Stochastic phonological knowledge and word formation in Japanese

Abstract

The question of whether linguistic knowledge is binary or stochastic is one of the most important questions in general linguistic inquiry. Much recent work in the last few decades argues that phonological knowledge is stochastic (e.g. Hayes & Londe 2006). Building on this body of research, we show that in Japanese, gradient phonological knowledge affects several word formation patterns in stochastic ways. Concretely, we show that identity avoidance effects hold at both the segmental and the CV-moraic levels. These identity avoidance effects stochastically affect two types of word formation patterns in Japanese: group name formation and rendaku. We show that Maximum Entropy Grammar (Goldwater & Johnson 2003), together with multiple OCP constraints (Coetzee & Pater 2008), successfully models both of the observed morphological word formation patterns, without any further stipulation. In addition to this theoretical contribution, one of the patterns discussed in this paper—group name formation—has not been analyzed from the perspective of formal phonological theories before, and hence this paper has descriptive novelty as well.

1. Introduction

Whether linguistic knowledge is dichotomous/binary or gradient is one of the most important questions in the current linguistic inquiry. At the outset of the generative enterprise, sentences were divided into two distinct sets: those that could be generated by the posited grammar (i.e. "grammatical sentences"), and those that could not be generated by the grammar (i.e. "ungrammatical sentences") (Chomsky 1957). In reality, however, acceptability judgment patterns in syntax often show gradient patterns, as indicated by the common use of a set of different prefixal symbols (?, ??, ???, ?*,*?,*) used in sentential judgments in the syntactic literature (see e.g. Chomsky 1965; Lasnik 2004; Lasnik & Saito 1984; Pullum 2013a,b; Schütze 1996; Sprouse 2015, among many others). However, it is still debated whether syntactic knowledge itself is binary or not; some researchers argue that grammar/competence makes only a binary distinction (yes grammatical vs. not grammatical), and it is other cognitive processes—

i.e. performance—that yields graded judgments (e.g. Neelman 2013; Schütze 1996; Sprouse 2007). Other researchers, like Bresnan & Hay (2008), Kellar (2006), Lasnik (2000), Lasnik & Saito (1984), Pullum (2013a,b), and Sorace & Keller (2005), accept the thesis that syntactic knowledge itself is gradient, and maintain that linguistic models should be able to capture this gradiency. Some specific proposals have been put forward to capture the gradient nature of syntactic knowledge, such as Linear Optimality Theory (Keller 2006) and Model Theoretic Syntax (Pullum 2013a,b).

As with generative syntax, generative phonology began with the assumption that phonological knowledge is binary; a famous example is that whereas *brick* and *blick* are well-formed in English, *bnick* is not (Halle 1978). One of the fundamental tenets of early generative phonology is that phonological grammar should be able to capture the (binary) distinction between possible words and impossible words (rather than existing words and non-existing words). However, it has become increasingly clear that phonological knowledge is stochastic, not a simple matter of possible vs. impossible (see also Pierrehumbert 1997 and Cohn 2006 for historical reviews). First, phonotactic judgment patterns have now long been known to be stochastic; i.e. the intuition about whether a particular string can be a word or not is usually not a matter of a yes/no dichotomy. This gradient nature of phonotactic judgments was shown, for example, by the word-likeliness judgment experiment reported in Greenberg & Jenkins (1964). For instance, native speakers of English tend to judge [klæb] to be more natural—or more "English-sounding"—than [kleb], although both forms are generally grammatical in English. It is also known that consonant clusters with sonority plateau (e.g. [bdif]) are judged by English speakers to be better than clusters with falling sonority (e.g. [lbif]), despite the fact that both types of clusters are unattested in English (Berent et al. 2007 *et seq*.). See Daland et al. (2011) for recent extensive results showing gradient phonotactic judgment patterns in English and relevant discussion on the gradient nature of phonotactic knowledge.

Another type of well-known case of gradient phonotactics is the pattern of similarity avoidance, found in many Semitic languages, in which pairs of similar adjacent consonants are underrepresented in their lexicon. In the similarity avoidance pattern, the more similar two paired consonants are, the less likely it is that that pair exists in the lexicon (Frisch et al. 2004).

These sorts of gradient phonotactic identity avoidance effects have been observed in many languages, beyond Semitic languages, including, English (Berkley 1994), Muna (Coetzee & Pater 2008), Russian (Padgett 1992), and the native words in Japanese (Kawahara et al. 2006), among others (see also Alderete & Frisch 2007; Yip 1998; Zuraw & Lu 2009 for other cases of identity avoidance). In short, phonotactic distribution patterns, as well as native speakers' judgments on word-likeliness, are undoubtedly gradient, which cannot be reduced to a yes/no dichotomy. This observation led to the recent development of theories with numerically weighted constraints, such as Harmonic Grammar (Coetzee & Pater 2008) and MaxEnt Grammar (Hayes & Wilson 2008; Goldwater & Johnson 2003). Hayes & Wilson (2008: 382) explicitly declare that they "consider the ability to model gradient intuitions to be an important criterion for evaluating phonotactic models". Gradiency in phonotactics is now generally considered to be an essential aspect of grammar that any grammatical theory is required to capture, at least in phonology.

What has been less clear is whether phonological *alternations* can show systematic stochastic variations. However, recent work again demonstrates that some phonological alternations show patterned, stochastic variations (e.g. Boersma & Hayes 2001; Hayes to appear, Hayes & Londe 2006; McPherson & Hayes 2016; Moore-Cantwell & Pater 2016; Zuraw 2000, 2010). For example, Hayes & Londe (2006), in a paper titled "Stochastic phonological knowledge", have demonstrated that the probabilities of suffixes undergoing vowel harmony in Hungarian are different for different suffixes, and their likelihood of undergoing vowel harmony is affected by various phonological considerations. Zuraw (2000, 2010) shows that in Tagalog, different segments undergo nasal substitution with different probabilities in the lexicon, and that native speakers are sensitive to these gradient—yet regular—patterns, when they are tested with nonce words. These phonological patterns are not only *optional*, but *systematic* in the sense that their patterns make phonological sense (see Hayes to appear for recent discussion). Although the issue of whether or not phonological alternations can be systematically stochastic may be less well-established than the issue of the gradient nature of phonotactics, in the last few decades, we have witnessed a growing body of evidence which suggests the stochastic nature of phonological alternation patterns. One theoretical impetus that drove our research is to add more case studies to address this question of whether phonological alternations can be gradient or not.

Against this theoretical background, this paper offers two new pieces of evidence for stochastic phonological knowledge from Japanese, both of which affect word formation patterns. To the best of our knowledge, the issue of stochastic phonological knowledge has not been seriously tested using Japanese (perhaps except for Kawahara 2013 and Kilbourn-Ceron & Sonderegger to appear). Moreover, the current paper shows that such patterns can be successfully analyzed using Maximum Entropy (MaxEnt) Grammar (e.g. Colavin et al. 2014; Goldwater & Johnson 2003; Hayes to appear, Hayes & Wilson 2008; Hayes et al. 2009; Hayes et al. 2012; Jäger & Rosenbach 2006; Kumagai to appear; Martin 2011; McPherson & Hayes 2016; Shih 2016; Shih & Inkelas 2016; Tanaka 2017; Wilson 2006; Zhang et al. 2011; Zuraw & Hayes to appear), by positing multiple OCP constraints (Coetzee & Pater 2008). Again, this paper is one of the first attempts to fit a MaxEnt grammar to Japanese data (see also Tanaka 2017).[1]

The first case study, developed in section 2, deals with the formation of group names, which are created by combining the name of each member. As far as we know, this paper is the first attempt to describe and analyze this word formation pattern in the formal linguistic literature. Japanese speakers often make up a group name for a pair of people. For example, a group consisting of two identical twin sister actresses, *mana* and *kana*, is called *mana-kana*. The current project started with a simple question of why the group name is *mana-kana*, instead of *kana-mana*. Our hypothesis is that phonological considerations affect the formation of such group names. For example, ***k*a*n*a-*m*a*n*a** is disfavored because of the consecutive three CV-moras[2] with nasal onset. This is a reminiscent of the blockage of "-ly" adverb formation in English, in which "-ly" cannot be attached to those roots that already end with "ly" (e.g. **friendly-ly* and **silly-ly*: Katamba 1993). Shih (2014) likewise shows through a corpus study

[1] One alternative for modeling gradient patterns is noisy Harmonic Grammar (see e.g. Coetzee & Kawahara 2013), which was implemented in Praat (Boersma 2001) as early as 2006. We do not intend to engage ourselves in the comparison between a MaxEnt analysis and other related frameworks in this paper. See Hayes & Wilson (2008: section 9.1) and Hayes (to appear) for extended comparison between MaxEnt Grammar and other related constraint-based approaches.

[2] A CV-mora is a unit that plays an active role in Japanese phonology, orthography, speech production and perception (see, e.g., Ito 1989; Kubozono 1989; Labrune 2012; Otake et al. 1993). Since all the stimuli discussed in this paper are light syllables, CV-moras can be considered to be identical to light syllables. We use the term "CV-mora", following Kawahara & Sano (2016).

that in English names, name pairs are subject to a similar phonotactic restriction, in such a way that for example, Josh Smith [ʃ-s] is less likely to occur than Jack Smith [k-s] as a full name (see also Yip 1998 for other similar cases).

The experiment reported below in section 2 is designed to test the hypothesis that identity avoidance constraints are at work in determining the order of two elements. The results show that identity avoidance restrictions do indeed affect the group name formation patterns, although it is not the case that those names that violate an identity avoidance constraint are categorically prohibited. To model the results, we develop a MaxEnt analysis. We demonstrate that having multiple OCP constraints, following Coetzee & Pater (2008), successfully models the results without any further stipulation.

The second type of word formation that this paper explores in depth in section 3 is rendaku, which is a well-studied morphophonological process. Rendaku is the phenomenon in which the initial voiceless obstruents of the second member of a compound appear as voiced (e.g., /nise+**t**anuki/ → /nise+**d**anuki/ 'fake raccoon') (McCawley 1968; Tanaka 2017; Vance 1980, 1987, 2015; Vance & Irwin 2016, among many others; see Irwin 2016 for an extended bibliography list). We build upon the results of Kawahara & Sano (2016), who show that identity avoidance restrictions apply stochastically to the application of rendaku in nonce words. Kawahara & Sano demonstrated with a nonce-word experiment that the more similar the pairs of segments are that rendaku creates, the less likely rendaku is to apply. In one condition of their experiment, two consonants across the word boundary were identical after rendaku applies (e.g., schematically, /i**g**a+**g**omoke/ from /i**g**a/+/**k**omoke/); in the other condition, two CV moras across the word boundary were identical after rendaku applies (e.g., schematically, /i**ga**+**ga**niro/ from /i**ga**/+/**ka**niro/). The results show that rendaku was less likely to occur when it resulted in consecutive identical consonants, compared to the control condition in which no identity violations were involved (e.g. forms like /i**g**a+**g**omoke/ are avoided); furthermore, the applicability of rendaku was even more reduced when rendaku resulted in adjacent identical CV-moras (e.g. forms like /i**ga**+**ga**niro/ are even more strongly avoided). Importantly, it is not the case that either of the identity avoidance constraints blocks rendaku entirely; they stochastically reduce the application probability of rendaku. As is the case with the group name formation, these results can be modeled by multiple OCP constraints and a MaxEnt grammar. This analysis supports the generality of the analysis that we develop in section 2.

To summarize, in this paper we show that empirically, phonological knowledge can stochastically and systematically affect Japanese word formation patterns, and that theoretically, a MaxEnt grammar is a useful tool with which to model that stochastic knowledge. We also emphasize the descriptive value of what we report in section 2, which has hitherto not been analyzed in the theoretical literature. We would also like to highlight the fact that the methodology that we deploy in section 2—asking native speakers to order two words to form a larger word—is not very often used in experimental linguistics: Parker (2002) is the only exception as far as we are aware. We hope that this methodology will be used more widely to explore other phonological and morphological patterns in other languages.

2. Group name formation in Japanese

2.1. Background

This section explores the compound formation pattern of group names in which two names are combined. As mentioned in section 1, the pair of Japanese identical twin sister actresses, *mana* and *kana*, is called *mana-kana*. Another example is a pair of two Japanese Ping-Pong players, *mima* and *miu*, which is *miu-mima, not *mima-miu*. In both of these examples, the possible-yet-unattested forms—*ka**n**a#**m**a**n**a* and ***m**i**m**a#**m**iu*—contain three onset nasal consonants across the word boundary, whereas the attested examples—***m**a**n**a#ka**n**a* and ***m**i_u#**m**i**m**a*—contain no sequence of onset nasal consonants across the word boundary.[3] In the rest of the section, the sequence of nasals is referred to as nasal clash (cf. "stress clash": Prince 1983). We experimentally examine whether nasal clash generally affects compound formation patterns in Japanese. We also examine whether degrees of similarity (e.g. /m/-/m/ vs. /m/-/n/) matter. The previous studies (e.g. Coetzee & Pater 2008; Frisch et al. 2004; Kawahara & Sano 2016) have shown that the more similar sequences are, the more strongly they are disfavored; hence it is predicted that the degrees of similarity should impact the Japanese group name formation pattern as well. On the other hand, in some languages, total identity has been found to provide "an escape hatch" for similarity avoidance restrictions (e.g. Berent & Shimron 1997; Frisch et al. 2004), and hence it may be the case that an /m/-/m/ pair may be favored over an /m/-/n/ pair. This is an empirical question, which remains unsettled in the phonology of Japanese (though

[3] We assume that the vowel sequence of [iu], with no fall in sonority, is syllabified separately as [i.u]. The onsetless nature of the second syllable is represented by "_" in the text. See Kubozono (2015) for extensive discussion on Japanese diphthong and hiatus.

see Kawahara et al. 2006 and Kawahara & Sano 2016 for some discussion).

Going beyond the segmental level, we also test the identity effects in the CV-mora. Recall that in Kawahara & Sano's (2016) experiment, rendaku was more likely to be blocked when it resulted in CV moraic identity (e.g. *[…**ga**-**ga**…]) than when it resulted in mere consonantal identity (e.g. *[**g**a…**g**o]). Therefore, Japanese speakers may disfavor a sequence of two identical CV moras in general, which may affect the group name formation as well.

Although an inquiry into the nasal clash effect—more generally, the effect of similarity avoidance—is the main focus of this paper, there is another phonological factor that went into the consideration of this experiment, which is sonority (e.g. Clements 1990; Kenstowicz 1994; Parker 2002, 2011)—in the general sonority hierarchy, although some details are debated, segments are ordered in the following order: stop < fricative < nasal < liquid < glide. In English, when two words are combined with *and*, the word with the more sonorous onset tends to come first.[4] Some existing examples include, for example, ***l**ovey-**d**ovey*, ***w**alkie-**t**alkie*, and ***w**illy-**n**illy* (Parker 2002: 246). Parker (2002) further experimentally examined this tendency, by preparing several pairs of compounds such as *weeby-leeby* and *leeby-weeby*. The results showed that *weeby-leeby* was indeed preferred to *leeby-weeby*, which suggests that English speakers prefer to have the word with more sonorous consonant at the beginning of the derived word. Given this observation, we needed to make sure that the preference for *mana-kana* over *kana-mana* does not (solely) come from some sonority-based preference, instead of avoidance of consecutive nasal onset consonants; it could be the case that Japanese speakers, just like English speakers, may order names in such a way that more sonorous consonants are placed word-initially, which prefers *mana-kana* over *kana-mana*, although this sonority-based theory cannot explain the *miu-mima* example.

To summarize, in this experiment, we examine whether various similarity-related factors affect word formation patterns in Japanese; in particular, (i) whether nasal clash is avoided, and if so, (ii) whether the number of nasal clashes matters, (iii) whether consonantal identity and moraic identity show different degrees of influence, and in addition, (iv) whether, as with English, sonority matters when speakers combine two words to make a larger word. In what follows, we

[4] There are several studies of sonority effects on blend formation in other languages. Bat-El (1996) discusses the role of sonority in blend formation in Hebrew. Likewise, Labrune (2006) suggests that similar tendency may be observed in Japanese blending formation.

express general nasal clash as the effects of OCP(nasal), nasal clash with identical nasal consonants as OCP(C), and nasal clash in identical CV moras as OCP(CV), respectively (where OCP=Obligatory Contour Principle: Leben 1973; McCarthy 1986).

2.2. Stimuli

The current experiment used disyllabic Japanese girls' names as stimuli. All of the names used were existing (or at least possible) names. Sets 1 and 3 consisted of pairs that could result in two nasals in sequence, either non-identical (e.g., *ha**n**a-**m**oka*), or identical (e.g. *ha**n**a-**n**iko*). Sets 2 and 4 consisted of pairs that could result in three nasals in sequence (e.g., *ha**n**a-**m**o**n**a* and *ku**m**i-**m**i**n**a*).

Table 1: The overall stimulus structure

	Number of nasals	Non-nasal segment
Set 1	2	obs
Set 2	3	obs
Set 3	2	son
Set 4	3	son

The number of nasal consonants involved in nasal clash was included as a condition in the experiment, because in the *mana-kana* and *miu-mima* example, it may be three consecutive nasal onset consonants that make the unattested *ka**n**a-**m**a**n**a* and ***m**i**m**a-**m**iu* unviable options; we were interested in whether two consecutive nasal onset consonants were enough to affect group name formation patterns.

Sets 1 and 2 consisted of pairs in which one word begins with an obstruent and the other word begins with a nasal (e.g., *ha**n**a* and ***m**oka*),[5] and Sets 3 and 4 consisted of pairs in which one word begins with a liquid, and the other word begins with a nasal (e.g., *ri**n**a* and ***m**oka*). Recall that we wanted to tease apart the effects of identity avoidance and the effects of sonority.

Within each set, there were three conditions that were characterized in terms of different OCP violation profiles (i.e., OCP(nasal); OCP(nasal)+OCP(C); OCP(nasal)+OCP(CV)). In Set 1,

[5] Some consider /h/ to be a voiceless approximant; i.e., a voiceless sonorant (Chomsky & Halle 1968). We follow other work (Lass 1976: 64–68, Jaeger & Ohala 1984, Sagey 1986, Parker 2002) demonstrating that /h/ is a voiceless fricative.

shown in Table 2, the first syllable of one word had a nasal onset, and the second syllable of the other word had a nasal onset (e.g. ***m****oka* and *ha****n****a*). The word that did not begin with a nasal began with an obstruent (e.g. ***h****ana*). The condition in Table 2a was used to test whether the violation of OCP(nasal) is avoided. If *moka-hana* is preferred over *ha****na-mo****ka*, it would indicate that nasal clash (i.e., …***na-mo***…) is avoided. The condition in Table 2b was used to test the effects of identical consonants, in addition to the occurrence of two nasals; i.e. the effects of OCP(C). Given *niko* and *hana*, *ha****n****a-****n****iko* has a sequence of identical nasals (i.e., …***na-ni***…), thus violating OCP(C) in addition to OCP(nasal). The condition in Table 2c was used to test the OCP(CV), in addition to the OCP(C) and OCP(nasal). If *natu-hana* is favored over *ha****na-na****tu*, an identical mora across the word boundary (i.e., ...***na-na***...) may be being avoided. There are four possible combinations for each condition, and thus Set 1 consists of 12 combinations in total, as in Table 2.

Table 2: Set 1: 2 nasals (M = /m/; N = /n/; O = an obstruent; R = a sonorant)

	α	+	*β*	→	*α-β or β-α*
a.	*moka* (MO)	+	*hana/kana* (ON)	→	***m****oka-ha****n****a* (MOON) or *ha****n****a-****m****oka* (ONMO)
	natu (NO)	+	*kumi/fumi* (OM)	→	***n****atu-ku****m****i* (NOOM) or *ku****m****i-****n****atu* (OMNO)
b.	*niko* (NO)	+	*hana/kana* (ON)	→	***n****iko-ha****n****a* (NOON) or *ha****n****a-****n****iko* (ONNO)
	moka (MO)	+	*kumi/fumi* (OM)	→	***m****oka-ku****m****i* (MOOM) or *ku****m****i-****m****oka* (OMMO)
c.	*natu* (NaO)	+	*hana/kana* (ONa)	→	***n****atu-ha****n****a* (NaOONa) or *ha****n****a-****n****atu* (ONaNaO)
	mika (MiO)	+	*kumi/fumi* (OMi)	→	***m****ika-ku****m****i* (MiOOMi) or *ku****m****i-****m****ika* (OMiMiO)

Set 2, shown in Table 3, was prepared to examine whether three consecutive nasals would be avoided more strongly than two consecutive nasals. Sequences with different OCP violation profiles were also examined, as in Set 1. The nasal clash in Table 3a violates only OCP(nasal), the nasal clash in Table 3b violates OCP(nasal) and OCP(C), and the nasal clash in Table 3c violates all of OCP(nasal), OCP(C), and OCP(CV).

Table 3: Set 2: 3 nasals (M = /m/; N = /n/; O = an obstruent; R = a sonorant)

	α	+	*β*	→	*α-β or β-α*
a.	*mona* (MN)	+	*hana/kana* (ON)	→	*mona-hana* (MNON) or *hana-mona* (ONMN)
	nami (NM)	+	*kumi/fumi* (OM)	→	***n****a****m****i-ku****m****i* (NMOM) or *ku****m****i-****n****a****m****i* (OMNM)
b.	*nina* (NN)	+	*hana/kana* (ON)	→	***n****i****n****a-ha****n****a* (NNON) or *ha****n****a-****n****i****n****a* (ONNN)
	mona (MN)	+	*kumi/fumi* (OM)	→	***m****o****n****a-ku****m****i* (MNOM) or *ku****m****i-****m****o****n****a* (OMMN)
c.	*nami* (NaM)	+	*hana/kana* (ONa)	→	***n****a****m****i-ha****n****a* (NaMONa) or *ha****n****a-****n****a****m****i* (ONaNaM)
	mina (MiN)	+	*kumi/fumi* (OMi)	→	***m****i****n****a-ku****m****i* (MiNOMi) or *ku****m****i-****m****i****n****a* (OMiMiN)

In Sets 3 and 4, shown in Table 4 and Table 5, the word that did not begin with an obstruent began with a sonorant. If there is a sonority-driven word-ordering preference in Japanese, we

would expect to observe different results between Sets 1 & 2 on the one hand, and Sets 3 & 4 on the other.

Table 4: Set 3: 2 nasals (M = /m/; N = /n/; O = an obstruent; R = a sonorant)

	α	+	*β*	→	*α-β or β-α*
a.	*moka* (MO)	+	*rina/rena* (RN)	→	***m**oka-ri**n**a* (MORN) or *ri**n**a-**m**oka* (RNMO)
	natu (NO)	+	*rumi/remi* (RM)	→	***n**atu-ru**m**i* (NORM) or *ru**m**i-**n**atu* (RMNO)
b.	*niko* (NO)	+	*rina/rena* (RN)	→	***n**iko-ri**n**a* (NORN) or *ri**n**a-**n**iko* (RNNO)
	moka (MO)	+	*rumi/remi* (RM)	→	***m**oka-ru**m**i* (MORM) or *ru**m**i-**m**oka* (RMMO)
c.	*natu* (NaO)	+	*rina/rena* (RNa)	→	***n**atu-ri**n**a* (NaORNa) or *ri**n**a-**n**atu* (RNaNaO)
	mika (MiO)	+	*rumi/remi* (RMi)	→	***m**ika-ru**m**i* (MiORMi) or *ru**m**i-**m**ika* (RMiMiO)

Table 5: Set 4: 3 nasals (M = /m/; N = /n/; O = an obstruent; R = a sonorant)

	α	+	*β*	→	*α-β or β-α*
a.	*mona* (MN)	+	*rina/rena* (RN)	→	*mona-rina* (MNRN) or *rina-mona* (RNMN)
	nami (NM)	+	*rumi/remi* (RM)	→	***n**a**m**i-ru**m**i* (NMRM) or *ru**m**i-**n**a**m**i* (RMNM)
b.	*nina* (NN)	+	*rina/rena* (RN)	→	***n**i**n**a-ri**n**a* (NNRN) or *ri**n**a-**n**i**n**a* (RNNN)
	mona (MN)	+	*rumi/remi* (RM)	→	***m**o**n**a-ru**m**i* (MNRM) or *ru**m**i-**m**o**n**a* (RMMN)
c.	*nami* (NaM)	+	*rina/rena* (RNa)	→	***n**a**m**i-ri**n**a* (NaMRNa) or *ri**n**a-**n**a**m**i* (RNaNaM)
	mina (MiN)	+	*rumi/remi* (RMi)	→	***m**i**n**a-ru**m**i* (MiNRM) or *ru**m**i-**m**i**n**a* (RMiMiN)

2.3. Participants and Procedure

A total of 83 naive native speakers of Japanese participated in the experiment. All of the participants were undergraduate students at a Japanese university. There is no overlap of the participants between the current experiment and the one reported in section 3. In the instruction session, they were told that they would make up a group name for a pair of girls. In the test session, they were first given two names, and then were asked to choose one of the two combined forms (e.g., given two personal names, *mana* and *kana*, which order would you use to make up a group name, *mana-kana* or *kana-mana*?). All the names were written in the Japanese *katakana* orthography, which is commonly used to write personal names. There were a total of 48 questions (4 sets*12 combinations). The order of the questions was randomized.

2.4. Results

For statistical analysis, a generalized mixed-effects logistic regression was fit to the response using the *glmer* function in *R* (e.g., Baayen 2008). Subjects and items were coded as random effects. The first model included all the fixed factors (obs vs. son; two nasals vs. three nasals; OCP(C); OCP(CV)); follow-up specific comparisons were made based on contrast analyses using more specific logistic regression models. The resulting figures below show the ratios of

the responses that contain nasal clash on the y-axis. The results of Set 1 and Set 2 are shown in Figure 1, and those of Set 3 and Set 4 are shown in Figure 2. Error bars represent 95% confidence intervals.

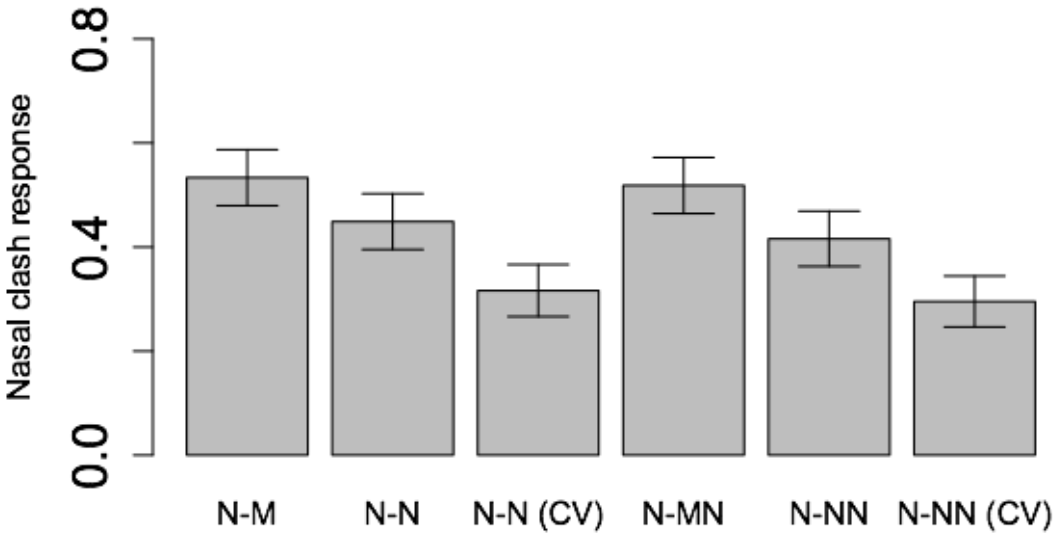
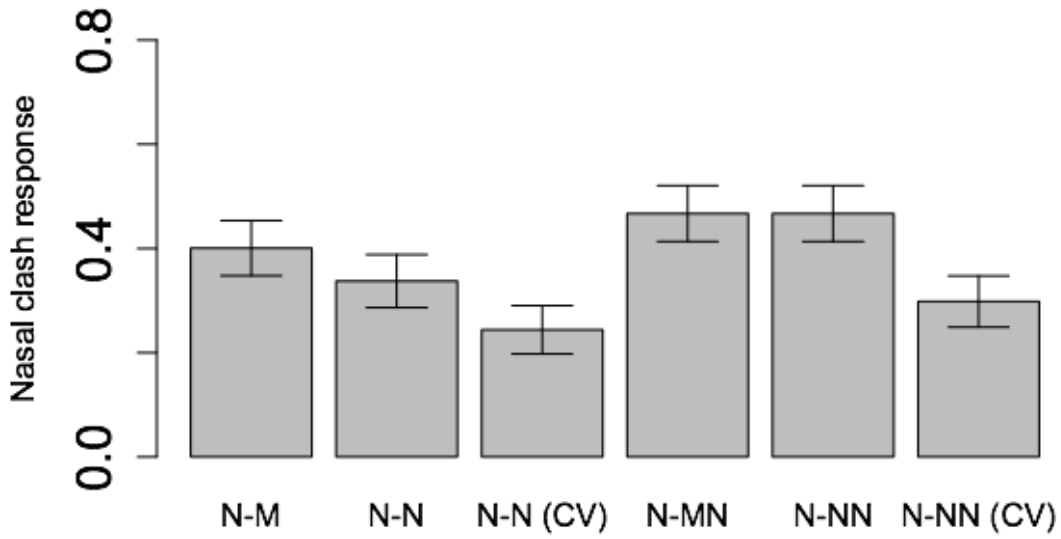


Figure 1: Nasal clash response ratio with 95% confidence intervals. Cases in which the words that do not begin with a nasal begin with an obstruent.

In Figure 1, the first three bars show cases in which two nasals are placed in adjacent syllables (e.g. *ha**n**a-**m**oka*), whereas the last three bars show cases in which three nasals are placed in proximity (*ha**n**a-**m**o**n**a*). Within each set, the three bars are ordered in the order of degrees of similarity (non-identical nasals (N-M), identical nasals (N-N), identical CV moras with a nasal onset (N-N (CV)). The actual observed average values are: 0.53 vs. 0.45 vs. 0.32 for the first three bars and 0.52 vs. 0.42 vs. 0.30 for the last three bars. For the two-nasal condition (the leftmost three bars), there were significant differences between each condition: N-M vs. N-N, z = -2.366, p < .05; N-M vs. N-N (CV), z = -6.035, p < .001; N-N vs. N-N (CV), z = -3.874, p < .001. The same holds true of three-nasal condition (the rightmost three bars) (N-MN vs. N-NN, z = -2.885, p <.01; N-MN vs. N-NN (CV), z = -6.245, p <.001; N-NN vs. N-NN (CV), z = -3.618, p <.001). We thus observe a clear tendency for the more similar sequences to be avoided more strongly. It is important to note here that the effects are gradient; we see a three-way distinction, according to different violation profiles of OCP constraints. We maintain that this

315 instantiates the effect of gradient phonological knowledge that affects the group name
316 formation pattern.
317
318 There were no effects of the number of nasal consonants involved; i.e. there were no differences
319 between the first three bars and the last three bars (z = *1.12*, *n.s.*). Finally, looking at the two
320 N-M(N) conditions, the nasal clash response ratios are over 0.5 (i.e. 0.53 and 0.52); i.e. slightly
321 higher than expected by chance. This may indicate that the avoidance of non-identical nasal
322 consonants—OCP(nasal)—is not so strong as to show tangible effects in this experiment. The
323 weak effect of OCP(nasal) will be made clearer in the MaxEnt analysis that is presented below,
324 in which the weight of OCP(nasal) is low. As we will observe below, there may be a preference
325 to put less sonorous consonants word-initially (Smith 2002), which would coerce nasal clash in
326 this condition; i.e. ***h****ana-moka* is better than ***m****oka-hana* in that the former has an obstruent
327 word-initially. This sonority-based effect may have "cancelled out" the effects of OCP(nasal).



328
329 Figure 2: Nasal clash response ratios with 95% confidence intervals. Cases in which the
330 words that do not begin with a nasal begin with a sonorant.
331
332 The first three bars in Figure 2 show the two-nasal condition, in which there were significant
333 differences between N-M and N-N (CV) (z = -4.663, p < .001) and between N-N and N-N (CV)
334 (z = -2.944, p < .01) (0.40 vs. 0.34 vs. 0.24). Though the difference between N-M and N-N did
335 not reach significance (z = -1.852, *n.s.*), it is in the expected direction. For the three-nasal

condition (the rightmost three bars), there were also significant differences between N-MN and N-NN (CV) (z = -4.919, p < .001) and between N-NN and N-NN (CV) (z = -4.956, p < .001). However, there were no significant differences between N-MN and N-NN (z = 0, *n.s.*) (0.47 vs. 0.47 vs. 0.30); there were no obvious effects of OCP(C) in this context. Surprisingly, there were slightly more nasal clash responses when there were three nasal consonants than when there were only two nasal consonants (z = 2.087, p<.05) (here but not in Figure 1). We do not have a clear explanation of these unexpected results.

Comparing Figure 1 (the obstruent condition) and Figure 2 (the sonorant condition), the proportion of nasal clash is on average lower in the sonorant conditions than in the obstruent condition (z = 3.189, p<.01). This difference shows that Japanese speakers are more likely to tolerate nasal clash when it results in word-initial obstruents (e.g. ***h**ana-mona*) than when it results in word-initial liquid (e.g. ***r**ina-mona*). There are two possible reasons for this difference. The first possibility is that /r/ is avoided as a word-initial sound. This hypothesis is possible, as there are few Japanese native words that begin with /r/ (e.g., Labrune 2014), and hence there can be a constraint like *INITIAL-/r/ at work in Japanese phonology (Kawahara 2015). The second possibility is that, as was the case for Parker's (2002) experiments with English speakers, the ordering of the two words was affected by sonority considerations: obstruent-initial words were preferred to come before nasal-initial words, and nasal-initial words were preferred to come before liquid-initial words (see Smith 2002 for related observations). Under this interpretation, while English prefers more sonorous word-initial segments, Japanese prefers less sonorous word-initial segments. In the analysis that follows, we adapt the second explanation, because it explains why there were no clear effects of OCP(nasal) in Figure 1.[6] With the second explanation, we can assume that the sonority preference and OCP(nasal) canceled each other out, resulting in the near-chance performance.

To summarize, the results indicate that when Japanese speakers are asked to make a group name based on two names, various factors affect the ordering; (i) sequences of two identical nasals are avoided; (ii) sequences of identical CV-moras are avoided even more; (iii) a word with a lower sonority consonant is preferred to be placed word-initially. As we will see, each of these factors can be represented by phonological constraints, and a MaxEnt analysis is suitable to

[6] Of course, it is possible to tease apart these two hypotheses empirically by using glide initial words in place of /r/-initial words. In our experiment, however, we found it hard to have an enough number of glide-initial, disyllabic, girls' names in Japanese.

model the overall results.

2.5. A MaxEnt analysis

To model the stochastic nature of the Japanese name ordering patterns we observed in the experiment above, we used a MaxEnt grammar model (Hayes & Wilson 2006). MaxEnt is similar to Optimality Theory (OT: Prince & Smolensky 2004) in that a set of candidates are evaluated against a set of constraints. Unlike OT, however, the constraints are weighted (rather than ranked), as in Harmonic Grammar (HG: Legendre et al. 1990, 2006; Pater 2009, 2016; Potts et al. 2010). The probabilities of each candidate are assigned based on their constraint violation profiles. More specifically, for each candidate, weighted constraint violations are summed, which is its H(armonic)-score. H-score is mapped to probabilities in such a way that $P(cand_i)=exp(-H(cand_i))$, relativized to all the other candidates so that all probabilities sum to 1.

The procedure of calculating probabilities is as follows (Hayes to appear; Hayes et al. 2009; Hayes et al. 2012; Zuraw & Hayes to appear, and Hayes & Wilson 2008, in particular):

1) Like HG, for each candidate, harmonic score (H-score) is calculated as the sum of C_i*w_i, where the candidate's violation of each constraint (C_i) is multiplied by its weight (w_i);
2) Each candidate's "bare" probability is calculated as $e^{-(\text{H-score})}$;
3) $e^{-(\text{H-score})}$ are summed over all candidates;
4) P(x), the predicted probability of candidate x, is its $e^{-(\text{H-score})}$ divided by the sum of the $e^{-(\text{H-score})}$ of all of the candidates.

We used the MaxEnt Grammar Tool (Hayes et al. 2009) to implement the analysis, which calculates optimal weights for each constraint, given the frequency distributions of actual outcomes. To implement the MaxEnt analysis, we use the following four constraints. First, *SON(C_2) > SON(C_1) disfavors forms in which the second word begins with a less sonorous consonant than the first word (e.g., /m/ > /h/ in ***m**ona#**h**ana*; /r/ > /m/ in ***r**ina#**m**ona*). Second, OCP(nasal) is a constraint that is violated by two consecutive nasal consonants across a word boundary (e.g., *ha**n**a#**m**ona*; *ri**n**a#**m**ona*).[7] Since the experimental results did not generally

[7] Since two consecutive nasal consonants within a word (e.g. ***m**o**n**a*) are shared by compared

398 show a substantial difference between sequences of two nasals and sequences of three nasals,
399 their violation profiles were not distinguished. Third, OCP(C) is violated if the two nasals
400 across the word boundary are identical (e.g., *ku**m**i#**m**ona*; *ru**m**i#**m**ona*). Fourth, OCP(CV) is
401 violated if there is a pair of adjacent identical CV-moras (e.g., *ha**na**#**na**mi*; *ri**na**#**na**mi*). The
402 violation profiles of these constraints as well as the candidate sets fed to the MaxEnt Grammar
403 Tool are shown in (1) and (2).
404
405 Table 6 shows the results of constraint weight that we obtained by the MaxEnt Grammar Tool.
406 Each MaxEnt analysis is given in (1) and (2), respectively.[8] (3) and (4) compare the observed
407 probabilities obtained in the experiment with the predicted probabilities by the MaxEnt Tool.
408 We observe that the two probabilities are highly correlated, indicating the success of the
409 MaxEnt analysis.
410
411 Table 6: Constraints used, and their weights obtained by the MaxEnt Grammar Tool

Constraints	Weight
*SON(C_2) > SON(C_1)	0.11
OCP (nasal)	0.082
OCP (C)	0.263
OCP (CV)	0.579

412

candidates, they can be ignored in our tableaux thanks to Cancellation Lemma (Prince and Smolensky 1993/2004).

[8] The harmonic scores of candidates can be used to model acceptability judgments as well (e.g., Coetzee & Pater 2008; Kumagai submitted). The idea is that, provided that the optimal candidate of each candidate set has the same violation profile, the lower a candidate's harmonic-score is *across* candidate sets, the more unlikely it is to be considered acceptable. To take the analysis in (1) for example, we can predict that *ha**n**a#**m**ona* (= -0.082) is the most harmonic, *ha**na**#**na**mi* (= -0.924) is the least harmonic, and *ku**m**i#**m**ona* (= -0.345) is in-between; as a result, *ha**na**#**na**mi* is judged to be less acceptable than *ku**m**i#**m**ona* and also that *ku**m**i#**m**ona* is less acceptable than *ha**n**a#**m**ona*.

(1) MaxEnt analysis (the obstruent condition)

	*S(C_2) > S(C_1)	OCP (nasal)	OCP (C)	OCP (CV)				
weights	0.11	0.082	0.263	0.579		H-score	$e^{-(\text{H-score})}$	Predicted Prob.
mona + (hana/kana)								
mona # (hana/kana)	-1					-0.11	0.8958	0.493
(hana/kana) # mona		-1				-0.082	0.9213	0.507
mona + (kumi/fumi)								
mona # (kumi/fumi)	-1					-0.11	0.8958	0.5585
(kumi/fumi) # mona		-1	-1			-0.345	0.7082	0.4415
nami + (hana/kana)								
nami # (hana/kana)	-1					-0.11	0.8958	0.693
(hana/kana) # nami		-1	-1	-1		-0.924	0.3969	0.307

(2) MaxEnt analysis (the sonorant condition)

	*S(C_2) > S(C_1)	OCP (nasal)	OCP (C)	OCP (CV)				
weights	0.11	0.082	0.263	0.579		H-score	$e^{-(\text{H-score})}$	Predicted Prob.
mona + (rina/rena)								
mona # (rina/rena)						0	1	0.5479
(rina/rena) # mona	-1	-1				-0.192	0.8253	0.4521
mona + (rumi/remi)								
mona # (rumi/remi)						0	1	0.6118
(rumi/remi) # mona	-1	-1	-1			-0.455	0.6344	0.3882
nami + (rina/rena)								
nami # (rina/rena)						0	1	0.7377
(rina/rena) # nami	-1	-1	-1	-1		-1.034	0.3556	0.2623

(3) Set 1 & 2

Forms	Observed P	Predicted P
mona # (hana/kana)	0.47	0.49
(hana/kana) # mona	0.53	0.51
mona # (kumi/fumi)	0.57	0.56
(kumi/fumi) # mona	0.43	0.44
nami # (hana/kana)	0.70	0.69
(hana/kana) # nami	0.30	0.31

(4) Set 3 & 4

Forms	Observed P	Predicted P
mona # (rina/rena)	0.57	0.55
(rina/rena) # mona	0.43	0.45
mona # (rumi/remi)	0.60	0.61
(rumi/remi) # mona	0.40	0.39
nami # (rina/rena)	0.73	0.74
(rina/rena) # nami	0.27	0.26

2.6 Summary

In this section, we examined the group-name formation pattern in Japanese, in which two names are combined together to form a group name. We observed that similarity avoidance plays a

visible role in this word formation in such a way that similarity at the word boundary is avoided, and the higher the similarity, the more strongly it is disfavored. In particular, sequences of two nasals and sequences of CV-moras with two identical nasals were particularly disfavored. Importantly, however, no phonological constraints were deterministic, i.e. inviolable. They simply reduced the probability of nasal clash. In this sense, identity avoidance constraints stochastically affect the word formation pattern. We modeled these gradient patterns using a MaxEnt grammar as well as different types of OCP constraints. We also found that Japanese speakers may prefer to have less sonorous consonant word-initially. Although this preference toward lower sonority has been known cross-linguistically (Smith 2002), we believe that it is a new finding for Japanese.

3. Rendaku as evidence for stochastic phonological knowledge

3.1. Identity Avoidance in rendaku

We next turn to an analysis of another word formation pattern, rendaku, which shows another case of the stochastic and systematic influences of identity avoidance constraints on a word formation pattern. This section analyzes the experimental data presented by Kawahara & Sano (2016), in order to show the generality of the constraints and analysis developed in section 2. Before delving into the analysis, we first briefly review the experiment design and results.

The purpose of Kawahara & Sano (2016) was to examine whether identity avoidance blocks rendaku application. The set of stimuli in Table 7 was used to test the effects of identity avoidance at the consonantal level (i.e., OCP(C)), and the set in Table 8 was used to test the effect of identity avoidance at the CV-moraic level (i.e., OCP(CV)). In each set, their stimuli contained four first elements (E1s) and three different second elements (E2s) for each consonant /k, t, s, h/ that potentially undergoes rendaku, which yielded 12 E2s for each E1. There were thus 48 combinations in total.

Table 7: The list of the stimuli used in Set 1. All combinations of E1 and E2 (4 * 12 =48) were tested. E2 were nonce words.

E1		E2		
/iga/	*	/keniro/	/komoke/	/korimo/
/aza/		/seniro/	/somoke/	/sorimo/
/kuda/		/teniro/	/tomoke/	/torimo/
/kaba/		/heniro/	/homoke/	/horimo/

Table 8: The list of the stimuli used in Set 2.

E1		E2		
/iga/	*	/kaniro/	/kamoke/	/karimo/
/aza/		/saniro/	/samoke/	/sarimo/
/kuda/		/taniro/	/tamoke/	/tarimo/
/kaba/		/haniro/	/hamoke/	/harimo/

The participants were 43 native speakers of Japanese, who were undergraduate students of a Japanese university. None of them participated in the experiment presented in Section 2. The experiment was conducted online using SurveyMonkey. In the test, they were presented with two elements (E1 and E2) and two forms (rendaku and non-rendaku forms), and were then asked which was more natural; i.e. it was a forced-choice wug test (Berko 1958). The stimuli were presented in the hiragana Japanese orthography, the standard orthography to write native words (rendaku generally applies only to native words). The order of the stimuli was randomized. See Kawahara & Sano (2016) for further details.

Figure 3 shows the results of the applicability of rendaku for each condition. The results showed that there was a significant difference between cases that violate moraic identity avoidance and those without any violation (0.27 vs. 0.44; $z = 5.32$, $p < .001$). The results also show that there was a significant difference between consonantal identity avoidance and the control group (0.39 vs. 0.45; $z = 2.23$, $p < .05$). They also found a significant difference between moraic identity avoidance and consonantal identity avoidance ($z = 4.55$; $p < .001$), which suggests that the effect of identity avoidance is stronger at the CV-moraic level (the first bar) than at the consonantal level (the third bar).

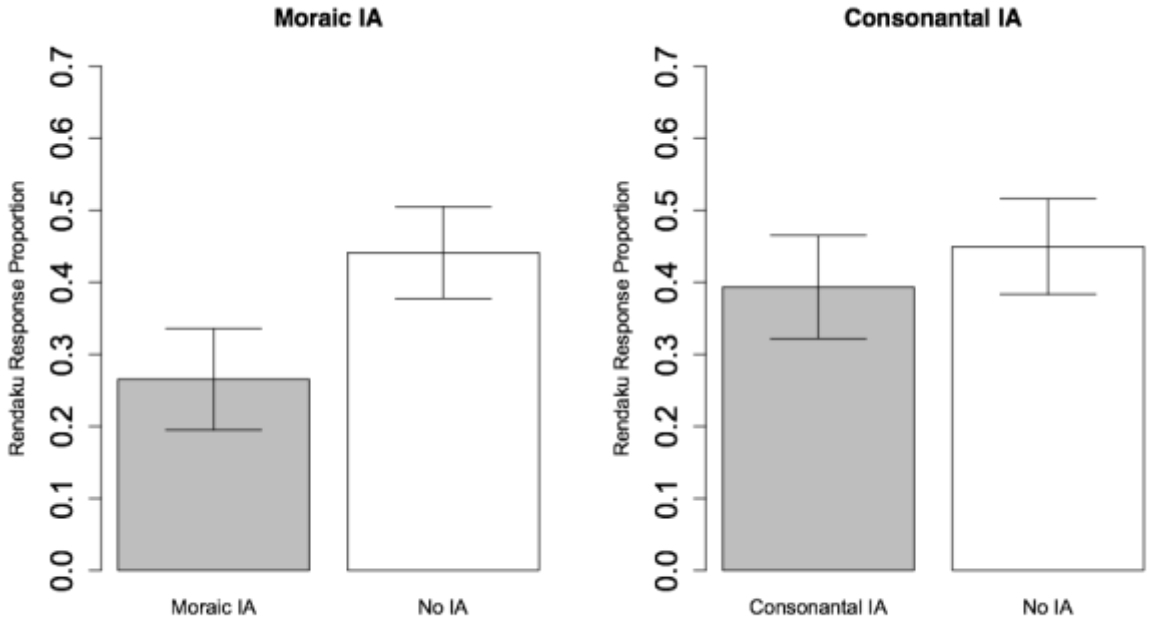


Figure 3: Proportion of rendaku application in each condition (adapted from Kawahara & Sano 2016)

To sum up, Kawahara & Sano (2016) showed that rendaku is less likely to occur when it results in identical consonants in adjacent moras. Furthermore, the applicability of rendaku was even more reduced when rendaku resulted in adjacent identical CV moras. These results exemplified a case in which the more similar the strings of segments that rendaku creates, the more likely it is avoided, again a case of gradient phonological effects on word-formation patterns. Like the case we analyzed in section 2, the effects of phonological constraints were stochastic; they did not deterministically block rendaku—they merely reduced the probability of rendaku application.

3.2. A MaxEnt analysis

For the current MaxEnt analysis of rendaku, we used four constraints. Following the most comprehensive OT analysis of Japanese rendaku presented by Ito & Mester (2003), we use REALIZE MORPHEME (RM) and IDENT (voice); the former constraint encourages rendaku, assuming that rendaku is a realization of a compound juncture morpheme. IDENT(voice) disfavors rendaku, because rendaku changes the underlying specification of a [voice] feature. We also used OCP(C) and OCP(CV) defined in Section 2.

Like the MaxEnt analysis presented in section 2, two candidates (rendaku and non-rendaku forms) were evaluated for each input form, with the violation profiles shown in (5). The results appear in Table 9 and (6). The MaxEnt learner learned the experimental results with success, with the multiple OCP constraints we posited in section 2; the predicted probabilities are almost identical to the observed probabilities, as shown in (6).

(5) A MaxEnt analysis of rendaku

	RENDAKU	IDENT (voice)	OCP (C)	OCP (CV)		H-Score	$e^{-(\text{H-score})}$	Predicted Prob.
weights	4.89	5.1	0.24	0.60				
/…pa+ta…/								
…pata…	-1					-4.89	7.52*10^-4	0.55
… pada…		-1				-5.1	6.10*10^-4	0.45
/…ga+ko…/								
…gako…	-1					-4.89	7.52*10^-4	0.61
…gago…		-1	-1			-5.34	4.80*10^-4	0.39
/…ga+ka…/								
… gaka	-1					-4.89	7.52*10^-4	0.74
… gaga…		-1	-1	-1		-5.69	3.38*10^-4	0.26

Table 9: The posited constraints, and the obtained weights.

Constraints	Weight
RM	4.89
IDENT (voice)	5.1
OCP (C)	0.24
OCP (CV)	0.6

(6) Observed and predicted probabilities.

Forms	Observed	Predicted
…pa#ta…	0.55	0.55
…pa#da…	0.45	0.45
…ga#ko…	0.61	0.61
…ga#go…	0.39	0.39
…ga#ka…	0.74	0.74
…ga#ga…	0.26	0.26

4. Conclusions

The current paper explored a stochastic yet systematic aspect of Japanese word formation in group name formation and rendaku. In both types of word formation, sequences of two moras with the same nasal consonants are avoided, and sequences of two identical moras are avoided even more. However, it is not that case that a violation of one of these constraints entirely

dictates the word formation pattern; the effects of phonological constraints are probabilistic, suggesting that phonological constraints can impose stochastic influences on word formation. We also showed that a MaxEnt grammar is a general, useful tool to model such stochastic patterns. Overall, this research contributes to the growing body of literature showing that phonological knowledge can be stochastic and systematic.

In addition to these contributions to the issue of gradiency, we would like to highlight the fact that we are the first ones to systematically analyze the formation of group names in Japanese from the perspective of formal phonological theory. Moreover, the type of experiment we conducted, in which the participants were asked to order two words, is not very often used in experimental linguistics (except for Parker 2002). The results in section 2 show that this result is useful in revealing some aspects of phonological knowledge that Japanese speakers possess. In particular, we discovered that Japanese speakers may favor to place less sonorous consonant word-initially. We hope that this methodology will be used to explore the nature of other phonological and morphological patterns in other languages. In particular, since identity avoidance is observed across many languages, it is of interest to test the generality of how identity avoidance may affect the formation of new coordinate compounds, like those tested in section 2 of this paper.

Acknowledgments

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