. Overall, this example too illustrates the importance of considering the interplay between orthographic knowledge and lexical/phonological knowledge.

Finally, many studies of loanword adaptation have shown that the role of orthography is non-

negligible (Daland et al., 2015; Silverman, 1992; Smith, 2007; Vendelin & Peperkamp, 2006). To take an example from Japanese, the English word *manager* is borrowed as [maneezaa] in Japanese. Note that the second vowel in the original word *manager* is a schwa in English, and there is no reason that it had to be borrowed as a long vowel /ee/ in Japanese (p.c. Junko Ito, Oct. 2016). In this example, the orthography “a” in the original English word, and knowledge that this letter sometimes represents a diphthong in English (as in “ape”) may have led Japanese speakers to borrow it as a long vowel. See Smith (2007) for other examples of the influence of orthography in loanword adaptation in Japanese. Yet again, though, it is mistaken to consider that orthography is the only factor that dictates loanword adaptation; phonological and perceptual factors undoubtedly play a role in loanword adaptation (e.g. Kenstowicz & Suchato 2006; LaCharité & Paradis 2005; Peperkamp & Dupoux 2003; Peperkamp et al. 2008; Yip 2006). The most productive research strategy for studying loanword adaptation patterns, therefore, seems to be the one that considers the interplay among orthography, speech perception and phonology (Kang, 2011).

Importantly, none of these proposals undermine the importance of phonology or morphology as an explanation of our linguistic behavior. To the extent that orthography offers a simple explanation of our linguistic behavior, and to the extent that that behavior is also dictated by phonological and other grammatical considerations, it seems that the most natural conclusion is that phonological and morphological grammar has access to orthographic knowledge. More concretely, in current theoretical frameworks using (violable) constraints (e.g. Optimality Theory: Prince & Smolensky 2004), constraints should be able to refer to orthographic information. This paper further explores this sort of grammar-orthography interaction, by studying in detail *rendaku* and Lyman’s Law from this fresh perspective.

1.2 The current case study: *rendaku*

The interaction of *rendaku* and Lyman’s Law is probably one of the most well-studied phenomena in the phonological studies of Japanese (Irwin, 2016a; Vance & Irwin, 2016). A traditional phonological description of *rendaku* is that “the first consonant of the second member of a compound becomes voiced”; e.g., /oo/ ‘big’ + /tako/ ‘octopus’ → [oo+**d**ako] ‘big octopus’. Lyman’s Law (Lyman, 1894; Vance, 2007) blocks *rendaku* when there is already another voiced obstruent in the second member of the compound; for example, /oo/ ‘big’ + /tokage/ ‘lizard’ → *[oo+**d**okage], [oo+**t**okage] ‘big lizard’.

Rendaku and Lyman's Law were studied extensively by the traditional grammarians (see Irwin 2016a), and were brought to the attention of theoretical linguists by Otsu (1980), who presented the first analysis of rendaku in the SPE-style (Chomsky & Halle, 1968).^{*2} Ito & Mester (1986) made rendaku and Lyman's Law famous in the field of theoretical phonology, as they provided an elegant analysis of rendaku and Lyman's Law using theoretical devices that were being developed at that time: autosegmental spreading, underspecification, and OCP (Obligatory Contour Principle). Later, Ito & Mester (2003a) in their monograph developed a comprehensive reanalysis of rendaku and Lyman's Law within the framework of Optimality Theory (OT: Prince & Smolensky 2004). Reflecting the fact that they are now well-known in the field of theoretical phonology, rendaku and Lyman's Law appear in a number of introductory phonology textbooks (Gussenhoven & Jacobs 2011, p. 58; Kenstowicz 1994, p. 493, pp. 511-512; Roca 1994, pp. 75-76; Roca & Johnson 1999, p.663, Spencer 1996, pp. 60-61). Most generative studies on rendaku and Lyman's Law consider them to be purely phonological or morphophonological (however, see Kawahara 2015a and Vance 2014 for critical assessment of this common assumption in theoretical linguistics).

Building on some previous work (Kawahara, 2015a; Vance, 2007, 2015, 2016), this paper presents an alternative conception of rendaku and Lyman's Law, which explains their properties arguably better than the purely phonological view. In essence, this paper proposes the following:

- (1) Orthographic interpretations of rendaku and Lyman's Law.
 - a. Rendaku is a process that adds a *dakuten* mark, an orthographic diacritic to represent obstruent voicing.
 - b. Lyman's Law prohibits two occurrences of diacritics within a single morpheme.

For this theory to work out, one needs to assume that Japanese speakers' phonological mental representations contain *kana* representations (following Ito et al. 1996; Nagano & Shimada 2014; Shaw et al. 2014), and that the phonetic component knows how to phonetically implement *kana* letters, the system which is summarized in Table 1 below. In particular, the phonetic component of Japanese implements those elements with a *dakuten* mark as voiced obstruents. It is important to note here, however, that

^{*2} The first comprehensive generative treatment of Japanese phonology appeared in McCawley (1968), but McCawley gave up on the analysis of rendaku because he could not make sense of its irregularity. He states that the behavior of rendaku is "completely bewildering" (p. 87, note 18).

knowledge about how to pronounce each *kana* letter is something that all literate Japanese speakers have. Therefore, the only novel assumption that this paper adds to phonological theory is that Japanese speakers' phonological representations also contain *kana* representations. Even this assumption is, as reviewed in the introduction, not in and of itself an entirely new proposal.

Now consider Table 1, which illustrates the basic Japanese *kana*-orthographic system, in which one letter generally corresponds to a (C)V mora. As shown in rows (a1-3), Japanese orthography marks voiced obstruents by putting two dots (called *dakuten*) on the upper right corner of the letter for the corresponding voiceless obstruents. As shown in (b), /ba/ is written with *dakuten* on the letter for /ha/. /pa/ is represented by putting a little circle—known as *han-dakuten* 'half *dakuten*'—on the upper right corner of the letter for /ha/, as in (c). Sonorant consonants and vowels, despite being phonetically voiced, are not written with *dakuten*, as in (d1-3).

Table1 The basic Japanese *kana*-orthography systems.

	Sounds	Letters	Sounds	Letters
(a1)	ta	た	da	だ
(a2)	ka	か	ga	が
(a3)	sa	さ	za	ざ
(b)	ha	は	ba	ば
(c)	ha	は	pa	ぱ
(d1)	na	な	ma	ま
(d2)	ja	や	ra	ら
(d3)	wa	わ	a	あ

This paper proposes that (i) *rendaku* is a process that assigns *dakuten*, and that (ii) Lyman's Law prohibits two diacritics (*dakuten* or *han-dakuten*) within a morpheme. In this view, Lyman's Law can be considered as orthotactics, restrictions on letter configurations (Bailey & Hahn, 2001), rather than pure phonotactics, restrictions on sound configurations. Although this proposal may seem rather radical, it did not come out of the blue—Vance (2007, 2015, 2016) drew attention to the relevance of Japanese orthography in the patterning of *rendaku*, as we will see below in section 3.1. This proposal is also inspired by other work showing the interplay between orthographic and linguistic knowledge in shaping our phonological behaviors, which was reviewed in the introduction of this paper (Ito et al., 1996; Nagano & Shimada, 2014; Poser, 1990; Shaw et al., 2014; Smith, 2007).

Under the current proposal, formally speaking, rendaku can be understood as follows. The compound juncture morpheme postulated by Ito & Mester (2003a) is actually a *dakuten* diacritic, instead of a floating [+voice] feature, and the morpheme realization constraint requires this *dakuten* diacritic to realize on the surface. Lyman's Law can be understood as OCP(diacritic), which prohibits two diacritics within a morpheme, where "diacritic" can be either *dakuten* or *han-dakuten*. Once rendaku assigns *dakuten* to a target consonant, the phonetic implementation component of Japanese produces it as a voiced obstruent.

2 Some properties of rendaku and Lyman's Law

Before developing this orthographic theory of rendaku and Lyman's Law, let us first review some crucial properties of rendaku (Kawahara & Zamma, 2016). As stated in the introduction, rendaku was first formalized in the SPE format by Otsu (1980), and later analyzed by a series of work by Ito and Mester (1986; 1996; 1997b; 2003a; 2003b). There are a number of theoretical contributions that they have made over the years, but this section focuses on those aspects that will become relevant later. First, rendaku has been treated as a manifestation of several grammatical operations, including a feature-changing SPE-style rule (Otsu, 1980), an autosegmental spreading rule (Ito & Mester, 1986), morphophonologized intervocalic voicing (Ito & Mester, 1996), and a morpheme realization requirement of a compound juncture morpheme (Ito & Mester, 2003a).

Second, rendaku has been discussed in the context of the internal organization of the Japanese lexicon (Ito & Mester, 1995, 1999, 2008) in that rendaku mainly occurs in native words, and somewhat regularly in some Sino-Japanese words (Irwin, 2005; Takayama, 2005), but very rarely in recent loanwords (what is referred to as *gairai-go* in Japanese). Third, Ito & Mester (1986) proposed that Lyman's Law is an instantiation of a universal constraint schema, the OCP on the [+voice] feature (Goldsmith, 1976; Leben, 1973; McCarthy, 1986). They further argued that OCP(+voice) acts as a morpheme structure condition on the Japanese lexicon as well, in that there are only a few native morphemes that contain two voiced obstruents.

Fourth, Lyman's Law is not triggered by [+voice] on sonorants, and hence Ito & Mester (1986) argue that the [+voice] feature is underspecified for sonorants. Mester & Ito (1989) argue instead that [voice] is a privative feature and sonorants do not bear that feature at all throughout the phonological derivation. Rice (1993, 2005) instead argues that sonorant voicing and obstruent voicing are represented by

different features ([SV] for “Sonorant Voicing” and [LV] for “Laryngeal Voicing”), and that Lyman’s Law targets only the [LV] feature. Alderete (1997) and Ito & Mester (2003b) formulated Lyman’s Law as the result of the self-conjunction of an OT constraint *VOICEOBS (=D²), which allows one not to commit themselves to a particular representation of [voice] for sonorants. This short review shows that rendaku and Lyman’s Law have been extensively discussed in multiple theoretical frameworks (see Kawahara & Zamma 2016 for more details).

3 Arguments for the orthographic characterizations of rendaku and Lyman’s Law

This section develops the orthography-based theory of rendaku and Lyman’s Law in (1), presenting four pieces of evidence. It is probably worth pointing out at this point that some arguments are stronger than others. However, it is also worth emphasizing here that this orthography-based theory explains *a constellation of properties* about rendaku and Lyman’s Law, which is the reason that I put forward this analysis in this paper. Taken in isolation, the arguments presented in each of the following subsections may not be entirely convincing—or rather theory-dependent—but we should evaluate the orthographic theory of rendaku and Lyman’s Law in light of all of the arguments.

3.1 Phonetic diversity, orthographic unity

The first argument to treat rendaku as a matter of orthography comes from the fact that when viewed from the phonetic point of view, rendaku is not simply a matter of “voicing of initial consonants”, but instead involves more complicated pairings of sounds. This observation was reiterated in a series of work by Timothy Vance (Vance, 2007, 2015, 2016), but did not seem to receive serious attention from formal phonologists. The surface phonetic pairs that are related by rendaku are shown in Table 2. In the left column, for each pair, the original sound is shown on the left, and the one that appears after the application of rendaku is shown on the right. The middle column shows examples. The right column shows how these sounds are written before and after rendaku.

Table2 Phonetic diversity, orthographic unity

	Phonetic pair	Example	Orthographic pairing
(a)	[ϕ]–[b]	[ϕue]–[bue] ‘flute’	ふ vs. ぶ
(b)	[ç]–[b]	[çi]–[bi] ‘fire’	ひ vs. び
(c)	[h]–[b]	[ha]–[ba] ‘tooth’	は vs. ば
(d)	[t]–[d]	[ta]–[da] ‘field’	た vs. だ
(e)	[tʃ]–[z]	[tʃuma]–[zuma] ‘wife’	つ vs. づ
(f)	[tʃ]–[z]	[tʃikara]–[zikara] ‘power’	ち vs. ぢ
(g)	[k]–[g]	[ki]–[gi] ‘tree’	き vs. ぎ
(h)	[s]–[z]	[sora]–[zora] ‘sky’	そ vs. ぞ
(i)	[ç]–[ʒ]	[çima]–[ʒima] ‘island’	し vs. じ

Table 2 highlights the fact that *rendaku* is not simply a matter of “voicing the target consonant.” Among those in Table 1, (d, g, h, i) are straightforward minimal pairs that differ in voicing, but the others are not; for example, in (b), [ç] is a voiceless palatal fricative, but [b] is a voiced labial stop; in (c), [h] is a glottal fricative, but [b] is a labial stop; in (e) and (f), the original sounds are affricates, but the resulting sounds are fricatives.

I am not arguing that this complexity is impossible to solve with a phonological analysis; for example, for (a-c), it is possible to posit an underlying labial stop /p/ (McCawley, 1968), which is realized as [h] in non-voicing contexts and as /b/ in voicing contexts; /h/ further undergoes allophonic changes before /i/ and /u/, realizing as [çi] and [ϕu] and as [h] before non-high vowels. The deaffrication in (e, f) can be attributed to independently motivated intervocalic deaffrication (see Maekawa 2010 for details and complications of this deaffrication process), because *rendaku* usually occurs in intervocalic contexts.

It is not impossible to construct a phonological analysis of the complicated patterns in Table 2 in this way. However, it does face some problems. Concretely, positing underlying /p/ for surface [h] can be problematic, because /p/ realizes faithfully in native words as well, as in *tanpopo* ‘dandelion’ and *paipan* ‘shaved genitalia’ (Fukazawa & Kitahara, 2002).^{*3} The stronger evidence against positing the /p/ → [h] alternation in native phonology comes from a reversing argot pattern (Ito et al., 1996): the purported process that turns underlying /p/ to [h] is not active even for native items; e.g. /((kap)(pa)/

^{*3} Whatever the actual etymological origins of these words may be, what is important is that native speakers of Japanese do not consider these words to be recent loanwords; nevertheless the /p/ → [h] alternation does not apply to these words.

→ [(p)ak)(ka)], *[(h)ak)(ka)] ‘river imp’ and /-(op)(pai)/ → [(p)ai)(o)tsu)], *[(h)ai)(o)tsu)] ‘breast’. These considerations show that the purported rule that turns underlying /p/ to [h] is not active in the native phonology of Japanese.

It is also possible to posit underlying /ϕ/, instead of /p/ to explain the alternations in (a-c) in Table 2. When voiced by *rendaku*, since Japanese does not allow a voiced bilabial fricative /β/, it becomes a bilabial stop [b]. /ϕ/ is palatalized before /i/, becoming [ç]. One problem of this approach is that one has to further postulate a delabialization rule before /a/, /e/, /o/, but this delabialization rule seems unmotivated phonetically, especially before [o], because [o] involves lip rounding. Note that Japanese /o/ is more protruded than /u/ (Vance, 2008), which can be observed in MRI data (Isomura, 2009). The point of this discussion is that although it is not impossible to construct a phonological analysis of Table 2, it will always face some complications.

More crucially, it is important to note that from the viewpoint of orthography, all the pairings in Table 2 can be treated very simply as a unitary rule—the addition of the same diacritic mark (*dakuten*) (Vance, 2007, 2015, 2016). All the letters for the sounds that appear on the right are identical to those letters that represent the sounds on the left, with addition of the *dakuten* diacritic mark. *Rendaku* therefore can simply be understood as “the addition of a *dakuten* mark”. As Vance (2016) (p. 4) states, “the Japanese writing system represents all the [*rendaku*] alternations in a uniform way”. In short, the orthography-based analysis is undoubtedly *simpler* than the purely phonology-based analyses.^{*4}

In the discussion of the Japanese argot in which /tsu/ (ツ) appears as the argot correspondent of a gemination marker (ッ), Ito et al. (1996) entertain some possible phonological analyses, but conclude that “such proposals have a ring of artificiality in comparison with the perfectly straightforward kana account.” The same argument can be made against the possible phonological analyses of *rendaku* in Table 2, given that the orthographic characterization is so simple.

Besides *rendaku*, there is another type of alternation that can be captured straightforwardly by the current theory in which phonology can operate on orthographic representation.^{*5} As in (2)a, there are several numeral classifiers that begin with /h/. When they appear after a nasal, they can turn into [b].

^{*4} An anonymous reviewer states s/he does not see how “the orthographic analysis *explains* these alternations any better, considering that one simply would have to stipulate that /h/ with *dakuten* is pronounced [b]”. I agree with the first clause: the orthographic analysis may not *explain* the phonetic diversity, but it does provide a *simple characterization*. I do not agree with the second statement, because the fact that /h/ with *dakuten* is pronounced as [b] is an established fact in the Japanese orthographic system—it is not a stipulation that one posits for the sake of analyzing *rendaku*.

^{*5} Thanks to two anonymous reviewers for pointing this out.

- (2) a. [ni-hai] (に-はい) “two cups of”/ [ni-hon] (に-ほん) “two sticks of”
 b. [sam-bai] (さん-ぱい) “three cups of”/ [sam-bon] (さん-ぼん) “three sticks of”

In the orthography-based theory pursued in this paper, this alternation can straightforwardly be described as “add a diacritic to resolve a /nh/ sequence”. On the other hand, as discussed above, it is not trivial to form a phonological analysis to turn /h/ into [b]. In particular, explaining where the labiality of the surface [b] comes from is not a simple matter; if anything, dorsal sounds are closer to /h/ than labial sounds in terms of place of articulation, so why does /h/ turn into [b] instead of [g]? Again, it is possible that some phonological analyses are able to explain the /h/-[b] alternations, but they are not without problems.

3.2 /p/-driven geminate devoicing

The second argument for the orthographic theory of rendaku and Lyman’s Law comes from the patterns of geminate devoicing found in loanwords, which is arguably caused by Lyman’s Law. In Japanese loanwords, geminates can devoice when they co-occur with another voiced obstruent (e.g. /beddo/ → [betto] ‘bed’), but not when voiced geminates do not appear with an additional voiced obstruent (/heddo/ → [heddo], *[hetto] ‘head’) (Kawahara, 2006, 2011, 2015b; Nishimura, 2006). As Nishimura (2006) and Kawahara (2006) argue, this devoicing can be understood as an effect of Lyman’s Law, because devoicing avoids morphemes with two voiced obstruents. Interestingly, /p/ seems to cause devoicing of geminates as well (e.g. /piramiddo/ → [piramitto] ‘pyramid’; /kjuupiddo/ → [kjuupitto] ‘cupid’). This /p/-driven geminate devoicing is productive in the current phonology, as it applies to new words like /ai-paddo/ → [ai-patto] ‘i-pad’ and /ai-poddo/ → [ai-potto] ‘i-pod’.

Since this /p/-driven devoicing of geminates seems counterintuitive, Kawahara & Sano (2016) ran a judgment experiment to investigate whether this devoicing is real. In this experiment, they presented native speakers of Japanese with a list of words that contain particular sorts of structures: (i) geminates that appear with /p/ (e.g. /paddo/ ‘pad’), (ii) geminates that appear with another voiced obstruent (e.g. /baddo/ ‘bad’), (iii) geminates that occur neither with /p/ or a voiced obstruent (e.g. /heddo/ ‘head’), (iv) two voiced singletons (e.g. /baado/ ‘bird’), and (v) one voiced singleton (e.g. /haado/ ‘hard’). In that experiment, for each word, they presented participants with two forms, one “faithful form” (e.g. /beddo/) and one “devoiced form” (e.g. /betto/), and asked them which pronunciation they would

use. The stimuli were presented in Japanese *katakana* orthography, which is conventionally used for loanwords. Although the test was based on orthography, the participants were asked to read each stimulus in their heads, and make judgments based on their auditory impression rather than on the orthography.

The results of Kawahara & Sano (2016) are reproduced in Figure 1, which shows that geminates are indeed judged to be pronounced as devoiced 40% or 30% of the time when they co-occur with /p/ or another voiced obstruent (the first two bars); the results also show, on the other hand, that the other conditions show very few devoiced responses—most importantly, context-free devoicing of geminates rarely occurs (the third bar).

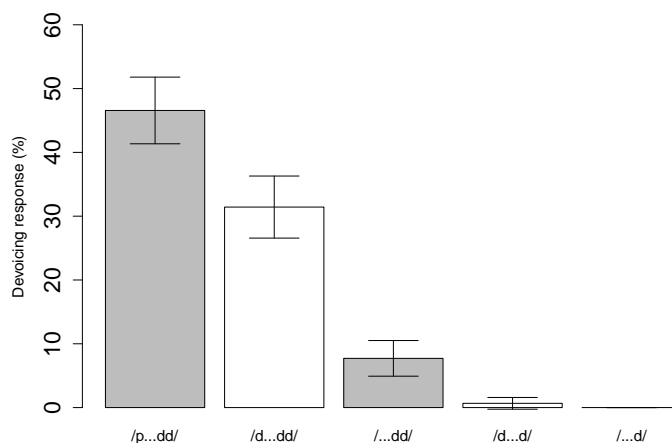


Figure1: Devoicability of each type of consonant. Based on Kawahara & Sano (2016).

Kawahara & Sano (2016) also examined corpus data, and found some instances of /p/-driven geminate devoicing as well as devoicing of geminates that co-occur with a voiced obstruent. On the other hand, context-free devoicing of geminates was barely found. Given these results, the question that arises is why /p/ would cause devoicing of geminates, or in other words, why /p/, in addition to voiced obstruents, triggers Lyman’s Law. OCP(+voice) (Ito & Mester, 1986) or *D² (Ito & Mester, 2003a) cannot be the explanation, because /p/ is not a voiced obstruent—it would turn into [b] if it were [+voice].

If Lyman’s Law prohibits two diacritics within a morpheme, this /p/-driven devoicing makes sense, because /p/ also has a diacritic mark (*han-dakuten*: see Table 1). In summary, the triggers of geminate

devoicing in Japanese loanwords include /p, b, d, g/. There does not seem to be a phonological natural class to characterize this group of sounds. However, all of these sounds have an orthographic diacritic in Japanese: ぱ (pa), ば (ba), だ (da), が (ga). In essence, then, it is natural to consider Lyman’s Law as OCP(diacritic). It may be that OCP is a general cognitive schema to avoid adjacent similar entities (Frisch, 2004; Pierrehumbert, 1993), which can take both phonological features and orthographic characteristics as its arguments. Alternatively, one could say that ぱ, ば, だ, が (=p, b, d, g/) form a *phonological* natural class in Japanese as [+dakuten] sounds, as long as we admit that phonology can have orthographic features like [+dakuten].

Mark Irwin (p.c., December 2014) pointed out that the orthography-based theory of Lyman’s Law makes a certain prediction about geminate devoicing. Since devoicing /bb/ would result in /pp/, which would still have a diacritic mark, /bb/ should not devoice. Loanwords containing /bb/ are rare in the first place (Ito et al., 2017; Katayama, 1998; Shirai, 2002), but there is one word that contains both /bb/ and a voiced stop, /gebberusu/ ‘Göbbels,’ and the prediction seems to be borne out. In the naturalness judgment using a 5-point scale reported by Kawahara (2011), the devoicing of this word was rated much less natural than the devoicing of geminates in other Lyman’s-Law-violating words: 3.16 vs. 3.86. This score for the devoicing of /gebberusu/ (3.16) is in fact *lower* than the average naturalness of devoicing of non-Lyman’s-Law-violating words (3.26) in Kawahara (2011), whose devoicing was deemed almost impossible in Kawahara & Sano (2016) (see Figure 1, the third bar). This result further supports the formulation of Lyman’s Law as an orthotactic constraint which prohibits two diacritics.*⁶

An anonymous reviewer asked whether /p/-driven geminate devoicing (the first bar in Figure 1) and geminate devoicing caused by a voiced obstruent (the second bar in Figure 1) are the same phenomenon. In Kawahara & Sano’s (2016) corpus data, the latter showed higher devoicing probabilities, and the difference was statistically significant; on the other hand, in the judgment experiment, the former showed higher devoicing probabilities (Figure 1), although the difference did not reach significance. The current analysis, which relies on OCP(diacritic), treats the two devoicing patterns as one and the same phenomenon, which may at first sight seem to predict that they should occur with equal probability; however, it is not easy to tell from the observed probabilities alone whether they are

*⁶ Another possible candidate that can be potentially used to examine the prediction is /gubbai/ ‘Good bye’, which is arguably heteromorphemic, and thus has not been tested in the previous judgment experiments. I have consulted a few native speakers about the possibility of devoicing this /bb/ in /gubbai/—many feel that it is impossible to devoice /bb/ for this word too, to the degree that they laugh at the devoiced form of this word. Therefore, it seems generally the case that /bb/ cannot devoice, and this provides further evidence for characterizing Lyman’s Law as OCP(diacritic).

caused by the same constraint—hence the same devoicing pattern—because the probability of devoicing is influenced by several other factors such as the number of triggers and the lexical frequencies of each item under question (Coetzee & Kawahara, 2013; Kawahara, 2011; Kawahara & Sano, 2013; Sano & Kawahara, 2013). Thus in order to falsify the orthographic theory of Lyman’s Law from this perspective, one has to show that devoicing caused by /p/ and devoicing caused by a voiced obstruent are quantitatively different, *with all other relevant factors controlled*.

3.3 Explaining why sonorants do not cause Lyman’s Law

Treating rendaku and Lyman’s Law as a matter of orthography comes with additional virtues. Recall that Lyman’s Law ignores voicing in sonorant consonants and vowels, and that several theoretical apparatuses were proposed to account for that observation: underspecification (Ito & Mester, 1986), a privative feature (Mester & Ito, 1989), and obstruent-specific voicing feature (Rice, 1993, 2005). However, there is a very simple explanation in terms of orthography: as shown in Table 1, Japanese orthography marks voicing on obstruents with a diacritic mark, but not on sonorants. Therefore, if Lyman’s Law were to be understood as a prohibition against two diacritics—or OCP(diacritic)—then the inactivity of sonorant voicing directly follows. No additional theoretical machinery is necessary.*⁷

This argument is admittedly theory-dependent, and possibly weak to the extent that mechanisms such as underspecification or obstruent-specific voicing features are independently motivated. And indeed there is currently a heated debate about whether phonological and lexical representations are underspecified or richly detailed (or both) (see e.g. Archangeli 2011; Johnson 1997; Lahiri & Reetz 2002; Pierrehumbert 2016; Steriade 1995). Therefore, the argument in this subsection largely depends on the choice of whether one embraces underspecification or not. However, as emphasized at the beginning of this section, it is the constellation of these pieces of evidence that makes the orthographic-based theory of rendaku and Lyman’s Law plausible. Put differently, if Lyman’s Law operates on orthography, it predicts that voicing on sonorants should be ignored; the actual data supports this prediction.

*⁷ Japanese arguably has a pattern of postnasal voicing, which may require a [voice] specification on sonorants (Ito et al., 1995; Rice, 1993, 2005). For example, the past tense suffix [ta] is realized as [da] after a nasal consonant (e.g. [tabeta] ‘ate’ vs. [cin-da] ‘died’). However, the evidence for the *productivity* of postnasal voicing in Japanese phonology, especially the one observed in verbal conjugation patterns, is weak at best (Batchelder, 1999; Griner, 2005; Vance, 1987, 1991). Even if post-nasal voicing is productive, it can be attributed to an Optimality Theoretic constraint *NT (Pater, 1999), without assuming that nasals have [+voice] feature (Hayashi & Iverson, 1998).

3.4 Explaining the opacity

Another argument for the orthographic theory of rendaku comes from the interaction of rendaku, Lyman’s Law, and yet another phonological process. In some dialects of Japanese, word-medial /g/ becomes [ŋ] (Ito & Mester, 1997a, 2003b; Vance, 1987). This segment [ŋ] is not a voiced obstruent, but it still blocks rendaku, as in [saka-toŋe] ‘reverse thorn’ and [oo-tokaŋe] ‘big lizard’.

This interaction is opaque because the surface [ŋ] acts as if it is a voiced obstruent: it triggers Lyman’s Law, although its surface realization is a sonorant. In other words, the blockage of rendaku due to Lyman’s Law overapplies and rendaku underapplies, despite the application of velar nasalization. In a derivational sense, velar nasalization needs to occur after rendaku applies; when rendaku occurs, /g/ is still /g/ (Table 3). Ito & Mester (2003b) developed this derivational ordering analysis in OT (Prince & Smolensky, 2004). Ito & Mester (1997b) and Honma (2001) instead proposed analyses based on Sympathy Theory (McCarthy, 1999).

Table3 Derivational analysis of the opacity.

	The right order		The wrong order
UR	/saka+toge/		UR
rendaku	—blocked by Lyman’s Law—		velar nasalization
velar nasalization	/saka+toŋe/		rendaku
SR	[saka+toŋe]		SR
			*[saka+doŋe]

One particular challenge that this opaque pattern presents is as follows. To the extent that [g] and [ŋ] are in an allophonic relationship (*a la* Ito & Mester 1997a,b; Honma 2001), the Richness of the Base hypothesis (Prince & Smolensky, 2004; Smolensky, 1996) makes us consider a case in which /ŋ/ appears in the input; e.g. /toŋe/. In order for this form to block rendaku, the underlying /ŋ/ has to be changed to /g/ at the level in which rendaku applies, and then has to turn back to [ŋ] at the surface. This pattern would thus instantiate a “Duke-of-York” derivation (Pullum, 1976) (schematically, /A/ → /B/ → [A]; in this case, /ŋ/ → /g/ → [ŋ]). However, the existence of such derivation is debatable (McCarthy, 2003; Rubach, 2003; Wilson, 2000); granting phonological theory enough power to allow this type of derivation may overgenerate.

The orthographic formulation of Lyman’s Law explains why /g/, after becoming [ŋ], would still

block rendaku, because [ŋ] is still written with a *dakuten* mark, because velar nasalization is not reflected in the Japanese orthography—[ŋ] is written using the same letter as [g]. No theoretical machinery to deal with derivational opacity is necessary, and in fact, there is no opacity in this analysis at all. See arguments by Hooper (1976), Sanders (2003), Green (2004) and Padgett (2010) that there are perhaps no productive synchronic cases of opacity*⁸

One may argue that natural languages do show (Duke-of-York) opacity, and hence phonological grammar must be powerful enough to deal with opacity (Idsardi, 2000; McCarthy, 2007; Rubach, 2003), in which case the argument presented in this subsection does not hold. Hence the argument in this section, like the one presented in section 3.3, is theory-dependent. With that said, again, the orthographic theory of rendaku and Lyman's Law, independently motivated for other reasons, actually predicts that velar nasalization should not affect rendaku application, and this prediction is supported by actual data.

4 Discussion

4.1 Summary of arguments and further considerations

In summary, many properties of rendaku and Lyman's Law make sense, once we consider them from the viewpoint of Japanese orthography. When viewed at the surface phonetic level, rendaku is not a simple matter of "voicing the target consonant", but involves different sets of more complicated pairings. However, in terms of orthography, rendaku is simply an addition of *dakuten*; it allows us to characterize rendaku much more simply than a purely phonology-based analysis. Treating Lyman's Law as orthotactics comes with three additional virtues: (i) it explains why /p/ can cause devoicing of geminates; (ii) it explains why Lyman's Law ignores [+voice] of sonorants; and (iii) it explains why /g/ blocks rendaku, even after it turns into [ŋ]. Admittedly, some arguments may not be as strong as one wishes, especially when considered in isolation. For example, the fact that Lyman's Law ignores [+voice] in sonorants (section 3.3) may follow if sonorants are indeed underspecified for [+voice] or if there is an obstruent-specific [+voice] feature. The argument in section 3.4 holds only insofar as

*⁸ Bruce Hayes also mentions some statement to this effect in his lecture at "50 Years of Linguistics at MIT", which succinctly summarizes the problem: "We don't understand the opaque languages well enough. In particular, I don't think we fully understand the degree to which the opaque pattern is internalized by language learners, and it is time to do more checking" (viewable on Youtube).

phonological systems should not allow (Duke-of-York) opacity patterns.

The orthographic theory of rendaku and Lyman’s Law makes one specific prediction about rendaku, which is unfortunately not easy to test—/p/ should block rendaku, because it should trigger Lyman’s Law.*⁹ Unfortunately, rendaku applies mainly to native items, and native items rarely contain non-geminate /p/, because Japanese lost this phoneme at some point in its history (Frellesvig, 2010; Ito & Mester, 1995, 1999, 2008; Takayama, 2015; Ueda, 1898). In the rendaku database (Irwin, 2016b; Irwin & Miyashita, 2016), there is one monomorphemic native stem that contains /p/ or /pp/, *suppa-i* ‘sour’, which undergoes rendaku (e.g. *ama-zuppa-i* ‘sweet and sour’). This word would have to be treated as an exception. There are two more relevant native words *happa* ‘leaves’ and *sippo* ‘tail’, neither of which undergoes rendaku (Vance, 2007) . Another relevant word *kappa* ‘coat’ undergoes rendaku (e.g. *ama-gappa* ‘rain coat’), contra the prediction of the orthographic theory of Lyman’s Law. This word, however, is doubly exceptional, because this word is a loanword from Portuguese *capa* (Labrune, 2012) (recall that rendaku is usually limited to native words). Overall, there are exceptions for the original formulation of Lyman’s Law based on [+voice] as well (e.g. *hasigo* ‘ladder’ and *saburoo* (personal name), which undergo rendaku)—I thus contend that these exceptions are not detrimental to the orthographic theory of Lyman’s Law.

Table4 Summary.

	Triggering devoicing	Blocking rendaku	[+voice]	[+voice, -son]	diacritic
/b/	yes	yes	+	+	+
/d/	yes	yes	+	+	+
/g/	yes	yes	+	+	+
/p/	yes	?	-	-	+
/t/	no	no	-	-	-
/k/	no	no	-	-	-
/m/	no	no	+	-	-
/n/	no	no	+	-	-
/ŋ/	?	yes	+	-	+

*⁹ Interestingly, though, Lyman (1894) himself states that /p/ blocks rendaku: “the second part of a compound word takes the nigori [=rendaku]; that is if beginning with ch, f, h, k, s, sh, or t, those consonants are changed into the corresponding sonant [=voiced] ones ... the general rule does not apply ... when b, d, g, j, p, or z already occurs anywhere in the second part of the compound” (p.2). See also Vance (2007) for relevant discussion.

Table 4 provides a summary of what has been discussed in the paper. The leftmost column shows whether each segment triggers devoicing of geminates. Whether [ŋ] triggers devoicing of geminates is unclear, because there are no words with a voiced geminate and a word-medial /g/ (and no other potential trigger).^{*10} The second column shows whether each segment blocks rendaku. The third column shows whether they are phonetically voiced. The fourth column shows voicing in obstruents. The last column shows whether each sound is written with a diacritic mark in Japanese orthography. It seems that the last column matches the first two columns best.

The orthographic theory of rendaku expressed in this paper is strictly about rendaku in Modern Japanese. This paper has little to say about how rendaku and Lyman’s Law were mentally represented before *dakuten* entered into the Japanese orthographic system. One point that is worth some discussion, however, is that Japanese voiced obstruents were prenasalized (Frellesvig, 2010; Unger, 1975; Vance, 2005), and therefore Lyman’s Law at that time can and should be characterized as OCP(nasal) (Kawahara, 2008; Vance et al., 2016). This version of Lyman’s Law demystifies why [+voice] in sonorants does not trigger Lyman’s Law (section 3.3), because Lyman’s Law was about nasality not about voicing. It also demystifies why [ŋ] blocks rendaku (section 3.4), because [ŋ] is a nasal consonant and should trigger OCP(nasal). It is thus when prenasalization of voiced obstruents disappeared, Lyman’s Law started showing the complications discussed in sections 3.3 and 3.4—it may be the case that Lyman’s Law started as a purely phonological OCP(nasal) constraint, but when the sound change occurred, it became harder to interpret Lyman’s Law as a purely phonological constraint OCP(voice); as a result, Japanese speakers may have reinterpreted Lyman’s Law as OCP(diacritic).

4.2 Do we need the [voice] feature in Japanese?

The current proposal, according to which Japanese phonology has a class of *dakuten* sounds, raises the question of whether we need a phonological [+voice] feature in Japanese phonology. There are cases which require reference to “[+voice]” in Japanese phonology; for example, native words do not have voiced geminates, but they allow [pp] (Ito & Mester, 1995, 1999, 2008)^{*11}. To capture this characteristic of Japanese phonology, we may need to posit a constraint like *[+voice, -son, +gem]

^{*10} The word /bagudaddo/ ‘Bagdad’ contains a word-medial /g/ and a voiced geminate, but it also contains other voiced obstruents.

^{*11} This generalization does not hold for those geminates that appear in emphatic contexts (Kawahara, 2002)

(Ito & Mester, 1999, 2008; Kawahara, 2006). However, these cases can be reformulated using *dakuten* diacritics instead—the constraint can be reformulated as $*[+dakuten, +gem]$, or even $*[\text{ㄿ } X \text{ ˆ }]$. In general, any phonological generalizations that involve [+voice,-son] can be equally well characterized with *dakuten*.

Since voicing in sonorants is not marked by *dakuten*, if sonorant voicing is active in Japanese phonology, we would need a feature for sonorant voicing, in addition to *dakuten*. Rice (1993, 2005) in fact argues that such a feature is necessary because nasals cause post-nasal voicing in Japanese. However, this post-nasal voicing has been reanalyzed as an effect of a *NT constraint (Pater, 1999), which has independent motivations (Hayashi & Iverson, 1998) (see footnote *7). Based on these considerations, it seems possible to eliminate the [+voice] feature from Japanese phonology entirely in favor of *dakuten*. The advantage of *dakuten* over [+voice], to reiterate the argument from section 3.2, is that it can form a natural class with *han-dakuten*, which is necessary to model the geminate devoicing pattern.

It is more difficult to eliminate the [-voice] feature. For example, Japanese high vowels devoice between two voiceless obstruents, and after a voiceless obstruent before a pause (see e.g. Fujimoto 2015; Tsuchida 1997, 2001 and many references cited therein). Crucially, Japanese orthography does not distinguish voiceless obstruents from sonorants in terms of diacritics, and therefore, there is no way in which we can describe the environment for high vowel devoicing in terms of Japanese orthography. Neither is it possible to describe the high vowel devoicing itself with Japanese orthography. In this sense, we would need the [-voice] feature to describe the high vowel devoicing pattern. It is possible, however, that voicelessness can and should be represented as [+spread glottis] in Japanese (Tsuchida, 1997, 2001), in which case, Japanese phonology may lack the [voice] feature entirely in its system.

4.3 Comparison with other theories

Kawahara & Sano (2016) entertained possibilities other than the orthographic-based explanation for /p/-driven geminate devoicing, discussed in section 3.2. This subsection compares the current proposal with these alternatives to model /p/-driven geminate devoicing. For example, one alternative possibility is to posit OCP(INFREQUENT) (Fukazawa et al., 2015), which prohibits two segments that are infrequent within the same word; indeed, singleton /p/s and voiced geminates are both infrequent in the entire Japanese lexicon, as they in principle appear only in loanwords. Another possibility that Kawahara & Sano (2016) entertained is OCP(LARYNGEALLYMARKED) to the extent that both

singleton /p/ and voiced geminates are laryngeally marked (Hayes, 1999; Hayes & Steriade, 2004).

One general argument against these alternatives is that they do not explain the other aspects of rendaku that are discussed in this paper (i.e., phonetic diversity of pairs related by rendaku, inertness of [voice] in Lyman's Law, and opacity of rendaku with respect to velar nasalization). To reiterate, the orthographic explanation accounts for a constellation of properties of rendaku and Lyman's Law. These alternatives do not have this general explanatory power.

Another major difference between the current proposal and the other alternatives is that the current proposal predicts that /p/-driven devoicing of geminates occurs only if a language uses the same or similar diacritic marks for /p/ and voiced obstruents, as in Japanese. Kawahara & Sano (2016) consulted the P-Base (Mielke, 2007) (<http://pbase.brohan.ca/query>) to examine whether /p/-driven geminate devoicing exists in other languages. The search did not find any example of devoicing that was caused by /p/ at a distance. The P-Base contains 7318 phonological patterns from 629 languages, indicating that /p/-driven devoicing is a very rare process cross-linguistically. The orthographic theory explains why this phenomenon is limited to Japanese—it is because Japanese (and only Japanese), for a historical reason, marks /p/ with a diacritic. Admittedly, I did not check whether the rest of the languages in the P-base do not mark /p/ with the same or similar diacritic as voiced obstruents, because the P-Base does not provide orthographic information for these languages, but it seems to be a safe assumption to make. Of course, if there is a language with an orthographic system that is similar to Japanese, the prediction is that /p/-driven geminate devoicing would be possible in that language. Neither OCP(INFREQUENT) nor OCP(LARYNGEALLYMARKED) makes this connection between the language's orthography system and /p/-driven geminate devoicing.

There are specific problems with these alternative analyses as well; as for OCP(INFREQUENT), if it is the infrequency of singleton [p] that causes devoicing of geminates, it could be that other infrequent segments or segmental sequences like [ɸi] or [ti/tu] can cause devoicing. Sequences like [ɸi] or [ti/tu] are infrequent in Japanese just like [p], as they appear only in recent loanwords, but to the best of my knowledge, these segments do not trigger devoicing of geminates. In general, the constraint OCP(INFREQUENT) allows any two infrequent items to interact, but this sort of interaction does not seem to happen. Note that OCP(INFREQUENT) is predicted to cause not only devoicing, but also other phonological processes. For example, it predicts the existence of a pattern in which [ti] undergoes affrication—a process obligatory in the native phonology of Japanese—if and only if there

is [ɸi] elsewhere in the same word. Such alternations do not occur, at least in Japanese.

OCP(LARYNGEALLYMARKED) comes with its own problems. It predicts for example that there could be a constraint like OCP(MANNER-WISEMARKED), which for instance predicts a co-occurrence restriction on fricatives and clicks, assuming that fricatives and clicks are marked in terms of their manner of articulation. Likewise, OCP(PLACE-WISEMARKED) can prohibit a co-occurrence of a labial consonant and a dorsal consonant (assuming that coronal is the least marked place of assimilation: de Lacy 2006; Prince & Smolensky 2004). These co-occurrence restrictions do not seem to be observed in natural languages. In short, both OCP(INFREQUENT) and OCP(MARKEDINSOMEPHONOLOGICALDIMENSION) predict a range of interactions that are unlikely to occur in natural languages.

4.4 Can phonology refer to other orthographic information?

The overall proposal of this paper is that phonological systems can refer to orthographic information. A question that naturally arises is whether other orthographic representations can be referred to in phonology. There is evidence from Japanese phonology that OCP(diacritic) may not actually be an isolated example in which phonological constraints refer to orthographic information. Based on patterns of loanword adaptation, Ito & Mester (2003a) (pp. 49-50) propose that Japanese prohibits two instances of geminates within a word, and hence OCP(gem) is active. Their evidence comes from the observation that gemination in loanword adaptation does not occur twice within a word, as in (3)(a-c); the examples in (c-e) show that word-medial gemination is possible, when the word-final consonant in the source word is not geminable. This constraint OCP(gem) can easily be reformulated as OCP(っ), where っ is an orthographic marker for gemination. Ito et al. (2017) recently reiterate the argument for OCP(gem) (which should be formalized as OCP(っ), if the current proposal is on the right track).

- (3) a. [piketto], *[pikketto] ‘picket’
b. [pikunikku], *[pikkunikku] ‘picnic’
c. [pipetto], *[pippetto] ‘pipette’
d. cf. [pikkoro] ‘piccolo’
e. cf. [zukkiini] ‘zucchini’
f. cf. [rokkuφooru] ‘Roquefort’

Therefore, it may be that phonological constraints referring to orthographic information may not be as rare as we think, once we accept the view that phonology and orthography can interact in non-trivial ways.

This prediction should certainly be tested in languages other than Japanese. A possible candidate for an orthography-based constraint outside of Japanese is found in Slovak, in which long vowels are not allowed in adjacent syllables (Kenstowicz & Rubach, 1987). In the Slovak writing system, the length of vowels is represented by an acute accent mark on the vowels. Slovak may have OCP(AcuteAccentMark).

Can there be a constraint like OCP(umlaut), which prohibits two front rounded vowels? Can there be a constraint like OCP(diaereses), which prohibits two non-diphthongal pronunciations of vowel sequences within a morpheme? There are likely to be limits on how much orthographic information phonology has access to, and there should be a principled way to impose such a restriction. However, it is beyond the scope of this paper to explore and examine the general properties and limitations of the phonology-orthography interaction.

4.5 Rendaku is also sensitive to phonology

Even if the current proposal is on the right track, we need to make sure not to throw the baby out with the bathwater; i.e. banishing rendaku and Lyman's Law from the field of phonology entirely. As summarized in the introduction, recent work shows that orthographic knowledge may have a deep connection with our linguistic knowledge (Ito et al., 1996; Nagano & Shimada, 2014; Shaw et al., 2014). Likewise, it is unlikely that every aspect of rendaku can be reduced to orthography. Rendaku for instance interacts with several kinds of linguistic information, such as branching structures and morphosyntactic categories (Kubozono, 2005; Vance & Irwin, 2016), which cannot be reduced to orthography. Rendaku is also blocked by Identity Avoidance constraints (Kawahara & Sano, 2014a,b), as well as by OCP(labial) (Kawahara et al., 2006; Kumagai, 2017; Tanaka, 2017). It also interacts with pitch accent, in such a way that rendaku often correlates with unaccentedness in compounding (Kurusu, 2010; Sugito, 1965; Zamma, 2005).

It is also important to note that in the loanword devoicing pattern discussed in section 3.2, only voiced geminates, not singletons, can get devoiced in response to Lyman's Law, as shown in Figure 1—i.e. devoicing due to Lyman's Law is delineated by a grammatical distinction like singletons vs.

geminates (Kawahara, 2006, 2016). Therefore, a grammatical consideration comes into play, even if the trigger of devoicing is defined in terms of orthography, i.e., OCP(diacritic). It thus seems most productive to consider an interplay between orthography and other grammatical principles in order to explain our linguistic behavior. Japanese speakers should have an orthographic representation as part of their linguistic knowledge (Nagano & Shimada, 2014), and that representation can affect their speech behavior, in tandem with phonological and other linguistic representations.

5 Overall conclusion

Recent work has shown that both phonological knowledge and orthographic knowledge influence our linguistic behavior. This paper has shown that many properties of rendaku and Lyman's Law automatically follow, if we take the orthographic patterns of Japanese into consideration. First, at the surface phonetic level, rendaku is not a simple matter of "voicing the target consonant", but involves different sets of more complicated pairings. However, in terms of orthography, rendaku can be characterized as an addition of *dakuten*. Second, postulating Lyman's Law as OCP(diacritic) explains why /p/ can cause devoicing of geminates. Third, this theory explains why Lyman's Law ignores the voicing of sonorants. Fourth, it explains why /g/ blocks rendaku, after it turns into [ŋ]. However, some aspects of rendaku are undoubtedly phonological, which suggest that rendaku is phonological as much as it is orthographic. Taken together, then, we should develop a model of phonology in which phonological operations and constraints can refer to orthographic information.

One interesting prediction that the current proposal makes about rendaku is that pre-literate children should not be able to apply rendaku productively, and that as their orthographic knowledge develops, so does their knowledge of rendaku and Lyman's Law. This prediction has to be tested independently (for evidence that rendaku is acquired gradually, see Sugimoto 2013, who unfortunately does not report the development of the children's orthographic knowledge). A related question is how OCP(diacritic) is learned by Japanese children, because obviously, OCP(diacritic) cannot be an innate constraint. The most obvious candidate is that it is learned based on Japanese phonotactics. How existing theories of phonotactic learning, such as the one proposed by Hayes & Wilson (2008), can extend to OCP(diacritic) and how that prediction aligns with the actual acquisition processes would be a very important line of future research.

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