Testing OCP-labial effect on Japanese rendaku

Abstract

In Japanese rendaku, there are a number of factors that inhibit rendaku. One of them is that, although /h/ usually becomes labial /b/ when rendaku applies (e.g., *hako* 'box' + *hune* 'ship' → *hako**b**une* 'ark'), the rendaku application of /h/ is blocked if the following consonant is labial /m/ (e.g., *suna* 'sand' + *hama* 'beach' → *suna-**h**ama* 'sand beach'/**sun-a**b**ama*). One contributing factor to this rendaku blocking is that, if /h/ became labial /b/, it would beget a sequence of homorganic consonants /**b**…m…/, which would violate the OCP-labial effect. The current paper is the first report of an experiment that examined whether this restriction applies productively to nonce words that contain labial consonants. The results show that 1) the OCP-labial effect can be generalized in rendaku; 2) it works locally rather than non-locally; and 3) the applicability of rendaku is gradient according to the following labial consonant: The more similar two consonants are, the more strongly they are disfavored. To account for this gradient effect, I argue that the process involves two OCP-labial constraints: OCP (labial) and OCP (labial, -continuant).

Keywords: Japanese; rendaku; OCP-labial; wug-tests; Maximum Entropy Grammar

1. Introduction

Japanese rendaku is a morphophonological phenomenon in which a morpheme-initial voiceless obstruent becomes voiced when it is the non-initial member of a compound. It is well known that rendaku is blocked by Lyman's Law if the second member of a compound already contains a voiced obstruent. In addition to Lyman's Law, there are other factors that inhibit rendaku. One of them is that, although /h/ usually becomes labial /b/ when rendaku applies (e.g., *hako* 'box' + *hune* 'ship' → *hako-**b**une* 'ark'; *hude* 'pencil' + *hako* 'box' → *hude-**b**ako* 'pencil case'), the rendaku application of /h/ is blocked if the following consonant is labial /m/ (e.g., *suna* 'sand' + *hama* 'beach' → *suna-**h**ama* 'sand beach'/**suna-**b**ama*; *kutsu* 'shoe' + *himo* 'lace' → *kutsu-**h**imo* 'shoelace'/**kutsu-**b**imo*) (Kawahara et al. 2006; Kawahara 2015). One contributing factor to this rendaku blocking is that, if /h/ became labial /b/, it would beget a sequence of homorganic consonants /**b**…m…/ (labial…labial), which would violate the OCP effect on consecutive labial consonants (OCP-labial) as observed in various languages (see, e.g., Alderete & Frisch 2007; Bye 2011; Odden 1994; Selkirk 1993; Zuraw & Lu 2009 for examples of OCP-labial effects).[1] As far as I know, there is no wug-test study reported on the OCP-labial effect on Japanese rendaku.[2]

The current paper is the first report of an experiment that examined whether this restriction applies productively to nonce words that contain labial consonants. The results show that 1) the OCP-labial effect can be generalized in rendaku; 2) it works locally rather than non-locally; and 3) the applicability of rendaku is gradient according to the following labial consonant: for instance, /m/ shows a stronger blocking effect on the applicability of rendaku than /Φ/. The last finding is what is observed in various languages: The more similar two consonants are, the more strongly they are disfavored (e.g., Berent & Shimron 2003; Berent et al. 2004; Buckley 1997; Frisch et al. 2004; Greenberg 1950; Pierrehumbert 1993). To account for this gradient effect, I argue that the process involves two OCP-labial constraints: OCP (labial) and OCP (labial, -continuant), and that they show a ganging-up effect (Pater 2009, 2016; Potts et al. 2010) with other faithfulness constraints on blocking rendaku.

The organization of the current paper is as follows: Section 2 explicates the restriction on rendaku that this paper focuses on. Section 3 explains the experimental design and reports the results of the current experiment. Section 4 provides an analysis of the results in the Harmonic Grammar (HG) (e.g., Legendre et al. 1990, 2006; Pater 2009, 2016; Potts et al. 2010) and Maximum Entropy (aka MaxEnt) Grammar frameworks (e.g., Colavin et al. 2014; Goldwater & Johnson 2003; Hayes & Wilson 2008; Hayes et al. 2009; Hayes et al. 2012; Hayes 2017; Jäger & Rosenbach 2006; Martin 2011; McPherson & Hayes 2016; Shih 2016; Shih & Inkelas 2016; Tanaka 2017; Wilson 2006; Zhang et al. 2011; Zuraw & Hayes to appear). Section 5 discusses the issue of the nature of the OCP-labial effect. Section 6 gives a brief conclusion.

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[1] For OCP effects, see, e.g., Bye (2011), Goldsmith (1978), Leben (1973), McCarthy (1986), Odden (1986, 1988), Rose (2001), Suzuki (1998), Yip (1988), and many others.

[2] Kawahara & Sano (2014a, 2014b, 2016) tested for any avoidance of consecutive identical consonants including labial consonants across the word boundary (i.e. Identity Avoidance). The current experiment examines whether the OCP-labial effect works within the second member of compounds.

2. OCP-labial effect on Japanese rendaku

Japanese rendaku, called sequential voicing (Martin 1952), is a morpho-phonological phenomenon in which a morpheme-initial voiceless obstruent becomes voiced when it is the non-initial member of a compound (e.g., McCawley 1968; Vance 1987, 2015, 2016; see also Vance & Irwin 2016 for a collection of recent papers on rendaku). Illustrative examples are given in (1), where /t, k, s, h/ become [d, g, z, b], respectively.

(1) Typical examples of Japanese rendaku

aka	'red'	+	tama	'ball'	→	aka-**d**ama 'red ball'
oo	'big'	+	tako	'octopus'	→	oo-**d**ako 'big octopus'
umi	'sea'	+	kame	'turtle'	→	umi-**g**ame 'sea turtle'
hi	'sun'	+	kasa	'umbrella'	→	hi-**g**asa 'parasol'
oo	'big'	+	same	'shark'	→	oo-**z**ame 'big shark'
oo	'big'	+	sake	'alcohol'	→	oo-**z**ake 'heavy drinking'
hako	'box'	+	hune	'ship'	→	hako-**b**une 'ark'
hude	'pencil'	+	hako	'box'	→	hude-**b**ako 'pencil case'

It is well known that rendaku is blocked by Lyman's Law if the second member of a compound already contains a voiced obstruent, as illustrated in (2). The initial consonant /t, k, s, h/ of the second example does not undergo rendaku because the second member of the compound already contains a voiced obstruent /b, d, g/.

(2) Lyman's Law

hitori	'alone'	+	tabi	'travel'	→	hitori-tabi/ *hitori-**d**abi 'travelling alone'
ie	'house'	+	kagi	'key'	→	ie-kagi/ *ie-**g**agi 'house key'
kuro	'black'	+	sabi	'rust'	→	kuro-sabi/ *kuro-**z**abi 'black rust'
tori	'bird'	+	hada	'skin'	→	tori-hada/ *tori-**b**ada 'gooseflesh'

In addition to Lyman's Law, there are other factors that block rendaku.[3] As already seen in (1), /h/ usually becomes labial /b/ when rendaku applies, but the rendaku application of /h/ is inhibited if the following consonant is labial /m/, as in (3) (Kawahara et al. 2006; Kawahara

[3] See Irwin (2012) for other factors that dampen rendaku.

2015a). Note that labial /m/ per se is not the potential segment that blocks rendaku, as can be seen in examples (1). Hypothesizing that the blocking on rendaku may be attributed to OCP-labial effect, the current experiment examines whether it can be generalized in rendaku, and whether it works locally, non-locally, or both.[4]

(3) [b…m]

suna	'sand'	+	hama	'beach'	→	suna-hama/ *suna-**b**ama 'sand beach'
mai	'dancing'	+	hime	'princess'	→	mai-hime/ *mai-**b**ime 'dancing girl'
kutsu	'shoe'	+	himo	'lace'	→	kutsu-himo/ *kutsu-**b**imo 'shoe lace'
ma	'genuine'	+	hamo	'pike conger'	→	ma-hamo/ *ma-**b**amo 'genuine pike conger'

Are there no cases where rendaku applies in real native words with labials /m, ɸ, w/? I examined whether bi- and tri-moraic real native words with /h…C_2(…C)/ and /h…C…C_3/, where C_2 and C_3 is any of /m, ɸ, w/, undergo rendaku. The results showed that there were only two bi-moraic words and only three tri-moraic words that undergo rendaku (see Table 1),[5] all of which are mono-morphemic (see Appendix for actual examples)[6] Taking this into consideration, if there are some significant differences in the applicability of rendaku between

[4] Regarding the four segments' potential to undergo rendaku, /h/ is the only segment that changes its place feature when rendaku applies. Thus, there seems to be no clue to examine whether there are other OCP effects of place features (i.e., OCP-coronal or OCP-dorsal effect on rendaku).

[5] Table 1 indicates that there are few native words with /h-m/, /h-ɸ/, or /h-w/. Considering the historical change wherein the word-initial *[p] was replaced with *[ɸ] and then with /h/ (e.g., Sato 1977; cf. Hamano 2000), one may wonder if the number of native words with /ɸ-ɸ/, /p-m/, or /p-w/ is also few. No native words with these sequences can be found in contemporary Japanese.

[6] This survey includes bi-morphemic words, which are believed to be reluctant to undergo rendaku, due to the Right-branch condition (see Otsu 1980 for his original proposal; see Vance 2007 for discussion; see Kozman 1998 for psycholinguistic experiments).

each experimental group, then this suggests that the OCP-labial effect is gradient in rendaku.

/h…C_2(…C)/	h…m(...C)	h…ɸ(…C)	h…w(…C)
Real words	40	0	1
Rendaku	2*	0	0
/h…C…C_3/	h…C…m	h…C...ɸ	h…C…w
Real words	38	0	0
Rendaku	3*	0	0

Table 1: Survey of bi- and tri-moraic real native words

3. Experiment

3.1 Background

Rendaku experiments have been extensively conducted to confirm the generalizability of rendaku rules and the psychological reality of constraints such as Lyman's Law and the Right-Branch Condition (e.g., Kawahara 2012; Kawahara & Sano 2014a, 2014b, 2016; Kozman 1998; Ohno 2000; Vance 1979, 1980, 2014; see Kawahara 2016 for referential lists). Since there has been no report on the OCP-labial effect on rendaku, I believe that the report of the current experiment can contribute to the discussion.

3.2 Stimuli

As shown in Table 2, the current experiment prepared two conditions to test locality: each target segment was located (i) on the second-initial mora and (ii) on the third-initial mora. For each condition, we had five groups of nonce words: (a) b-C was used as a control group that did not contain any labial consonants, while (b) b-b, (c) b-m, (d) b-ɸ, and (e) b-w contained a labial consonant, which can violate the OCP-labial constraint if rendaku applies.[7] The group (b) also violates Lyman's Law since it contains two voiced obstruents. In each group, the first

[7] Rendaku is applicable when the second member of compounds is a native word, rather than Sino-Japanese or loan words (e.g., Otsu 1980; see Irwin 2016 for a recent survey). Thus, we have excluded singleton [p] from the set of stimuli, since it does not appear in Japanese native words (e.g., Fukazawa et al. 2002; Ito & Mester 1995, 1999, 2008). Similarly, we have also excluded a long vowel because it does not appear in native monomorphemic words.

vowel (V_1) was any of /a, i, o/, and we thus used 30 trimoraic nonce words (2 conditions*5 groups*3vowels each).[8] For V_2 and V_3, we used /a/ in (a, b, c, e), but /u/ in (d), as the bilabial fricative ɸ is an allophone of /h/ after /u/ (e.g., Labrune 2012; Tsujimura 2014) (Note that ɸ is represented with brackets (i.e., /ɸ/) throughout this paper).

	(a) b-C	(b) b-b	(c) b-m	(d) b-ɸ	(e) b-w
(i) Local Condition	/b-t/	/b-b/	/b-m/	/b-ɸ/	/b-w/
Nonce words /h$V_1C_2V_2$ra/	hV_1tara	hV_1bara	hV_1mara	hV_1Φura	hV_1wara
	↓	↓	↓	↓	↓
Rendaku	bV_1tara	bV_1**b**ara	bV_1**m**ara	bV_1**ɸ**ura	bV_1**w**ara
(ii) Non-local Condition	/b-C-r/	/b-C-b/	/b-C-m/	/b-C-ɸ/	/b-C-w/
Nonce words /hV_1saC_3V_3/	hV_1sara	hV_1saba	hV_1sama	hV_1saɸu	hV_1sawa
	↓	↓	↓	↓	↓
Rendaku	bV_1sara	bV_1sa**b**a	bV_1sa**m**a	bV_1sa**ɸ**u	bV_1sa**w**a

Table 2: Nonce words used in the current experiment

3.3 Participants and procedure

Participants were 76 naïve native speakers of Japanese, all of whom were undergraduate students in a Japanese university. None of them had majored in linguistics.

The current experiment was conducted online using SurveyMonkey. In the instruction session, the participants were informed about the concept of rendaku, and given a couple of actual examples. For the test, they were told that the target nonce words were used in Old Japanese, in order for them to assume they are underlying forms. They were then asked to choose which of the forms seemed more natural than the other if each target word was combined with the word *nise*, meaning fake. Each question comprised original words and those that undergo for each nonce word rendaku (e.g., *nise-**h**amara*; *nise-**b**amara*). The nonce words and compounds were written in *hiragana*, a Japanese orthography, which is usually used to represent native words. The order of 30 questions was randomized and different for each participant.

[8] Following a number of previous wug-tests on rendaku (e.g., Kawahara 2012; Kawahara & Sano 2014a, 2014b, 2016), the current experiment used only trimoraic words with a light syllable (CV).

3.4 Statistics

For analysis, I implemented a generalized mixed-effects logistic regression, using the *glmer()* function of the *language R* and *lme4* packages (Baayen 2008) of R (R Development Core Team 2013). In the current analysis, random effects were subjects and items.

3.5 Results

The ratio of rendaku application for each condition was shown in Figures 1 and 2, where error bars represented 95% confidence intervals. As shown in Figure 1, in the local condition, the ratio of the rendaku application is as follows: /b-t/ = 0.711; /b-b/ = 0.189; /b-m/ = 0.39; /b-ɸ/ (represented as b-f) = 0.592; /b-w/ = 0.697. There were significant differences between /b-t/ and /b-b/ (z = -11.034, p < .001), between /b-t/ and /b-m/ (z = -7.206, p < .001), and between /b-t/ and /b-ɸ/ (z = -2.854, p < .01). This means that the OCP-labial effect can be generalized in a local condition, and also that Lyman's Law (*/b-b/) is active. We also found significant differences between /b-b/ and /b-m/ (z = 659.9, p < .001) and between /b-m/ and /b-ɸ/ (z = -4.739, p < .001), which suggests that the OCP-labial effect on rendaku works gradiently. In other words, the more similar the two consonants are, the more unlikely the application of rendaku is to apply. However, there was no significant difference between /b-t/ and /b-w/ (z = -0.332, *n.s*). The reason why /w/ does not participate in the OCP-labial effect will be discussed in Section 3.6.

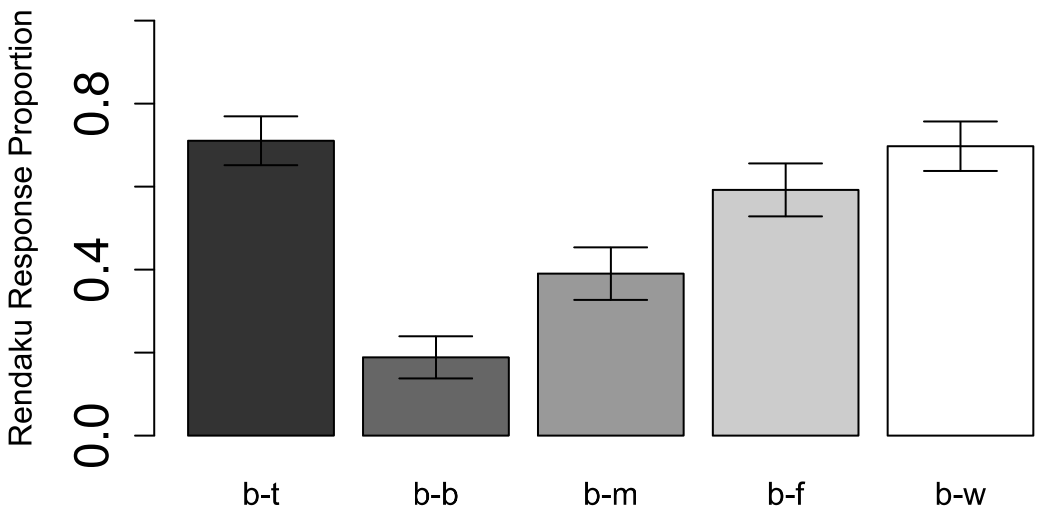

Figure 1: Results of Rendaku Applicability (Local Condition)

As shown in Figure 2, in the non-local condition, the ratio of the rendaku application is as follows: /b-C-t/ = 0.715; /b-C-b/ = 0.39; /b-C-m/ = 0.671; /b-C-ɸ/ (represented as b-C-f) = 0.719; /b-C-w/ = 0.588. There were no significant differences between /b-C-t/ and /b-C-m/ (z = -0.737, *n.s*) and between /b-C-t/ and /b-C-f/ (z = -0.006, *n.s*), which suggests that the OCP-labial effect does not show up when a non-labial consonant intervenes between the two labial consonants. In other words, the OCP-labial constraints on rendaku do not exhibit a long-distance effect.

We found a significant difference between /b-C-t/ and /b-C-b/ (z = -4.722, $p < .001$), which we believe comes not from the OCP-labial effect but from Lyman's Law effect. This result is consistent with the results of some previous experiments (Kawahara 2012; Vance 1980).[9] There was also a slightly significant difference between /b-C-t/ and /b-C-w/ (z = -2.001, $p < .05$), which will be left for discussion in Section 3.6.

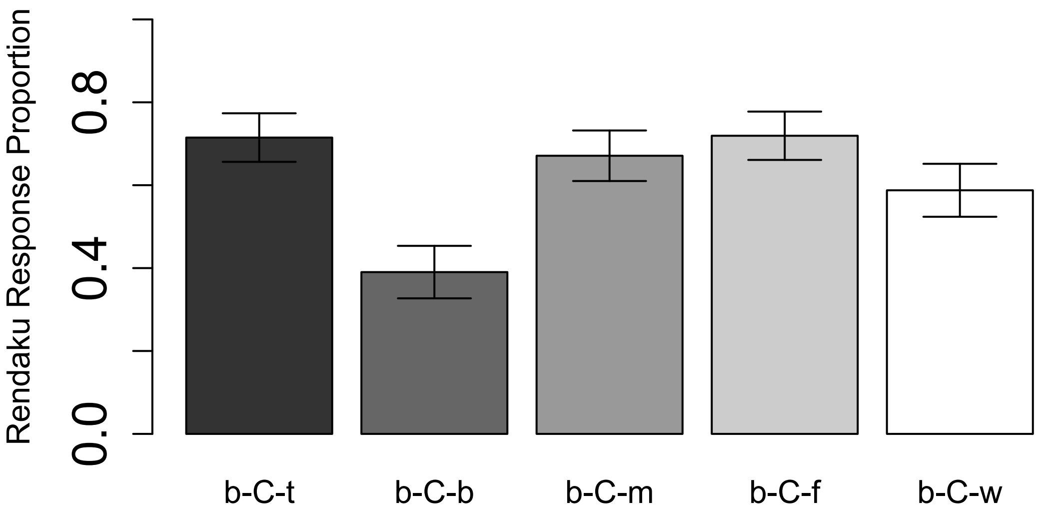

Figure 2: Results of Rendaku Applicability (Non-local Condition)

To summarize, the results of the current experiment show that 1) the OCP-labial effect can be generalized in Japanese rendaku; 2) that it works locally rather than non-locally; and 3) that the OCP-labial blocking effect is gradient.

3.6 Discussion

[9] There was also a significant difference between /b-C-b/ and /b-b/ (z = 4.101, $p < .001$), which provides evidence for the locality effect of Lyman's Law. This result is consistent with the results in Vance (1980) and Ihara et al. (2009) (cf. Kawahara 2012; Kawahara & Sano 2014b).

We saw in Section 2 that real native words with labials /m, ɸ/ rarely undergo rendaku. Nevertheless, the current experiment showed that the OCP-labial effect is gradient in a local condition. This result is not consistent with the studies that show that the statistical pattern of the lexicon matches with the applicability of phonological processes (e.g., Becker et al. 2011; Ernestus & Baayen 2003; Gouskova & Becker 2013; Hayes & Londe 2006; Hayes et al. 2009; Zuraw 2000), but with the studies on OCP effects that demonstrate that the more similar two consonants are, the more strongly they are disfavored (e.g., Berent & Shimron 2003; Berent et al. 2004; Buckley 1997; Frisch et al. 2004; Greenberg 1950; Pierrehumbert 1993). In the current case, similarity can be defined in terms of Place features and continuancy. For Place features, [labial] is specified for /b, m, ɸ/. For continuancy, /b, m/ have a negative value (i.e., [-continuant]) while [ɸ] have a positive one (i.e., [+continuant]). From the perspective of the feature specification, /b/ is more similar to /m/ than to /ɸ/. We can thus account for why /m/ displayed a stronger blocking effect on rendaku than /ɸ/ did.

Continuancy plays an essential role in accounting for the gradient OCP effect on Japanese rendaku. This can also be found in other languages. Padgett (1991, 1992) argues that continuancy (i.e. stricture) and sonorancy, as well as place features, are the key to account for consonant cooccurrence restrictions in Russian. For example, the root *sad-* 'sit' is well-formed because the value of [continuant] differs between /s/ and /d/, but the root *s'oz-* is ill-formed because the two consonants share [+continuant]. See also Coetzee & Pater (2008), who make a similar assumption in the analysis of Muna and Arabic.

As for /w/, further explanation needs to be added. Although introductory textbooks describe the Japanese glide /w/ as labial (e.g., Kubozono 2015; Shibatani 1990), as velar (e.g., Tsujimura 2014), or as labiovelar (e.g., Labrune 2012), there is no clear evidence for place features of the Japanese /w/. The results of the current experiment showed that /w/ did not participate in the local OCP-labial effect, which may imply that it is *phonologically* non-labial. The experiment also revealed that the applicability of rendaku was slightly reduced in the /b-C-w/ condition. We conjecture that this result does not come from the OCP-labial effect in question because it probably only works locally, but there seems to be no factor that could block rendaku in the /b-C-w/ condition. This should be examined in future research.

There is a growing body of experiments demonstrating that phonological behavior shows a gradient aspect (e.g., Albright 2009; Berent & Simron 1997; Hayes 2000; Hayes & Londe 2006; Kawahara 2011a, 2011b, 2013a, 2013b; McPherson & Hayes 2016; Zuraw 2000). However, a generative grammar, like standard Optimality Theory (Prince & Smolensky 1993/2004), cannot account for it in a straightforward way, as it holds a two-way distinction between “grammatical/ acceptable” and “ungrammatical/ unacceptable” (see Coetzee & Pater 2008; Coetzee 2008; 2009; Ernestus 2011 for discussion). To model the gradient applicability of rendaku, I will provide an HG analysis in the next section.

4. Harmonic Grammar analysis

4.1 Harmonic Grammar analysis

HG (e.g., Legendre et al. 1990, 2006; Pater 2009, 2016; Potts et al. 2010) is a constraint-based theory in which constraints are numerically weighted. Harmony maximization is calculated in terms of the sum of C_i*w_i, where the candidate's violation of each constraint (C_i) is multiplied by the weight (w_i). In the current HG analysis, constraints assign negative scores to candidates, and thus the candidate that has the value closest to zero will be optimal.

Since the results of the current experiment showed that the OCP-labial effect works locally, the current HG analysis focuses on the OCP-labial effect in a local condition. We use six constraints in (4). Following the OT analysis of Japanese rendaku (Itô & Mester 2003), I use REALIZE MORPHEME (RM), IDENT (voice), and OCP (-son, voice), the last of which is known as Lyman's Law. In the current case, RM can be interpreted as requiring the initial consonant of the second member to become voiced. I also use IDENT (Place), which penalizes the /h/→[b] alternation, as the OCP violation in question can also be seen in the alternation.[10] To account for the gradient aspect of OCP-labial effect on rendaku, I propose two constraints of OCP-labial: OCP (labial) and OCP (labial, -continuant). Note that the latter is violated only when /b/ is followed by /m/.

(4) Constraint Set

REALIZE MORPHEME	Every morpheme in the input has a nonnull phonological exponent in the output (Itô & Mester 2003:87).
IDENT (voice)	A voiced/voiceless consonant must have a correspondent with the same value between input and output.

[10] An anonymous reviewer pointed out the possibility of IDENT (continuant). In the current case, we are not certain whether the /h/→[b] alternation involves IDENT (Place), IDENT (continuant), or both. The current HG analysis assumes only IDENT (Place).

IDENT (Place)	A consonant must have a correspondent with the same value of Place features between input and output.
OCP (-son, voice)	Violated if the second element of compounds contains two and more voiced obstruents. (Bans /b…b/.)
OCP (labial, -continuant)	Violated if /b/ is immediately followed by /m/ in the second element of compounds.
OCP (labial)	Violated if /b/ is immediately followed by /m, ɸ/ in the second element of compounds.

The constraint violation profile for each candidate relevant to the current experiment is presented in (5). The non-rendaku forms presented in (5) violate RM, since they do not undergo rendaku. The rendaku forms violate IDENT (voice) and IDENT (Place), since voiceless glottal (or placeless) /h/ becomes voiced labial /b/. For OCP violation, the rendaku form /b…ɸ/ violates OCP (labial), and the rendaku form /b-m/ violates not only OCP (labial) but also OCP (labial, -continuant). The rendaku form /b-b/ violates these two constraints as well as OCP (-son, voice). Since all constraints but RM can block rendaku, they can show a gang effect, in which lower-weighted constraints overcome a constraint with a higher weight (e.g., Jäger & Rosenbach 2006; Pater 2009, 2016; Potts et al. 2010).[11]

[11] In a gang effect of HG, one constraint can in principle gang up with another. Japanese loanword devoicing (e.g., Nishimura 2001, 2006; Kawahara 2006, 2015b) is an example of the ganging-up of two markedness constraints: a constraint on voiced geminates and OCP-voice (Pater 2009, 2016; see also Kawahara 2015b). Another pattern is a cumulativity of violations of faithfulness constraints: violations of two faithfulness constraints tradeoff for a violation of a third faithfulness constraint (e.g., Farris-Trimble 2008). The current paper provided us with evidence for the ganging-up of markedness (OCP-labial) and faithfulness (IDENT) constraints.

(5) Constraint Violation Profile under Harmonic Grammar

	REALIZE MORPHEME	IDENT (voice)	IDENT (Place)	OCP (-son, voi)	OCP (lab, -cont)	OCP (lab)
/+ h-t/						
… h-t	-1(No RM)					
… b-t		-1(h → b)	-1(h → b)			
/+ h-ɸ/						
… h-ɸ	-1(No RM)					
… b-ɸ		-1(h → b)	-1(h → b)			-1(b…ɸ)
/+ h-m/						
… h-m	-1(No RM)					
… b-m		-1(h → b)	-1(h → b)		-1(b…m)	-1(b…m)
/+ h-b/						
… h-b	-1(No RM)					
… b-b		-1(h → b)	-1(h → b)	-1(b…b)	-1(b…b)	-1(b…b)

4.2 A MaxEnt Analysis

The current paper determines weights for each constraint by using a MaxEnt model (e.g., Colavin et al. 2014; Goldwater & Johnson 2003; Hayes & Wilson 2008; Hayes et al. 2009; Hayes et al. 2012; Hayes 2017; Jäger & Rosenbach 2006; Martin 2011; McPherson & Hayes 2016; Shih 2016; Shih & Inkelas 2016; Tanaka 2017; Wilson 2006; Zhang et al. 2011; Zuraw & Hayes to appear), which is a probabilistic model used in a wide range of fields, including computational linguistics (e.g., Goldwater & Johnson 2003; Jäger 2007). Based on the data of frequency and experimental results, it calculates probabilities of output forms, thus accounting for differences in free variation and gradiency of acceptability judgment. In the present case, the results of the experiment are used as frequency data.

The procedure for calculating probabilities is as follows. First, like HG, for each candidate, harmonic score (H-score) is calculated in terms of the sum of C_i*w_i, where the candidate's violation of each constraint (C_i) is multiplied by the weight (w_i). Second, we calculate $e^{-(\text{H-score})}$, where e is the base of natural logarithms. Third, we sum $e^{-(\text{H-score})}$ of all candidates produced by GEN to the input. Finally, P(x), the predicted probability of candidate x, is its $e^{-(\text{H-score})}$ divided by the sum of $e^{-(\text{H-score})}$ of all candidates. With constraint violation profile and frequency data, We can leave the procedure to the maxent software created by Hayes, Wilson, and George

(2009).[12]

The results of calculating weights are shown in Table 3: RM (*w* = 6.97); IDENT (voice) (*w* = 3.03); IDENT (Place) (*w* = 3.03); OCP (-son, voice) (*w* = 1); OCP (labial, -continuant) (*w* = 0.82); OCP (labial) (*w* = 0.53). These weights for each constraint are used to calculate probabilities of output forms. Table 4 compares the experimental data and the rate of occurrences with predicted probabilities by MaxEnt analysis, which shows that the raw rate and the predicted probabilities are compatible with each other.

Constraints	Weight
REALIZE MORPHEME	6.97
IDENT (voice)	3.03
IDENT (Place)	3.03
OCP (-son, voice)	1.0
OCP (labial, -continuant)	0.82
OCP (labial)	0.53

Table 3: Constraints and Weights by MaxEnt

input	output	Experiment Results	Predicted Probabilities
/h-t/	/h-t/	0.289	0.289
	/b-t/	0.711	0.711
/h-ɸ/	/h-ɸ/	0.408	0.408
	/b-ɸ/	0.592	0.592
/h-m/	/h-m/	0.61	0.61
	/b-m/	0.39	0.39
/h-b/	/h-b/	0.801	0.81
	/b-b/	0.189	0.19

Table 4: Experimental Data and Predicted Probabilities

[12] In this implementation, the initial weight of all constraints is set across the board. However, the initial state in HG may require further discussion. See Jesney & Tessier (2011) for a proposal of the plasticity of faithfulness constraints in Noisy HG.

The current HG Tableau is presented in (6). In the current experiment, we saw the gradient aspect that, for example, /m/ showed a stronger blocking effect on the applicability of rendaku than /ɸ/. How can this be accounted for? The current HG analysis assumes that harmonic scores of candidates can be used to model acceptability judgments (e.g., Coetzee & Pater 2008, Sect 3.2 – 3.3). The idea here is that, provided that the optimal candidate of each candidate set has the same violation profile, the lower a candidate's harmonic-score is *across* candidate sets, the more unlikely it is to be considered acceptable (cf. Keller 2006). To compare the harmonic score of each rendaku forms, /b-t/ is the most harmonic, /b-b/ is the least, and /b-m/ and /b-ɸ/ are intermediate, from which it follows that /b-b/ is less harmonic than /b-m/ and /b-ɸ/, and also that /b-m/ is less harmonic than /b-ɸ/ and /b-t/.

(6) Harmonic Grammar Tableau

	RM	IDENT (voi)	IDENT (Pl)	OCP (-son, voi)	OCP (lab, -cont)	OCP (lab)	H-score	$e^{-(\text{H-score})}$	P
weight	6.97	3.03	3.03	1	0.82	0.53		($*10^{-4}$)	
/+ h-t/									
… h-t	-1						6.97	9.4	0.287
… b-t		-1	-1				6.06	23.3	0.713
/+ h-ɸ/									
… h-ɸ	-1						6.97	9.4	0.405
… b-ɸ		-1	-1			-1	6.59	13.7	0.594
/+ h-m/									
… h-m	-1						6.97	9.4	0.608
… b-m		-1	-1		-1	-1	7.41	6.1	0.392
/+ h-b/									
… h-b	-1						6.97	9.4	0.808
… b-b		-1	-1	-1	-1	-1	8.41	2.2	0.192

5. General discussion

The current experiment led us to admit that rendaku involves the OCP-labial constraints. As seen in Section 2, Lyman's Law is a well-known constraint that prevents rendaku from being applied. However, there are two differences between Lyman's Law and OCP-labial constraints. First, while Lyman's Law does work even on an underlying level, OCP-labial constraints do not. Since Lyman's Law prohibits voiced obstruents from occurring twice or more in a word, it can play a role in accounting for the fact that, in Japanese, there are few monomorphemic words with two voiced obstruents. For example, we have *ɸuta* 'lid,' *ɸuda* 'tag,' *buta* 'pig,' but not *buda* (Itô & Mester 1995:819), the last one of which contains two voiced obstruents. Instead, we find native and loan monomorphemic words with consecutive labial consonants (e.g., *mame* 'bean'; *mimi* 'ear'; *momo* 'peach'; *ɸumi* 'letter'; *mama* 'Mom'; *memo* 'memo'; *obama* 'Obama'; *maɸuraa* 'muffler')[13], which means that OCP-labial constraints do not work on an underlying level. Second, while Lyman's Law works even in the long distance, OCP-labial constraints exhibited its effects only in the local condition. Lyman's Law blocks rendaku if the resulting form will contain two or more voiced obstruents (e.g., *kuro* 'black' + *sabi* 'rust' → *kuro-sabi*/ **kuro-zabi* 'black rust'; *oo* 'big' + *sawagi* 'fuss' → *oo-sawagi*/**oo-zawagi* 'big fuss'), but as the current experiment demonstrated, OCP-labial constraints seem not to be active when there is a consonant intervening between initial /h/ and the third labial consonant.

In light of the hallmarks of OCP-labial constraints mentioned above, OCP-labial constraints are similar to Identity Avoidance in Japanese, which bans sequential identical mora. Though there are a number of Japanese words with sequential identical mora (e.g., *mimi* 'ear'; *momo* 'peach'; *nana* 'seven'; *sasa* 'bamboo'; *haha* 'mother'), Kawahara & Sano's (2014a, 2014b, 2016) wug-test studies show that rendaku is triggered or blocked if the resulting sequential mora across the boundary is identical (see Kawahara & Sano 2016 for a related discussion).[14] The features that Identity Avoidance and OCP-labial constraints possess in common are that, in creating novel combination, identical or featurally similar consonants are disallowed from occurring in succession. However, the issue to be resolved is why such

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[13] Historically, voiced obstruents used to appear intervocalically as prenasalized stops (e.g., [^{m}b, ^{n}d, ^{ŋ}g, ^{n}z]) (e.g., Frellesvig 2010:35; Yamane-Tanaka 2005; see also Labrune 2012). It would be interesting if the OCP-labial effect originally comes from the OCP-nasal effect (e.g., *[^{m}b…m]). However, this is less probable, as we do not find other OCP-place effects such as OCP-coronal or OCP-dorsal that would come from *[^{n}d…n] or *[^{ŋ}g…n]; these sequences indicate rendaku application (e.g., *hon* 'book' + *tana* 'shelf' → *hon-dana* 'book shelf'; *ke* 'hair' + *kani* 'crab' → *ke-gani* 'hair crab').

[14] Irwin (2014) rejects this hypothesis based on statistical evidence.

constraints do not affect words in the lexicon. Presumably, they could work only in the word formation or (morpho)phonological processes that produce novel combinations, as (some) speakers are more "resistant to novel combination" than to lexicalized words or conventionalized phrases. This topic will be tackled in future research.

6. Conclusion

The current paper reported on the wug-test study that examined the OCP-labial effect on Japanese rendaku. The results showed that 1) it can be generalized in rendaku; 2) that it works only in a local condition; and 3) that the applicability of rendaku is gradient according to the following labial consonant: The more similar two consonants are, the more strongly they are disfavored. This gradient effect can be captured in the HG framework. In the current analysis, OCP-labial constraints gang up with IDENT to overcome RM with higher weight.

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To be added.

Competing Interests

The author declares that he has no competing interests.

Appendix

Survey of native words (* words that undergo rendaku)

bimoraic	/h…m/ (n = 9)	hama 'beach'; hame 'fitting'; hamo 'conger pike'; hima 'time to spare'; hime 'princess'; himo 'string'; *humi 'trample; letter'; hema 'blunder'; *home 'praise'
	/h…ɸ/ (n = 0)	-
	/h…w/ (n = 0)	-
trimoraic	/h…m...C/ (n = 31)	e.g., hamaki 'cigarette'; hamono 'knife'; himono 'dried fish'; humoto 'bottom'; homare 'honor'
	/h…ɸ…C/ (n = 0)	-
	/h…w…C/ (n = 1)	hiwari 'schedule'
trimoraic	/h…C…m/ (n = 38)	e.g., *hakama 'hakama'; hasama 'interval' *hasami 'scissors'; *husuma 'husuma'; hanawa 'wreath'
	/h…C...ɸ/ (n = 0)	-
	/h…C…w/ (n = 0)	-

*Actual Examples

asi	'foot'	+	humi	'trample'	→	asi-**b**umi 'halt'
e	'foot'	+	humi	'trample'	→	e-**b**umi 'stepping on a picture'
koi	'love'	+	humi	'letter'	→	koi-**b**umi 'love letter'
ya	'arrow'	+	humi	'letter'	→	ya-**b**umi 'letter affixed to an arrow'
beta	'over-'	+	home	'praise'	→	beta-**b**ome "overpraise"

sentaku	'washing'	+	hasami	'scissors'	→	sentaku-**b**asami
ita	'board'	+	hasami	'scissors'	→	ita-**b**asami

kawa	'leather'	+	hakama	'hakama'	→	kawa-**b**akama
siro	'white'	+	hakama	'hakama'	→	siro-**b**akama
gin	'silver'	+	husuma	'husuma'	→	gin-**b**usuma
kiri	'fog'	+	husuma	'husuma'	→	kiri-**b**usuma

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