Effects of lexical accent type on *rendaku* in noun compounds: evidence from production experiments

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Abstract

This study investigates morpho-phonological processes involved in Noun-Noun compound production, focusing on the interaction between segmental level processing and suprasegmental-level processing. Our production experiments manipulate lexical accent type in the first and second constituents of compounds in Tokyo Japanese, which in turn controls the explicitness of the application of the Compound Accent Rule (CAR). This allows us to examine whether the explicitness of compound processing at the suprasegmental-level influences the occurrence of *rendaku*, which results from segmental planning in compound production.

The study finds that *rendaku* is more likely to occur when CAR application is obvious from the accent pattern of the second constituent. This result is consistent with an interactive model in which compound construction at a suprasegmental-level facilitates *rendaku* application at the segmental level. On the other hand, no reliable effect of the accent type of the first constituent was observed. This study thus supports Kawahara and Sano’s (2012, 2014) claim that the original version of Lyman’s law, but not the strong version, plays a role in the process of producing novel compounds.

**Keywords:** *rendaku*, pitch accent, Japanese, Compound Accent Rule

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Section 1. Introduction

This research investigates morpho-phonological processes involved in Noun-Noun compound production, focusing on the interaction between phenomena at two distinct levels, namely sequential voicing, or rendaku, at the segmental level, and the application of the Compound Accent Rule (CAR) at the suprasegmental level. Our two experiments manipulate lexical accent type in the first and second constituents of compounds in Tokyo Japanese (hereafter, “Japanese”), which in turn controls the explicitness of the application of the Compound Accent Rule. A finding that the explicitness of the accent change affects the occurrence of rendaku would be the first evidence that the output of suprasegmental processing feeds into a segmental level planning process. In both experiments’ compound-noun production tasks, the second constituents were nonce words. Experiment 1 focused on the effect of accent change in the head (second) constituent on the occurrence of rendaku; for example, in kasura- (Unaccented) versus ka’sura (Initial-accented) when preceded by a common modifier constituent. In Experiment 2, we tested the effect of the lexical accent type (Unaccented vs. Initial-accented) of the modifier (first) constituent on the occurrence of rendaku in addition to that of the head (second) constituent; for example, in mori- ‘forest’ (Unaccented) versus u’mi ‘sea’ (Initial-accented), when followed by a common compound heads (An apostrophe indicates the location of the accented mora, which is to be discussed below).

By examining the interaction between processing at the segmental level and processing at the suprasegmental level, we will explore the process of computing the phonological representation of a compound. Two contrasting views of word production consider it to be either a discrete process (e.g., Levelt, 1989) or an interactive process (e.g., Dell, 1986). If the process is discrete, then suprasegmental planning is initiated only after the segmental process is completed. Thus, the output of suprasegmental planning should not affect the outcome at the segmental level. In contrast, interactive models suggest that each planning level permits feedback to the other level. Thus, the output of suprasegmental planning could influence segmental planning. While there have been a number of studies on the process of spoken word production (Dell, 1986; Levelt, 1989, 1999), relatively few of them have
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Dealt with compound production (Roelofs, 1996; Jacobs & Dell, 2014). Hence, the production process of compounds has not been sufficiently investigated from the psycholinguistic perspective.

The organization of this paper is as follows: Section 2 provides basic facts about Japanese compounding processes, covering phenomena related to pitch accent (word accent and compound accent) and sequential voicing (\textit{rendaku}). It also provides an overview of word formation models. Section 3 presents our two production experiments. Section 4 provides a general discussion and conclusions.

\section*{Section 2. Phonological processes associated with compound formation in Japanese}

\subsection*{2.1. \textit{Rendaku} (sequential voicing)}

\textit{Rendaku} is a morpho-phonological process in which an initially voiceless obstruent in the second constituent of a compound becomes voiced (Vance, 1987; Ito & Mester, 2003). For example, as in (1), when the two words \textit{u'mi} ‘sea’ and \textit{ka'me} ‘turtle’ form a compound, the initial consonant of the second constituent, /k/ in \textit{ka'me}, becomes voiced to /g/.

\begin{equation}
\begin{array}{ccc}
\text{sea} & \text{turtle} & \rightarrow \\
\text{umi-game} & \\
\end{array}
\end{equation}

However, there are a number of cases in which \textit{rendaku} does not occur. Lyman’s law is a well-known phonological restriction that prohibits two voiced obstruents within the same morpheme (Lyman, 1894). When the second constituent already contains a voiced obstruent, \textit{rendaku} application is blocked as in (2a): \textit{kaze} does not become \textit{gaze}. However, there are a few examples where \textit{rendaku} still applies in spite of the second constituent containing a voiced obstruent as in (2b): \textit{hashigo} becomes \textit{bashigo}. (Note that the \textit{rendaku} counterpart of \textit{h} is \textit{b} in modern Japanese due to a diachronic sound change from \textit{p} to \textit{h})

\begin{equation}
\begin{array}{ccc}
\text{autumn} & \text{wind} & \rightarrow \\
\text{aki-ka'ze} & (*\text{aki-ga'ze}) & \\
\end{array}
\end{equation}
Numerous studies have investigated what factors might facilitate or block *rendaku*, considering, for example, the effect of lexical stratification (Ito & Mester, 1995), the effect of the first constituent of two-constituent compounds (Tamaoka et al., 2009), and the right branch condition (Otsu, 1980). Most of these studies have been based on naturally occurring examples. In recent years, an increasing number of experimental approaches employing non-existent compounds have been developed (Vance, 1979; Tamaoka et al., 2009; Ihara et al., 2011; Kawahara & Sano, 2012, 2014). One purpose of such experimental research on *rendaku* is to test whether the factors that are claimed to affect *rendaku* in the lexicon are psychologically real, or if they have become part of native speaker knowledge as the result of grammaticalization (Kawahara & Sano, 2014). Tasks in which participants create novel compounds out of existing words or even non-existing pseudo nouns (Kawahara & Sano, 2014; Kumagai, 2017) eliminate the issues of frequency (i.e., how often the target words undergo *rendaku*) and the degree to which the target compounds are lexicalized.

Most of the factors controlling *rendaku* are related to the characteristics of the second constituent of the compound, as in Lyman’s law (2a). Lexical items in modern Japanese are generally categorized into three etymological types: native vocabulary (*wago*), Sino-Japanese (*kango*), and (other foreign) loan words (*gairaigo*). In general, *rendaku* applies only when a compound’s second constituent is *Wago* (Otsu, 1980; Ito & Mester, 1995, 2003). In addition, some words are “*rendaku immune*” (e.g., *hi’me* ‘princess’, *himo* ‘cord’, *ka’su* ‘dregs’, *saki* ‘tip’, and *tuti* ‘soil’) (Vance, 1980; Irwin, 2014). However, there are a few cases in which the characteristics of the first constituent influence *rendaku*.

While Ito and Mester (2003) claimed that the characteristics of first constituents have little or no effect on the application of *rendaku*, some studies have provided evidence that certain phonological conditions of the first constituent of a compound can influence the occurrence of *rendaku* in a gradient manner (Rosen, 2001; Tamaoka et al., 2009). Rosen’s rule
describes an effect of the phonological length of the first element on *rendaku* occurrence: if the first element is three or more moras long, the compound is more likely to undergo *rendaku* (Rosen, 2001). However, Kawahara and Sano (2014) found no reliable effect of length of the first element (two moras vs. three moras) in their experimental study with nonce words, suggesting that Rosen’s rule may be applicable only to existing words.

Kawahara and Sano (2012, 2014) further showed that *rendaku* is subject to Lyman’s law to different degrees depending on domain, that is, the second constituent or the entire compound including the first constituent. The effect of Lyman’s law is typically considered to be limited to the second constituent. Nevertheless, it is reasonable in some cases to consider that this restriction requires a larger domain, because the presence of a voiced obstruent in the first constituent can inhibit *rendaku* application; this is often called “the strong version of Lyman’s law” (Kawahara and Sano, 2012). Sugito (1965) pointed out that *rendaku* is less likely to be applied to the morpheme -*ta* in a personal name formation when the first constituent includes a voiced obstruent (e.g., *ku’zu-ta* vs. *kusu-da*). Similar effects have also been reported in other studies (Kubozono, 2005; Zamma, 2005; Tamaoka & Ikeda, 2010). However, Kawahara and Sano (2012, 2014) demonstrated that the strong version (i.e., the domain is the entire compound) cannot be generalized to compounding with nonce words, which, they argued, implies that the strong version of Lyman’s law is not psychologically real for contemporary Japanese speakers.

As this discussion suggests, whether the phonological environment of the first constituent has any impact on the occurrence of *rendaku* is still a controversial matter. Our experiments examining how lexical accent type affects *rendaku* application therefore investigate the first and second constituents separately.

The effect of lexical accent type (the explicitness of accent change due to CAR application) on *rendaku* has not been experimentally investigated before. The next section describes basic facts about Japanese pitch accent. We further discuss the relationship between *rendaku* and accent and its implications for compound production models in the subsequent sections.
2.2. Japanese word accent

Japanese is a pitch-accent language, and each word belongs to a certain accent type, which is lexically determined. Regarding noun accent, words in Tokyo Japanese are first divided into two types: accented and unaccented. The tonal representations of nouns are predictable based on whether a word is accented or unaccented (henceforth, “accentedness”) and if accented, the location of the accent nucleus. According to the tone assignment rules proposed by McCawley (1968), the H tone and the L tone of the HL tonal sequence (a sharp fall) are linked to the designated accented mora (as indicated by an apostrophe) and the immediately following mora, respectively. All the subsequent moras will be linked to the L tone. An H tone is linked to all other moras by default, except for the initial mora, which receives an L tone by a rule called initial lowering/rise as in (3).

(3) a. ta’nu.ki  H’-L-L  raccoon
    b. ta.ma’go  L-H’-L  egg
    c. ya.ma.za’.ku.ra  L-H-H’-L-L  wild cherry tree

Accented nouns composed of three moras can be one of the following three types, as illustrated in (4): initial-accented (4a), middle-accented (4b), and final-accented (4c). In addition, in unaccented words, the first mora is assigned an L tone and the following moras an H tone, as in (4d), by default.

(4) a. mi’ka.n  (initial-accented)  H’-L-L  orange
    b. ta.ma’go  (middle-accented)  L-H’-L  egg
    c. a.ta.ma’  (final-accented)  L-H-H’  head
    d. ri.n.go  (unaccented)  L-H-H  apple

2.3. The Compound Accent Rule (CAR)

The formation of a compound is often accompanied by phonological changes at the suprasegmental level as well (e.g., compound stress in English). The Compound Accent Rule (CAR) describes changes in accent assignment in the process of forming noun compounds in Japanese. According to the CAR, as discussed by Kubozono (1995) and Kubozono et al. (1997), when a noun compound is generated, the accent of the first
element is completely deleted, and the whole compound becomes one accent-bearing unit. The location of the accent assigned as a result of the application of the CAR depends on the number of moras in the second constituent; when the second constituent of a compound has two moras or less, the compound accent is assigned to the last mora of the first element as in (5). However, there are some exceptions. As in (6a), when the second element consists of certain words that are two moras or less, the entire compound behaves like an unaccented noun. Furthermore, some second elements retain their original accent after the application of the CAR, as in (6b).

(5) a. zi’nzi + bu’ > zinzi’-bu
   personnel department personnel department
b. ka’buto + musi > kabuto’-misi
   helmet insect beetle

(6) a. zi’nzi + ka’ > zinzi-ka
   personnel section personnel section
b. pe’rusya + ne’ko > perusya-ne’ko
   Persia cat Persian cat

In contrast, when the second element is tri-moraic, the compound accent is relatively predictable. It is assigned to the initial mora of the second element as in (7), except when the second element is middle-accented. (Note that a’o can cover both blue and green.)

(7) a. a’o + ringo (unaccented) > ao-ri’ngo
   blue apple green (unripen) apple
b. e’hime + mi’kan (initial-accented) > ehime-mi’kan
   place name orange oranges grown in Ehime

As a result of CAR application, the accent pattern of each constituent of the compounds in (7) differs from the accent pattern of the same item when it is pronounced as a single noun.
2.4. Implications for word production models

Most word production models take one of the two positions: the process of word production is either *discrete* or it is *interactive*. In the discrete process models, a subsequent stage of processing cannot influence the processing that occurs at preceding stages (e.g., Roelofs, 1997, 2000); in the interactive process models, it can (e.g., Dell, 1988).

In a description of a discrete process of morpho-phonological encoding, Levelt (1999) used the example of the word *selecting*. He divided the process into three steps. First, the morpho-phonological codes are accessed. The target lemma is *select*, marked for progressive tense. Two codes are successively accessed, first the code for the head morpheme, <select>, then the code for the suffix morpheme, <ing>. Next, the phonological code is spelled out. Each morpheme’s segments (/s/, /i/, /l/, …) are simultaneously selected. The third step is prosodification. The spelled-out segments are incrementally grouped into syllables that attach to the spelled-out morpheme.

Such models imply that selecting the phonological code of a word precedes prosodification. Roelofs (1996) also indicated that a word’s morphemes are phonologically encoded in a uni-directional way. So these models maintain that the output of the prosodification process (suprasegmental planning) does not feed back into the planning at the segmental level.

In contrast, in interactive models, all connections are bi-directional. Dell (1988) assumed the existence of a network that is accessed by spreading activation. The network includes nodes for conceptual features, lemmas, morphemes, syllables, segments, and phonological features. The nodes in the network facilitate each other’s activation in a bi-directional way. Hence, in these models, the phonological encoding of a morpheme and its prosodification can interact with each other.

As far as Japanese compounds are concerned, *rendaku* is considered to be part of segmental level processing while the CAR is handled at the suprasegmental level. The next section will consider the order in which *rendaku* and the CAR are applied in compound encoding.
2.5. Interaction between pitch accent and rendaku

A few studies have discussed the relationship between rendaku and accentedness in existing compounds. Tanaka (2005) observed a relationship between the accent pattern of the entire compound and the occurrence of rendaku; that is, rendaku tends to be blocked when the last mora of the first element of the compound includes an accent, whereas rendaku tends to occur when the entire compound form is unaccented, as illustrated in (8ab).

(8) a. family names: asa’-kawa vs. asa-gawa (Sugito, 1965; Zamma, 2005; Ohta, 2013)
   b. island names: itsuku’-sima vs. sakura-zima (Tanaka, 2005)

Tanaka (2005) pointed out that both accent and rendaku function to display a compound boundary, thus providing information on the internal structure of the compound (i.e., the boundary between the constituents).

There is some evidence suggesting that the lexical accent type of the second constituent has an effect on rendaku application. Sugimoto (2013) examined factors influencing the occurrence of rendaku in children’s compound production. She elicited target compounds with four Wago (Japanese origin) words as the second element: sakana- ‘fish’, hati- ‘bee’, kuruma- ‘car’, and ta’nuki ‘raccoon’. She found that the children were less likely to apply rendaku to compounds including ta’nuki, the only initial-accented word of the four. This finding suggests that rendaku is more likely to occur if the second constituent does not have a lexical accent.

The application of rendaku and the CAR both can function as evidence that a series of two nouns constitutes a compound rather than two juxtaposed independent nouns. However, the application of the CAR is less obvious in some cases than in others, as (9) demonstrates.

(9) a. a’o + ringo (unaccented) > ao-ri’ngo
    blue/green apple green (unripen) apple

b. a’o + mi’kan (initial-accented) > ao-mi’kan
    blue/green orange green (unripen) orange

When pronounced as part of a compound, an unaccented noun such as ringo is assigned an accent on the initial mora as a result of the CAR, which
in turn changes its tone representation (9a; LHH → HLL). The change in the accent can be viewed as evidence of compound status. On the other hand, for initial-accented words such as *mi’kan*, the output of the CAR coincides with the original tonal representation (9b; HLL → HLL). Thus, the compound in (9a) exhibits the application of the CAR (and hence, of the sequence’s compound status) more explicitly than does the compound in (9b).

A similar contrast can be seen in the accentedness of the first constituent nouns in the pair in (10).

(10) a. *mori* (LH) + *mi’kan* > *mori* (LH) - *mi’kan*  
    forest orange  

b. *u’mi* (HL) + *mi’kan* > *umi* (LH) - *mi’kan*  
    sea orange

When the first constituent of a compound is originally an accented word such as *u’mi*, the tone representation changes (10b; HL → LH) after CAR application, which deletes the lexical accent. In contrast, an unaccented word such as *mori-* as the first constituent does not change its surface tone representation explicitly after the application of the CAR (10a; LH → LH). In this case, the application of the CAR is more explicit in (10b) than in (10a). There is psycholinguistic evidence that the real-time comprehension of a compound with an explicit accent change on the first constituent is faster (Hirose & Mazuka, 2015).

2.6. Computing segmental and suprasegmental representations in word-production models

We have discussed the two contrasting concepts of discrete (henceforth, “uni-directional”) and interactive (henceforth, “bi-directional”) word production processes. We will now discuss how segmental planning and suprasegmental planning are handled in Japanese compound production. The premise of our discussion is that *rendaku* occurs at the segmental level, while the application of the CAR occurs at the suprasegmental level.

In a uni-directional process, word encoding runs from segmental planning to suprasegmental planning. If the production process of compounds is uni-directional, then suprasegmental planning (e.g., changes to the lexical
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accent) should not have any impact on *rendaku* application, which is determined at the level of segmental planning.

On the other hand, if the process is bi-directional, then segmental planning and suprasegmental planning can interact with each other. It is thus conceivable that the manipulation of lexical accent type (at the suprasegmental level) can influence the application of *rendaku* (at the segmental level). We will present two possible ways in which accent change could influence the occurrence of *rendaku* in the compound production process.

### 2.6.1. Mutual facilitation

If accent change as a result of the application of the CAR activates a compound representation in the speech planning process, then it should facilitate *rendaku* application, which should also have a link to the compound representation. That is, when the phonological representation of the first constituent is computed to have a compound accent in (10b), the obvious change in accent should enhance the activation of the compound representation. By the time the phonological representation of the second constituent is computed, the compound representation that has been activated would in turn have activated the segmental representation in which *rendaku* is applied. If this is the case, then a *rendaku* representation is more likely to be chosen over a non-*rendaku* representation in the segmental planning of the second constituent. In contrast, such an effect would not be observed in (10a), where there is no obvious signal that the CAR has applied.

The effect of the overt sign of CAR application on the second item on compound planning is less clear. This is because, by the time a speaker computes and produces the compound accent on the second item, the segmental planning of that same word will already have been completed. In tasks where participants have time to introspectively weigh two possible compound outputs (with and without *rendaku*), however, the accent change on the second constituent may have some impact on the choice of whether to apply *rendaku*, though it may be weaker than when the accent information is in the first constituent.
2.6.2. Compensation

Tanaka (2005) observed that both *rendaku* and accent function to represent a boundary cue inside a compound, and that either can compensate for the other’s absence; in other words, one of them is more likely to occur when the other does not, because the compound would not otherwise have sufficient evidence of its compound status. If so, we can imagine that when a boundary cue (the explicitness of accent change due to CAR application) is absent, the presence of the other boundary cue (*rendaku*) would be more desirable to provide the information of compound status. This leads to a prediction that *rendaku* is more likely to occur when CAR application is less explicit.

As far as the first constituent is concerned, initial-accented words indicate that tone change has occurred through the process of CAR application, thus signaling compound representation sufficiently to affect the processing of the first constituent (e.g., 10b; HL → LH). On the other hand, unaccented words retain their accent and tone (e.g., 10a; LH → LH), and thus do not provide evidence of compound representation or a boundary cue of a compound before the processing of the second constituent. So, if the lack of a boundary cue in a compound requires another boundary cue (*rendaku*) to show compound status, the other boundary cue (*rendaku*) should be facilitated more often when the first constituent is unaccented.

When it comes to the second constituent, initial-accented words show no superficial clue of accent change associated with the application of the CAR, and therefore they would be more likely to undergo *rendaku* to compensate for the lack of a boundary cue (the explicitness of accent change) than unaccented words, which undergo accent change in the process of compound formation.

In real-time compound planning, it is more conceivable that the lack of an obvious accent change on the first constituent would have an impact on the *rendaku* planning for the second constituent than that the lack of information in the second constituent would have such an effect on the first. However, the absence of effects of the phonological environment on the first constituent reported in the literature could suggest that there is no advantage of accent manipulation on the first constituent.

Any effect of accent type, whether on the first constituent or the second
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constituent, would be consistent with models in which suprasegmental information (the lack of a boundary cue for a compound representation) influences segmental planning (*rendaku*) in producing a compound, supporting the view that suprasegmental planning and segmental planning interact with each other.

**Section 3. Experiments**

Our two experiments control the difference in the explicitness of accent change associated with CAR application from the standpoint of compound production. By manipulating the lexical accent type of the first and the second constituent independently, we created situations where we control the explicitness of CAR application. This allows us to examine whether the explicitness of compound processing at the suprasegmental level influences the occurrence of *rendaku*, which results from segmental planning in compound production.

Experiment 1 manipulated the accent type (Unaccented vs. Initial-accented) of the targets in the second constituent of compounds while keeping the accent type of the first constituent constant. Experiment 2 manipulated the accent type of the first constituent while keeping that of the second constituent constant. The two experiments’ results could potentially contribute to resolving the controversy as to whether the phonological environment of the first constituent is as influential as that of the second constituent on *rendaku* application from a prosodic perspective. Another possible difference between the manipulations of the two experiments is the timing by which the explicitness information becomes available in the real-time compound computation process, which may play different roles in the real-time compound production process.

### 3.1. Experiment 1: The effect of lexical accent type on the SECOND constituent

Experiment 1 examined the effect of the difference of the lexical accent types (Unaccented vs. Initial-accented) of the second constituent of compounds on the occurrence of *rendaku*. 
3.1.1. Participants
Eighteen Tokyo Japanese-speaking adults took part in the experiment, receiving in exchange a small remuneration.

3.1.2. Design and stimuli
Experiment 1 utilized five existing words for the first constituents (sato- ‘countryside’, mori- ‘forest’, yama- ‘mountain’, oo- ‘big’, and ko- ‘small’) and created forty-eight nonce words with two accent types (Unaccented vs. Initial-accented) for the second constituents. The advantage of using nonce words is that the frequency issue can be better controlled, whereas memorizing nonce words could impose a cognitive burden. In our experimental items, only the head constituents were nonce words.

As illustrated in (11), half of the forty-eight nonce words included two identical adjacent CV moras (Identical) such as “kakara.” In contrast, the other half of the nonce words were composed of all different CV moras (Non-identical) as in “kasura.” (The effect of segment identicality on rendaku is discussed in detail in Sone and Hirose (in press).) We manipulated the accent type (Unaccented vs. Initial-accented) of all nonce words. Participants were presented twenty-four unaccented targets as in (11a) and twenty-four initial-accented targets as in (11b).

(11) a. mori- + kasura (unaccented) > mori-ka’sura / mori-ga’sura  
   b. mori- + ka’sura (initial-accented) > mori-ka’sura / mori-ga’sura

3.1.3. Procedure
Because many of the participants in our pilot study appeared to believe that they were not allowed to make any segmental change to the material presented to them, we decided to include an explicit explanation about the concept of rendaku in the instructions. In a practice session preceding the experimental session, we demonstrated to the participants that when two words are combined into a compound, the sound can sometimes change, by referring to some existing compounds where rendaku occurs. This was done to ensure that the participants understood that making certain changes to the original sounds was acceptable in this task. We also included practice items where rendaku was not relevant (e.g. compounds in which the second
constituent started with a sonorant sound) so as to keep the participants from paying excessive attention to *rendaku*. In each trial, they were asked to learn a new (nonce) word played from an audio file, with a matching picture (e.g., 12a, *kasura* ‘flower’s name’). Then they were told to repeat the target nonce word with the correct lexical accent (i.e., as they had just heard it). The experimenter checked whether the participant repeated the word correctly with the designated accent type. The participants were then shown a picture and prompted to use the nonce word to create a compound to express what the picture depicted (e.g., 12b, which shows the same flower blooming in a forest). In this case, for example, the participants were asked, “What do you call a kasura which blooms in the forest?” The participants were expected to produce a compound combining the word *mori*- (forest) with the nonce word. The experiment’s interest was whether they pronounced the compound with or without *rendaku* (e.g., *mori-*ka’sura or *mori-*ga’sura).

(12) a

3.1.4. Predictions

First of all, while a uni-directional process model would predict that lexical accent type will not influence the occurrence of *rendaku*, a bi-directional process model would predict that the manipulation of lexical accent type will affect *rendaku* application. If lexical accent type does affect *rendaku* application, we can make two predictions based on compensation
or mutual facilitation.

The compensation model would predict that *rendaku* will be more likely to apply to initial-accented words than unaccented words. The mutual facilitation model would predict that unaccented words will undergo *rendaku* more often than initial-accented words.

### 3.1.5. Analysis

The data were analyzed with logistic linear mixed effects models using the R statistical program’s lme4 package (Jaeger, 2008). The participants’ use or non-use of *rendaku* was treated as a binomial dependent variable, and the lexical accent type in the first constituent was entered as a fixed effect. Participants and items were entered as random effects. The best-fit model was selected by using a backward selection approach.

### 3.1.6. Results

The vertical line in Figure 1 represents the percentage of *rendaku* application, and the horizontal line shows the accent types (Unaccented and Initial-accented). The details of the results of the LME analysis are shown in Table 1. The analysis shows that unaccented words undergo *rendaku* more often than initial-accented words ($\beta=-0.633$, $z=-2.91$, $p=0.003$). The average percentages of *rendaku* responses in initial-accented words and unaccented words were 20.8% and 26.6%, respectively.

|                  | Estimate | SE    | z-value |
|------------------|----------|-------|---------|
| Intercept        | -2.5192  | 0.6113| -4.121  |
| Accent type      | -0.633   | 0.218 | -2.910  |

Table 1. Experiment 1 statistical result from mixed-effects models.
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3.1.7. Discussion

The results provide evidence that accent change in unaccented second constituents after the application of the CAR facilitates *rendaku*. This finding is consistent with an interactive model in which the compound construction at a suprasegmental level influences *rendaku* application.

3.2. Experiment 2: The effect of lexical accent type on the FIRST constituent

Experiment 2 examined the effect of the two lexical accent types in the first constituent on *rendaku* application.

3.2.1. Participants

Twenty-three Tokyo Japanese-speaking adults participated in the experiment, for which they received a small remuneration.

3.2.2. Design

Experiment 2 focuses on the effect of the lexical accent type of the first constituent. We adopted two real words as the first constituents to manipulate their accent type: *u’mi* ‘sea’ (Initial-accented) and *mori*- ‘forest’ (Unaccented). In addition, we created forty-eight nonce words for the second constituent and manipulated their accent type (Unaccented vs. Initial-accented). Half of the forty-eight nonce words included two identical
consecutive consonants, as in *kakura* (Identical). The other half employed all different consonants, as in *kasura* (Non-identical). (The effect of segment identicality on *rendaku* is discussed in detail in Sone and Hirose (in press).)

(13) a. *mori*- (unaccented) + *kakura* (unaccented) > *mori-ka’ura* or *mori-ga’ura*
    forest                  nonce word

b. *mori*- (unaccented) + *ka’ura* (initial-accented) > *mori-ka’ura* or *mori-ga’ura*
    forest                  nonce word

c. *u’mi* (initial-accented) + *kakura* (unaccented) > *uni-ka’ura* or *uni-ga’ura*
    sea                     nonce word

d. *u’mi* (initial-accented) + *ka’ura* (initial-accented) > *uni-ka’ura* or *uni-ga’ura*
    sea                     nonce word

### 3.2.3. Predictions

Items in which the first constituent is initial-accented (*u’mi*; 13c,d) show a change of tone representation (HL → LH) more explicitly (i.e., higher explicitness of CAR application) than items in which the first constituent is unaccented (*mori*;- 13a,b) and therefore retains its tone representation (LH → LH).

As in Experiment 1, if the explicitness of accent change as a result of CAR application facilitates *rendaku* application (i.e., mutual facilitation), the initial-accented condition (13c,d) will be more likely to facilitate the application of *rendaku* than the unaccented condition (13a,b).

### 3.2.4. Procedure

The procedure was the same as that used in Experiment 1.

### 3.2.5. Analysis

The data analysis procedure was the same as in Experiment 1, except that there were two fixed factors: accent type in the first constituent and accent type in the second constituent.

### 3.2.6. Results

The y-axis in Figure 2 represents the rate of *rendaku* application, and the
horizontal line shows accent type in the first constituent (C1) for both unaccented and initial-accented conditions in the second constituent (C2). The results of the mixed-effects analysis are shown in Table 2. Only the main effect of the accent type of the second constituent was significant (Unaccented > Initial-accented, $\beta=0.312$, $z=1.987$, $p=0.046$). No reliable main effect of the accent type of the first constituent was observed ($\beta=-0.09$, $z=-0.583$, $p=0.56$). No reliable interaction of the effects of accent type in the first constituent and in the second constituent was found ($\beta=0.14$, $z=0.453$, $p=0.651$).

**Table 2.** Experiment 2 statistical result from mixed-effects models.

| Factor               | Estimate | SE    | z-value |
|----------------------|----------|-------|---------|
| Intercept            | 2.5499   | 0.6077| 4.196   |
| Accent type (C1)     | -0.09    | 0.155 | -0.583  |
| Accent type (C2)     | 0.312    | 0.157 | 1.987   |
| Accent type (C1×C2)  | 0.140    | 0.310 | 0.453   |

**Figure 2.** Average probability of *rendaku* application by lexical accent type in the first and second constituents. The error bars represent the standard error in each condition, based on subject means.

**3.2.7. Discussion (Experiments 1 & 2)**

The results of the two experiments show that the accent type of the second constituent had a significant impact on the occurrence of *rendaku: rendaku*
occurred more when there was an explicit accent change from unaccented to accented, as a result of re-assignment of the compound accent. On the other hand, the accent type of the first constituent did not have a reliable influence on the occurrence of rendaku (i.e., ń’mi vs. mori-). The explicitness of the accent change (accented \(\rightarrow\) unaccented) on the first constituent of the compound was reported to be informative in real-time comprehension and was thus expected to trigger the *rendaku* process. Our results suggest, however, the accent change information on the head constituent was more influential than that on the modifier constituent in compound production.

These results are consistent with those of Kawahara and Sano (2012, 2014), who showed that the original version of Lyman’s law (which is limited to the second constituent) applies in nonce word compounds, but the strong version (which includes the first constituent as well) does not.

**Section 4. Conclusion**

The results of Experiments 1 and 2 provide evidence that the manipulation of lexical accent type at the suprasegmental level influences *rendaku* application at the segmental level. These results support the bi-directional process models, which permit feedback between distinct planning levels in the process of compound production. In addition, both experiments indicate that unaccented words in the second constituent, which signal that the CAR has applied, are more likely to undergo *rendaku* than initial-accented words. These results are explained by the mutual facilitation of the compound representation between the suprasegmental and segmental processing levels. The fact that the explicitness of the CAR’s application in the second but not the first constituent plays a role leads to further questions regarding the mechanism (and its time course) by which accent information is processed and influences the segmental level.
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Appendix 1. The stimuli in the Experiment 1.

| kasera  | kasure  | kakare  | kakana  |
|---------|---------|---------|---------|
| saseya  | sasure  | sasare  | sasaya  |
| tasema  | tasure  | tatare  | tatama  |
| hasena  | hasure  | hahare  | hahara  |
| kusira  | kukane  | kukune  | kukuma  |
| susire  | sukano  | susuni  | susura  |
| tusiri  | tukana  | tutuno  | tutuna  |
| husiro  | hukani  | huhuna  | huhuya  |
| kosura  | kosura  | kokona  | kokore  |
| sosure  | sosuna  | sosoni  | sosoro  |
| tosuro  | tosuma  | totono  | totori  |
| hosuri  | hosuya  | hohone  | hohora  |

All items were presented either as an initially-accented word or an unaccented word.

Appendix 2. The stimuli in the Experiment 2.

| katuri  | kanoma  | kakura  | kakora  |
|---------|---------|---------|---------|
| kusara  | kunore  | kukane  | kukora  |
| kotara  | koture  | kokara  | kokuma  |
| sakumo  | satotu  | sasuna  | sasore  |
| sukaro  | sutoma  | susama  | susona  |
| sokama  | sokure  | sosara  | sosura  |
| tasuma  | takome  | tatura  | tatona  |
| tukara  | tukona  | tutana  | tutore  |
| tokama  | tosure  | totara  | toture  |
| hasema  | hasore  | hahero  | hahoro  |
| hekema  | hekora  | hehara  | hehoka  |
| hoseri  | hosata  | hohena  | hohama  |

All items were presented either as an initially-accented word or an unaccented word.