# *Japanese Mental Syllabary and Effects of Mora, Syllable, Bi-mora and Word Frequencies on Japanese Speech Production*

**Katsuo Tamaoka**[1], **Shogo Makioka**[2]

[1] *Nagoya University, Nagoya, Japan*
[2] *Osaka Prefecture University, Sakai, Japan*

**Key words**

*bi-mora frequency*

*Japanese language*

*light and heavy syllables*

*mental syllabary*

*mora frequency*

*word frequency*

## Abstract

The present study investigated the existence of a Japanese mental syllabary and units stored therein for speech production. Experiment 1 compared naming latencies between high and low initial mora frequencies using CVCVCV nonwords, indicating that nonwords with a high initial mora frequency were named faster than those with a low frequency initial mora. Experiments 2 and 3 clarified the possibility of CV light and CVN/CVR heavy syllables as being units implicated in speech production. CVNCV nonwords in Experiment 2 and CVRCV nonwords in Experiment 3 displayed shorter naming latencies and lower error rates than their baseline (same bi-mora frequencies) of CVCVCV-structured nonwords. Since bi-mora frequencies between CVN/CVR and CVCV were the same, heavy syllables comprised of CVN and CVR units may contribute to ready-made motor-programs stored in the Japanese mental syllabary as variations of the 100 core light syllables (300 units in total). Experiment 4 further tested the effects of bi-mora frequency on the naming of nonwords, and found that CVCVCV-structured nonwords with high bi-mora frequencies were named more quickly and accurately than those with low bi-mora frequencies, although some bi-mora combinations seem to exhibit nonconforming tendencies (i.e., null significance in item analysis). Experiment 5 demonstrated that the naming of real words with high word frequency was quicker than for other real word conditions with low word frequencies (i.e., word frequency effects), with little effect of bi-mora frequencies. Unlike the nonword condition of Experiment 4, bi-mora frequency had only a minor influence on the naming of real words. Based on these findings, the present study proposes a possible model of the Japanese mental syllabary accompanied by a discussion of bi-mora and word frequency effects.

## 1 Introduction

Single Japanese words like “family” /kazoku/ can be phonologically classified into three different units: a lexical unit of /kazoku/, bi-mora units of /kazo/ and /zoku/, and

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*Address for correspondence.* Katsuo Tamaoka, Graduate School of Languages and Cultures, Furou-cho, Chikusa-ku Nagoya University, 464-8601, Japan; <ktamaoka@gc4.so-net.ne.jp>

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mora units of /ka/, /zo/, and /ku/. It is a well-known fact that word frequency affects phonological processing (e.g., Forster & Chambers, 1973; Rubenstein, Garfield, & Milllikan, 1970; Taft, 1979, 1991; Whaley, 1978, for word frequency effect in English; Fushimi, Ijuin, Patterson, & Tatsumi, 1999; Hino & Lupker, 1998; Tamaoka & Takahashi, 1999, for word frequency effect in Japanese) in the way that the thresholds of frequently-seen words is lower, making activation of phonological representations easier. However, it has not yet been conclusively demonstrated whether smaller non-lexical units of mora, syllable, and bi-mora frequencies affect Japanese phonological processing independent of word frequency. Thus, the present study conducted five experiments using a naming task for Japanese words and nonwords to investigate the four factors of mora, syllable, bi-mora, and word frequencies.

## 2 The unit of Japanese speech production

Previous studies (e.g., Cutler & Otake, 1994; Kubozono, 1985, 1989, 1995; Otake, Hatano, Cutler, & Mehler, 1993; Otake, Hatano, & Yoneyama, 1996) reported that native Japanese speakers use moraic units for auditory perception and speech segmentation. This claim seems reasonable when certain examples of Japanese script, culture and children’s play are considered.

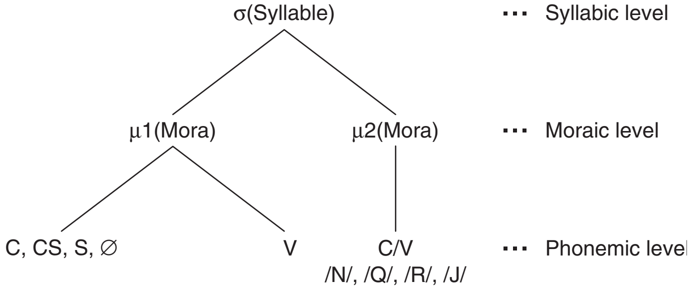
The most common observational intuition is that the Japanese phonetic script *kana* represents moraic units, so that the unit of mora should be used for Japanese orthographic and phonological processing. From a cultural perspective, it is a popular notion that since the well-known Japanese *haiku* is composed on the basis of 17 morae (i.e., three phrases of 5–7–5 morae), the mora unit is most likely to be the unit for Japanese phonetic counting. From a developmental perspective, through the phonetic game *shiritori*, a word game requiring the segmentation of beginning and ending morae, Japanese children become aware of morae as important units for Japanese speech segmentation and phonetic assembly. As such, observations based on selected examples of Japanese script, poetic verse and children’s play suggest the possibility of the *mora* as a Japanese phonetic unit.

However, as shown in Figure 1, recent studies in Japanese phonology (e.g., Haraguchi, 1996; Kubozono, 1989, 1995, 1999; Kubozono & Ota, 1998; Terao, 2002) propose that morae and syllables may coexist in a single hierarchical structure. In this structure, the lowest phonological level is the phonemic level, representing consonants, semivowels, and vowels. The next higher level is the moraic level. The first mora ($\mu_1$) is constructed from a consonant (C), a semivowel (S; more precisely referring to the semivowels /y/ and /w/), a vowel (V) and empty (Ø), and the second mora ($\mu_1$) from a consonant (i.e., a moraic nasal /N/ or a moraic geminate /Q/) or a vowel (i.e., a long vowel /R/ or a dual vowel /J/). The highest level in the figure is the syllabic level. Units at this level are constructed from C(S)V and C/V, which create CVC and CVV syllables, with the occasional single V or SV structure with an empty consonant (i.e., ØV and ØSV).

Japanese sounds are usually represented by a CV structure including ØV and ØSV which consist of one mora, while all the four special sounds (i.e., moraic nasal /N/, geminate /Q/, long vowel /R/ and dual vowel /J/), which form a CVC or a CVV

**Figure 1**

Fundamental structure of Japanese phonemes, morae, and syllables.



*Note*: A combination of C (consonant) and S (semivowel) is considered as one phonemic unit. "∅;" refers to an empty phonemic unit.

phonological structure, are a single syllable. If a CV-structured single mora is regarded as a *light syllable*, the CVC/CVV structure can be understood as unit comprising a *heavy syllable*. Based on this syllabic concept, then, it is quite possible that all Japanese morae can be interpreted as syllabic units.

Tamaoka and Terao (2004) conducted two experiments to investigate the unit for naming visually presented stimuli, focusing on the special sounds /N/, /Q/, /R/ and /J/. These special sounds create two morae when there is only one syllable. Their experiments compared the production of three-mora three-syllable (i.e., CVCVCV) and three-mora two-syllable (i.e., CVNCV, CVRCV, CVQCV and CVJCV) nonsense words. Findings indicated that native Japanese speakers named the three-mora nonwords containing the special sounds more quickly than those of the former group. Accordingly, we posited that special sounds would be named as syllables rather than morae. The computational load of Japanese speech production could be greatly decreased by assembling sounds at the syllabic level in Figure 1. Consequently, in addition to evidence provided in Tamaoka and Terao (2004), the present study also investigated whether or not syllables (as opposed to morae) are used for speech production by controlling bi-mora frequencies.

## 3 Type and token frequencies of morae, syllables, and bi-morae

There are two ways to represent "frequency": *type* and *token*. *Type frequency* counts a word only once, whereas *token frequency* simply represents the number of times a target item appears. Should the item in question be a word, the token frequency is also known as *word frequency*. Amano and Kondo (2000, and 2003 for the CD-ROM version) established a lexical database 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. According to this database, the four-mora word "economic" /ke i za i/ appears 130,052 times, the token frequency of the word. In contrast, the value of type frequency for this word remains as 1. *Mora frequency* refers to how often each mora appears in Japanese texts. The mora /ke/ in

/keizai/ is counted as 1 for type frequency while the token frequency for /ke/ in the word is 130,052 and the mora /i/ is counted as 2 for type frequency while the token frequency for /i/ in this word doubles to become 260,104.

In that all Japanese words can be presented in kana, using the lexical database of Amano and Kondo (2000, 2003), Tamaoka and Makioka (2004) created an index of mora frequencies by counting how often each mora appears in Japanese texts. Since token frequency represents how often morae, bi-morae, and words are encountered in real life, the present study used this as an index to investigate the frequency effects of morae, syllables, bi-morae, and words on Japanese phonological processing. It should, however, be noted that the lexical database of Amano and Kondo is based on the written form used in a newspaper, not the spoken form of daily conversation. Nevertheless, this lexical frequency index is the largest collection of Japanese lexical items currently available, and the only existing speech corpora in Japanese are yet too limited in size to be used for our purpose of determining frequency counts. The use of such corpora would only serve to skew moraic distribution as a result of being biased on a limited number and nature of both words and topics. Thus, the present study utilized the lexical database of written form provided by Amano and Kondo (2000, 2003).

*Bi-mora frequency* refers to how often two morae are combined in Japanese, and is calculated on the basis of kana combinations using the same lexical database. For example, the frequency of the combination of the morae, /hi/ and /to/ (in this order) appears as a lexical unit (or word meaning "human") 229,773 times, whereas the same combination appears 615,869 times as a part of words (e.g., counting appearances of /hitode/ meaning "a starfish" and /hitomi/ meaning "pupils of one's eyes"), including its combination in the single word "human" /hito/. Syllable frequencies of CVR, CVJ, CVN and CVQ depicted in Figure 1 are possible to count as bi-mora frequencies of CV plus R, J, N or Q. Since the lexical database of Amano and Kondo (2000, 2003) stores word frequency counts as lexical units, bi-mora frequencies in the present study refer to those used in Tamaoka and Makioka (2004), which are limited to within-word boundaries; cross-word boundaries were therefore excluded.

## 3.1
## Mora frequencies

As shown in Table 1, the top 20 mora frequencies were ranked based on token frequencies taken from Appendixes A and B of Tamaoka and Makioka (2004). The token frequency for the most frequently-used mora, the vowel /i/, was 43,985,426. The sound /i/ is a single phoneme, but it is also regarded as a single mora constructed by a combination of an empty consonant and a single vowel (i.e., Ø+V structure). The second most commonly used mora was /u/, one of the five vowels which is also the same Ø+V structure, being counted 39,052,254 times. The third most common mora was the nasal /N/, regarded as a single mora. Although the sound /N/ is considered one of the "special" sounds, this should not be confused as implying "unusual." Rather, being counted 35,719,268 times, the /N/ sound is quite common among Japanese morae. Interestingly, the nasal /N/ never appears in the initial position of Japanese words, so that it is always part of a CVN structure (C can be empty, represented as VN) which can be regarded as a single (heavy) syllable. While the commonly-appearing

**Table 1**

The top 20 single morae frequencies

| | | *Single mora frequency* | | |
|---|---|---|---|---|
| # | *Kana* | *Phoneme* | *Structure* | *Token freq.* |
| 1 | イ | i | ØV | 43,985,426 |
| 2 | ウ | u | ØV | 39,052,254 |
| 3 | ン | N | N | 35,719,268 |
| 4 | ル | ru | CV | 28,899,891 |
| 5 | カ | ka | CV | 20,530,065 |
| 6 | ノ | no | CV | 19,326,674 |
| 7 | ク | ku | CV | 17,211,261 |
| 8 | ト | to | CV | 17,102,180 |
| 9 | シ | si | CV | 16,518,016 |
| 10 | タ | ta | CV | 16,442,465 |
| 11 | ニ | ni | CV | 14,757,618 |
| 12 | オ | o | ØV | 14,053,377 |
| 13 | ハ | ha | CV | 12,594,714 |
| 14 | コ | ko | CV | 12,154,255 |
| 15 | ガ | ga | CV | 11,996,376 |
| 16 | テ | te | CV | 11,037,767 |
| 17 | ナ | na | CV | 10,498,607 |
| 18 | ダ | da | CV | 9,953,427 |
| 19 | キ | ki | CV | 9,926,212 |
| 20 | ツ | tu | CV | 9,612,206 |

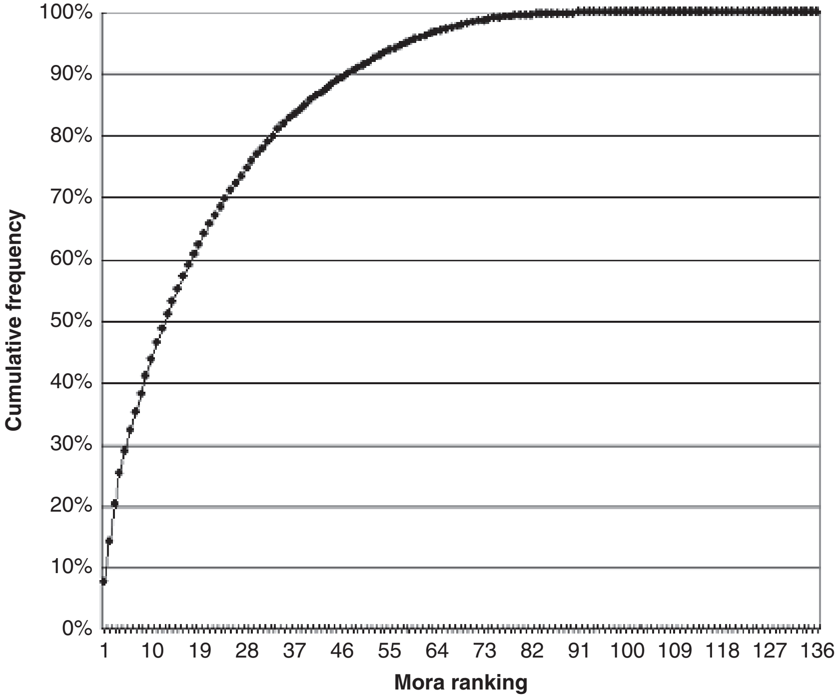
C+V-structured moraic sounds comprised 16 of the top 20 morae, they are not included among the top three.

Both the English and Dutch languages have more than 12,000 different syllables; however, 500 different syllables comprise about 80% of English and 85% of Dutch (Schiller, Meyer, Baayen, & Levelt, 1996; Schiller, Meyer, & Levelt, 1997) utterances. Furthermore, a small number of 80 syllables cover 50% of speech in these languages. Contrary to English and Dutch, there are commonly-used 100 basic mora and 3 Japanese moraic special sounds of /N/, /R/ and /Q/. The massive adoption of alphabetic loanwords, especially from English, has resulted in various new sounds used in modern Japanese. Taking this new trend into consideration, a list of an additional 33 morae (or kana) was officially issued for these loanwords through a cabinet announcement by the Government of Japan (1991); however, these 33 morae are rare in comparison with mora frequencies of the core 100 morae. As Levelt, Roelofs, and Meyer (1999, p.32, Figure 15) depicted for English syllables, Figure 2 presents the cumulative frequency of use for the 136 morae (i.e., 100 core mora, 3 special moraic sounds and 33 additional sounds), ranked according to token frequencies using frequency data taken from Tamaoka and Makioka (2004). A remarkable departure from English and Dutch syllabic frequency data is found with Japanese, in that the top 13 morae encompass 51.12%, the top 33 morae 80.04%, the top 47 morae 90.05%, and the top 75 morae 99.05% out of the total 579,424,250 mora appearances in a Japanese newspaper.

Another great difference between Japanese and English is seen in terms of the proportion of possible syllables/morae. The 80 major English syllables cover only 0.67% of total possible syllables (80 divided by 12,000) while the top 13 morae in Japanese consist of 9.55% of a total of 136 morae. Therefore, it takes less than 5% of the possible syllables to cover 80% of English syllables, but 24.26% of the possible morae (33 morae divided by 136) to cover 80% of all Japanese morae. Consequently, Japanese takes a far greater percentage of morae to cover the same number of syllables in English.

**Figure 2**

Cumulative frequency distribution for the 136 morae in Japanese



*Note*: Data taken from Tamaoka and Makioka (2004).

Since a smaller proportion of syllables were repeatedly used in Dutch and English, Levelt and his colleagues (Levelt, 1999, 2001; Levelt et al., 1999) suggested the existence of an independent mental storage consisting of a small number of ready-made, syllabic motor-programs. Within the theoretical framework of lexical access in speech production, syllables act at the interface of phonological and phonetic encoding. Abstract phonological syllables, which provide pre-compiled gestural scores for the articulators, are converted into phonetic syllables, rather than motor syllables online. Since stored representations corresponding to syllabic units are retrieved from the mental syllabary, the retrieval process should be sensitive to their frequencies. Based on this hypothesis, Levelt and Wheeldon (1994) tested their hypothesis of the *mental syllabary* by comparing access latencies of high- and low-frequency syllables controlling for word frequency, finding that words with high-frequency syllables were named faster than those with low-frequency syllables. This observation supported the notion of the mental syllabary. Further, recent studies report syllable frequently effects on speech production in Spanish (Carreiras & Perea, 2004; Stenneken, Conrad, & Jacobs, 2007), French (Brand, Rey, Peereman, & Spieler, 2002), and Dutch (Cholin, Levelt, & Schiller, 2006). Since the Japanese language has a limited number of easily-identifiable syllabic (or moraic) units, these findings imply that a similar mental syllabary also exists in the Japanese language.

### 3.2

### Syllable and bi-mora frequencies

As shown in Table 2, the most frequently-used bi-mora was the combination of /ka/ and /i/, having been counted 4,269,940 times. Similarly, the second most commonly used bi-mora /te/+/i/ represents a combination in which the first CV is followed by the vowel /i/. The third most commonly used bi-mora /ko/+/u/ appears very often as a unit /koR/. The second mora /u/ becomes the sound /o/ which most frequency results in a long vowel /R/. The fourth most frequently occurring bi-mora, /se/+/i/, reflects the same pattern as the first and the second cases. All these combinations of the top four bi-morae are often regarded as either two moraic units or a single syllabic unit. Surprisingly, 15 of the top 20 bi-morae fall into the category of CVC or CVV syllabic structures as depicted in Figure 1 (e.g., Haraguchi, 1996; Kubozono, 1989, 1995, 1998, 1999; Kubozono & Ota, 1998; Terao, 2002). Thus, it is interesting to find that syllabic units are commonly seen in Japanese bi-mora structures. As previously mentioned, since CVV/CVC-structured syllabic units occur only with the four special sounds which cover about 8–9% of Japanese morae, it may be more suitable to consider the units of the mental syllabary in the Japanese language as light/heavy syllables, rather than morae.

### 3.3

### Outline of five experiments

The present study consisted of five experiments to separately investigate the complex effects of mora, syllable, bi-mora, and word frequencies.

Experiment 1 was conducted to prove the effects of mora frequency using the naming task of CVCVCV-structured nonwords comprised of high- and low-frequency items for the initial CV mora. If nonwords with a high-frequency initial mora were

**Table 2**

The top 20 single bi-morae frequencies

| | | *Bi-mora frequency* | | |
|---|---|---|---|---|
| # | *Kana* | *Phoneme* | *Structure* | *Token freq.* |
| 1 | カイ | ka + i | CVV | 4,269,940 |
| 2 | テイ | te + i | CVV | 3,851,691 |
| 3 | コウ | ko + u | CVV | 3,669,655 |
| 4 | セイ | se + i | CVV | 3,661,544 |
| 5 | カン | ka + N | CVN | 3,044,363 |
| 6 | イル | i + ru | ØVCV | 3,016,280 |
| 7 | スル | su + ru | CVCV | 2,935,841 |
| 8 | トウ | to + u | CVV | 2,708,538 |
| 9 | ナイ | na + i | CVV | 2,653,620 |
| 10 | レル | re + ru | CVCV | 2,643,258 |
| 11 | タイ | ta + i | CVV | 2,632,623 |
| 12 | ウシ | u + si | ØVCV | 2,282,422 |
| 13 | ケン | ke + N | CVN | 2,221,991 |
| 14 | ダイ | da + i | CVV | 2,120,498 |
| 15 | セン | se + N | CVN | 2,106,924 |
| 16 | ヨウ | yo + u | CVV | 1,999,208 |
| 17 | ドウ | do + u | CVV | 1,930,217 |
| 18 | シン | si + N | CVN | 1,915,000 |
| 19 | コク | ko + ku | CVCV | 1,851,379 |
| 20 | サン | sa + N | CVN | 1,764,878 |

named faster than those with the low-frequency initial mora, it would support the idea of the mental syllabary (Levelt et al., 1999) at the moraic level. We therefore extended the processing unit from mora to syllable through two additional experiments, Experiments 2 and 3.

Since the special sound /N/ can be attached to any basic mora unit (ØV, CV, ØSV, CSV), the present study hypothesized that the syllabic CVN unit (as equal to the CV unit) could be the processing unit for Japanese speech production. Once the moraic units of ØV, CV, ØSV and CSV are regarded as light syllables and the syllabic units of +N and +R as heavy syllables, units in the Japanese language for speech production can be considered as *syllables*, not *morae*. Thus, Experiment 2 compared the naming latencies of CVNCV (three morae or two syllables) and CVCVCV (three morae or three syllables) nonwords, controlling for the bi-mora frequencies of these two conditions (CV+N and N+CV for the CVNCV condition, and the initial bi-mora and secondary bi-mora combinations for the CVCVCV condition).

One other special sound, /R/, can also be attached to any basic mora unit. Thus, Experiment 3 compared naming latencies between the CVRCV-structured nonwords (three morae or two syllables) and the CVCVCV-structured nonwords (three morae or three syllables), again by controlling for bi-mora frequencies. If both Experiments 2 and 3 would show that three-mora CVNCV and CVRCV have shorter naming latencies than their counter nonwords of CVCVCV, two types of heavy syllables, CVN and CVR could be a part of the Japanese mental syllabary produced as two variations from the core 100 basic morae or light syllables.

Independent of mora frequency effects, Experiment 4 compared the naming latencies of three-mora CVCVCV-structured nonwords with high bi-mora frequencies and low bi-mora frequencies using identical moraic units with different bi-mora combinations. The high-frequency bi-morae would likely be activated more quickly and accurately than less frequently-used bi-morae.

Finally, Experiment 5 compared naming latencies for three-mora CVCVCV-structured real words (1) with high word and high bi-mora frequencies, (2) with high word and low bi-mora frequencies, and (3) with low word and low bi-mora frequencies. This experiment expected that the effects of mora and bi-mora frequencies influence the speed of speech production (or shorter naming latencies) independent of the lexical nature of word frequency.

# 4 Experiment 1: Comparison of CVCVCV-structured nonwords with high and low frequency initial mora

Experiment 1 was conducted to compare naming latencies and error rates of nonwords between the high and low initial mora ($CV_1$) frequency using $CV_1\,CV_2\,CV_3$ -structured nonwords.

## 4.1
## Method

### 4.1.1
### Participants

Twenty-eight graduate and undergraduate students (12 females and 16 males) at Hiroshima University in Japan, all native speakers of Japanese, participated in Experiment 1. Ages ranged from 19 years and 1 month to 24 years and 5 months, with the average age being 20 years and 8 months on the day of Experiment 1.

### 4.1.2
### Stimuli

Nonwords in the present study were defined as items which did not exist in a large lexical database of 341,771 morphemes (type frequency) established from newspapers containing 287,792,797 morphemes (token frequency), all of which were taken from editions of the *Asahi Newspaper* printed from 1985 to 1998 (Amano & Kondo, 2000, 2003). Only basic 100 morae, excluding the 33 additional morae and the 3 special sounds (see Appendix A of Tamaoka & Terao, 2004), were used to produce nonword stimuli.

In light of high and low initial mora ($CV_1$) frequencies, two types of $CV_1CV_2CV_3$-structured nonwords were created by a pair-matched selection. For example, a $CV_1CV_2CV_3$-structured nonword ノケガ /no ke ga/ has a high initial mora frequency /no/, appearing 19,326,674 times in the newspaper lexical database of Amano and Kondo (2000, 2003) calculated by Tamaoka and Makioka (2004). A $CV_1CV_2CV_3$-structured nonword with a low initial mora frequency ヌケガ /nu ke ga/ was paired with this nonword. The initial mora frequency of this nonword is 411,356 times. The difference in initial mora frequencies between this pair was a quite large, being 18,915,318 times. Yet, /no ke ga/ and /nu ke ga/ share identical second $CV_2$/ke/ and third $CV_3$/ga/ morae.

Furthermore, since it is known that initial phonemes affect the terminating point of a voice-key device for measuring naming latencies (e.g., Sakuma, Fushimi, & Tatsumi, 1997; Tamaoka & Hatsuzuka, 1997; Yamada & Tamaoka, 2003), the same initial consonant /n/ was selected for the pair. Thus, the only difference in the pair is actually the first vowel /o/ and /u/ included in $CV_1$ . In addition, since vowel repetition such as /no ko go/ is likely to slow down Japanese naming latency (Tamaoka & Murata, 2001; Tamaoka, Makioka, & Murata, 2004), three different vowels in $CV_1CV_2CV_3$ were selected for producing nonword items. In this manner, 20 sets, or pairs (40 nonwords), were created as shown in Appendix 1. A set of 40 CVCVCV-structured dummy nonwords (not analyzed) were mixed with the aforementioned 40 experimental nonwords, so that a total of 80 nonwords (40 experimental + 40 dummy nonwords) were created for Experiment 1. All these nonwords were visually presented in the katakana script, which is generally used to present foreign loanwords consisting of a fewer proportion of Japanese lexical items.

The means and standard deviations of initial mora and bi-mora frequencies are reported in Table 3. Paired sample *t*-tests were conducted on frequencies of 20 sets of stimuli. As expected, two nonword groups of high and low initial mora frequencies significantly differed, $t(19) = 6.085$, $p < .001$. Three-mora $CV_1CV_2CV_3$-structured stimuli were divided into two left- and right-side bi-mora CVCV combinations. A

**Table 3**

$CV_1CV_2CV_3$-structured nonwords comparison of high- and low-frequency first mora

| *Condition of mora frequency* | *First mora frequency* | | *Left side* | | *Right side* | |
|---|---|---|---|---|---|---|
| | *M* | SD | *M* | SD | *M* | SD |
| High | 9,633,236 | 6,822,595 | 2134 | 2945 | 2266 | 4486 |
| Low | 652,803 | 492,691 | 2259 | 5045 | 2266 | 4486 |

*Note 1:* 20 stimulus items; *M* = mean; SD = standard deviation.

*Note 2:* "Left side" refers to $CV_1$,$CV_2$ bi-mora frequency while "right side" to $CV_2CV_3$ frequency.

paired sample *t*-test was conducted for bi-mora frequencies on the left side (bi-mora frequencies of $CV_1$ and $CV_2$) between nonwords of the high and low initial mora ($CV_1$) frequencies. Results showed no significant difference, $t(19) = -0.214$, $p = .833$. Bi-mora frequencies on the right side ($CV_2$ and $CV_3$) were identical. As such, these 20 sets of nonwords were suitable for examining the effect of initial mora frequency.

#### 4.1.3
#### Procedure

Stimulus items of CVCVCV-structured nonwords were randomly presented to participants in katakana at the center of a computer screen 600 ms after the appearance of an eye fixation point marked by an asterisk ("*"). Participants were required to pronounce each visually-presented nonword appearing on the screen as quickly and accurately as possible. A voice-activated key turned off the timer to measure the naming latency. The correctness of pronunciation was entered into the computer by the examiner as being either "correct" or "incorrect." The next fixation point was presented 600 ms after the examiner pressed the key.

### 4.2
### Analysis and results

Only correctly pronounced stimulus items were used in the analyses of naming latencies. No extremes in naming latencies (less than 200 ms and longer than 2000 ms) were found. Before performing the analysis, reaction times outside 2.5 standard deviations at both the high and low ranges were replaced by boundaries indicated by 2.5 standard deviations from the individual means of participants in each category. The statistical tests which follow analyze both participant ($F_1$) and item ($F_2$) variability. The means and standard deviations of naming latencies and error rates of the high and low initial mora frequencies of CVCVCV-structured nonwords are shown in Table 4.

One-way ANOVAs with repeated measures were conducted for naming latencies. The results indicated that nonwords with high initial mora frequency were named faster (i.e., exhibited shorter naming latencies) than those with low initial mora frequency in both participant analysis, $F_1(1, 27) = 6.657$, $p < .05$, and item analysis, $F_2(1, 19) = 6.510$, $p < .05$. Unlike naming latencies, nonwords with high initial mora frequency resulted in error rates equal to those with low initial mora frequency in both participant analysis, $F_1(1, 27) = 0.006$, $p = .939$, and item analysis, $F_2(1, 19) = 0.023$, $p = .880$.

**Table 4**

Naming latencies and error rates for three mora nonwords in Experiment 1

| | *Naming latencies (ms)* | | *Error rates (%)* | |
|---|---|---|---|---|
| *First-mora condition* | *M* | SD | *M* | SD |
| High frequency | 717 | 95 | 13.21 | 10.11 |
| Low frequency | 739 | 108 | 13.04 | 10.66 |

*Note:* *n* = 28 participants; *M* = mean; SD = standard deviation

### 4.3
### Discussion

In order to prove the effects of mora frequencies, Experiment 1 was conducted by comparing $CV_1CV_2CV_3$-structured nonwords with high and low initial mora frequencies. Results indicated that nonwords with a high initial mora frequency were named faster than those with the low frequency initial mora. Experiment 1 controlled bi-mora frequencies of $CV_1 + CV_2$, and $CV_2 + CV_3$ using identical morae for both $CV_2$ and $CV_3$. Since the stimulus items used in Experiment 1 were all nonwords, the mora frequency effect influencing naming speed was independent from lexical involvement. At the moraic level, this finding thus supports the idea of the mental syllabary (Levelt et al., 1999) as being applicable to the core 100 moraic units. However, as discussed in Figure 2, all Japanese morae can be classified by the concept of a light (e.g., CV,CSV) or a heavy (e.g., CVN, CVR) syllable. Experiment 2 further investigated the possibility of the syllable as a stored unit of the mental syllabary.

## 5 Experiment 2: Comparison of CVNCV- and CVCVCV-structured nonwords

In Experiment 2, $CV_1N_2CV_3$-structured nonwords were comprised of three morae ($CV_1$,$N_2$, and $CV_3$) or two syllables ($CV_1N_2$, and $CV_3$). In contrast, there were three $CV_1CV_2$,$CV_3$-structured nonwords in either a mora or a syllable unit ($CV_1$,$CV_2$, and $CV_3$). The primary assumption of Experiment 2 was that if a moraic unit is used for naming (three mora units in both cases), both $CV_1N_2CV_3$- and $CV_1CV_2CV_3$-structured nonwords should exhibit similar naming latencies. However, if syllabic units are used for naming (two versus three syllabic units), $CV_1N_2CV_3$-structured nonwords must be named faster than $CV_1CV_2CV_3$-structured nonwords. Thus, in order to examine whether or not CVN is a speech production unit equal to CV, Experiment 2 was conducted to compare CVNCV- and CVCVCV-structured nonwords with the same bi-mora frequencies in naming latencies and error rates.

### 5.1
### Method

#### 5.1.1
#### Participants

The same as Experiment 1.

#### 5.1.2
#### Stimuli

$CV_1N_1CV_3$ - and $CV_1CV_1CV_3$ -structured nonwords were created by a pair-matched approach. The definition of nonwords and the lexical database (Amano & Kondo, 2000, 2003) used for stimulus selection were the same as in Experiment 1. Again, only basic 100 morae and the special sound /N/ were used to construct target nonword stimuli. For example, the $CV_1N_1CV_3$ -structured nonword マンブ /ma N bu/ has a bi-mora frequency of 448,183 times for $CV_1N_1$ and 365,135 times for $N_1CV_3$ . Paired with this nonword, another $CV_1CV_1CV_3$ -structured nonword マデス /ma de su/ was selected by keeping the $CV_1$ initial mora /ma/ the same. This nonword has a $CV_1$ and $CV_2$ bi-mora frequency

**Table 5**

Stimuli of three mora nonwords with the same bi-mora frequencies in Experiment 2

| *Three mora conditions* | *Left side (1st and 2nd morae)* | | *Right side (2nd and 3rd morae)* | |
|---|---|---|---|---|
| | *M* | SD | *M* | SD |
| $CV_1N_2CV_3$ | 153,172 | 126,850 | 121,388 | 85,794 |
| $CV_1CV_2CV_3$ | 152,759 | 136,066 | 119,382 | 92,511 |

*Note:* 24 stimulus items; *M* = mean; SD = standard deviation.

of 497,101 times and a $CV_2$ and $CV_3$ bi-mora frequency of 277,152 times, both of which are similar to the bi-mora frequencies of the nonword /ma N bu/. In this approach, 24 sets or pairs (48 nonwords) were created as shown in Appendix 2. An additional 48 CVCVCV-structured and 24 CVRCV-structured dummy nonwords (not analyzed in Experiment 2) were mixed with these 48 experimental nonwords. Among dummy items, 24 CVCVCV-structured and 24 CVRCV-structured nonwords were actually experimental items for Experiment 3, so that target nonwords for both Experiments 2 and 3 can act as dummy items for each other. In sum, a total of 120 nonwords (48 experimental items for Experiment 2, 48 dummy items, also used as target items in Experiment 3, and 24 dummy items not used for either experiment) were created for Experiment 2.

The initial mora of $CV_1CV_2CV_3$-structured and $CV_1N_2CV_3$-structured nonwords were the same in each pair, so that the effects of initial phonemes triggering a voice-key device (e.g., Sakuma, Fushimi, & Tatsumi, 1997; Tamaoka & Hatsuzuka, 1997; Yamada & Tamaoka, 2003) were not expected to influence the measurement of naming latencies. Again, as with Experiment 1, different vowels were selected for each nonword item to avoid any same-vowel repetition effect (Tamaoka, Makioka, & Murata, 2004; Tamaoka & Murata, 2001).

The means and standard deviations of bi-mora frequencies are reported in Table 5. Paired-sample *t*-tests were conducted on frequencies of 24 sets of stimuli. Three-mora $CV_1N_1CV_3$- and $CV_1CV_2CV_3$-structured nonwords were divided into two left- and right-side bi-mora combinations. A paired-sample *t*-test was conducted for nonwords of bi-mora frequencies separately on the left side (a combination of the first and second morae) and on the right side (a combination of the second and third morae). Results showed no significant difference on either the left, $t(23) = 0.038$, $p = .970$, or the right, $t(23) = 0.166$, $p = .869$, side. Thus, these 24 sets of nonwords were suitable for examining CVN as being a speech production unit equal to CV.

### 5.1.3
### Procedure

The same as Experiment 1.

## 5.2
## Analysis and results

Only correctly pronounced stimulus items were used in the analyses of naming latencies. No extremes in naming latencies (less than 200 ms and longer than 2000 ms)

**Table 6**

Naming latencies and error rates for three mora nonwords m Experiment 2

| | *Naming latencies (ms)* | | *Error rates (%)* | |
|---|---|---|---|---|
| *Three mora conditions* | *M* | SD | *M* | SD |
| $CV_1N_2CV_3$ | 654 | 71 | 1.49 | 2.33 |
| $CV_1CV_2CV_3$ | 735 | 100 | 7.44 | 5.71 |

*Note: n* = 28 participants; *M* = mean; SD = standard deviation.

were found. Before performing the analysis, reaction times outside of 2.5 standard deviations at both the high and low ranges were replaced by boundaries indicated by 2.5 standard deviations from the individual means of participants in each category. The statistical tests which follow analyze both participant ($F_1$) and item ($F_1$) variability. The means and standard deviations of naming latencies and error rates of CVNCV- and CVCVCV-structured nonwords are shown in Table 6.

One-way ANOVAs with repeated measures were conducted for naming latencies. The results indicated that CVNCV-structured nonwords were named 81 ms faster than CVCVCV-structured nonwords in both participant analysis, $F_1(1, 27) = 93.988$, $p < .001$, and item analysis, $F_2(1, 23) = 85.768$, $p < .001$. Likewise, CVNCV-structured nonwords exhibited error rates which were 5.95% lower than those for CVCVCV-structured nonwords in both participant analysis, $F_1(1, 27) = 32.927$, $p < .001$, and item analysis, $F_2(1, 23) = 7.894$, $p < .01$.

### 5.3
### Discussion

Experiment 2 was conducted to investigate whether or not a CVN heavy syllable is a speech production unit as well as a CV light syllable (equal to a CV mora). Controlling bi-mora frequencies with the same initial mora, Experiment 2 revealed that CVNCV-structured nonwords had shorter naming latencies and lower error rates than CVCVCV-structured nonwords. Since bi-mora frequencies between CVN and CVCV were the same, CVN heavy syllables must contribute to ready-made motor-programs stored in the Japanese mental syllabary as variations of the 100 core morae or light syllables. Thus, the findings of Experiment 2 support the view of a syllable unit as implicated in Japanese speech production. Experiment 3 further investigated the heavy syllable CVR as another potential candidate involved in the Japanese metal syllabary.

## 6 Experiment 3: Comparison of CVRCV- and CVCVCV-structured nonwords

The same assumption for the CVN unit in Experiment 2 was extended to the CVR unit in Experiment 3. To investigate CVR as being a speech production unit equal to CV, Experiment 3 was conducted to compare CVRCV- and CVCVCV-structured nonwords with the same bi-mora frequencies in naming latencies and error rates.

## 6.1
## Method

### 6.1.1
### Participants

The same as Experiments 1 and 2.

### 6.1.2
### Stimuli

As with Experiment 2, $CV_1R_2CV_3$- and $CV_1CV_2CV_3$-structured nonwords were created by a pair-matched approach. Again, only 100 basic morae and the special sound /R/ were used to construct nonword target stimuli. For example, the $CV_1R_2CV_3$-structured nonword キーゼ /ki R ze/ has 113,212 times of bi-mora frequency for $CV_1R_2$ and 87,867 times for $R_2CV_3$. Paired with this nonword, a $CV_1CV_2CV_3$-structured nonword キロガ /ki ro ga/ was selected due to its sharing the $CV_1$ initial mora, /ki/. This nonword has a $CV_1$ and $CV_2$ bi-mora frequency of 123,726 times and a $CV_2$ and $CV_3$ bi-mora frequency of 83,285 times. This pair shares similar bi-mora frequencies. In this approach, 24 sets or pairs (48 nonwords) were created as shown in Appendix 3. In addition, different 48 CVCVCV-structured and 24 CVNCV-structured dummy nonwords (not analyzed) were mixed with these 40 experimental nonwords. As explained in Experiment 2, 24 CVNCV-structured and 24 CVCVCV-structured dummy nonwords were used for experimental items in Experiment 2. A total of 120 nonwords (48 targets for Experiment 3, 48 dummy items also used in Experiment 2, and 24 items not used for either experiment) were used for Experiment 3. The initial morae of $CV_1CV_2CV_3$-structured and $CV_1R_2CV_3$-structured nonwords were identical in each pair. As with Experiments 1 and 2, different vowels were selected for each nonword.

The means and standard deviations of bi-mora frequencies are reported in Table 7. Paired-sample $t$-tests were conducted on the frequencies of 24 sets of stimuli. Three-mora $CV_1R_2CV_3$- and $CV_1CV_2CV_3$-structured nonwords were divided into two left- and right-side bi-mora combinations. A paired sample $t$-test was conducted for nonwords of bi-mora frequencies separately on the left side and on the right side. Results showed no significant difference on either the left, $t(23) = 0.149$, $p = .883$, or right, $t(23) = 0.721$, $p = .478$, side. Thus, these 24 sets of nonwords were suitable for examining CVR as being a speech production unit equal to CV.

**Table 7**

Stimuli of three mora nonwords with the same bi-mora frequencies in Experiment 3

| | *Left side (1st and 2nd morae)* | | *Right side (2nd and 3rd morae)* | |
|---|---|---|---|---|
| *Three mora conditions* | *M* | SD | *M* | SD |
| $CV_1R_2CV_3$ | 14,574 | 28,802 | 14,267 | 27,131 |
| $CV_1CV_2CV_3$ | 14,467 | 29,173 | 13,539 | 24,398 |

*Note:* 24 stimulus items; *M* = mean; SD = standard deviation.

### 6.1.3
### Procedure

The same as Experiments 1 and 2.

## 6.2
## Analysis and results

Only correctly pronounced stimulus items were used in the analyses of naming latencies. No extremes in naming latencies (less than 200 ms and longer than 2000 ms) were found. Before performing the analysis, reaction times outside of 2.5 standard deviations at both the high and low ranges were replaced by boundaries indicated by 2.5 standard deviations from the individual means of participants in each category. The statistical tests which follow analyze both participant ($F_1$) and item ($F_2$) variability. The means and standard deviations of naming latencies and error rates of CVRCV- and CVCVCV-structured nonwords are shown in Table 8.

**Table 8**

Naming latencies and error rates for three mora nonwords in Experiment 3

| | *Naming latencies (ms)* | | *Error rates (%)* | |
|---|---|---|---|---|
| *Three mora conditions* | *M* | SD | *M* | SD |
| $CV_1R_2CV_3$ | 643 | 66 | 4.17 | 4.24 |
| $CV_1CV_2CV_3$ | 737 | 102 | 11.46 | 9.12 |

*Note: n* = 28 participants; *M* = mean; *SD* = standard deviation.

One-way ANOVAs with repeated measures were conducted for naming latencies. The results indicated that CVRCV-structured nonwords were named 94 ms faster than CVCVCV-structured nonwords in both participant analysis, $F_1(1, 27) = 102.782, p < .001$, and item analysis, $F_2(1, 23) = 99.432, p < .001$. Likewise, CVRCV-structured nonwords showed 7.29% fewer errors than CVCVCV-structured nonwords in both participant analysis, $F_1(1, 27) = 25.941, p < .001$, and item analysis, $F_2(1, 23) = 9.304, p < .01$.

## 6.3
## Discussion

Experiment 3 was conducted to investigate whether or not a CVR heavy syllable is a speech production unit as well as a CV light syllable. Controlling bi-mora frequencies with the same initial mora, Experiment 3 revealed that CVRCV-structured nonwords have shorter naming latencies and lower error rates than CVCVCV-structured nonwords. As with Experiment 2, bi-mora frequencies between CVR and CVCV were the same. Thus, units of CVR heavy syllables may also contribute to ready-made motor-programs stored in the Japanese mental syllabary. Consequently, as shown in Figure 2, both the CVN (Experiment 2) and CVR (Experiment 3) units are processed for Japanese speech production as syllabic units prepared in the mental syllabary as variations of the 100 core morae or light syllables.

# 7 Additional analysis of Experiments 2 and 3 and further discussion

Based on the findings of Experiments 2 and 3, both heavy syllabic units of CVN and CVR were assumed to reflect two variations of the 100 core morae. Thus, similarities in naming latencies and error rates were further tested by directly comparing the 24 sets of CVNCV- and CVRCV-structured nonwords. Naming latencies and error rates of CVNCV nonwords in Experiment 2 and the CVRCV nonwords in Experiment 3 were compared by a *t*-test of independent samples. The results showed no significant difference in naming latencies, $t(46) = 0.190$, $p = .850$, but a significant difference in error rates, $t(46) = 2.932$, $p < .01$. The CVN units were phonologically processed with equal naming latencies as the CVR units, although the CVN units were more easily named than the CVR units. In addition, the 24 sets of CVCVCV-structured nonwords used as counter stimuli for Experiments 2 and 3 showed no significant difference in both naming latencies, $t(46) = 1.033$, $p = .307$, and error rates, $t(46) = 1.464$, $p = .150$. Since naming latencies are considered to be more sensitive as a measurement index than error rates, it would be safe to state that heavy syllables comprised of CVN (Experiment 2) and CVR (Experiment 3) units may contribute to ready-made motor-programs stored in the Japanese mental syllabary. Consequently, as shown in Figure 3, both the CVN and CVR units are likely to be processed for Japanese speech production as syllable units prepared in the mental syllabary as variations of the 100 core morae or light syllables. However, it should be noted that this direct comparison of Experiments 2 and 3 provides only partial evidence for the existence of CVN and CVR units in the mental syllabary, since initial consonants and bi-mora frequencies of the two sets of nonwords did not match across both experiments.

# 8 Experiment 4: Effects of bi-mora frequency

In order to investigate the effects of bi-mora frequency, Experiment 4 also used a naming task which required participants to pronounce three-mora CVCVCV-structured nonwords with high bi-mora frequencies (e.g., /ki no be/) and low bi-mora frequencies (e.g., /ki be no/) using identical moraic units with different bi-mora combinations.

## 8.1
## Method

### 8.1.1
### Participants

Twenty-eight graduate and undergraduate students (22 females and 6 males) at Hiroshima University in Japan, all native speakers of Japanese, participated in Experiment 4. None of these participants took part in Experiments 1–3. Ages ranged from 21 years and 1 month to 29 years and 0 months, with the average age being 23 years and 2 months on the day of testing.

### 8.1.2
### Stimuli

Two types of $CV_1CV_2CV_3$-structured nonwords were created by recombining the same three morae: Nonwords with high bi-mora frequency (e.g., $CV_1CV_2CV_3$, キノベ, /ki no be/) and nonwords with low bi-mora frequency (e.g., $CV_1CV_3CV_2$,キベノ, /ki be no/). In this method of stimulus selection, since the morae remained unchanged in the two conditions, mora frequencies of each paired-stimuli (e.g., /ki no be/ versus /ki be no/) were identical. A total of 48 nonwords (24 sets) were presented in katakana (see details of stimulus items in Appendix 4). Again, only the 100 basic morae were used to produce target nonword stimuli.

Bi-mora frequencies are reported in Table 9. Paired sample *t*-tests were conducted on 24 sets of stimuli. Three-mora CVCVCV-structured stimuli were divided into two left- and right-side bi-mora CVCV combinations. A paired sample *t*-test was conducted for bi-mora frequencies on the left side between the conditions of high and low bi-mora frequencies. Results indicated a significant difference between the two conditions, $t(23) = 4.097$, $p < .001$. The same analysis was carried out for the right side, which also indicated a significant difference, $t(23) = 6.157$, $p < .001$. Furthermore, bi-mora frequencies of the left and right sides together were examined by the same *t*-test. The result showed a significant difference between the two conditions, $t(23) = 7.137$, $p < .001$. The same *t*-tests were conducted on bi-mora frequencies between the left and right sides within the same high or low bi-mora frequencies. The results showed no significant differences in either of the conditions of high bi-mora frequency, $t(23) = 0.528$, $p = .603$, or low bi-mora frequency, $t(23) = -0.147$, $p = .884$. The results of these *t*-tests suggest that the category of high and low bi-mora conditions was appropriately divided to investigate the effect of bi-mora frequency. In addition, as presented in Appendix 4, the initial morae of all nonwords were controlled to be the same. The effect of the initial phoneme observed in the naming task measuring naming latencies (e.g., Sakuma et al., 1997; Tamaoka & Hatsuzuka, 1997; Yamada & Tamaoka, 2003) was therefore avoided.

**Table 9**

Bi-mora frequencies of CVCVCV-structured three-mora nonwords used in Experiment 4

| | *Left side* | | *Right side* | | *Both together* | |
|---|---|---|---|---|---|---|
| *Bi-mora condition* | *M* | SD | *M* | SD | *M* | SD |
| High frequency | 141,761 | 167,337 | 119,617 | 93,058 | 261,378 | 176,162 |
| Low frequency | 2,329 | 1,655 | 2,403 | 1,448 | 4,731 | 1,911 |

*Note: M* = mean; *SD* = standard deviation.

### 8.1.3
### Procedure

The same as for Experiments 1–3.

## 8.2
## Analysis and results

Only correctly pronounced stimulus items were used in the analyses of naming latencies. No extremes in naming latencies (less than 200 ms and longer than 2000 ms) were found. Before performing the analysis, reaction times outside of 2.5 standard deviations at both the high and low ranges were replaced by boundaries indicated by 2.5 standard deviations from the individual means of participants in each category. The statistical tests which follow analyze both subject ($F_1$) and item ($F_2$) variability. The means and standard deviations of naming latencies of two nonword conditions are shown in Table 10.

**Table 10**

Naming latencies and error rates for three-mora nonwords in Experiment 4

| | *Naming latencies (ms)* | | *Error rates (%)* | |
|---|---|---|---|---|
| *Bi-mora condition* | *M* | SD | *M* | SD |
| High frequency | 573 | 89 | 4.69 | 5.26 |
| Low frequency | 607 | 93 | 8.85 | 9.30 |

*Note:* $n$ = 28 participants; $M$ = mean; SD = standard deviation.

One-way ANOVAs with repeated measures indicated that nonwords with high bi-mora frequencies exhibited shorter naming latencies than those with low bi-mora frequencies in participant analysis, $F_1(1, 27) = 27.83$, $p < .001$, but not in item analysis, $F_2(1, 23) = 2.64$, $p = .118$. Likewise, nonwords with high bi-mora frequency resulted in significantly lower error rates than those with low bi-mora frequencies in both participant, $F_1(1, 27) = 7.67$, $p < .05$, and item analysis, $F_2(1, 23) = 8.90$, $p < .01$. Thus, bi-mora frequency seems to be an important factor influencing speed and accuracy in the phonological processing of nonwords. However, as indicated by the null effect of naming latencies in the item analysis, some mora combinations seem to behave unpredictably.

### 8.3
### Discussion

Experiment 4 showed significant effects of bi-mora frequency, while the item analysis on naming latency did not show any significance. Generally speaking, with some irregularity in bi-mora combinations, Experiment 4 demonstrated that the three-mora CVCVCV-structured nonwords with high bi-mora frequency were named more quickly and accurately than those with low bi-mora frequency. The frequency feature of two-mora combinations appears to affect Japanese phonological processing. However, it is quite possible that bi-mora frequencies might only be apparent in the processing of nonwords. Thus, Experiment 5 investigated bi-mora frequency together with word frequency.

## 9 Experiment 5: Effects of word and bi-mora frequencies

Experiment 5 conducted a naming task requiring participants to pronounce three-mora CVCVCV-structured real words with high word and high bi-mora frequencies (e.g., /ka ta ti/), with high word and low bi-mora frequencies (e.g., /ka ta ki/), and with low word and low bi-mora frequencies (e.g., /ka yu mi/).

## 9.1
## Method

### 9.1.1
### Participants

Twenty-five graduate and undergraduate students (10 females and 15 males) at Hiroshima University in Japan, all native speakers of Japanese, participated in Experiment 5. None of these participants were involved in Experiments 1–4. Ages ranged from 21 years and 7 months to 30 years and 9 months, with the average age being 25 years and 3 months on the day of testing.

### 9.1.2
### Stimuli

Experiment 5 used three sets of 24 CVCVCV-structured real words with (1) high bi-mora and high word frequency, (2) high bi-mora frequency and low word frequency, and (3) low bi-mora frequency and low word frequency (a total of 72 real words). Combinations of high word frequency with low bi-mora frequency do not exist. Initial consonants were controlled to be the same throughout each pair of the three conditions (see details of stimulus items in Appendix 5). Only the 100 basic morae were used for constructing nonword stimuli. The means of mora, bi-mora, and word frequencies are reported in Table 11.

One-way ANOVAs were conducted on these frequencies. Mora frequency showed no significant main effect. The bi-mora frequency showed a significant main effect, $F(2, 69) = 35.739, p < .001$. Scheffe's multiple comparisons indicated that the condition of low word and low bi-mora frequencies was significantly lower in bi-mora frequency than the other two conditions. Likewise, word frequency showed a significant main effect, $F(2, 69) = 75.615, p < .001$. Scheffe's multiple comparisons indicated that the condition of high word and high bi-mora frequency was significantly higher in word frequency than the other two conditions. Thus, real words stimuli in Experiment 5 were suitable for examining bi-mora and word frequency effects independent from mora frequency, and furthermore the three real word conditions could allow the independent observation of bi-mora and word frequencies.

**Table 11**

Word and bi-mora frequencies for three-mora CVCVCV-structured real words used in Experiment 5

| | *Mora frequency* | | *Bi-mora frequency* | | *Word frequency* | |
|---|---|---|---|---|---|---|
| *Condition of frequencies* | *M* | SD | *M* | SD | *M* | SD |
| High word and high bi-mora frequencies | 1,418,147 | 393,312 | 407,598 | 213,688 | 27,875 | 15,550 |
| Low word and high bi-mora frequencies | 1,340,683 | 521,743 | 409,965 | 245,403 | 274 | 117 |
| Low word and low bi-mora frequencies | 906,392 | 328,596 | 13,694 | 2,721 | 264 | 220 |

*Note: M* = mean; SD = standard deviation.

### 9.1.3
### Procedure

The same as for Experiments 1–4.

## 9.2
## Analysis and results

Only correctly pronounced stimulus items were used in the analyses of naming latencies. No extremes in naming latencies (less than 200 ms and longer than 2000 ms) were found. Before performing the analysis, reaction times outside of 2.5 standard deviations at both the high and low ranges were replaced by boundaries indicated by 2.5 standard deviations from the individual means of participants in each category. The statistical tests which follow analyze both subject ($F_1$) and item ($F_2$) variability. The means and standard deviations of naming latencies of three real words conditions are shown in Table 12.

**Table 12**

Naming latencies and error rates for three-mora CVCVCV-structured real words in Experiment 5

| *Stimulus type* | *Condition of frequencies* | *Naming latencies (ms)* | | *Error rates (%)* | |
|---|---|---|---|---|---|
| | | *M* | SD | *M* | SD |
| | High word and high bi-mora frequencies | 524 | 71 | 2.33 | 2.97 |
| Real words | Low word and high bi-mora frequencies | 539 | 72 | 3.00 | 5.54 |
| | Low word and low bi-mora frequencies | 548 | 72 | 1.83 | 3.42 |

*Note:* $n = 25$ participants; $M$ = mean; SD = standard deviation.

One-way ANOVAs with repeated measures indicated main effects on naming latencies in participant analysis, $F_1(2, 48) = 31.94$, $p < .001$, and in item analysis, $F_2(2, 46) = 3.449$, $p < .05$. Further analyses showed that real words with high word frequency and high bi-mora frequency had significantly shorter naming latencies than real words with low word frequency and high bi-mora frequency in participant analysis, $F_1(1, 24) = 35.47$, $p < .001$, but a significant tendency in item analysis, $F_2(1,23) = 3.44$, $p = .077$. Again, real words with high word frequency and high bi-mora frequency and real words with low word frequency showed significantly shorter latencies than low bi-mora frequency in both participant and item analyses, $F_1(1, 24) = 62.06$, $p < .001$; $F_2(1, 23) = 5.15$, $p < .05$, which can be considered to be the effect of word frequency. The naming latencies of real words with low word frequency and high bi-mora frequency were shorter than those of words with low word frequency and low bi-mora frequency in participant analysis, $F_1(1, 24) = 6.99$, $p < .05$, but not in item analysis, $F_2(1, 23) = 0.66$, $p = .425$. Since word frequencies were low in both conditions, participant analysis supported an effect of bi-mora frequency, but item analysis did not support this result. Unlike naming latencies, error rates of real words did not show any main effect. This result indicates that neither word nor bi-mora frequency has an effect upon error rates of real word naming.

### 9.3
### Discussion

The results of Experiment 5 were subtle. The facilitation effect of word frequency was supported by comparisons of three real word conditions. Naming of real words with high word frequency was faster than the other real word conditions with low word frequency. However, the effect of bi-mora frequency was not fully supported by the comparisons. Under the conditions of low word frequency, naming of real words with high bi-mora frequency was significantly faster than those with low bi-mora frequency, as was indicated by participant analysis but not item analysis. To some degree, similar to null significance in item analysis on naming latencies in Experiment 4 (but significant in both participant and item analyses on error rates), bi-mora frequencies in Experiment 5 had only a minor effect on the phonological processing of real words.

## 10 General discussion

The present study tested how each unit of mora, syllable, bi-mora and word affects speech production of Japanese using a naming task of visually-presented nonwords and real words.

### 10.1
### Effects of initial more frequency—the 100 core moraic units

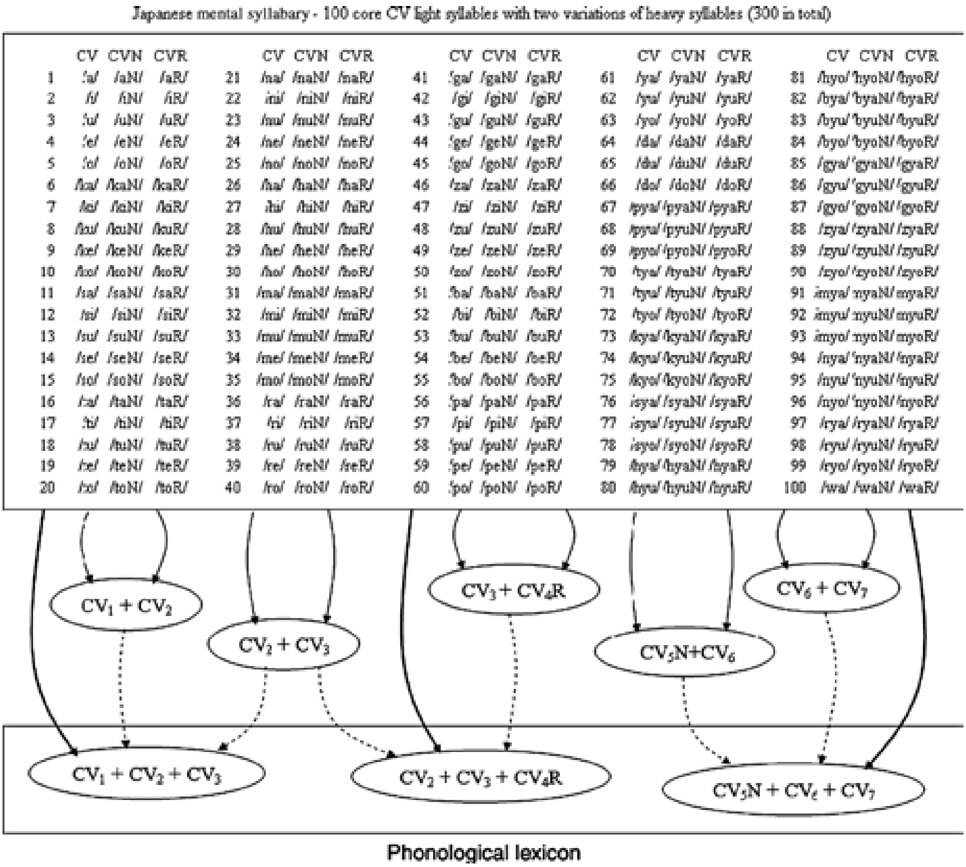
In order to examine whether or not the mental syllabary as proposed by Levelt et al. (1999) exists in the Japanese language, Experiment 1 was conducted to compare naming speed of CVCVCV-structured nonwords with high and low initial mora frequencies. Results indicated that nonwords with a high initial mora frequency were named faster than those with low frequency initial mora. Stimulus items in Experiment 1 were all nonwords with controlled bi-mora frequencies of $CV_1$+ $CV_2$, and $CV_2$ + $CV_3$ using identical morae for both $CV_2$ and $CV_3$. The effects of mora frequency were seen to influence the speed of production independent of lexical involvement. It is hypothesized that if stored representations corresponding to moraic units are retrieved from the Japanese mental syllabary, the retrieval process should be sensitive to their frequencies. Therefore, the finding of frequency effects in Experiment 1 supported the concept of mental syllabary at the Japanese moraic level. As soon as Japanese native speakers see nonwords of a CVCVCV-structured three-mora string presented in katakana moraic symbols, they retrieve the corresponding mora articulatory units from the mental syllabary. Experiment 1 suggested that Japanese morae seem to play an important role for the interface between phonological and phonetic encoding.

Applying the idea of the mental syllabary by Levelt et al. (1999), it is proposed that a limited number of frequently-used phonological moraic units are stored as ready-made motor-programs in the Japanese mental syllabary. Since Japanese sounds consist of only the 100 core moraic units, all of them will be candidates. In fact, effects of syllable frequencies in Experiment 1 were found within the 100 core morae. In addition to the 100 morae and the three special sounds (i.e., /N/, /R/, and /Q/), a list of an additional 33 morae was officially announced by the Government of Japan (1991), but these 33 morae are exclusively used for alphabetic loanwords whose sounds cannot be described within traditional Japanese moraic units. Therefore, as depicted in Figure 3, the present study assumes that only the 100 core moraic units must be stored in the mental syllabary as pre-compiled motor programs ready made for speech production. However, once these 33 additional morae come to be used frequently in the Japanese language, they may possibly come to be stored in the Japanese mental syllabary in the future.

Levelt and his colleagues did not specify actual syllabic units stored in the mental syllabary in Dutch, English, or German. Since the Japanese language requires only a limited number of syllabic or moraic units for speech production, the present study proposed the 100 core moraic units to be the actual units stored in the Japanese mental syllabary. In this sense, the Japanese language is an ideal example to investigate the mental syllabary. Yet, a further possibility remains of the *syllable*, rather than *mora* (see Figure 1) as a unit of Japanese speech production.

**Figure 3**

Structure of the Japanese mental syllabary for speech production



Japanese mental syllabary - 100 core CV light syllables with two variations of heavy syllables (300 in total)

| | CV | CVN | CVR | | CV | CVN | CVR | | CV | CVN | CVR | | CV | CVN | CVR | | CV | CVN | CVR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | /a/ | /aN/ | /aR/ | 21 | /na/ | /naN/ | /naR/ | 41 | /ga/ | /gaN/ | /gaR/ | 61 | /ya/ | /yaN/ | /yaR/ | 81 | /hyo/ | /hyoN/ | /hyoR/ |
| 2 | /i/ | /iN/ | /iR/ | 22 | /ni/ | /niN/ | /niR/ | 42 | /gi/ | /giN/ | /giR/ | 62 | /yu/ | /yuN/ | /yuR/ | 82 | /bya/ | /byaN/ | /byaR/ |
| 3 | /u/ | /uN/ | /uR/ | 23 | /nu/ | /nuN/ | /nuR/ | 43 | /gu/ | /guN/ | /guR/ | 63 | /yo/ | /yoN/ | /yoR/ | 83 | /byu/ | /byuN/ | /byuR/ |
| 4 | /e/ | /eN/ | /eR/ | 24 | /ne/ | /neN/ | /neR/ | 44 | /ge/ | /geN/ | /geR/ | 64 | /da/ | /daN/ | /daR/ | 84 | /byo/ | /byoN/ | /byoR/ |
| 5 | /o/ | /oN/ | /oR/ | 25 | /no/ | /noN/ | /noR/ | 45 | /go/ | /goN/ | /goR/ | 65 | /du/ | /duN/ | /duR/ | 85 | /gya/ | /gyaN/ | /gyaR/ |
| 6 | /ka/ | /kaN/ | /kaR/ | 26 | /ha/ | /haN/ | /haR/ | 46 | /za/ | /zaN/ | /zaR/ | 66 | /do/ | /doN/ | /doR/ | 86 | /gyu/ | /gyuN/ | /gyuR/ |
| 7 | /ki/ | /kiN/ | /kiR/ | 27 | /hi/ | /hiN/ | /hiR/ | 47 | /zi/ | /ziN/ | /ziR/ | 67 | /pya/ | /pyaN/ | /pyaR/ | 87 | /gyo/ | /gyoN/ | /gyoR/ |
| 8 | /ku/ | /kuN/ | /kuR/ | 28 | /hu/ | /huN/ | /huR/ | 48 | /zu/ | /zuN/ | /zuR/ | 68 | /pyu/ | /pyuN/ | /pyuR/ | 88 | /zya/ | /zyaN/ | /zyaR/ |
| 9 | /ke/ | /keN/ | /keR/ | 29 | /he/ | /heN/ | /heR/ | 49 | /ze/ | /zeN/ | /zeR/ | 69 | /pyo/ | /pyoN/ | /pyoR/ | 89 | /zyu/ | /zyuN/ | /zyuR/ |
| 10 | /ko/ | /koN/ | /koR/ | 30 | /ho/ | /hoN/ | /hoR/ | 50 | /zo/ | /zoN/ | /zoR/ | 70 | /tya/ | /tyaN/ | /tyaR/ | 90 | /zyo/ | /zyoN/ | /zyoR/ |
| 11 | /sa/ | /saN/ | /saR/ | 31 | /ma/ | /maN/ | /maR/ | 51 | /ba/ | /baN/ | /baR/ | 71 | /tyu/ | /tyuN/ | /tyuR/ | 91 | /mya/ | /myaN/ | /myaR/ |
| 12 | /si/ | /siN/ | /siR/ | 32 | /mi/ | /miN/ | /miR/ | 52 | /bi/ | /biN/ | /biR/ | 72 | /tyo/ | /tyoN/ | /tyoR/ | 92 | /myu/ | /myuN/ | /myuR/ |
| 13 | /su/ | /suN/ | /suR/ | 33 | /mu/ | /muN/ | /muR/ | 53 | /bu/ | /buN/ | /buR/ | 73 | /kya/ | /kyaN/ | /kyaR/ | 93 | /myo/ | /myoN/ | /myoR/ |
| 14 | /se/ | /seN/ | /seR/ | 34 | /me/ | /meN/ | /meR/ | 54 | /be/ | /beN/ | /beR/ | 74 | /kyu/ | /kyuN/ | /kyuR/ | 94 | /nya/ | /nyaN/ | /nyaR/ |
| 15 | /so/ | /soN/ | /soR/ | 35 | /mo/ | /moN/ | /moR/ | 55 | /bo/ | /boN/ | /boR/ | 75 | /kyo/ | /kyoN/ | /kyoR/ | 95 | /nyu/ | /nyuN/ | /nyuR/ |
| 16 | /ta/ | /taN/ | /taR/ | 36 | /ra/ | /raN/ | /raR/ | 56 | /pa/ | /paN/ | /paR/ | 76 | /sya/ | /syaN/ | /syaR/ | 96 | /nyo/ | /nyoN/ | /nyoR/ |
| 17 | /ti/ | /tiN/ | /tiR/ | 37 | /ri/ | /riN/ | /riR/ | 57 | /pi/ | /piN/ | /piR/ | 77 | /syu/ | /syuN/ | /syuR/ | 97 | /rya/ | /ryaN/ | /ryaR/ |
| 18 | /tu/ | /tuN/ | /tuR/ | 38 | /ru/ | /ruN/ | /ruR/ | 58 | /pu/ | /puN/ | /puR/ | 78 | /syo/ | /syoN/ | /syoR/ | 98 | /ryu/ | /ryuN/ | /ryuR/ |
| 19 | /te/ | /teN/ | /teR/ | 39 | /re/ | /reN/ | /reR/ | 59 | /pe/ | /peN/ | /peR/ | 79 | /hya/ | /hyaN/ | /hyaR/ | 99 | /ryo/ | /ryoN/ | /ryoR/ |
| 20 | /to/ | /toN/ | /toR/ | 40 | /ro/ | /roN/ | /roR/ | 60 | /po/ | /poN/ | /poR/ | 80 | /hyu/ | /hyuN/ | /hyuR/ | 100 | /wa/ | /waN/ | /waR/ |

*Note 1*: "CV" in this figure represents all light syllables including ØV, CV, ØSV and O.

*Note 2*: A thicker line indicates faster activation of a real word in the Phonological lexicon.

*Note 3*: A dotted line indicates weaker influence to activate a real word in the phonological lexicon.

## 10.2

## Light and heavy syllables in the Japanese mental syllabary

At the stage of Experiment 1, the repository of the mental syllabary was assumed to be stored as units of moraic size. From the perspective of syllabic units, all 100 morae can be combined with /N/ (nasal) and /R/ (long vowel) to produce heavy syllables. As discussed in Figure 1, in that all Japanese morae can be classified by the concept of a light (e.g., ØV, CV, ØSV, CSV) or a heavy (e.g., ØVN, CVN, ØSVN, CSVN, ØVR, CVR, ØSVR, and CSVR) syllable, the syllable is seen to serve as the unit of Japanese speech production. Thus, Experiments 2 and 3 were conducted to clarify the possibility of light/heavy syllables as being stored as representations within the Japanese mental syllabary.

Experiment 2 indicated that CVNCV-structured nonwords had shorter naming latencies and lower error rates than CVCVCV-structured nonwords. Similar to the investigation of CVN heavy syllables in Experiment 2, Experiment 3 considered the possibility of CVR heavy syllables as speech production units. The results of Experiment 3 also revealed that CVRCV-structured nonwords have shorter naming latencies and yield lower error rates than CVCVCV-structured nonwords. Results of Experiments 2 and 3 confirmed the previous findings of Tamaoka and Terao (2004) under more scrupulous stimulus conditions by controlling bi-mora frequencies of nonwords. Since bi-mora frequencies between CVN/CVR and CVCV were the same in both Experiments 2 and 3, this consistent finding further illustrated the involvement of heavy syllables in the mental syllabary. Stored units in the mental syllabary may be regarded as both the core 100 light syllables (rather than *morae*) and their two variations of +N/+R heavy syllables as depicted in Figure 3.

The results of Experiments 1–3 furthermore suggest that heavy syllables comprised of CVN and CVR units contribute to ready-made motor-programs stored in the Japanese mental syllabary as variations of 100 light syllables. This supports previous findings regarding the importance of the syllable as a relevant unit in speech production in various languages such as Chinese (Chen, Lin, & Ferrand, 2003), Dutch (Cholin et al., 2006; Cholin, Schiller, & Levelt, 2004; Schiller, 1998, 1999; Schiller et al., 1996), English (Ferrand, Segui, & Humphreys, 1997; Schiller, 1999; 2000) and Spanish (Carreiras & Perea, 2004). In this sense, the syllable is a much more universal unit for speech production.

## 10.3

## Effects of bi-mora and word frequency

Experiment 4 tested the assumption that high-frequency bi-morae would be activated more quickly and accurately than less frequently-used bi-morae, independent of mora and word frequencies. In accordance with this assumption, the overall result of Experiment 4 was that the three-mora CVCVCV-structured nonwords with high bi-mora frequency were named more quickly and accurately than those with low bi-mora frequency. However, it should be noted that the item analysis of naming latency showed no significant effect, $p = .118$, indicating that some bi-mora items may affect speech production independent of bi-mora frequency. Bi-mora frequencies might only be apparent, to some degree, in the processing of nonwords; in other words, the possibility that bi-mora frequency influences phonological processing only in the absence of lexical status cannot be totally disregarded. Therefore, Experiment 5 investigated bi-mora frequency together with word frequency.

As had been anticipated in previous studies on the effects of word frequency (e.g., Fushimi et al., 1999; Hino & Lupker, 1998; Tamaoka & Takahashi, 1999), Experiment 5 demonstrated the facilitation effects of word frequency. Results indicated that the naming of real words with high word frequency was quicker than other real word conditions with low word frequency. Experiment 5 focused on the effect of bi-mora frequency when co-existing with word frequency. Naming latencies of real words with high bi-mora frequencies were significantly shorter than those with low bi-mora frequencies, as was indicated by participant analysis and a significant tendency in item analysis, $p = .077$. Unlike the clear trend in error rates between high and low bi-mora frequencies shown in Experiment 4, error rates in Experiment 5 did not reveal any difference between words with high and low bi-mora frequencies. Although comparison of high and low bi-mora frequencies within low word frequency showed a minor effect on naming latencies for real words, the effect of bi-mora frequency was not as clear-cut as had been expected.

A more general understanding of the three CVCVCV-structured real words can be achieved through the activation process, as follows. During the processing of real words, the ready-made motor-programs of light/heavy syllables (see Figure 3) are retrieved from the mental syllabary for speech production. For example, the real word “novel,” pronounced /syoR se tu/, is pronounced by three syllables /syoR/ (heavy syllable CSVR), /se/ (light syllable CV) and /tu/ (light syllable CV), not by four morae /syo/, /R/, /se/ and /tu/. Since the initial light syllable (or mora) frequency affects the speed of naming, vocalization takes place before activating a whole phonological representation of the target word; at this stage, the bi-morae frequencies also come into play. However, since word frequencies have much stronger effects on the activation of real word phonological representations, bi-mora frequencies have only a minor effect. The phonological representation of the whole word /syoRsetu/ could be reached by assembling three syllabic units of /syoR/, /se/ and /tu/, and by completing pronunciation at the whole-word level prior to the apparent effects of bi-mora frequencies.

In contrast, since nonwords lack lexical status in the phonological lexicon, their constructing units are simply assembled at the syllabic level. In the process of assembly, the effect of bi-mora frequencies becomes apparent since there is no influence of word frequency. However, some bi-mora items showed irregular behavior (item analysis was not significant in Experiment 4). Consequently, the present study found that bi-mora frequency has only a partial effect on the phonological processing of Japanese when word frequency is apparent (i.e., real words); in contrast, when word frequency does not exist (i.e., nonwords), bi-mora frequency has great bearing on speech production, accepting the existence of some irregularly-behaved bi-mora combinations.

## 10.4

## A methodological issue of the present study—naming task

The present study utilized a naming task which required participants to pronounce a visually-presented katakana stimulus. This process can be regarded as “reading aloud,” not natural speech production. However, discussion in the present study is limited to the function of the mental syllabary as the interface between phonological and phonetic encoding. Therefore, we assume that the same mechanism is shared between reading aloud and natural speech production at the level of interface.

As visual presentations for the naming task in the present study, the katakana script is used for the following two reasons: (1) the long vowel is represented by a horizontal bar (hiragana cannot precisely represent long vowels), and (2) there are far fewer lexical items presented in katakana (basically, only alphabetic loanwords). The naming latencies of the present experiments include times required for katakana-to-mora conversion. The inclusion of conversion time is necessary in implementing the naming task. However, if the katakana-to-mora conversion is performed by one-to-one mapping, the pronunciation of nonwords of CVCVCV-structured three light syllables (or three morae) presented by three katakana symbols should be processed at the same speed as CVNCV-structured nonwords (also presented by three katakana symbols). Interestingly, Experiments 2 and 3 showed the consistent result that CVNCV and CVRCV nonwords including heavy syllables of CVN and CVR were named faster than their baseline of CVCVCV nonwords, even though all these items are represented by the same number of three katakana symbols. In other words, CVN or CVR units represented by two katakana symbols are possibly processed as a single syllabic unit, equivalent to CV units represented by a single katakana symbol. Therefore, mappings between katakana symbols and moraic sounds do not necessarily imply exact conversion of one-to-one kana-to-mora correspondence for speech production. In this sense, although naming latencies in Experiments 1–5 are bound to include times required for katakana-to-mora conversion, they nevertheless seem to provide meaningful indications for speech production.

To ascertain the function of the mental syllabary, Laganaro and Alario (2006) utilized two experimental methods with a standard naming task: delayed naming and articulatory suppression. The delayed naming task requires participants to pronounce the visually-presented items after a short delay upon presentation of a response cue. Laganaro and Alario found no effects of syllabic frequency in the delayed naming task, although effects were apparent in the standard naming task. In addition, they also tested the effects of syllabic frequencies by delayed naming with articulatory suppression. As their method of articulatory suppression, the syllable /ba/ (“ba-ba- …” was presented on the screen as well) required participants to repeat until the time the response cue appeared on the screen. This time, syllabic frequency effects were observed. Laganaro and Alario (2006) concluded that syllabic-sized representations were retrieved from the mental syllabary in the process of phonetic encoding. These two methods can be applied to further studies investigating the Japanese mental syllabary.

## 10.5

## Remaining questions for further studies

The present study reported five experiments. These experiments per se cannot lead to concrete generalizations as to the mechanism of speech production in the Japanese language. At the end of the present study, at least three unsolved questions remain.

First, the mental syllabary in the present study included CVN and CVR units of heavy syllables. These heavy syllables are created by combining one of the 100 core light syllables and the special moraic units of /N/ or /R/. This inclusion was supported by the consistent finding that CVNCV (Experiment 2) and CVRCV (Experiment 3) units were processed for the naming task faster than their counter stimuli of CVCVCV (bi-mora frequencies being controlled in both conditions). As illustrated in Figure 3, the present study assumed that heavy syllables are stored as a paired set of the 100 core light syllables (e.g., a set of /ka/, /kaN/ and /kaR/). However, it is still uncertain whether these heavy syllables are represented in the mental syllabary or whether they are actually created by phonological *manipulation* of /N/ or /R/ addition.

Second, the present study tested the special sounds of /N/ in Experiment 2 and /R/ in Experiment 3, which create a whole set of heavy syllables based on the 100 core light syllables. The one remaining special sound /Q/ is untested because this moraic sound only appears in middle of words as a voiceless obstruent placed before the four consonants /p/, /t/, /k/ and /s/ such as /gaQki/ “musical instrument,” /kiQte/ “a stamp.” As the present study proposed both light and heavy syllables as stored units in the mental syllabary, a set of heavy syllables with /Q/ (i.e., CVQ) should also be investigated as candidates of stored units in the Japanese mental syllabary.

Third, frequencies of mora (or light syllables) and bi-mora (including heavy syllables) in the present study were taken from the frequency database of Tamaoka and Makioka (2004). There are two possible biases inherent in this index. The database provided by Tamaoka and Makioka was calculated on the basis of a written form of a particular Japanese newspaper called the *Asahi Newspaper*. As for studies of speech production, it is ideal to have mora and bi-mora frequencies calculated in the use of Japanese spoken corpus. Another bias could result from the fact that mora and bi-mora frequencies of Tamaoka and Makioka were calculated within lexical units. However, actual speech production continues until the next pause separating each unit. Ideally speaking, mora and bi-mora frequencies should be counted cross-lexically (i.e., including cross-word boundaries) as a unit divided by the point of each pause.

## 11 Summary

The present study puts forward the following five proposals in Japanese speech production. First, frequency effects of mora (or light syllable) units among the 100 core morae were observed. Based on this finding, the present study proposes the 100 core light syllables (or morae) as fundamental ready-made motor-programs stored in the mental syllabary used for speech production. Second, CVN and CVR units displayed shorter naming latencies than their counter CVCV units. Thus, the present study proposes these heavy syllables of CVN and CVR are also stored candidates in the mental syllabary. Third, combining these two findings, the present study further proposes that the 100 core light syllables and their two variations of CVN and CVR heavy syllables are stored as 100 sets in the mental syllabary. In other words, the number of stored units is the 100 core light syllables and their two variations of heavy syllables, totaling 300 syllabic units in all. Fourth, bi-mora frequencies showed some effects on nonword naming, but only a minor effect on real word naming. This finding proposes that bi-mora frequencies have some effects only on a string of non-lexical items for speech production. Fifth, word frequency had substantial effects on real word naming. Thus, the present study proposes that word frequencies are likely to overtake bi-mora frequencies, and to influence speech production of lexical items.

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## Appendix 1

The $CV_1CV_2CV_3$-structured nonwords with high and low intitial mora (CVT) frequencies used for Experiment 1

| Condition of high-frequency initial mora | | | Condition of low-frequency initial mora | | |
|---|---|---|---|---|---|
| *#* | *Nonword* | *Phoneme* | *#* | *Nonword* | *Phoneme* |
| 1 | ハロシュ | he ro syu | 1 | ヘロシュ | ha ro syu |
| 2 | ハプキョ | ha pu kyo | 2 | ヘプキョ | he pu kyo |
| 3 | ハミボ | ha mi bo | 3 | ヘミボ | he mi bo |
| 4 | ハキゾ | ha ki zo | 4 | ヘキゾ | he ki zo |
| 5 | ガヘト | ga he to | 5 | グヘト | gu he to |
| 6 | ガモベ | ga mo be | 6 | グモベ | gu mo be |
| 7 | ガセト | ga se to | 7 | グセト | gu se to |
| 8 | ガコゼ | ga ko ze | 8 | グコゼ | gu ko ze |
| 9 | ノレチ | no re ti | 9 | ヌレチ | nu re ti |
| 10 | ノワミ | no wa mi | 10 | ヌワミ | nu wa mi |
| 11 | ノケガ | no ke ga | 11 | ヌケガ | nu ke ga |
| 12 | ノシャヒ | no sya hi | 12 | ヌシャヒ | nu sya hi |
| 13 | チョメユ | tyo me yu | 13 | チャメユ | tya me yu |
| 14 | チョビヘ | tyo bi he | 14 | チャビヘ | tya bi he |
| 15 | チョゲビ | tyo ge bi | 15 | チャゲビ | tya ge bi |
| 16 | チョジニュ | tyo zi nyu | 16 | チャジニュ | tya zi nyu |
| 17 | ジョレギ | zyo re gi | 17 | ジャレギ | zya re gi |
| 18 | ジョケヌ | zyo ke nu | 18 | ジャケヌ | zya ke nu |
| 19 | ジョヒム | zyo hi mu | 19 | ジャヒム | zya hi mu |
| 20 | ジョフピ | zyo hu pi | 20 | ジャフピ | zya hu pi |

## Appendix 2

Three mora CVNCV- and CVCVCV-structured nonwords used for Experiment 2

| *CVNCV-structured nonwords* | | | *C VCVCV-structured nonwords* | | |
|---|---|---|---|---|---|
| # | *Nonword* | *Phoneme* | # | *Nonword* | *Phoneme* |
| 1 | クンゾ | ku N zo | 1 | クトレ | ku to re |
| 2 | スンヘ | su N he | 2 | スロバ | su ro ba |
| 3 | ソンパ | so N pa | 3 | ソクテ | so ku te |
| 4 | チンハ | ti N ha | 4 | チコナ | ti ko na |
| 5 | トンラ | to N ra | 5 | トハチ | to ha ti |
| 6 | ナンビ | na N bi | 6 | ナスト | na su to |
| 7 | ノンズ | no N zu | 7 | ノセグ | no se gu |
| 8 | ヒンゼ | hi N ze | 8 | ヒツカ | hi tu ka |
| 9 | フンミ | hu N mi | 9 | フタシ | hu ta si |
| 10 | マンブ | ma N bu | 10 | マデス | ma de su |
| 11 | ヨンベ | yo N be | 11 | ヨブチ | yo bu ti |
| 12 | ランビ | ra N bi | 12 | ラシセ | ra si se |
| 13 | ロンビ | ro N bi | 13 | ロクナ | ro ku na |
| 14 | ギンセ | gi N se | 14 | ギカズ | gi ka zu |
| 15 | ゴンム | go N mu | 15 | ゴヤブ | go ya bu |
| 16 | ザンモ | za N mo | 16 | ザステ | za su te |
| 17 | ゾンク | zo N ku | 17 | ゾレカ | zo re ka |
| 18 | デンス | de N su | 18 | デモク | de mo ku |
| 19 | ドンヒ | do N hi | 19 | ドリマ | do ri ma |
| 20 | ビンフ | bi N hu | 20 | ビトマ | bi to ma |
| 21 | ベンユ | be N yu | 21 | ベキナ | be ki na |
| 22 | ボンユ | bo N yu | 22 | ボシゼ | bo si ze |
| 23 | パンボ | pa N bo | 23 | パツメ | pa tu me |
| 24 | ペンロ | pe N ro | 24 | ペキゴ | pe ki go |

# Appendix 3

Three mora CVRCV-and CVCVCV-structured nonwords used for Experiment 3

| *CVRCV- structured nonwords* | | | *CVCVCV-structured nonwords* | | |
|---|---|---|---|---|---|
| # | *Nonword* | *Phoneme* | # | *Nonword* | *Phoneme* |
| 1 | カーソ | ka R so | 1 | カヒメ | ka hi me |
| 2 | キーゼ | ki R ze | 2 | キロガ | ki ro ga |
| 3 | ケーニ | keRni | 3 | ケバヌ | ke ba nu |
| 4 | サーコ | sa R ko | 4 | サドニ | sa do ni |
| 5 | セーポ | se R po | 5 | セヒム | se hi mu |
| 6 | ターピ | ta R pi | 6 | タゴビ | ta go bi |
| 7 | ナーブ | na R bu | 7 | ナキブ | na ki bu |
| 8 | ヌーピ | nu R pi | 8 | ヌレチ | nu re ti |
| 9 | ネーマ | ne R ma | 9 | ネジガ | ne zi ga |
| 10 | ハーベ | ha R be | 10 | ハソム | ha so mu |
| 11 | ヒーパ | hi R pa | 11 | ヒネグ | hi ne gu |
| 12 | フーレ | hu R re | 12 | フカネ | hu ka ne |
| 13 | ヘーブ | he R bu | 13 | ヘコヌ | he ko nu |
| 14 | マービ | ma R bi | 14 | マヒド | ma hi do |
| 15 | ミープ | mi R pu | 15 | ミノタ | mi no ta |
| 16 | メーユ | me R yu | 16 | メビズ | me bi zu |
| 17 | ヤープ | ya R pu | 17 | ヤニモ | ya ni mo |
| 18 | ラーモ | ra R mo | 18 | ラドブ | ra do bu |
| 19 | リーヌ | ri R nu | 19 | リフサ | ri hu sa |
| 20 | レーヒ | re R hi | 20 | レジホ | re zi ho |
| 21 | ザーブ | za R bu | 21 | ザベコ | za be ko |
| 22 | ジーユ | zi R yu | 22 | ジサメ | za sa me |
| 23 | ダーヘ | da R he | 23 | ダヒネ | za hi ne |
| 24 | ブーヨ | bu R yo | 24 | ブヘジ | bu he zi |

## Appendix 4

Nonwords with high and low bi-mora frequencies used for Experiment 4

| *High frequency bi-mora combinations* | | | *Low frequency bi-mora combinations* | | |
|---|---|---|---|---|---|
| # | *Nonword* | *Phoneme* | # | *Nonword* | *Phoneme* |
| 1 | キノベ | ki no be | 1 | キベノ | ki be no |
| 2 | サキボ | sa ki bo | 2 | サボキ | sa bo ki |
| 3 | サトズ | sa to zu | 3 | サズト | sa zu to |
| 4 | サヒロ | sa hi ro | 4 | サロヒ | sa ro hi |
| 5 | スメザ | su me za | 5 | スザメ | su za me |
| 6 | タスギ | ta su gi | 6 | タギス | ta gi su |
| 7 | タノデ | ta no de | 7 | タデノ | ta de no |
| 8 | タメグ | ta me gu | 8 | タグメ | ta gu me |
| 9 | ナジユ | na zi yu | 9 | ナユジ | na yu zi |
| 10 | ニガレ | ni ga re | 10 | ニレガ | ni re ga |
| 11 | ニトメ | ni to me | 11 | ニメト | ni me to |
| 12 | ニホケ | ni ho ke | 12 | ニケホ | ni ke ho |
| 13 | ハチロ | ha ti ro | 13 | ハロチ | ha ro ti |
| 14 | ヒクセ | hi ku se | 14 | ヒセク | hi se ku |
| 15 | フトバ | hu to ba | 15 | フバト | hu ba to |
| 16 | ベキモ | be ki mo | 16 | ベモキ | be mo ki |
| 17 | ホクギ | ho ku gi | 17 | ホギク | ho gi ku |
| 18 | マレビ | ma re bi | 18 | マビレ | ma bi re |
| 19 | ヨクベ | yo ku be | 19 | ヨベク | yo be ku |
| 20 | ヨサケ<br>ヨネラ | yo sa ke | 20 | ヨケサ<br>ヨラネ | yo ke sa |
| 21 | ラニヨ | yo ne ra | 21 | ラヨニ | yo ra ne |
| 22 | ルマケ | ra ni yo | 22 | ルケマ | ra yo ni |
| 23 | レキソ | ru ma ke | 23 | レソキ | ru ke ma |

# Appendix 5

Three mora CVCVCV- structured real words used for Experiment 5

| *High bi-mora and high word frequencies* | | | *High bi-mora and low word frequencies* | | | *Low bi-mora and low word frequencies* | | |
|---|---|---|---|---|---|---|---|---|
| # | *Real word* | *Phoneme* | # | *Real word* | *Phoneme* | # | *Real word* | *Phoneme* |
| 1 | カタチ | ka ta ti | 1 | コソク | ko so ku | 1 | カユミ | ka yu mi |
| 2 | カツテ | ka tu te | 2 | カタキ | ka taki | 2 | コユビ | ko yu bi |
| 3 | カゾク | ka zo ku | 3 | コノハ | ko no ha | 3 | コグマ | ko gu ma |
| 4 | キロク | ki ro ku | 4 | ケマリ | ke ma ri | 4 | コベヤ | ko be ya |
| 5 | シゴト | si go to | 5 | シキソ | si ki so | 5 | シグサ | si gu sa |
| 6 | スガタ | su ga ta | 6 | ステキ | su te ki | 6 | スハダ | su ha da |
| 7 | タチバ | ta ti ba | 7 | トリコ | to ri ko | 7 | テヌキ | te nu ki |
| 8 | ツモリ | tu mo ri | 8 | タマゴ | ta ma go | 8 | テジナ | te zi na |
| 9 | トナリ | to na ri | 9 | テガラ | te ga ra | 9 | トダナ | to da na |
| 10 | ナカマ | na ka ma | 10 | ネムケ | ne mu ke | 10 | ネワザ | ne wa za |
| 11 | ナガレ | na ga re | 11 | ナラク | na ra ku | 11 | ネジレ | ne re re |
| 12 | ノコリ | no ko ri | 12 | ノハラ | no ha ra | 12 | ノドカ | no do ka |
| 13 | ハシラ | ha si ra | 13 | ヒカゲ | hi ka ge | 13 | ハレギ | ha re gi |
| 14 | ハヤシ | ha ya ri | 14 | ハナワ | ha na wa | 14 | ハダギ | ha da gi |
| 15 | ヒカリ | hi ka ri | 15 | ヒガサ | hi ga sa | 15 | ヒケメ | hi ke me |
| 16 | ヒリツ | hi ri tu | 16 | ハタチ | ha ta ti | 16 | ヒネリ | hi ne ri |
| 17 | フクシ | hu ku si | 17 | ヒラメ | hi ra me | 17 | ヒグレ | hi gu re |
| 18 | フソク | hu so ku | 18 | ハカマ | ha ka ma | 18 | ホロビ | ho ro bi |
| 19 | ミカタ | mi ka ta | 19 | マルミ | ma ru mi | 19 | マヨケ | ma yo ke |
| 20 | ミヤコ | mi ya ko | 20 | マドリ | ma do ri | 20 | ミソギ | mi so gi |
| 21 | ムカシ | mu ka si | 21 | モトデ | mo to de | 21 | モロテ | mo ro te |
| 22 | ムスメ | mu su me | 22 | マモノ | ma mo no | 22 | モグサ | mo gu sa |
| 23 | ヨソク | yo so ku | 23 | ヤスリ | ya su ri | 23 | ヤモメ | ya mo me |
| 24 | レキシ | re ki si | 24 | ラレツ | ra re tu | 24 | リザヤ | ri za ya |