Journal of Japanese Linguistics 25 (2009)

Effects of first-element phonological-length and etymological-type features on sequential voicing (*rendaku*) of second elements*

Katsuo Tamaoka, Mutsuko Ihara, Tadao Murata, and Hyunjung Lim
Nagoya University, St. Marianna University School of Medicine, Kyushu Institute of Technology, Yamaguchi Prefectural University

Using a questionnaire comprising voiced-or-voiceless choices by native Japanese speakers, the present study investigated the influence of the phonological-length and etymological-type of first elements on sequential voicing or *rendaku* of the initial consonant of the CVCVCV-structured *Wago*-like nonwords /hukari/ and /hasuri/. Experiment 1 revealed an overall trend where voicing determination (i.e., voicing power) from one mora to three morae was observed to have a descending order of strength. After controlling for printed-frequency, script type, and free-standing single kanji, Experiment 2 showed that single-mora *Wago* first-elements had stronger voicing power on second elements than those consisting of two and three morae. Considering the combined results of Experiments 1 and 2, it may be concluded that a single CV mora *Wago* of first elements had greater voicing power than two or three morae cases. Experiment 3 demonstrated that first element *Wago* exerted stronger voicing power upon second elements than either *Kango* or *Gairaigo*, which exerted equally influence. However, after controlling for printed-frequency and script type, Experiment 4 indicated that the first element *Wago* and *Kango* resulted in *rendaku* on second elements with greater voicing power than *Gairaigo*. Thus, the present study demonstrated that both the first-element phonological-length and etymological-type appear to influence *rendaku* of the voiceless consonants of second elements.

Areas of interest: *rendaku*, psycholinguistics

1. Purpose of the present study

In the Japanese language, when two words or morphemes, such as the first element of /naga(i)/ ('long') and the second element of /hanasi/ ('talk') are compounded, the initial consonant of the second element /h/ is voiced to /b/, as in /naga-banasi/ ('a long talk').[1] This is called *sequential voicing* in English, or *rendaku* in Japanese (hereafter, *rendaku*). As this example indicates, *rendaku* refers to the voicing of the initial voiceless obstruent of a second element in the case of two-element nominal compounds (Vance, 1979). However, *rendaku* does not occur with consistency. For example, when the above example of /naga/ is combined with /sikaku/ ('square'), the first consonant /s/ of the second element is not voiced as /z/, but rather remains voiceless in being sounded as /naga-sikaku/ ('rectangle'). Similarly, in the case that the first element /ko/ ('small') is combined with the second element /tori/ ('bird'), the initial consonant /t/ of the second element 'bird' is not voiced to be /d/, but remains /ko-tori/ ('a small bird'). In contrast, when the same morpheme /ko/ is combined with /hako/ ('box'), the initial consonant /h/ is voiced as /b/ to produce /ko-bako/ ('a small box'). As these examples indicate, it seems difficult to identify consistent rules for *rendaku*.

* The authors would like to express their sincere gratitude to the JJL Editor-in-Chief, Mineharu Nakayama, and two anonymous reviewers for their insightful and constructive comments to complete the present paper.

[1] Through historical change, the modern Japanese /h/ was derived from /p/ via a voiceless bilabial fricative. In *rendaku*, /h/ is voiced to be /b/. The phoneme /h/ behaves in Japanese like an obstruent whose voiced counterpart is /b/. See Hashimoto (1950), Komatsu (1981) and Vance (1979), among others, for further details of the transition of /h/.

Although various studies (e.g., Haraguchi, 2001; Itô & Mester, 1986, 2003; McCawley, 1968; Otsu, 1980; Rosen, 2001; Vance, 1979, 1987, 2006) have investigated *rendaku* extensively, the effect of individual differences on *rendaku* have not received much attention. Itô and Mester (2003) claimed that "the class membership of the first member plays no role in the realization of linking morphemes" (p. 147). They provided three different examples of etymological types for first-elements: *ume-dayori* (/ume/ + /tayori/) for a *Wago* (words of Japanese origin) first element (they used the term *Yamato* for words of Japanese origin), *kankyoo-banasi* (/kankyoo/ + /hanasi/) for a *Kango* (Sino-Japanese) first element, and *supootsu-dayori* (/supootu/ + /tayori/) for a *Gairaigo* (foreign Japanese) first element (see more details in Itô & Mester, 2003, p.147). Based on these examples, they concluded that characteristics of first elements have no influence on the *rendaku* of a second element. However, 'a spirit distilled from barley' can be pronounced as either *mugi-shoochuu* /mugi-syoRtyuR/ ('R' refers to a long vowel) with the voiceless sound or *mugi-joochuu* /mugi-zyoRtyuR/ with voiced sound depending upon the preference of the speaker. Likewise, native Japanese speakers pronounce a combination of *kome* ('rice') and *shoochuu* as either *kome-shoochuu* /kome-syoRtyuR/ or *kome-joochuu* /kome-zyoRtyuR/ ('a spirit distilled from rice'). Tamaoka and Ikeda (2008, in press) indicated that the *rendaku* frequency of the second element *shoochuu* depended on whether the first ingredient was *mugi* ('buckwheat'), *kome* ('rice') or *imo* ('sweet potato'). It is quite possible that both first and second elements could be important factors in determining the occurrence of *rendaku*, which fluctuates even with the same words among native Japanese speakers. As observed in these examples, because individual preferences are likely to affect the determination of *rendaku*, linguistic arguments become somewhat more complex when psychological aspects of individual differences become implicated.

The present study investigated how the nature of first-element phonological-length and etymological-type affects *rendaku* (i.e., '*rendaku* determination') for second elements in compound words from the perspective of individual preferences.

2. Questionnaire-based approach to individual differences influencing *rendaku*

The present research used a questionnaire-based approach to *rendaku* as was initiated by Vance (1979). Instead of searching for existing *rendaku* examples, Vance used a data-driven questionnaire to determine individuals' determinations of *rendaku* in compound words. Using 14 native Japanese speakers with the Tokyo *Yamanote* accent, Vance asked participants to determine whether or not 645 compound words exhibited *rendaku*. This study showed clear differences in *rendaku* frequencies among compound words. However, Vance did not employ a statistical approach to classify these compound words, such as a cluster or correspondence analysis. Furthermore, a statistical investigation into individual differences or preferences determining *rendaku* cannot be practically run with such a small number of participants.

Taking this into consideration, Murata's (1984) questionnaire-based approach expanded the sample size and employed carefully selected and elaborated test items exhibiting specific examples of *rendaku*. He covered a wide range of *rendaku* occurrences such as effects of first elements on second elements (e.g., comparing the non-words *ko-hasuri* and *naga-hasuri*), *rendaku* relation to Lyman's Law (e.g., comparing the non-words *naga-tagi* and *naga-haragi*), and its variations related to the first element etymological types (e.g., comparing *Wago*, *Kango*, and *Gairaigo* using *naga-hashigo* 'long ladder', *tetusei-hashigo* 'steel ladder', and *sutenresu-hashigo* 'stainless ladder' as respective examples and right-/left-branched sub-compounds (e.g., comparing [*ko* [*sakura hako*]] 'small cherry-box' and [*ko-sakura* [*hako*]] 'small-cherry box'). Following an interval of 21 years, Ihara and Murata (2006) repeated the same questions. The details of the related Murata (1984), and Ihara and Murata (2006) experiments are explained in the following section of this study.

In the present study, adapting the questionnaire-based approach used in previous studies (Murata, 1984; Ihara & Murata, 2006; Vance, 1979), we focused upon the influence of first elements in causing *rendaku* of second elements by using nonexistent compounds with a large number of participants.

3. Evidence of first-element influence on *rendaku*

The present study focused on the phonological length, the final /N/, and the etymological types of first elements. /N/ denotes the so-called 'moraic nasal', which is also known as one of the three special morae (i.e., nasal /N/, geminate consonant /Q/ and long vowel /R/). The influence of the final /N/ is relevant to both the phonological length and the etymological type of first elements as considered in this section.

The etymological types of modern Japanese are generally categorized into *Wago*, *Kango*, and *Gairaigo*. Little attention has been focused on the effects of the phonological length of first elements on *rendaku* so far. Some existing research refers to a correlation between the final nasal of first elements and *rendaku* in *Kango*. Using a corpus of *Kango* developed from the texts of 8th century Buddhist sutras, Okumura (1952) counted 123 'new *rendaku*' (*shin-daku*[2]) cases after the nasal /N/, as in /keN-g̲o/ ('solid'), to suggest that *rendaku* in *Kango* has a very strong tendency to occur after a nasal.[3] Soon thereafter, Okumura (1955) expanded on his earlier data-based findings to offer a more theoretical proposal that *rendaku* is most likely to occur where the end of first elements is nasal. Later, Okumura (1964) examined the relationship between *rendaku* and first element final nasals in modern Japanese using verbs comprising a *Kango* morpheme (verb stem) plus *suru* ('to do'), as in *yuu-suru* ('to possess') and *sei-suru* ('to suppress'). Okumura reported that the voiced form *–zuru*, as in *mei-zuru* ('to order') and *sin-zuru* ('to believe') is more likely to occur with *Kango* morphemes having a final nasal than in cases where the *Kango* morpheme ends otherwise.

Likewise, Endo (1966) examined approximately 600 *Kango* examples of *rendaku* found in a Japanese-Portuguese dictionary containing about 30,000 words published in Japan in the early 17th century. Among the 600 examples, 95 cases fluctuated (co-existent cases with and without *rendaku*); of this number, 52 were *Kango* and 43 *Wago*. Furthermore, excluding *Kango* words which sound differently in *Kan-on* and *Go-on* (adopted pronunciations from different Chinese dialects), Endo (1966) analyzed 44 *Kango* and 43 *Wago*. Counting *rendaku* cases classified by the final sounds of first elements among these cases, Endo (1966) found 25 *rendaku* cases out of 44 (56.82%) in *Kango* voiced after the nasal /N/, such as /aN-z̲yuR/ ('inside hermitage'). Among 43 *Wago rendaku* cases, Endo (1966) counted only a single case /oN-d̲ori/ ('a rooster') which showed *rendaku* after the nasal.

It should be noted that *Wago* are likely to show a great variety of *rendaku* forms. Therefore, the final nasal of first elements is a strong candidate for causing *rendaku* among *Kango* compounds. Yet, with respect to both first element phonological length and etymological type, it is still an open question whether or not the final /N/ of a first element causes *rendaku* to occur in a second element in modern Japanese.

---

[2] A sinograph which originally includes voiced consonants adopted from the Chinese language is called *hon-daku* 'original voicing'. When the voicing occurs after a sinograph is adopted into the Japanese language, it is called *shin-daku* 'new voicing'. Irwin (2005) provided an explanation with examples: The sinograph 地 ('ground') is probably read as both /ti/ and /zi/; /ti/ adapted from *kan-on* and /zi/ adapted from *go-on*. Thus, this sinograph can be voiceless 台地 /dai-t̲i/ ('plateau') and voiced 路地 /ro-z̲i/ ('alley'). However, since these two sounds of the sinograph exist in original Chinese readings, they are called *hon-daku*. On the other hand, the sinograph 国 /koku/ ('country') has only one prescribed reading. This sinograph may undergo sequential voicing when the second element is a Sino-Japanese binom (two-kanji compounds) as in 東国 /toR-g̲oku/ ('the east country'). Since the reading /g̲oku/ is not the original Chinese reading, this is called *shin-daku*.

[3] On the other hand, Vance (1979) implies that there are no psychologically real tendencies such as those Okumura (1955) mentions. Vance (1979) conducted a second experiment primarily designed for the purpose of examining the psychological status of Lyman's Law. In a part of this experiment relating to the final /N/, however, the first element used in the test examples was limited to only one kind of Sino-Japanese, *ningen* ('human being').

It has been well-documented and is uncontroversial that the etymological type of second elements affects *rendaku* in compound words. *Rendaku* occurs more frequently in cases that the second element is *Wago*, whereas it less frequently or hardly ever occurs where the second element is *Kango* or *Gairaigo*. Vance (1979) and Itô and Mester (2003) note that the first element has no effect on *rendaku* in nominal compounds based on observations of hybrid compounds exhibiting combinations of first and second elements of each different etymological type. However, results of experiments conducted by Murata (1984) and Ihara and Murata (2006) suggest that the etymological type of first elements also affect *rendaku*.

Lyman's Law (for details see Itô & Mester, 2003; Kubozono, 1999, 2005; Kubozono & Ota, 1998; Otsu, 1980) stipulates that the existence of a voiced obstruent in a second element prohibits *rendaku*. /Nawa-basigo/ ('rope ladder') is a well-known exception to Lyman's Law (Kindaichi, 1987). Murata (1984) and Ihara and Murata (2006) conducted experiments connecting three first elements (one of each etymological type) to a pair of second elements (i.e., /hasigo/, /basigo/), and asked participants to choose one of the paired choices (e.g., /X-hasigo/, /X-basigo/, with 'X' representing any first element). In both studies, a series of Chi-square tests for goodness-of-fit revealed that a significantly larger proportion of participants selected the voiced case X-basigo when the first element was *Wago*, while the voiced proportion was significantly smaller than the voiceless proportion (X-hasigo) when the first element was *Kango* or *Gairaigo*.

For instance, when the first element is the *Wago* /naga/ ('long'), a Chi-square test of goodness-of-fit showed that a significantly larger proportion of participants selected the voiced case /naga-basigo/ ('long ladder') both in Murata (1984) and in Ihara and Murata (2006).[4] In the case of the *Kango* /tetusei/ ('iron-made') for the first element, the number of participants selecting the voiced proportion /tetusei-basigo/ ('an iron-made ladder') was significantly smaller than those who chose the voiceless proportion (/tetusei-hasigo/) both in Murata (1984) and in Ihara and Murata (2006).[5] Also, when combined with the *Gairaigo* /sutenresu/ ('stainless-steel-made'), a Chi-square test of goodness-of-fit revealed that a significantly larger proportion of participants selected the voiceless case /sutenresu-hasigo/ ('a stainless-steel-made ladder') both in Murata (1984) and in Ihara and Murata (2006). Thus, examining the proportion of choices between voiceless and voiced cases, the result when combining /hasigo/ with *Wago* showed a reversed direction, compared to cases in which /hasigo/ was combined with *Kango* or *Gairaigo*.

Many phonologists (e.g., Haraguchi, 2001; Itô & Mester, 2003; Kurisu, 2006) have focused extensively on the nature of second elements for analyzing *rendaku* in the case of two-element compound words. However, as described above, Ihara and Murata (2006) clearly demonstrate a shift in percentage of choice between voiced and voiceless initial obstruents of second elements when the first element is altered from *Wago* to *Kango* and *Gairaigo*. This contrasting result implies that first elements actually affect voicing of initial obstruents of second elements.

The present study focused on the influence of first elements on *rendaku*. Using a questionnaire-based approach similar to that taken in the previous studies of Murata (1984) and Ihara and Murata (2006), we investigated the effects of first-element phonological-length. The length of the first element has not been empirically investigated from the perspective of individual differences. Thus, Experiments 1 and 2 tentatively hypothesized that the shorter the phonological construction of the first

[4] It is astonishing that the percentage of participants who chose voiceless cases increased 28.36% between 1984 and 2005 [$\chi^2(1)=56.883$, $p<.001$; a Chi-square test of independence]. The exceptional case of /hasigo/ has therefore become increasingly preferred as voiceless over the course of 21 years; these results are in close conformance to the tenets of Lyman's Law.

[5] Furthermore, this proportional change of 8.73% significantly increased over 21 years [$\chi^2(1)=3.994$, $p<.05$; a Chi-square test of independence]. This also reveals a tendency in close conformance to the tenets of Lyman's Law.

element, the more frequently *rendaku* will occur. Experiments 3 and 4 investigated whether first-element etymological-type and final /N/ affects *rendaku* in compound words. Although Itô and Mester (2003) suggested null effects of first element etymological types on *rendaku* of second elements, the present study hypothesized different *rendaku* frequencies varying by etymological type in the descending order of *Wago*, *Kango* and *Gairaigo*.

4. Experiment 1: Effects of first-element phonological-length

Experiment 1 examined whether or not phonological-length of first elements affects voicing of second elements in two-element compound words. Keeping second element CVCVCV-structured nonwords which sound like real words of Japanese origin (i.e., *Wago*), the phonological length of first elements was varied from one to three morae.

4.1. Participants

A total of 224 undergraduate students (75 females, 149 males) at Hiroshima Shudo University participated in Experiment 1. All were native Japanese speakers born and raised in the same accent area of the Chugoku Region of Japan. A majority of the 184 participants (82.1%) were from Hiroshima Prefecture (26 participants or 11.6% from Yamaguchi, 8 participants or 3.6% from Shimane, 5 participants or 2.2% from Okayama, 1 participant or 0.4% from Tottori). Ages ranged from 18 to 23 years, with the average age being 18 years and 6 months on the day of Experiment 1.

4.2. Stimulus items

As shown in Table 1, three real words were chosen in each of the three phonological categories of CV-, CVCV- and CVCVCV-structure as first elements. Two CVCVCV-structured *Wago*-like nonwords, /hukari/ and /hasuri/, were chosen as second elements to measure sequential voicing. This manipulation was intended to keep the second element semantically neutral, negating semantic influence. Each question consisted of two choices as the first element combined with a voiced or voiceless initial consonant as the second element. The first elements in Experiment 1 were selected from actual existing items with *rendaku* of the second element. For example, the first element of /te-gokoro/ (‘to use one’s discretion’), /te/ (‘hand’), is a frequently-used element in compound words which undergo *rendaku*. The word /te/ was presented as a single kanji character 手, with the katakana symbol テ presented at the top of the kanji character (*furigana*) to ensure that participants semantically understood the meaning as ‘hand’, was combined with the second element, the nonword /hukari/, presented in three katakana symbols フカリ. All participants were asked to choose between voiceless /te-hukari/ and voiced /te-bukari/ options as presented below.

- □ 手（テ）・フカリ (voiceless)
- □ 手（テ）・ブカリ (voiced)

Likewise, the same first element /te/ was combined with another nonword ‘ハスリ’ /hasuri/ as the second element, with participants being asked to choose from either voiceless /te-hasuri/ or voiced /te-basuri/ as presented below.

- □ 手（テ）・ハスリ (voiceless)
- □ 手（テ）・バスリ (voiced)

In this way, three *Wago* words used as the first element in each of CV-, CVCV- and CVCVCV-structured phonological categories were combined with the two nonwords /hukari/ and /hasuri/ as second elements (3 real words as first element × 2 nonwords as second element × 3 phonological categories = 18 questions), so that a total of 18 voiced-and-voiceless paired questions were used for Experiment 1. These voiced-and-voiceless paired questions were randomly presented to participants in a single questionnaire. All pairs were randomly mixed on the questionnaire form.

The semantic aspect of first elements might influence the results of *rendaku* frequencies. However, *Wago* stimulus items are strongly associated with their semantics, so that meanings attached to a kanji script are unavoidable. Romanization of stimulus items might be one possible means to avoid this. However, since many homophonic words exist in Japanese, Romanized presentation creates multiple meanings, which may only serve to confuse participants when determining *rendaku*. Similarly, since the items of the first element in Experiment 1 were selected from parts of already existing compounds exhibiting *rendaku*, word/morpheme types were not exactly matched across three phonological-length conditions. For example, the single kanji /sakura/ ('cherry tree') is frequently used as a single word, whereas the single kanji /ko/ ('small') is often used as a part of compound words such as /ko-bito/ ('a dwarf'), or /ko-buta/ ('a piglet'). All of these possible factors were considered in the next experiment (Experiment 2). According to the lexical database produced by Amano and Kondo (2000, and 2003 for the CD-ROM version) from editions of the *Asahi Newspaper* printed from 1985 to 1998, containing a total type frequency of 341,771 morphemic units and a total token frequency of 287,792,797 morphemic units, all items of the first element in Experiment 1 were familiar, being token frequencies as a kanji unit used for common nouns (proper nouns excluded for counting) 5,413 times for /ko/, 50,737 times for /te/ and 981 times for /to/, 38,708 times for /simo/ ('below'), 152,161 times for /naka/ ('middle'), 10,189 times for /naga/, 3,198 times for /sakura/, 46,168 times for /tikara/ ('power') and 3003 times for /maturi/ ('festival').

4.3. Procedure

All participants responded to 18 sets of voiced-or-voiceless choices in the questionnaire. Participants were given sufficient time to complete all questions at their own pace.

4.4. Item-by-item analyses and results

As shown in Table 1, compound words were examined by a series of Chi-square tests of goodness-of-fit setting an expected value of equal frequency (50% random chance) for choice of a voiceless or voiced initial consonant in the second element. Since three real words constructed with one to three morae as first elements were repeatedly combined with a nonword second element to ask participants whether or not they should be voiced, this manipulation resulted in nine repetitions (3 real words × 3 mora types = 9 times). Thus, to avoid an 'error of the first kind' (Type I Error), rejecting the null hypothesis when it is actually true, the Bonferrorni adjustment for the number of tests being carried out was used to examine the level of significance. In Experiment 1, the 0.05 level of significance was divided by the number of repetitions, resulting in 0.0056. Thus, the significance level was set at 0.001.

As shown in the results of Chi-square tests of goodness-of-fit reported in Table 1, 15 out of the 18 cases were more frequently selected as having a voiced initial consonant in second elements of compound words. The results of all nine CV-, CVCV- and CVCVCV-structured *Wago* first-element compound words combined with the second element /hukari/ indicated that voiced compounds were selected more frequently than voiceless compounds. The one exception was the first element was /sakura/ which was still selected at the random chance level. Likewise, in the case of the second element /hasuri/, all results, with two exceptions of the first element /sakura/ and /maturi/, also showed the same trend of being selected as a voiced compound. The case of /sakura/ showed a random frequency of *rendaku* in both nonword

Table 1. Choice of voiceless or voiced second-element nonwords *hukari* and *hasuri* as influenced by the number of morae in first elements of Japanese-originated words

First elements		Second element *hukari*			Chi-square test of goodness-of-fit	Second element *hasuri*			Chi-square test of goodness-of-fit	Chi-square test of independence
Script	Sound	Voiceless	Voiced	Rate		Voiceless	Voiced	Rate		
(1) One mora CV-structured words										
小 (コ)	/ko/	33	191	85.27%	$\chi^2(1)=111.446$, $p<.001$	40	184	82.14%	$\chi^2(1)=92.571$, $p<.001$	$\chi^2(1)=0.802$, *n.s.*
手 (テ)	/te/	30	193	86.55%	$\chi^2(1)=119.144$, $p<.001$	53	171	76.34%	$\chi^2(1)=62.161$, $p<.001$	$\chi^2(1)=7.701$, *n.s.*
戸 (ト)	/to/	49	175	78.13%	$\chi^2(1)=70.875$, $p<.001$	43	181	80.80%	$\chi^2(1)=85.018$, $p<.001$	$\chi^2(1)=0.492$, *n.s.*
(2) Two morae CVCV-structured words										
下 (シモ)	/simo/	69	155	69.20%	$\chi^2(1)=33.018$, $p<.001$	73	150	67.26%	$\chi^2(1)=26.587$, $p<.001$	$\chi^2(1)=0.192$, *n.s.*
中 (ナカ)	/naka/	46	178	79.46%	$\chi^2(1)=77.786$, $p<.001$	68	156	69.64%	$\chi^2(1)=34.571$, $p<.001$	$\chi^2(1)=5.695$, *n.s.*
長 (ナガ)	/naga/	62	161	72.20%	$\chi^2(1)=43.951$, $p<.001$	71	153	68.30%	$\chi^2(1)=30.018$, $p<.001$	$\chi^2(1)=0.811$, *n.s.*
(3) Three morae CVCVCV-structured words										
桜 (サクラ)	/sakura/	87	136	60.99%	$\chi^2(1)=10.767$, *n.s.*	105	117	52.70%	$\chi^2(1)=0.649$, *n.s.*	$\chi^2(1)=3.112$, *n.s.*
力 (チカラ)	/tikara/	53	171	76.34%	$\chi^2(1)=62.161$, $p<.001$	83	140	62.78%	$\chi^2(1)=14.570$, $p<.001$	$\chi^2(1)=9.705$, *n.s.*
祭り (マツリ)	/maturi/	75	149	66.52%	$\chi^2(1)=24.446$, $p<.001$	92	131	58.74%	$\chi^2(1)=6.821$, *n.s.*	$\chi^2(1)=2.885$, *n.s.*

Note 1 : Due to missing values, the number of participants for first element stimulus varies from 222 to 224.

Note 2 : 'Rate' in Table 1 refers to voiced rate out of total responses to each stimulus (50% is random).

Note 3 : In accordance with Bonferrorni's adjustment, a significance level of 0.001 was used, since the first element is repeated nine times for each nonword.

cases of /hukari/ and /hasuri/, while /maturi/ showed only a random frequency when combined with /hasuri/.

Furthermore, to compare voiced frequency between /hukari/ and /hasuri/, a series of Chi-square tests of equality for two sets of frequencies (Chi-square tests of independence) were carried out for each of the first nine elements. None of the set-cases of the first element was significant, suggesting that the ratios of voiceless and voiced frequencies of all first-element real words combined with second elements were equal between /hukari/ and /hasuri/. Thus, although the present study tested only two nonword cases, a general trend of higher voiced frequencies over voiceless frequencies is likely to be observed in the majority of compound words (only three out of 18 compound words were randomly voiced) regardless of the second elements.

Table 2. Voicing power of mora difference in the first *Wago* elements on second elements

First *Wago* elements	Phonological structure	Number of morae	Voicing power	
			M	SD
小 /ko/, 手 /te/, 戸 /to/	CV	1	4.88	1.43
下 /simo/, 中 /naka/, 長 /naga/	CVCV	2	4.24	1.55
桜 /sakura/, 力 /tikara/, 祭り /maturi/	CVCVCV	3	3.78	1.68
Results of pair-wise simple contrast comparisons			1 > 2 > 3	

Note: Participants=217. M=Mean. SD=Standard deviation.

4.5 Analysis and results for examining effects of first-element phonological-length

In each CV-, CVCV- and CVCVCV-structured phonological-length category (6 compound words each), voiced items were recorded as 1 and voiceless items as 0, so that the *voicing power* of a first element on a second element was defined by a single variable ranging from 0 to 6. The means and standard deviations are shown in Table 2. The means of one CV mora to three CVCVCV morae in the first element seem to suggest a tendency for voiced frequencies to decrease as the number of morae increases, as the data shows a mean of 4.88 for a CV mora, 4.24 for CVCV morae and 3.78 for CVCVCV morae (3 being considered random). A one-way analysis of variance (3 phonological-lengths of one to three morae) with repeated measures (the analysis being conducted with 217 participants due to 7 missing values) indicated that the main effect of phonological-length was significant [$F(2,432)=54.938$, $p<.001$]. Pair-wise simple contrast comparisons indicated that (1) the single CV mora *Wago* as first element significantly differed from the two CVCV morae *Wago* [$F(1,216)=46.684$, $p<.001$], (2) the single mora *Wago* significantly differed from the three CVCVCV morae *Wago* [$F(1,216)=102.65$, $p<.001$], and (3) two CVCV morae *Wago* significantly differed from the three CVCVCV morae *Wago* [$F(1,216)=16.701$, $p<.001$].

4.6. Findings of Experiment 1

Experiment 1 depicted a clear trend in which the greater the number of morae became, the lesser the voicing power was observed (i.e., 1 mora > 2 morae > 3 morae), supporting the hypothesized effect of the phonological length of first elements on *rendaku* of second elements.

5. Experiment 2: Effects of first-element phonological-length when controlling frequencies of first elements

First elements in Experiment 1 were selected from existing compound words exhibiting *rendaku*. Due to the limited selection of possible candidates among *rendaku* compound words, printed-frequencies and script types were not controlled. Therefore, Experiment 2 repeated the process of Experiment 1 with different participants in order to examine the effects of phonological-length using the stimuli of the first element controlling for these characteristics, although the selected elements in Experiment 2 do not necessarily exhibit *rendaku* in actual language use.

5.1. Participants

A total of 118 undergraduate students (50 females, 65 males, and 3 unidentified) enrolled at universities in the Kanto Region in Japan participated in Experiment 2. All participants were native Japanese speakers. Among them, 82 participants (69.49%) were born and raised in the same accent area of the Kanto Region, 33 were from Tokyo, 20 from Kanagawa, 10 from Chiba, 9 from Saitama, 6 from Ibaraki, 3 from Gunma and 1 was from Tochigi. The remaining 36 participants came from various regions in Japan including 6 from Shizuoka, 5 from Fukushima, 2 from Niigata and 2 from Akita. Ages ranged from 18 to 32 years, with the average age being 21 years and 2 months on the day of Experiment 2. Analyses were carried out depending on the number of participants who responded to each item while making accommodations for missing values. None of these participants took part in any other experiments of the present study.

5.2. Stimulus items

Real *Wago* words, which can stand freely as a single kanji, were chosen as first elements in each of the three phonological categories of one to three morae. Only free-standing single-kanji words were selected in order to keep their meanings contained as a noun unit. For example, the CV-structured item /ha/ is used as a single kanji meaning ‘tooth’. Likewise, the CVCVCV-structured item /minato/ is used as a single kanji meaning ‘harbor’. As shown in Table 3, three sets of one to three morae were matched by printed-frequencies, counted as a kanji unit which are used as general nouns in the *Asahi Newspaper* (Amano & Kondo, 2000, 2003). With this approach, the uncontrolled factors of script type (i.e., a single kanji), printed-frequency, lexical category and, to some degree, semantic influence were controlled in Experiment 2. However, unlike Experiment 1, the items used for the first elements in Experiment 2 were not necessarily found in existing compound words exhibiting *rendaku*.

Table 3. Stimuli of the first *Wago* elements

First elements	Sound	Phonological structure	Number of morae	Printed frequency
蚊	/ka/	CV	1	515
柿	/kaki/	CVCV	2	442
刀	/katana/	CVCVCV	3	588
歯	/ha/	CV	1	3,659
雲	/kumo/	CVCV	2	3,891
港	/minato/	CVCVCV	3	3,170
火	/hi/	CV	1	11,441
山	/yama/	SVCV	2	11,469
柱	/hasira/	CVCVCV	3	15,248

Table 4. Choice of voiceless or voiced second-element nonwords *hukari* and *hasuri* as influenced by the number of morae in first elements of Japanese origin words

First elements		Second element *hukari*			Chi-square test of goodness-of-fit	Second element *hasuri*			Chi-square test of goodness-of-fit	Chi-square test of independence
Script	Sound	Voiceless	Voiced	Rate		Voiceless	Voiced	Rate		
(1) One mora CV-structured words										
蚊 (カ)	/ka/	19	99	83.90%	$\chi^2(1)=54.237$, $p<.001$	11	107	90.68%	$\chi^2(1)=78.102$, $p<.001$	$\chi^2(1)=2.444$, *n.s.*
歯 (ハ)	/ha/	8	110	93.22%	$\chi^2(1)=88.169$, $p<.001$	5	113	95.76%	$\chi^2(1)=98.847$, $p<.001$	$\chi^2(1)=0.733$, *n.s.*
火 (ヒ)	/hi/	7	111	94.07%	$\chi^2(1)=91.661$, $p<.001$	6	112	94.92%	$\chi^2(1)=95.220.$, $p<.001$	$\chi^2(1)=0.081$, *n.s.*
(2) Two morae CVCV-structured words										
柿 (カキ)	/kaki/	34	84	71.19%	$\chi^2(1)=21.186$, $p<.001$	28	90	76.27%	$\chi^2(1)=32.576$, $p<.001$	$\chi^2(1)=0.788$, *n.s.*
雲 (クモ)	/kumo/	33	85	72.03%	$\chi^2(1)=22.915$, $p<.001$	40	78	66.10%	$\chi^2(1)=12.237$, $p<.001$	$\chi^2(1)=0.972$, *n.s.*
山 (ヤマ)	/yama/	23	95	80.51%	$\chi^2(1)=43.932$, $p<.001$	47	71	60.17%	$\chi^2(1)=4.881$, *n.s.*	$\chi^2(1)=11.698$, $p<.001$
(3) Three morae CVCVCV-structured words										
刀 (カタナ)	/katana/	29	89	75.42%	$\chi^2(1)=30.508$, $p<.001$	39	79	66.95%	$\chi^2(1)=13.559$, $p<.001$	$\chi^2(1)=2.066$, *n.s.*
港 (ミナト)	/minato/	35	83	70.34%	$\chi^2(1)=19.525$, $p<.001$	42	76	64.41%	$\chi^2(1)=9.797$, *n.s.*	$\chi^2(1)=0.945$, *n.s.*
柱 (ハシラ)	/hasira/	28	90	76.27%	$\chi^2(1)=32.576$, $p<.001$	22	96	81.36%	$\chi^2(1)=46.407$, $p<.001$	$\chi^2(1)=0.914$, *n.s.*

Note 1 : The number of participants was 118.

Note 2 : 'Rate' in Table 4 refers to voiced rate out of total responses to each stimulus (50% is random).

Note 3 : In accordance with Bonferrorni's adjustment, a significance level of 0.001 was used, since the first element is repeated nine times for each nonword.

5.3. Procedure

As in Experiment 1, all participants responded to 18 sets of voiceless-or-voiced choices in the questionnaire. Participants were given sufficient time to complete all questions at their own pace.

5.4. Item-by-item analyses and results

As shown in Table 4, each compound word was examined using a Chi-square test of goodness-of-fit, setting an expected value of equal frequency (50% random chance) for choice of a voiceless or voiced initial consonant in the second element. As in Experiment 1, the significance level was set at 0.001 according to the Bonferrorni adjustment. As shown in the results of Chi-square tests of goodness-of-fit reported in Table 4, second elements of compound words were more frequently selected as having a voiced initial consonant in 16 out of the 18 cases. The results of all nine CV-, CVCV- and CVCVCV-structured *Wago* first-element compound words combined with the second element /hukari/ indicated that voiced compounds were selected more frequently than voiceless compounds. In the case of the second element /hasuri/, all results with two exceptions in which the first element /yama/ ('mountain') and /minato/ appeared, also showed the trend of being selected as a voiced compound.

As in Experiment 1, ratios of voiced and voiceless frequencies between /hukari/ and /hasuri/ were examined using a series of Chi-square tests of equality (Chi-square test of independence) for each pair of the first nine elements. With the exception of the single case /yama/, none of the paired-cases of the first element showed significance, suggesting that ratios of voiceless and voiced frequencies of all first-element real words combined with second elements were almost equal between /hukari/ and /hasuri/. Thus, a general tendency of higher voiced frequencies over voiceless frequencies would likely be observed in the majority of compound words regardless of the second elements.

Table 5. Voicing power of mora difference in the first *Wago* elements on second elements

First *Wago* elements	Phonological structure	Number of morae	Voicing power	
			M	SD
蚊 /ka/, 歯 /ha/, 火 /hi/	CV	1	5.53	1.02
柿 /kaki/, 雲 /kumo/, 山 /yama/	CVCV	2	4.26	1.60
刀 /katana/, 港 /minato/, 柱 /hasira/	CVCVCV	3	4.35	1.66
Results of pair-wise simple contrast comparisons			1 > 2 = 3	

Note 1: Participants=118. M=Mean. SD=Standard deviation.

Note 2: /yama/ has a SVCV phonological structure, but it was included as one of the CVCV items.

5.5. Analysis and results for examining effects of first-element phonological-length

As in Experiment 1, voiced items were recorded as 1 and voiceless items as 0 in each CV-, CVCV- and CVCVCV-structured phonological-length category (6 compound words each), so that the *voicing power* of a first element on a second element was defined by a single variable ranging from 0 to 6. The means and standard deviations are shown in Table 5. It should be noted that single mora *Wago* indicated a very high voicing power of 5.53 out of the maximum of 6.00. A one-way analysis of variance (3 phonological-lengths of one to three morae) with repeated measures conducted with 118 participants indicated that the main effect of phonological-length was significant [$F(2,234)=58.787$, $p<.001$]. Pair-wise simple contrast comparisons indicated that (1) the single CV mora *Wago* as first element

significantly differed from the two CVCV morae *Wago* [$F(1,117)=90.642$, $p<.001$], and (2) the single mora *Wago* significantly differed from the three CVCVCV morae *Wago* [$F(1,117)=72.769$, $p<.001$], however (3) two CVCV morae *Wago* did not significantly differ from the three CVCVCV morae *Wago* [$F(1,117)=0.401$, *n.s.*].

5.6. Findings of Experiment 2

Unlike the results of Experiment 1 (see Table 2), Experiment 2 (see Table 5) did not show a difference in voicing power between two and three morae first elements. Since the first element in Experiment 2 wer real words, controlled for printed-frequency, script type, and free-standing single kanji, putting both results of Experiments 1 and 2 together, it would be safe to conclude that a single CV mora *Wago* first element had greater voicing power than two or three morae cases, even though all three phonological structures showed strong voicing power over the initial consonants of the second elements.

6. Experiment 3: Effects of first-element etymological-type

Experiment 3 examined whether or not the etymological-type of the first elements affected the voicing of the second elements. As with Experiments 1 and 2, the first element was controlled by varying CVN- and CVCV-structured etymological types of *Wago*, *Kango* and *Gairaigo* while holding the second element as CVCVCV-structured *Wago*-like nonwords,. All these first element stimuli were selected from real words/morphemes actually existing as compound words exhibiting *rendaku*.

6.1. Participants

The participants were the same as in Experiment 1, but different from those in Experiments 2 and 4.

6.2. Stimulus items

First elements were chosen according to three different etymological-types, *Wago, Kango*[6] and *Gairaigo*, exhibiting phonological structures of CVN and CVCV. As shown in Table 6, three different words for each etymological-type were combined with two *Wago*-like nonwords /hukari/ and /hasuri/, for both CVN and CVCV phonological structures. Thus, the stimulus items (questions) comprised 36 voiceless-and-voiced pairs (3 etymological types × 3 different words × 2 phonological structures × 2 second-element nonwords = 36 total questions). The same three CVCV-structured *Wago* first elements /simo/, /naka/ and /naga/ of Experiment 1 were also used in the data analyses of Experiment 3.

6.3. Procedure

The same as Experiments 1 and 2.

6.4. Item-by-item analyses and results

As shown in Table 6, each compound word was examined using a series of Chi-square tests of goodness-of-fit setting an expected value of equal frequency (50% random chance) for choice of a voiceless or voiced initial consonant of second elements. As in Experiments 1 and 2, to avoid a Type I Error, a level of significance 0.001 was used in accordance with the Bonferrorni adjustment.

---

[6] Many Japanese *kanji* have more than one way of being pronounced or read, which is called *on*. This *on* is classified into different kinds, based upon the time period in which the kanji were borrowed from Chinese. These are *go'on, kan'on, to'on*, and so on. Chronologically *go'on* is the oldest and is said to exhibit *rendaku* systematically, while *kan'on* was adopted later than *go'on* and rarely exhibits *rendaku*. In Experiment 3 we conducted for the present paper, we limited Sino-Japanese items to those with *kan'on*.

Table 6. Choice of voiceless or voiced second-element nonwords *hukari* and *hasuri* as influenced by first elements of CVN- and CVCV-structured etymological-type

First elements		Etymological-type	Second element *hukari*			Chi-square test of goodness-of-fit	Second element *hasuri*			Chi-square test of goodness-of-fit	Chi-square test of independence
Script	Sound		Voiceless	Voiced	Rate		Voiceless	Voiced	Rate		
(1) CVN-structured words											
どん	doN	Wago	33	191	85.27%	$\chi^2(1)=111.446$, $p<.001$	64	160	71.43%	$\chi^2(1)=41.143$, $p<.001$	$\chi^2(1)=12.645$, $p<.001$
踏ん (フん)	huN	Wago	37	187	83.48%	$\chi^2(1)=100.446$, $p<.001$	35	188	84.30%	$\chi^2(1)=104.973$, $p<.001$	$\chi^2(1)=0.056$, *n.s.*
飲ん (ノん)	noN	Wago	44	179	80.27%	$\chi^2(1)=81.726$, $p<.001$	61	162	72.65%	$\chi^2(1)=45.744$, $p<.001$	$\chi^2(1)=3.600$, *n.s.*
寒 (カン)	kaN	Kango	43	181	80.80%	$\chi^2(1)=85.018$, $p<.001$	44	179	80.27%	$\chi^2(1)=81.726$, $p<.001$	$\chi^2(1)=0.020$, *n.s.*
新 (シン)	siN	Kango	63	161	71.88%	$\chi^2(1)=42.875$, $p<.001$	64	160	71.43%	$\chi^2(1)=41.143$, $p<.001$	$\chi^2(1)=0.011$, *n.s.*
本 (ホン)	hoN	Kango	38	186	83.04%	$\chi^2(1)=97.786$, $p<.001$	49	173	77.93%	$\chi^2(1)=69.261$, $p<.001$	$\chi^2(1)=1.853$, *n.s.*
サン	saN	Gairaigo	77	146	65.47%	$\chi^2(1)=21.350$, $p<.001$	61	163	72.77%	$\chi^2(1)=46.446$, $p<.001$	$\chi^2(1)=2.788$, *n.s.*
ノン	noN	Gairaigo	72	152	67.86%	$\chi^2(1)=28.571$, $p<.001$	76	147	65.92%	$\chi^2(1)=22.605$, $p<.001$	$\chi^2(1)=0.189$, *n.s.*
ワン	waN	Gairaigo	71	153	68.30%	$\chi^2(1)=30.018$, $p<.001$	76	148	66.07%	$\chi^2(1)=23.143$, $p<.001$	$\chi^2(1)=0.253$, *n.s.*
(2) CVCV-structured words											
The following CVCV-structured Wago were the same as Experiment 1 - 下(シモ), 中(ナカ) and 長(ナガ)											
国 (コク)	koku	Kango	75	148	66.37%	$\chi^2(1)=23.897$, $p<.001$	80	144	64.29%	$\chi^2(1)=18.286$, $p<.001$	$\chi^2(1)=0.214$, *n.s.*
力 (リキ)	riki	Kango	61	162	72.65%	$\chi^2(1)=45.744$, $p<.001$	71	153	68.30%	$\chi^2(1)=30.018$, $p<.001$	$\chi^2(1)=1.012$, *n.s.*
仏 (ブツ)	butu	Kango	120	104	46.43%	$\chi^2(1)=1.143$, *n.s.*	118	105	47.09%	$\chi^2(1)=0.643$, *n.s*	$\chi^2(1)=0.019$, *n.s.*
ミニ	mini	Gairaigo	93	131	58.48%	$\chi^2(1)=6.446$, *n.s.*	73	151	67.41%	$\chi^2(1)=27.161$, $p<.001$	$\chi^2(1)=3.828$, *n.s.*
プロ	puro	Gairaigo	73	150	67.26%	$\chi^2(1)=26.587$, $p<.001$	80	144	64.29%	$\chi^2(1)=18.286$, $p<.001$	$\chi^2(1)=0.440$, *n.s.*
ポリ	pori	Gairaigo	65	159	70.98%	$\chi^2(1)=39.446$, $p<.001$	54	169	75.78%	$\chi^2(1)=59.305$, $p<.001$	$\chi^2(1)=1.319$, *n.s.*

Note 1: Due to missing values, the number of participants for first element stimulus varies from 222 to 224.

Note 2: 'Rate' in Table 3 refers to voiced rate out of total responses to each stimulus (50% is random).

Note 3: In accordance with Bonferrorni's adjustment, a significance level of 0.001 was used, since the first element is repeated nine times for each nonword in both CVN- and CVCV-structure.

The results of all 18 compound words of the CVN- and CVCV-structured *Wago*, *Kango* and *Gairaigo* first elements combined with the second element /hukari/, with the two exceptions of the CVCV-structured *Kango* /butu/ meaning 'Buddhism' and the *Gairaigo* /mini/ meaning 'mini', indicating that voiced compounds were selected more often than voiceless compounds (see details of Chi-square values in Table 6). This trend was also apparent in the case of the second element /hasuri/, with the single exception of /butu/. All results for both /hukari/ and /hasuri/ showed that compound words with initial consonants in second elements were more frequently selected as voiced in 33 out of the 36 compound word choices.

To compare ratios of voiced and voiceless frequencies between /hukari/ and /hasuri/, Chi-square tests of equality (Chi-square tests of independence) were carried out for each set-case of the 18 first elements. Only the case of the *Wago* first element /doN/ was significant, suggesting that the ratio of voiced and voiceless frequencies of this first element when combined with the second element /hukari/ were dissimilar to the same word combined with /hasuri/. In other words, when compounded with /doN/, /hukari/ was voiced as /bukari/ more frequently than was /hasuri/ voiced as /basuri/. Yet, the overall trend of higher voiced frequencies over voiceless frequencies remained consistent in the majority of the 33 compound words.

6.5. Analysis and results for examining effects of first-element etymological-type

Voicing power was calculated using the same method as Experiments 1 and 2. The means and standard deviations of voicing power in Experiment 3 are reported in Table 7. A 3 (etymological-type) × 2 (phonological structure) two-way analysis of variance (analysis was carried out with 213 participants due to 11 missing values) with repeated measures was conducted on the voicing power of first elements upon second elements for both of the nonwords /hukari/ and /hasuri/. Main effects were significant in variables of phonological structure [$F(1,212)=68.125$, $p<.001$] and etymological-type [$F(2,424)=14.815$, $p<.001$].

In addition, the interaction of these two variables was significant [$F(2,424)=24.521$, $p<.001$]. The CVN-structured first elements ($M=4.50$) influenced voicing of the second elements /hukari/ and /hasuri/ more than those of CVCV structure ($M=4.00$). As for etymological differences, pair-wise simple contrast comparisons revealed that *Wago* first elements ($M=4.52$) had significantly stronger voicing power on second elements than either *Kango* ($M=4.16$) [$F(1,212)=19.250$, $p<.001$] or *Gairaigo* ($M=4.07$) first elements [$F(1,212)=24.103$, $p<.001$], but no difference was found between *Kango* and *Gairaigo* [$F(1,212)=1.003$, *n.s.*].

Since the interaction of phonological structure and etymological-type was significant, pair-wise simple contrast comparisons were conducted on every combination of the six categories (see means of voicing power in Table 7). Detailed results are shown in Table 6 as '<u>A B</u> > <u>C D F</u> > <u>E</u>' (underlined categories indicate similarity). In sum, all results of pair-wise comparisons indicate that: (1) The first element words of CVN-structured *Wago* and *Kango* had similar influence on the voicing of second elements, but differed from the rest, (2) the first element CVN- and CVCV-structured *Gairaigo* and CVCV-structured *Wago* had similar voicing power but differed from the rest, and (3) the CVCV-structured *Kango* showed the weakest voicing power and was different from all others.[7]

[7] *F*-values of pair-wise simple contrast comparisons were as follows: $F(1,212)=1.540$, $p=.216$, *n.s.* for A and B, $F(1,212)=43.879$, $p<.001$ for A and C, $F(1,212)=22.797$, $p<.001$ for A and D, $F(1,212)=103.664$, $p<.001$ for A and E, $F(1,212)=37.452$, $p<.001$ for A and F, $F(1,212)=25.947$, $p<.001$ for B and C, $F(1,212)=10.483$, $p<.001$ for B and D, $F(1,212)=94.688$, $p<.001$ for B and E, $F(1,212)=26.022$, $p<.001$ for B and F, $F(1,212)=2.788$, $p=.096$, *n.s.* for C and D, $F(1,212)=14.017$, $p<.001$ for C and E, $F(1,212)=0.002$, $p=.961$, *n.s.* for C and F, $F(1,212)=27.382$, $p<.001$ for D and E, $F(1,212)=2.569$, $p=.110$, *n.s.* for D and F, and $F(1,212)=12.450$, $p=<.001$ for E and F.

Table 7. Voicing power of CVN- and CVCV-structured etymological-type on second elements

Etymological-type		Phonological structure	Stimulus words	Voicing Power	
				M	SD
(1) CVN structure					
A	Wago	CVN	踏ん(huN), 飲ん(noN), どん(doN)	4.78	1.53
B	Kango	CVN	寒(kaN), 新(siN), 本(hoN)	4.65	1.56
C	Gairaigo	CVN	サン(saN), ノン(noN), ワン(waN)	4.06	1.72
(2) CVCV structure					
D	Wago	CVCV	下(simo), 中(naka), 長(naga)	4.27	1.53
E	Kango	CVCV	国(koku), 力(riki), 仏(butu)	3.66	1.65
F	Gairaigo	CVCV	ミニ(mini), プロ(puro), ポリ(pori)	4.07	1.74
Results of pair-wise simple contrast comparisons				Wago > Kango = Gairaigo	
				A B > C D F > E	

Note: Participants=213. M=Mean. SD=Standard deviation.

6.6. Findings of Experiment 3

Experiment 3 indicated that *Wago* first elements showed stronger voicing power on second elements than those of either *Kango* or *Gairaigo* as indicated by 'Wago > Kango = Gairaigo'. In addition, CVN-structured first elements had greater voicing power than those of CVCV-structure. Pair-wise comparisons further suggested that CVN-structured *Wago* and *Kango* showed greater voicing power than others.

7. Experiment 4: Effects of first-element etymological-type by controlling frequencies of first elements

The first elements in Experiment 3 were selected from existing compound words exhibiting *rendaku*. Due to the limited selection of possible candidates among *rendaku* compound words, printed-frequencies and script types were not controlled. Therefore, Experiment 4 repeated the process of Experiment 3 with different participants in order to examine the effects of etymological categories. This was done using the stimuli of first elements, controlling for their printed frequencies and limiting them to a CVCVC-structure (CVSVCV and CVØVCV were considered CVCVCV for this experiment). The selected elements in Experiment 4 do not necessarily exhibit *rendaku* in actual language use.

7.1. Participants

A total of 136 undergraduate students (35 females, 101 males) enrolled at universities in the Kanto Region in Japan participated in Experiment 4. All participants were native Japanese speakers, and were born and raised in the same accent area of the Kanto Region, with 41 being from Tokyo, 41 from Kanagawa, 25 from Saitama, 14 from Chiba, 7 from Ibaraki, 6 from Gunma and 2 coming from Tochigi. Ages ranged from 18 to 21 years, with the average age being 18 years and 9 months on the day of Experiment 4. Analyses were carried out depending on the number of participants who responded to each item, and

varying according to missing values. None of these participants were involved in any of the other experiments of the present study.

7.2. Stimulus items

Real *Wago, Kango and Gairaigo* words consisting of three morae were chosen as first elements. As shown in Table 8, three etymological types were matched by printed-frequencies counted of use in the *Asahi Newspaper* (Amano & Kondo, 2000, 2003). All of these items were chosen from commonly-used nouns which have clear meanings. However, unlike in Experiment 3, the items used for first elements in Experiment 4 were not necessarily found in existing compound words exhibiting *rendaku*.

Table 8. Stimuli of the first three-mora elements

First elements	Etymological type	Sound	Phonological structure	Printed frequency
机	*Wago*	/tukue/	CVCVØV	4,086
袋	*Wago*	/hukuro/	CVCVCV	5,924
畑	*Wago*	/hatake/	CVCVCV	5,965
帰宅	*Kango*	/kitaku/	CVCVCV	5,172
麻薬	*Kango*	/mayaku/	CVSVCV	5,213
摩擦	*Kango*	/masatu/	CVCVCV	5,676
テニス	*Gairaigo*	/tenisu/	CVCVCV	4,099
ピアノ	*Gairaigo*	/piano/	CVØVCV	5,447
リスク	*Gairaigo*	/kisuku/	CVCVCV	4,511

7.3. Procedure

All participants responded to 18 sets of voiced-or-voiceless choices in the questionnaire. Participants were given sufficient time to complete all questions at their own pace.

7.4. Item-by-item analyses and results

As shown in Table 9, each compound word was examined by a series of Chi-square tests of goodness-of-fit set at an expected value of equal frequency (50% random chance) for choice of a voiceless or voiced initial consonant in a second element. As in Experiments 1 to 3, the significance level was set at 0.001 due to the Bonferrorni adjustment. As shown in the results of Chi-square tests of goodness-of-fit reported in Table 9, all first *Wago* elements compounded with either /hukari/ or /hasuri/ were more frequently selected as having a voiced initial consonant in second elements of compound words. Likewise, all first *Kango* elements compounded with either /hukari/ or /hasuri/ were more frequently selected as having a voiced initial consonant in second elements with the exception of the single combined case of /mayaku/ (‘illegal drug’) and /hasuri/. For the first *Gairaigo* elements, however, three of the six combinations showed random selection of either voiced or voiceless. When counting compound cases exhibiting *rendaku*, the first *Gairaigo* elements appeared to be less frequently voiced than those of *Wago* and *Kango*.

As in Experiments 1 to 3, a series of Chi-square tests of equality (Chi-square tests of independence) for two sets of frequencies was carried out on ratios of voiceless and voiced frequencies between /hukari/ and /hasuri/ for each of the first nine elements. None of the paired-cases of the first elements showed significance, suggesting that ratios of voiceless and voiced frequencies of all first-element real words

Table 9. Choice of voiceless or voiced second-element nonwords *hukari* and *hasuri* as influenced by first elements of three-mora etymological-type

First elements	Etymological-type	Second element *hukari*			Chi-square test of goodness-of-fit	Second element *hasuri*			Chi-square test of goodness-of-fit	Chi-square test of independence
Script		Voiceless	Voiced	Rate		Voiceless	Voiced	Rate		
机	Wago	42	94	69.12%	$\chi^2(1)=19.882$, $p<.001$	45	91	66.91%	$\chi^2(1)=15.559$, $p<.001$	$\chi^2(1)=0.152$, *n.s.*
袋	Wago	30	106	77.94%	$\chi^2(1)=42.471$, $p<.001$	45	91	66.91%	$\chi^2(1)=15.559$, $p<.001$	$\chi^2(1)=4.142$, *n.s.*
畑	Wago	34	102	75.00%	$\chi^2(1)=34.000$, $p<.001$	43	93	68.38%	$\chi^2(1)=18.382$, $p<.001$	$\chi^2(1)=1.467$, *n.s.*
帰宅	Kango	36	99	73.33%	$\chi^2(1)=29.400$, $p<.001$	44	92	67.65%	$\chi^2(1)=16.941$, $p<.001$	$\chi^2(1)=1.053$, *n.s.*
麻薬	Kango	41	95	69.85%	$\chi^2(1)=21.441$, $p<.001$	53	83	61.03%	$\chi^2(1)=6.618$, *n.s.*	$\chi^2(1)=2.341$, *n.s.*
摩擦	Kango	46	89	65.93%	$\chi^2(1)=13.696$, $p<.001$	40	96	70.59%	$\chi^2(1)=23.059$, $p<.001$	$\chi^2(1)=0.680$, *n.s.*
テニス	Gairaigo	42	94	69.12%	$\chi^2(1)=19.882$, $p<.001$	49	87	63.97%	$\chi^2(1)=10.618$, $p<.001$	$\chi^2(1)=0.809$, *n.s.*
ピアノ	Gairaigo	67	69	50.74%	$\chi^2(1)=0.029$, *n.s.*	51	85	62.50%	$\chi^2(1)=8.500$, *n.s.*	$\chi^2(1)=3.832$, *n.s.*
リスク	Gairaigo	54	82	60.29%	$\chi^2(1)=5.765$, *n.s.*	44	92	67.65%	$\chi^2(1)=16.941$, $p<.001$	$\chi^2(1)=1.595$, *n.s.*

Note 1: Due to missing values, the number of participants for first element stimulus varies from 135 to 136.

Note 2: 'Rate' in Table 3 refers to voiced rate out of total responses to each stimulus (50% is random).

Note 3: In accordance with Bonferrorni's adjustment, a significant level of 0.001 was used, since the first element is repeated nine times for each nonword.

combined with the second elements showed no distinction between /hukari/ and /hasuri/. Thus, a general tendency is likely to appear in the majority of compound words regardless of second elements.

7.5. Analysis and results for examining effects of the first-element etymological-type

As in Experiments 1 to 3, voiced items were recorded as 1 and voiceless items as 0 in each etymological category (6 compound words each), so that the *voicing power* of a first element on a second element was defined by a single variable ranging from 0 to 6. The means and standard deviations are shown in Table 10. A one-way analysis of variance with repeated measures of the three etymological-types conducted with 136 participants indicated that the main effect of etymological-type was significant [$F(2,270)=6.147$, $p<.01$]. Pair-wise simple contrast comparisons indicated that (1) the first *Wago* element significantly differed in voicing power from the first *Gairaigo* elements [$F(1,135)=13.190$, $p<.001$] and (2) the first *Kango* elements significantly differed in voicing power from the first *Gairaigo* elements [$F(1,135)=4.276$, $p<.05$], but (3) the first *Wago* elements did not significantly differ from the *Kango* elements [$F(1,135)=1.539$, *n.s.*].

7.6. Findings of Experiment 4

As was indicated in Experiment 3, *Wago* first elements in Experiment 4 also consistently showed stronger voicing power on second elements than those of either *Kango* or *Gairaigo*. Therefore, the overall trend of the first element 'Wago = Kango > Gairaigo' affecting the voicing power of second elements must be much more prevalent.

Table 10. Voicing power of three-morae etymological-type on second elements

Etymological-type	Stimulus words	Voicing Power	
		M	SD
Wago	机(tukue), 袋(hukuro), 畑(hatake)	4.24	1.70
Kango	帰宅(kitaku), 麻薬(mayaku), 摩擦(masatu)	4.07	1.78
Gairaigo	テニス(tenisu), ピアノ(piano), リスク(risuku)	3.74	1.85
Results of pair-wise simple contrast comparisons		Wago = Kango > Gairaigo	

Note 1 : Participants=136. M=Mean. SD=Standard deviation.

Note 2 : /tukue/ and /piano/ include empy consonants in their phonological CVCVCV-structure, but these were included in the CVCVCV items.

8. General discussion

Sequential voicing, or *rendaku*, was observed in varying degrees of consistency depending upon a combination of factors. The present study investigated the influence of the phonological-length (Experiments 1, 2 and partly 3) and etymological-type (Experiments 3 and 4) of first elements on *rendaku* of the initial consonant of the CVCVCV-structured *Wago*-like nonwords /hukari/ and /hasuri/. Findings indicate that the voicing of second elements within compound words as determined by native Japanese speakers is influenced by the nature of first-element phonological-length and etymological-type. Since a majority of previous studies regarding *rendaku* (e.g., Haraguchi, 2001; Irwin, 2005; Itô & Mester, 1986,

2003; Kurisu, 2006), limited their intensive investigations largely to the voicing of second elements, the present study represents an innovative contribution to the study of *rendaku*.

The following sections discuss the influence caused by the nature (i.e., phonological-length and etymological-type) of first elements on the *rendaku* of second elements.

8.1. Effects of first-element phonological-length

Particular phonological aspects of first elements which influence the degree of second element voicing were especially salient in the present study. Experiment 1 revealed an overall trend whereby voicing determination (i.e., voicing power) from one mora to three morae was observed to have a descending order of strength. However, after controlling the characteristics of the first *Wago* elements by three conditions of printed-frequency, script type and free-standing single kanji, Experiment 2 revealed that a single mora *Wago* showed greater voicing power than two or three morae. Although the phonological-length is limited to this small range of one to three morae, from the findings of Experiments 1 and 2, it is safe to conclude that a single *Wago* mora is more likely to have a stronger voicing power on the initial voiceless consonant in the second element than phonologically longer *Wago*.

Irwin (2005) collected samples of noun compounds with *Kango* second elements, showing that *rendaku* of mononoms (single kanji units) appeared twice as frequently as binoms (two-kanji units). A unit of mora differs from a unit of sinogram or sinograph (or *kanji*), but Irwin's corpus data suggests that the shorter the length of the second element, the more frequently *rendaku* occurs (type frequency) among *Kango*. Although the present study examined the effects of the first element on *rendaku* of a second element and Irwin's finding is related to the length of second elements, a shorter unit in either mora or sinogram may result in a higher frequency of *rendaku*.

Furthermore, as previous studies (Endo, 1966; Okumura, 1952, 1955) have indicated, the results of Experiment 3 showed a general likelihood that CVN first elements have stronger effects on *rendaku* of second nonword elements than their counter stimuli of CVCV in both *Wago* and *Kango*, but not *Gairaigo*. Concerning the CVN unit, a group of Japanese phonologists (e.g., Haraguchi, 1996; Kubozono, 1989, 1995a, 1999; Kubozono & Ota, 1998; Terao, 2002) have proposed that both morae and syllables are described in a single phonological structure. Phonemes, morae and CVC and CVV (including CVJ as a variation of CVV) syllables are illustrated together in a single hierarchical structure. The lowest phonological level is the phonemic level, representing consonants and vowels. The next higher level is the moraic level. The first mora (μ_1) is constructed from a consonant (C) and a vowel (V) and the second mora (μ_2) from a consonant (i.e., /N/ or /Q/) or a vowel (i.e., /R/ or /J/). The highest level in the figure is the syllable level. Units at this level are constructed from CV and C/V, which create CVC and CVV syllables. In this phonological structure, a CVN is considered as a single syllabic unit (or a single 'heavy' syllable), while a CVCV structure is two syllabic units (or two 'light' syllables). In addition, Tamaoka and Terao (2004) indicated in naming latencies that CVNCV-structured nonwords were named with the same latency as the CVCV-structured nonwords, suggesting that CVN as a single phonological unit is processed just fast as a CV unit. Therefore, as observed in CV units, CVN units also have a strong influence on the voicing of second elements. It should be noted that, since /N/ ending is seldom seen in *Wago*, the present study could not find appropriate stimulus items matched across other phonological lengths by printed-frequency and script type to conduct Experiment 2.

In sum, the findings of Experiments 1, 2 and, in part, 3 suggest the overall trend that within first elements, a single mora or syllable phonological structure of CV and CVN units results in higher frequency of *rendaku* in second elements.

8.2. Effects of the first-element etymological-type

As previously noted, intensive linguistic investigation into *rendaku* to date has focused almost exclusively on the voicing of second elements. In fact, Itô and Mester (2003) claimed that since many examples undergo *rendaku* regardless of the etymological-type of the first element, only the status of the second element is relevant. Despite this claim, the present study of three etymological-types in Experiment 3 demonstrated that the first element *Wago* words had stronger voicing power upon the second elements than either *Kango* or *Gairaigo*, both of which had equal influence. However, after controlling printed-frequency and script type in Experiment 4, *Wago* and *Kango* displayed a similar likelihood of *rendaku* and both showed higher *rendaku* frequency than *Gairaigo*. In the results of both Experiments 3 and 4, the etymological-type of first-elements appeared to exert influence on the *rendaku* in second elements.

It is commonly known that *rendaku* fundamentally occurs among Japanese origin words (*Wago*), but not among *Kango* or *Gairaigo* (e.g., Itô and Mester, 1986, 2003; Kubozono, 1995b). However, *Kango* also exhibit *rendaku* in their compounds. For instance, the compound word 株式会社 ('joint-stock company') composed of /kabusiki/ (株式) and /kaisya/ (会社) is pronounced /kabusiki-gaisya/ as the initial consonant /k/ of the second element becomes voiced /g/. According to Vance (1996), as described in Irwin (2005), the proportion of words exhibiting *rendaku* is approximately 90% for *Wago*, 20% for mononomes of *Kango*, 10% for binomes of *Kango*, and negligible for *Gairaigo* (rounded to the nearest 10%). In fact, Nakagawa (1966) suggested that rendaku among *Kango* is a barometer for 'nativization'. Likewise, Otsu (1980) also mentioned that *Kango* and *Gairaigo* also exhibit *rendaku* as one manifestation of the extent to which these words have become 'Japanized'. Takayama (1999) labeled these words as *zokukango* (vulgarized Sino-Japanese) to display *rendaku* as observed in *Wago*. Whichever term – 'nativization', 'Japanization' or 'vulgarization' – is used to describe *rendaku* among *Kango*, it appears to be a good candidate of *rendaku* phenomena. Unlike the etymological types of *Wago* and *Kango*, lexical items of *Gairaigo*, however, have not yet been sufficiently nativized to show a strong *rendaku* tendency.

Experiment 3 showed the tendency of *rendaku* in second elements to be influenced by the first-element *Wago* more strongly than *Kango* and *Gairaigo*. After controlling for the major factor of word-printed frequency, the results of Experiment 4 suggested that the first elements of both *Wago* and *Kango* displayed similar voicing power to affect *rendaku* in second elements. Although the present study focused on first-elements, as suggested by previous studies (Nakagawa, 1966; Otsu. 1980; Takayama, 1999), the tendency of nativization seems to be observed differently in the effects of *rendaku* on second elements depending on the etymological types of first elements.

9. Limitations of the present study and further possible investigations

The present study shed light the influences of voiced-or-voiceless choice on first-element phonological-length and etymological-type. However, due to the nature of data collection from over 100 participants in each Experiment, the scope of the present study was limited to investigating only two *Wago*-like nonwords (i.e., *hukari* and *hasuri*) as second elements to determine whether or not the voiceless /h/ remains unchanged or becomes a voiced /b/ when the first-element is varied. The *rendaku* pattern of /h/ to /b/ is a relatively rare phenomenon, unique to Japanese, which is caused by labial weakening; this weakening alters the sound of /p/ to /h/, resulting in a pattern of /h/ to/b/. As Kubozono (1999) explained, there are four distinct voiceless-to-voiced patterns: /k/ to /g/, /s/ to /z/, /t/ to /d/ and /h/ to /b/. All these *rendaku* patterns should be investigated using multiple examples. In addition, since many first elements ending with /N/ can be found among *Kango* (but not *Wago*), the effects of /N/ on *rendaku* in the cross morpheme condition should be examined by controlling the position of /N/ in first elements. Furthermore,

the influence of the position of voiced consonants in first elements should also be investigated. As such, the questionnaire-based approach will likely continue to have a prominent role in future studies.

References

Amano, Shigeaki and Kondo, Tadahisa. 2000. Nihongo-no goi tokusei – Dai-7-kan [Lexical properties of Japanese Vol. 7]. Tokyo: Sanseido.

Amano, Shigeaki and Kondo, Tadahisa. 2003. Nihongo-no goi tokusei – Dai-2-ki CD-ROM-ban [Lexical properties of Japanese – The second volume of CD-ROM verison]. Tokyo: Sanseido.

Endo, Kunimoto. 1966. Rendaku-go no yure [Alternation of syllable and phoneme in rendaku-words]. Kokugo Kokubun [Japanese Language and Literature] 35.5: 68-77.

Haraguchi, Shosuke. 1996. Syllable, mora and accent. In: Otake, Takashi and Cutler, Anne. (eds.), Phonological structure and language processing: Cross-linguistic studies, 45-75. New York: Mouton de Gruyter.

Haraguchi, Shosuke. 2001. On rendaku. On'in Kenkyuu [Phonological Studies] 4: 9-32.

Hashimoto, Shinkichi. 1950. Kokugo on'in no kenkyuu [Studies of phonology in National Language]. Tokyo: Iwanami Shoten.

Ihara, Mutsuko and Murata, Tadao. 2006. Nihongo no rendaku ni kansuru ikutukano jikken [Some experiments on sequential voicing]. On'in Kenkyuu [Phonological Studies] 9: 17-24.

Irwin, Mark. 2005. Rendaku-based lexical hierarchies in Japanese: The behavior of Sino-Japanese mononoms in hybrid non compounds. Journal of East Asian Linguistics 14: 121-153

Itô, Junko and Mester, Armin. 1986. The phonology of voicing in Japanese: Theoretical consequences for morphological accessibility. Linguistic Inquiry 17: 49-73.

Itô, Junko and Mester, Armin. 2003. Japanese morphophonemics: Markedness and word structure. Linguistic Inquiry Monograph Forty-one. Cambridge, MA: MIT Press.

Kindaichi, Haruhiko. 1987. Rendaku no kai [Solution of sequential voicing]. Sophia Linguistics 2: 1-22.

Komatsu, Hideo. 1981. Nihongo no on'in [Japanese Phonology]. Tokyo: Chuuookooron-sha.

Kubozono, Haruo. 1989. The mora and syllable structure in Japanese: Evidence from speech errors. Language and Speech 32: 249-278.

Kubozono, Haruo. 1995a. Perceptual evidence for the mora in Japanese. In: Connell, Bruce and Arvaniti, Amalia. (eds.), Phonology and phonetic evidence: Papers in laboratory phonology IV, 141-156. Cambridge: Cambridge University Press.

Kubozono, Haruo. 1995b. Gokeisei to on'inkoozoo [Lexical formation and phonological structure]. Tokyo: Kuroshio Shuppan.

Kubozono, Haruo. 1999. Nihongo-no onsei [The Japanese sounds]. Tokyo: Iwanami Shoten.

Kubozono, Haruo. 2005. Rendaku: Its domain and linguistic conditions. In: von de Weijer, Jeroen; Nanjo, Kensuke; and Nishihara, Tetsuo. (eds.), Voicing in Japanese, 5-24. Berlin: Mouton de Gruyter.

Kubozono, Haruo and Ota, Satoshi. 1998. On'in koozoo to akusento [Phonological structure and accents]. Tokyo: Kenkyuusha Shuppan.

Kurisu, Kazutaka. 2006. Phonological derivedness in Yamato-Japanese voicing phonology. On'in Kenkyuu [Phonological Studies] 9: 49-58.

McCawley, James. 1968. The phonological component of a grammar of Japanese. The Hague: Mouton.

Murata, Tadao. 1984. Nihongo no Rendaku ni tsuite [On Rendaku in the Japanese language]. A handout of the talk presented at the meeting of Fukuoka Linguistic Society.

Nakagawa, Yoshio. 1966. Rendaku rensei (kashoo) no keihu [A genealogy of sequential vocing and sequential non-voicing (working label)]. Kokugo Kokubun [Japanese Language and Literature] 35: 302-314.

Okumura, Mitsuo. 1952. Jion no rendaku ni tsuite [On rendaku in Sino-Japanese]. Kokugo Kokubun [Japanese Language and Literature] 21.6: 8-22.

Okumura, Mitsuo. 1955. Rendaku [Sequential Voicing]. In: Kokugo gakkai (ed.), Kokugogaku daijiten [Encyclopedia of Japanese language study]. Tokyo: Tokyodoo.

Okumura, Mitsuo. 1964. Shoo-suru to shoo-zuru: rendaku no yooin ni tuite. Kokugo-kokubungaku [Japanese Language and Literature] 3: 1-8. Gifu University.

Otsu, Yukio. 1980. Some aspects of rendaku in Japanese and related problems. MIT Working Papers in Linguistics 2, 207-227.

Rosen, Eric Robert. 2001. Phonological processes interacting with lexicon: Variable and non-regular effects in Japanese phonology. Doctoral dissertation, University of British Columbia (Publication number: AAT NQ61167).

Takayama, Tomoaki. 1999. Shakuyoogo no rendaku/koo'onka ni tsuite [Sequential voicing and fortis in loan vocabulary]. Report of the special research project for the typological investigation of languages and cultures of the East and West #1, 375-385. Tsukuba: Tsukuba University.

Tamaoka, Katsuo and Terao, Yasushi. 2004. Mora or syllable?: Which unit do Japanese use in naming visually-presented stimuli? Applied Psycholinguistics 25: 1-27.

Tamaoka, Katsuo and Ikeda, Fumiko. 2008. Influence of first-element and dialect region on voiced-or-voiceless decisions of shoochuu. Proceedings of the 137th conference of the Linguistic Society of Japan, 398-403.

Tamaoka, Katsuo and Ikeda, Fumiko. In press. Whiskey or Bhiskey?: Influence of first-element and dialect region on sequential voicing of *shoochuu*. Gengo Kenkyu.

Terao, Yasushi. 2002. Iiayamari wa dooshite okoru? [How do speech errors occur?]. Tokyo: Iwanami Shoten.

Vance, Timothy John. 1979. Nonsense-word experiments in phonology and their application to 'rendaku' in Japanese. Doctoral dissertation, University of Chicago (Publication number: AAT T-27344).

Vance, Timothy John. 1987. An introduction to Japanese phonology. Albany: State University of New York Press.

Vance, Timothy John. 1996. Sequential voicing of Sino-Japanese. Journal of the Association of Teachers of Japanese 30: 22-43.

Vance, Timothy John. 2006. Right branch or head? On'in Kenkyuu [Phonological Studies] 9: 181-186.

Katsuo Tamaoka
Graduate School of Languages and Cultures
Nagoya University
Japan
ktamaoka@lang.nagoya-u.ac.jp
or ktamaoka@gc4.so-net.ne.jp

Mutsuko Ihara
Faculty of Medical Education and Culture
St. Marianna University School of Medicine
Japan
m2ihara@marianna-u.ac.jp

Tadao Murata
Human Sciences
Interdisciplinary Department
Faculty of Engineering
Kyushu Institute of Technology
Japan
murata@dhs.kyutech.ac.jp

Hyunjung Lim
Department of International Cultures
Yamaguchi Prefectural University
Japan
hjlim@yamaguchi-pu.ac.jp