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Running head: MASKED SYLLABLE PRIMING IN CHINESE

Masked Priming of the Syllable in Mandarin Chinese Speech Production

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ABSTRACT

The syllable's role in Chinese (Mandarin) speech production was investigated using masked syllable priming combined with a word naming task. In three experiments, the prime (shown in the form of a Chinese character but masked) shared the first few segments with the beginning of the disyllabic target word. The segmental overlap either corresponded to a syllable or it did not. Aside from a neutral prime, there were two types of related primes: a CV (e.g., *ba*³) or a CVG (e.g., *bay*³) syllable, and two types of targets: a CV-GV (e.g., *ba*⁴-*ye*⁴) or a CVG-CVX (e.g., *bay*⁴-*ley*⁴) word, where numbers stand for tones. In Experiment 1, when the prime-target overlap corresponded to a syllable, the tones and the orthographies were also the same (i.e., the overlap in effect corresponded to the entire character). In Experiment 2, the syllable overlap included the tone but not the orthography. In Experiment 3, the syllable overlap was restricted to the syllable only, the tone and the orthography being different. A crossover interaction of the prime by target type was observed not only in Exp. 1 but also in Exp. 2 and Exp. 3, the effect being larger in Exp. 1 and about the same in Exps. 2 and 3. The crossover interaction effects from the last two experiments strongly support the view that the syllable (lacking the tone) is a stored phonological chunk and plays an independent role as a planning unit in Chinese word production.

Masked Priming of the Syllable in Mandarin Chinese Speech Production

The syllable plays an important role in language processing (MacKay, 1987; Wijnen, 1988; Levelt, 1989; Segui, Dupoux, & Mehler, 1990; Sevald, Dell, & Cole, 1995; MacNeilage, 1998). However, the nature of this role is a matter of much controversy in the literature of speech perception as well as of speech production (Cutler, McQueen, Norris, & Somejuan, 2001; Roelofs, 2002; Santiago, MacKay, & Palma, 2002; Segui & Ferrand, 2002). With respect to speech production, the controversy is particularly over the question of whether the phonological syllable is stored or constructed on the fly. Henceforth, when the syllable is mentioned, we mean the phonological syllable unless otherwise stated.

According to one view, the phonological syllable is not stored, but constructed on the fly (Shattuck-Hufnagel, 1979; Levelt, Meyer, & Roelofs, 1999). The main reasons are, first, the syllable, unlike the phoneme, the morpheme, and the word, rarely moves in error (Shattuck-Hufnagel, 1979; Wijnen, 1988), and second, in languages such as English and Dutch resyllabification across the word or morpheme boundary is often necessary (e.g., DE-FEND IT becomes DE-FEN-DIT) so that storing the syllable does not seem to serve any useful purpose (Levelt, 1989; Levelt, Meyer, & Roelofs, 1999; Levelt, 2001). In the Levelt-type theory of speech production (Roelofs, 1997; Levelt, Meyer, & Roelofs, 1999), the syllable is constructed on the fly via a segment-to-frame association process. When the phonological syllable has been constructed, it is used to activate and select the phonetic syllable, which is an articulatory gesture score or motor program.

According to another view, the phonological syllable has a stored representation which can be activated or selected during word production. In Dell's spreading activation model as well as MacKay's Node-Structure Theory, the syllable is a memory node which, when activated, serves to control the timing of the assignment of the segment to the syllable frame (Dell, 1986; MacKay, 1987; Santiago, MacKay, Palma, & Rho, 2000). In both theories, the

syllable is only activated but not selected, so as to account for the paucity of the syllable movement errors (cf. Chen, Chen, & Dell, 2002). Within this view, a distinction has also been made as to whether the stored syllable is a schema or a chunk (Sevald, Dell, & Cole, 1995).

Recently, Chen presented evidence which suggests that the phonological syllable might be a stored chunk in Chinese word production. First, he observed clear cases of syllable movement errors (i.e., independent of the tones) that could not be accounted for by chance expectation (Chen, 1999). Second, using the implicit priming paradigm of Meyer (1990), Chen and his colleagues (Chen, Chen, & Dell, 2002) found that response times were faster when the target words in a set shared the same initial syllable but not the tone than when they shared neither (i.e., the syllable-alone implicit priming effect). On the assumption that the tone is part of the prosodic frame of the syllable, the segment-to-frame association of the syllable cannot be prepared in advance when the frames of the same syllable are all different. Therefore, Chen and colleagues argued that the syllable-alone implicit priming effect must have occurred before the segment-to-frame association. Specifically, the effect must be the result of activating, and probably selecting, the syllable chunk in advance from the memory. This means, as the authors put it, that the phonological syllable can function as a planning unit in word production, at least in Chinese.

Evidence supporting the stored phonological syllables has also been obtained by other researchers using different paradigms (Ferrand, Segui, & Grainger, 1996; Santiago et al., 2000). For example, Ferrand, Segui, and Grainger (1996) used the classical masked priming technique combined with the naming task to study the possible role of the syllable in speech production in French. French has a regular syllable structure and clear syllable boundaries. For example, in the French word BALADE there is a clear syllable boundary between BA- and -LADE. If syllables play a central role over and above phoneme units in speech production, then a facilitation should be observed when primes and targets share phonemes that constitute a

syllable unit as opposed to when primes and targets share phonemes that do not constitute a syllable unit. This is what the authors demonstrated. In their study, target words were paired such that a given orthographic prime (a letter sequence) corresponded to a complete syllable only in one of the two words (e.g., BA is first syllable of BA.LADE, but less than the first syllable of BAL.CON; and BAL is first syllable of BAL.CON, but more than the first syllable of BA.LADE). The word BA.LADE was named faster when preceded by the prime BA than by BAL, whereas the word BAL.CON was named faster when preceded by the prime BAL than by BA. This crossover interaction effect was obtained not only in the word naming task, but also in the nonword naming and in the picture naming tasks.

The above results were subsequently replicated in British English (Ferrand, Segui, & Humphreys, 1997), French (Bonin, personal communication; Schiller, Costa & Colomé, in press), and Spanish (Carreiras & Perea, 2001). Together, these results are consistent with the view that the phonological syllables are stored in these languages.

However, the masked syllable priming paradigm has apparently produced conflicting results in the past. In particular, Schiller (1998, 1999, 2000) has failed to observe the critical crossover interaction effect in Dutch and in American English. Instead, a consistent length effect was found, i.e., the more phonemic segments in the prime, the greater the priming. The discrepancy may be due to the language difference. It has been suggested that English and Dutch, both belonging to the Germanic language family, are stress-timed, whereas French, a Romance language, is syllable-timed (Cutler, Mehler, Norris, & Segui, 1986; Cutler, Dahan, & van Donselaar, 1997). Therefore, the syllable may play a functional role in French, but not in English or Dutch. This is the classical explanation that was once proposed to account for the difference in speech segmentation between French and English (Cutler, Mehler, Norris, & Segui, 1986), and it can very well be used to account for the difference in speech production

between the same languages (Levelt, Roelofs, & Meyer, 1999; Levelt, 2001; Segui & Ferrand, 2002).

Unfortunately, evidence accumulated so far has begun to speak against the role of the syllable in speech segmentation even in French (cf. Cutler, , McQueen, Norris, & Somejuan 2001; Content, Meunier, Kearns, & Frauendelder, 2001). This tends to render it a bit shaky to apply the classical explanation to the production data, especially when only a few studies have been reported so far and there are concerns of unsuccessful replications of the French results (Schiller and Dijkstra, personal communications).

Perhaps French is not the best language to test the syllable's role. After all, resyllabification (e.g., *neuf ans*, *l'arc-en-ciel*) also occurs in French. Recall that in the Levelt and colleagues' theory of speech production (Levelt et al., 1999), resyllabification is the primary theoretical motivation for not storing the syllable. Mandarin Chinese, a language that is similar to French in the syllable structures and the rhythmic patterns but prohibits resyllabification across syllables, provides the ideal testing ground for investigating the issue here.

The Case of Chinese

Even more so than French, Mandarin Chinese too has a regular syllable structure and clear syllable boundaries. All syllables bear the canonical structure of (C)(G)V(X), where 'C' represents a consonant, 'G' a glide, 'V' a vowel, and 'X' a glide or a nasal stop (cf. M. Y. Chen, 2000). The number of syllables is relatively small (around 400 without counting the tone, or 1200 when tones are considered). The orthography is based on characters of syllable size. More importantly, resyllabification between syllables is generally prohibited. For example, *Tian-an-men Square* is never spoken as *Tia-nan-men Square* (cf. Cheng, 1973; Kuo, 1994). These properties make the syllable a potentially useful unit for lexical storage and may bias a word's phonological representation towards the form of syllables more so than an

Indo-European language. Therefore, the purpose of the present study was to seek converging evidence for the stored phonological syllables, by applying the masked syllable priming paradigm in Chinese.

The General Methodological Issue

To employ the masked priming paradigm in Chinese is not as straightforward as it first appears. The design and the procedure of the experiments followed those of Ferrand, Grainger, and Segui (1996). The problem lies in the stimuli. To create the kind of stimuli as used in the French studies, we need pairs of disyllabic words such that the two words within a pair share the initial three segments (typically CVC), but the syllable breaks at different places (i.e., CV-C in one word and CVC- in the other). Note that Chinese disyllabic words are formed by two characters (a character being a combination of syllable, tone and orthography), not just two syllables. The challenge we face is this: For any given CVC sequence, we have to make sure that (1) there is a character corresponding to it, (2) there is a disyllabic word that begins with such a character, (3) there is another character which bears a CV syllable with the same segments, (4) there is a third character whose syllable begins with the second C of the CVC, and (5) the characters in (3) and (4) can form a disyllabic word. It turns out that the only CVC syllables in Chinese are those ending with /n/ or /ng/, and /ng/ cannot begin a syllable. With the multiple and simultaneous constraints described above, we are left with very few pairs of disyllabic words for the experiments.

To overcome this problem, we decided to make use of the CVG sequence, instead of the CVC sequence. In all three experiments that are reported here, the prime was a single Chinese character that bore a CV or a CVG syllable, e.g., 把 (*ba3*, ‘a handle’) or 百 (*bai3*, ‘hundred’), and the target was a disyllabic word which started with a CV or a CVG syllable, e.g., 霸業 (*ba4-ye4*, ‘a superior enterprise’) or 拜神 (*bai4-shen2*, ‘worship’). Notice that when the target

word starts with a CV syllable, its second syllable begins with a glide, and therefore, the beginning portion of this target word contains the same segments as the CVG-initial target word (in these examples, the segments /b/, /a/, and /y/).

Using the CVG sequence may raise a concern, which is that the diphthong in the sequence is a single phonological unit. If this is true, then the CVG sequence and the CV-G sequence cannot be said to share the same segments. We believe that the diphthong contains two phonological units for two reasons. First, Chinese linguists typically consider a diphthong as comprising two units. For example, the canonical syllable structure that is widely accepted contains two slots for the diphthong, one for the nucleus vowel and the other for the glide (Cheng, 1973; Kuo, 1994; M. Y. Chen, 2000; Duanmu, 2000). Second, speech error analysis has shown that the constituents of a diphthong can be separately affected (MacKay, 1978).

In addition to the CVG sequence, we also used the CVV sequence. This requires some explanation. In Chinese, the high front vowel /i/ becomes a glide /y/ when it is followed by another vowel, but remains a full vowel otherwise. Traditionally, the vowel is given the name ‘medial vowel’ and is represented by the vowel symbol /i/ when it is followed by another vowel (Cheng, 1973). An example of the target words that use the CVV sequence is 西安 (*xi1-an1*, ‘name of a city in China’) and 瞎扯 (*xia1-che3*, ‘prate’). Here, the two words share the initial three segments /ʃ/, /i/, and /a/, but /ʃ/ and /i/ form a syllable in the first word, whereas /ʃ/, /i/, and /a/ form a syllable in the second.

To keep the notation simple, from now on we will use CVG to stand for both CVG and CVV. The arrangement of the materials as described above was the best match to the French experiment that is possible in Chinese. If the phonological codes of the disyllabic words are structured syllabically, then naming the CV words should be faster when preceded by the CV primes than by the CVG primes, and conversely, naming the CVG words should be faster when

preceded by the CVG primes than by the CV primes. In other words, the presence of a prime type \times target type crossover interaction would support the existence of stored phonological syllables.

EXPERIMENT 1

MASKED PRIMING WITH SYLLABLE, TONE, AND ORTHOGRAPHY OVERLAP

In Experiment 1 we sought to maximize the chance of observing a masked priming effect. Therefore, under the condition where the overlapped portion of the prime and the target corresponded to a syllable, the tones and the orthographies of the syllables were also made identical. That is, the overlap was of the entire character. Clearly, if a masked priming effect was observed, it might be due to the overlapping form of the character and/or the overlapping morpheme (in Chinese, a character generally corresponds to a morpheme), in addition to the overlapping syllable. But, because the purpose of the experiment was to check the effectiveness of our masked priming procedure, this did not concern us.

METHOD

Participants

Eighteen undergraduate students from the Psychology Subject Pool of National Chung-Cheng University, Taiwan, participated in this experiment. They all had normal or corrected-to-normal vision. The participants received course credits for their participation.

Equipment

The experiment was run on a Pentium III-667 MHz personal computer with a 17-inch color monitor, a sound card, and a microphone. The refresh rate of the monitor was 7 ms. The DMDX software (developed at the University of Arizona by K.I. Forster and J.C. Forster) was used to program the experiment.

Materials

The construction of the stimulus materials followed the principle outlined in the Introduction. The only difference was when the prime and the target overlapped in the syllables, the corresponding characters were also shared. This means that when the prime and the target only overlapped in the segments but not in the syllables, their characters necessarily differed too.

A total of 15 pairs of target words were prepared. The primes were simply the first characters of the target words. They are referred to as the CV and the CVG primes. A neutral prime containing an asterisk of the same font size as a Chinese character was also included. To anticipate that the priming effect might be position sensitive, each prime character was accompanied on the right side by a percent sign (%). This arrangement ensured that the prime and the target were of equal length and the relevant information pertained to the left side of both character strings. The full list of the stimulus materials is given in Appendix I.

Design and Procedure

The experiment employed a 3 (prime type) \times 2 (target type) within-participants design. Each type of prime was paired with each type of target to create 6 basic trials. The 6 trials were grouped into three types of trials: the homogeneous type, where the prime shared the same syllable as the beginning of the target, the heterogeneous type, where the prime shared the same segments but not the same syllable as the beginning of the target, and the neutral type, where the prime was the asterisk. Each type of trials consisted of 30 prime-target pairs. They were presented randomly within a block and were repeated three times by means of three blocks. The order of the three trial types was counterbalanced across participants by exhausting all the six possible combinations. A combination was assigned to a participant randomly.

On each trial, a plus sign appeared at the center of the screen to signal the location where the prime and the target would be shown. The participants were asked to fixate on the plus sign

before pressing the left button of the mouse. A forward mask, which was a double at sign ('@@') of the same font size as a Chinese character, appeared for 504 ms when the mouse was pressed. The prime (in Standard Kai font) followed the mask and stayed on the screen for 49 ms. A backward mask (the double at sign) replaced the prime and stayed for 14 ms. Finally, the target word (in New Ximing font) was shown until the participants responded. The participants were asked to respond by naming the word out loud as fast and accurately as possible.

The participants sat with a head-rest in front of the monitor. Their eye level was aligned with the center of the monitor and they were about 60 cm away from it. With this distance, each character subtended around 1 degree of visual angle horizontally and vertically.

RESULTS AND DISCUSSION

The mask proved to be effective as none of the participants reported any awareness of the presence of the prime when asked at the completion of the experiment. The overall error rate was less than 2% (1%~2% across conditions). Figure 1 displays the mean naming times for the correct responses averaged across participants for each of the prime by target conditions. In the data analysis, we left out the neutral prime because it was the CV prime and the CVG prime that were critical for testing the crossover interaction effect. We also chose not to define the priming effect by measuring it against the neutral prime condition. This is because the priming effect measured in this way often depends on the kind of neutral condition used in an experiment, and, as a result, is not an operationally reliable term to be useful for the present investigation. Therefore, a 3 (repeats) \times 2 (prime types) \times 2 (target types) repeated-measures analysis of variance was adopted in both the by-participant (indicated by F1) and the by-item (indicated by F2) analyses.

The results of the analysis showed the prime \times target interaction was highly significant

[$F(1, 17) = 39.78$, $MSe = 1155$, $p < .0001$; $F(1, 14) = 95.54$, $MSe = 415$, $p < .0001$]. Further analyses showed the simple main effect for prime type was significant for both types of targets, but in opposite directions [CV targets: $F(1, 17) = 26.89$, $MSe = 938$, $p < .0001$; $F(1, 14) = 41.77$, $MSe = 518$, $p < .0001$; CVG targets: $F(1, 17) = 28.78$, $MSe = 724$, $p < .0001$; $F(1, 14) = 79.81$, $MSe = 227$, $p < .0001$].

In addition to the crossover interaction, there was a significant main effect for repeat [$F(2, 34) = 3.14$, $MSe = 1377$, $p = .06$; $F(2, 28) = 7.89$, $MSe = 455$, $p < .002$], but the factor did not interact significantly with the other two factors [p 's ranging from .13 to .98]. There was also a main effect for target type, which is significant in the by-participant analysis but not in the by-item analysis [$F(1, 17) = 7.11$, $MSe = 528$, $p < .02$; $F(1, 14) = 1.24$, $MSe = 2904$, $p = .28$]. There was no significant main effect for prime type [F 's < 1].

To summarize, Experiment 1 tried to maximize the potential masked priming effect with the character prime, and demonstrated a significant prime \times target crossover interaction. The absolute size of the priming effect was about 30 ms, and it was in opposite directions for the CV and the CVG targets. The character priming effect is similar to what Taft and Zhu (1997) as well as Zhou, Marslen-Wilson, Taft, and Shu (1999, Exp. 1) found recently with similar procedures. In Taft and Zhu's study, the prime was a single character that matched the target's first or second character, the target was a disyllabic binding word or compound word, and the task was word naming. For 1st-character primes and compound words, the priming effect relative to the unrelated-character control was 23 ms. Zhou et al.'s experiment used disyllabic compound words as the primes and the targets. In addition, lexical decision was the task. When the prime and the target shared the first character, the authors observed a priming effect of about 26 ms, which was measured against a neutral condition that contained a different-first-character prime.

The consistency between the priming effect observed in our Experiment 1 and that found

in Taft and Zhu (1997) as well as in Zhou, Marslen-Wilson, Taft, & Shu (1999) demonstrated the effectiveness of the masked priming procedure as employed in the present experiment. In addition, the presence of a reliable crossover interaction further increased our confidence in observing a similar effect when the syllable became the prime. In the next two experiments, we used the same procedure to examine the masked priming effect for the syllable.

EXPERIMENT 2

MASKED PRIMING WITH SYLLABLE AND TONE OVERLAP

In this experiment, the orthographic form and the morpheme was not part of the overlap between the prime and the target. The overlap, when there was a syllable match, included the syllable and the tone. Otherwise, it included the segments and the tone. The difference, then, between the CV prime and the CVG prime with respect to a given type of target was whether the shared segments corresponded to a syllable. Accordingly, the anticipated crossover interaction between the prime type and the target type reflected the priming effect of the syllable only.

METHOD

Eighteen undergraduate students from the same subject pool were recruited for the experiment. The design and the procedure were identical to those of Experiment 1. It was the stimulus materials that were different.

An example of a pair of CV and CVG target words is 霸業 (*ba4-ye4*, ‘superior enterprise’) and 敗類 (*bay4-ley4*, ‘scum’). The corresponding primes are 爸 (*ba4*, ‘father’) and 拜 (*bay4*, ‘bow’). When 霸業 (*ba4-ye4*, ‘superior enterprise’) and 敗類 (*bay4-ley4*, ‘scum’) are preceded by 爸 (*ba4*), the prime shares the same segments with the initial portion of both target words

(i.e., /b/ and /a/), the difference being that 爸 (*ba4*) and 霸 (*ba4*) match in syllable, whereas 爸 (*ba4*) and 敗 (*bay4*) do not. Similarly, when 霸業 (*ba4-ye4*, ‘superior enterprise’) and 敗類 (*bay4-lei4*, ‘scum’) are preceded by 拜 (*bay4*), the prime shares the same segments with the initial portion of both target words (i.e., /b/, /a/, and /y/), the difference being that 拜 (*bay4*) and 敗 (*bay4*) match in syllable, whereas 拜 (*bay4*) and 霸 (*ba4*) do not.

A total of 13 pairs of target words with corresponding pairs of prime characters were prepared. The full list of the materials is given in Appendix II. The stimuli were arranged and presented in the same way as those in Experiment 1.

RESULTS AND DISCUSSION

Like in Experiment 1, the participants reported no awareness of the presence of the primes when asked at the completion of the experiment. The error rates for the CVG targets were 1% regardless of the primes. For the CV targets, they were higher, being 4%, 6%, and 7% for the neutral, the CV, and the CVG primes, respectively. The difference in error rates between the CV targets and the CVG targets is likely the result of the difference in word frequency. The mean frequency of the CV targets was 3.28 per million (range: 0~13.53); it was 6.81 for the CVG targets (range: 1.04~34.36). There were four CV words and no CVG words with zero frequency.

Figure 2 displays the mean naming times for the correct responses averaged across participants for each of the prime by target conditions. The data were analyzed in the same way as those of the previous experiment, i.e., by a $3 \times 2 \times 2$ repeated-measures analysis of variance.

The results of the analysis showed the prime \times target interaction was significant [$F1(1, 17) = 4.71$, $MSe = 1005$, $p < .05$; $F2(1, 12) = 6.48$, $MSe = 639$, $p < .03$]. Further analyses showed

the simple main effect for prime type was significant for the CV targets [$F(1, 17) = 9.57, MSe = 453, p < .01; F(1, 12) = 19.12, MSe = 231, p < .001$], but not for the CVG targets [$F(1, 17) = 1.23, MSe = 802, p = .28; F(1, 12) = 0.69, MSe = 874, p = .42$]. The effects were in the predicted direction for both types of targets.

There was a significant main effect for repeat [$F(2, 34) = 11.51, MSe = 2043, p < .0001; F(2, 24) = 25.11, MSe = 856, p < .0001$], but the factor did not interact significantly with the other two factors [F 's < 1]. There was also a main effect for target type, which is significant by-participant but not by-item [$F(1, 17) = 58.01, MSe = 944, p < .0001; F(1, 12) = 3.08, MSe = 21892, p = .10$]. The main effect for prime type was not significant [$F(1, 17) = 2.36, MSe = 251, p = .14; F(1, 12) = 1.89, MSe = 466, p = .19$].

To summarize, Experiment 2 used the syllable (or the segments) and the tone as the prime. The pattern of the results was similar to that of Experiment 1. The critical crossover interaction of prime type by target type was observed. The CV targets were named faster when preceded by the CV primes than by the CVG primes, whereas the opposite tended to be true for the CVG targets. The absolute size of the priming effect was about 10 ms (13 ms for the CV targets and 6 ms for the CVG targets), and it was in opposite directions for the two types of target words.

EXPERIMENT 3

MASKED PRIMING WITH SYLLABLE OVERLAP ONLY

Experiment 2 observed a crossover masked priming effect that was due to the shared syllable and not to the shared segments. But, this occurred in the context of shared tone between the prime character and the first character of the target word. In Experiment 3, we examined the masked priming effect for the syllable one more time, but in the context of different tones between the prime and the target. This experiment also served to check whether the priming effect would be significant for the CVG targets. It was not in Experiment 2.

METHOD

Eighteen undergraduate students from the same subject pool were recruited for the experiment. The design and the procedure were identical to those of Experiment 1. The stimulus materials were also the same except for the primes (see Appendix III).

An example of a pair of CV and CVG target words is 拔營 (*ba2-ying2*, ‘strike camp’) and 白首 (*bay2-shou3*, ‘whitehaired’). The corresponding primes are 爸 (*ba4*, ‘father’) and 敗 (*bay4*, ‘bow’). When 拔營 (*ba2-ying2*, ‘strike camp’) and 白首 (*bay2-shou3*, ‘whitehaired’) are preceded by 爸 (*ba4*), the prime shares the same segments with the initial portion of both target words (i.e., /b/ and /a/), the difference being that 爸 (*ba4*) and 拔 (*ba2*) match in syllable (but not the tone), whereas 爸 (*ba4*) and 白 (*bay3*) do not match in syllable or tone. Similarly, when 拔營 (*ba2-ying2*, ‘strike camp’) and 白首 (*bay2-shou3*, ‘whitehaired’) are preceded by 敗 (*bay4*), the prime shares the same segments with the initial portion of both target words (i.e., /b/, /a/, and /y/), the difference being that 敗 (*bay4*) and 白 (*bay3*) match in syllable (but not the tone), whereas 敗 (*bay4*) and 拔 (*ba2*) do not match in syllable or tone.

RESULTS AND DISCUSSION

Again, the participants reported no awareness of the presence of the primes when asked at the completion of the experiment. The error rate was between 1% and 3% across conditions. Figure 3 displays the mean naming times for the correct responses averaged across participants

for each of the prime by target conditions. The data were analyzed in the same way as those of the previous experiment, i.e., by a $3 \times 2 \times 2$ repeated-measures analysis of variance.

The results were similar to those of Experiment 1 and Experiment 2. The critical prime \times target interaction was significant [$F(1, 17) = 7.19, MSe = 919, p < .02; F(1, 14) = 27.27, MSe = 228, p < .0001$]. The analysis of the simple main effect for prime type showed it to be significant and in the predicted direction for both types of targets [CV targets: $F(1, 17) = 6.63, MSe = 374, p < .02; F(1, 14) = 7.37, MSe = 381, p < .02$; CVG targets: $F(1, 17) = 5.74, MSe = 739, p < .03; F(1, 14) = 14.05, MSe = 245, p < .003$].

The main effect for repeat was significant [$F(2, 34) = 6.86, MSe = 1964, p < .005; F(1, 14) = 31.39, MSe = 389, p < .0001$]; so was the main effect for target type, but only in the by-participant analysis [$F(1, 17) = 5.72, MSe = 524, p < .03; F(2, 34) < 1$]. The remaining effects were not significant.

To summarize, Experiment 3 replicated the masked priming effect for the syllable, but in the context of different tones between the prime and the target. Once again, the critical crossover interaction between prime type and target type was observed. The absolute size of the effect of the prime type was about 11 ms, and significant, for both types of targets, a finding similar to that of Experiment 2. The crossover interaction indicates that it was the overlapped syllable, not the overlapped segments that gave rise to the priming effect.

GENERAL DISCUSSION

Are the phonological syllables stored or computed? In the present study, we addressed this question by employing the masked syllable priming paradigm combined with word naming in the context of Mandarin Chinese. Results from three experiments all demonstrated the critical prime type \times target type crossover interaction. A CV target word was named faster when preceded by a CV prime than by a CVG prime; whereas a CVG target word was named

faster when preceded by a CVG prime than by a CV prime. This crossover interaction was observed not only when the prime and the target shared the syllable and the tone, but also when they shared the syllable only. Before discussing the implication of these results for our addressed question, we would like to note briefly their relevance for an important issue in the literature of visual word recognition.

The issue is the early automatic activation of phonology during reading. The masked syllable priming effects we observed in Experiments 2 and 3 are consistent with the findings of Perfetti and colleagues (Perfetti & Zhang, 1995; Perfetti & Tan, 1998; Tan & Perfetti, 1997), Shen and Forster (1999, Exp. 1), Wu and Chen (2000, naming of low-frequency words), and Chen and Shu (2001, at 57 ms SOA of Exp. 1). Together, these results demonstrated that the phonological information of a word could be activated early and automatically in the process of reading. Liu (2001), however, warned recently that the duration of the prime might not reflect the actual timing of the activation of the phonological information. According to him, when the prime duration was very short, processing of the prime may extend into the time window of the word naming process. Consequently, by the time the phonological effect sets in, it is likely way past the presentation of the prime. Thus, the word ‘early’ in this context should be interpreted with caution.

We now turn to the issue of the role of the syllable in speech production. Past studies investigating the issue were primarily done in Indo-European languages, and the results tended to be negative. In terms of speech errors, the consensus seems to be that “intrusions and transpositions of syllables are so rare that one is inclined to dismiss the syllable as a planning unit” (Wijnen, 1988, p. 188). In terms of the implicit priming effect, the Dutch studies (Meyer, 1991; Roelofs, 1998; Roelofs & Meyer, 1998; Levelt et al., 1999) and the Spanish study (Costa & Sebastián, 1996) have generally not supported the phonological syllable as a stored unit in word production. With respect to the masked syllable priming effect, the studies based on

French produced positive findings, whereas those based on English and Dutch tended to produce negative findings. Finally, using the picture naming task in English, Santiago, MacKay, Palma, and Rho (2000) obtained a number-of-syllables effect, which they interpreted as suggesting that “the syllable is a psychologically real unit in language production” (p. 32). Roelofs (2002) has recently questioned the authors’ interpretation. He argued that the results actually showed a word length (or number-of-segments) effect (but see Santiago, MacKay, & Palma, 2002 for a reply). Aside from this problem, it is also not clear whether the number-of-syllables effect implicates a stored syllable chunk or a stored syllable schema (see Sevald, Dell, & Cole, 1995 for the distinction). Roelofs (2002) has referred to the effect as the syllable structure effect, and Santiago, MacKay, and Palma (2002) seemed to comply with the term, even though they disagreed on the interpretation of the data.

By contrast, our work has been done in Mandarin Chinese, and so far it has provided three kinds of evidence supporting the view that the phonological syllable is stored and is stored as a chunk: (1) the syllable movement errors, (2) the syllable implicit priming effect, and (3) the masked syllable priming effect. Notice that in all cases the tones need not be involved. This is critical for our argument. None of the corresponding evidence from the Indo-European languages can be unambiguously taken to support the syllable as a stored phonological chunk. For example, acknowledging that syllable errors do occur in English, Levelt (personal communication) suggested that they could be handled at the syllabary level. Similarly, Levelt, Roelofs and Meyer (1999) argued that the masked syllable priming observed in French could be explained as priming of the mental syllabary via the input phonology, which takes the form of a syllable in French, and the perception-production link at the segment level. With regards to the implicit priming of the syllable in Dutch, the authors have presented ample evidence to show that it is in effect a segmental effect.

But, if the syllabary explanation for syllable effects is to apply to Chinese, the syllables

would have to include the tone, whether the effects concern speech error, implicit priming or masked priming. This is because the syllabary is a hypothesized repository for syllables as articulatory programs. Presumably the prosodic aspects of the syllables have already been integrated with their segmental aspects at this level. Yet, in all cases we have shown the syllable effect to be independent of the tone. Thus, compared to English, Dutch, or French, the evidence from Chinese clearly fares better in supporting the view that the syllables are stored phonological chunks.

The discrepancy between the studies based on the Indo-European languages and those based on Mandarin Chinese likely reflects the language-specific properties in language processing. As far as the syllable is concerned, the phonology of Chinese clearly favors a more prominent and explicit role for the syllable than that of English or Dutch. Perhaps the phonology of French also contains such a bias. After all, both Chinese and French are syllable-timed languages. If the rhythmic structure of a language can affect its perception, it might also affect its production (see also Levelt et al., 1999 and Levelt, 2001 for a similar view).

On the other hand, there may be something about the syllable that is universal. For example, the articulatory program is likely syllable-sized regardless of the language (cf. Levelt et al., 1999; MacNeilage, 1998). The syllable can also serve as a possible word constraint in all languages (cf. Cutler, McQueen, Norris, & Somejuan, 2001). Even the phonological syllable, the unit that we specifically addressed in this study, could be universal. We think this possibility needs to be considered given the methodological problems as well as the theoretical uncertainty in the existing research. We discuss the methodological problems first.

There is room for clarification in the Indo-European studies that have more or less given the negative findings. First, no one has seriously examined the probability of a syllable error in the existing error corpora (English, German, French, and Spanish), as we did in Mandarin

Chinese. Second, the reaction-time-based studies generally have not varied the prosodic value (i.e., stress) like we did in Mandarin Chinese (i.e., tone). For example, in the implicit priming studies, the syllables that served as the implicit prime in the homogeneous condition always shared the same stress value. By contrast, in our implicit priming study, the syllables that served as the implicit prime in the homogeneous condition had different tonal values. When the response words share the first syllables and their stress values, the syllables can be fully specified down to the level of articulatory programs. As a result, the implicit priming of the syllable may be an effect of preparing the articulatory program and recovering it from the output buffer (see also Levelt et al., 1999 for the same suggestion). Only when the shared syllables do not also share the stress values (analogous to our de-toned syllables) can the implicit priming of the syllable be unambiguously interpreted as a phonological phenomenon. The same criticism applies equally to the masked syllable priming effect in French. Third, past studies often did not make an explicit distinction between the phonological syllable and the phonetic syllable (but see Wijnen, 1988 for an exception), and between the syllable schema and the syllable chunk (but see Sevald, Dell, & Cole, 1995; Ferrand & Segui, 1998 for exceptions). Until these problems have been cleared, the language-specific and language-universal natures of the syllable's role are undetermined, and both possibilities should be considered.

Next, we discuss the theoretical uncertainty. Recall that Levelt et al.'s (1999) motivation for postulating computed, instead of stored, phonological syllables is because resyllabification renders the storage of the syllables undesirable. However, we are not sure whether this motivation is essential. First, the design of the human cognitive system consists of many redundant features, and Ockham's razor need not be the sole, or even a good, theoretical principle to follow during theory development (see also Ferrand, 1999). Second, even though resyllabification does not occur in Mandarin Chinese, the segment-to-frame association process appears to operate in the language. We know this because Chinese slips of the tongue

are full of phoneme anticipations, perseverations, and exchanges (cf. Chen, 1993; Shen, 1993). If the syllable is so salient in Chinese, why do the Chinese speakers bother to retrieve the syllable and go on to break it apart and put it back together? Clearly, parsimony is not the only concern in the design of a human cognitive system. Other motivations also exist, although what they are still evades us at this stage of our research.

To conclude, the evidence provided by the present study as well as our other Chinese studies speaks quite strongly to the view that the syllable (lacking the tone) is a stored phonological chunk and plays an independent role as a planning unit in Chinese word production. Whether this role of the syllable also applies in non-Chinese languages remains to be determined.

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Appendix I

Materials used in Experiment 1

CV prime	CVG prime	CV target	CVG target
拔 ba2	白 bay2	拔營 ba2-ying2 ‘strike camp’	白首 bay2-shou3 ‘whitehaired’
螞 ma3	買 may3	螞蟻 ma3-yi3 ‘ant’	買到 may3-dao4 ‘bought’
麻 ma2	埋 may2	麻油 ma2-you2 ‘sesame oil’	埋伏 may2-fu2 ‘ambush’
大 da4	代 day4	大意 da4-yi4 ‘gist’	代溝 day4-gou1 ‘generation gap’
拓 ta4	太 tay4	拓印 ta4-yin4 ‘make rubbings’	太座 tay4-zuo4 ‘wife’
西 xi1	瞎 xia1	西安 xi1-an1 ‘name of a city’	瞎扯 xia1-che3 ‘to waffle’
炸 zha4	債 zhay4	炸藥 zha4-yao4 ‘dynamite’	債務 zhay4-wu4 ‘debt’
茶 cha2	柴 chay2	茶油 cha2-you2 ‘tea-seed oil’	柴火 chay2-huo3 ‘firewood’
傻 sha3	骰 shay3	傻眼 sha3-yan3 ‘stunned’	骰子 shay3-zi ‘dice’
議 yi4	訝 ya4	議案 yi4-an4 ‘bill’	訝異 ya4-yi4 ‘surprised’
西 xi1	修 xiou1	西歐 xi1-ou1 ‘Europe’	修養 xiou1-yang3 ‘cultivation’
酷 ku4	跨 kua4	酷愛 ku4-ay4 ‘craze for’	跨入 kua4-ru4 ‘step into’
化 hua4	壞 huay4	化驗 hua4-yan4 ‘lab test’	壞事 huay4-shi4 ‘evil deed’
眨 zha3	窄 zhay3	眨眼 zha3-yan3 ‘blink’	窄小 zhay3-xiao3 ‘narrow’
霸 ba4	敗 bay4	霸業 ba4-ye4 ‘superior enterprise’	敗類 bay4-lei4 ‘scum’

Appendix II

Materials used in Experiment 2

CV prime	CVG prime	CV target	CVG target
差 cha1	釵 chay1	插秧 cha1-yang1 ‘tranplant rice seedlings’	拆除 chay1-chu2 ‘tear and remove’
納 na4	耐 nay4	捺印 na4-yin4 ‘press a fingerprint’	奈何 nay4-he2 ‘to no avail’
蟆 ma2	霾 may2	麻油 ma2-you2 ‘sesame oil’	埋伏 may2-fu2 ‘ambush’
踏 ta4	泰 tay4	拓印 ta4-yin4 ‘make rubbings’	太座 tay4-zuo4 ‘wife’
稀 xi1	蝦 xia1	西安 xi1-an1 ‘name of a city’	瞎扯 xia1-che3 ‘to waffle’
柵 zha4	寨 zhay4	炸藥 zha4-yao4 ‘dynamite’	債務 zhay4-wu4 ‘debt’
查 cha2	豺 chay2	茶油 cha2-you2 ‘tea-seed oil’	柴火 chay2-huo3 ‘firewood’
億 yi4	揶 ya4	議案 yi4-an4 ‘bill’	訝異 ya4-yi4 ‘surprised’
希 xi1	休 xiou1	西歐 xi1-ou1 ‘Europe’	修養 xiou1-yang3 ‘cultivation’
褲 ku4	跨 kua4	酷愛 ku4-ay4 ‘craze for’	跨入 kua4-ru4 ‘step into’
戶 hu4	劃 hua4	互愛 hu4-ay4 ‘love each other’	話筒 hua4-tung3 ‘receiver’
吐 tu3	妥 tuo3	土偶 tu3-ou3 ‘soil mate’	橢圓 tuo3-yuan2 ‘oval’
爸 ba4	拜 bay4	霸業 ba4-ye4 ‘superior enterprise’	敗類 bay4-ley4 ‘scum’

Appendix III

Materials used in Experiment 3

CV prime	CVG prime	CV target	CVG target
爸 ba4	敗 bay4	拔營 ba2-ying2 ‘strike camp’	白首 bay2-shou3 ‘whitehaired’
罵 ma4	邁 may4	螞蟻 ma3-yi3 ‘ant’	買到 may3-dao4 ‘bought’
嗎 ma	買 may3	麻油 ma2-you2 ‘sesame oil’	埋伏 may2-fu2 ‘ambush’
搭 da1	呆 day1	大意 da4-yi4 ‘gist’	代溝 day4-gou1 ‘generation gap’
它 ta1	臺 tay2	拓印 ta4-yin4 ‘make rubbings’	太座 tay4-zuo4 ‘wife’
昔 xi2	霞 xia2	西安 xi1-an1 ‘name of a city’	瞎扯 xia1-che3 ‘to waffle’
扎 zha2	摘 zhay1	炸藥 zha4-yao4 ‘dynamite’	債務 zhay4-wu4 ‘debt’
插 cha1	拆 chay1	茶油 cha2-you2 ‘tea-seed oil’	柴火 chay2-huo3 ‘firewood’
鯊 sha1	篩 shay1	傻眼 sha3-yan3 ‘stunned’	骰子 shay3-zi ‘dice’
衣 yi1	壓 ya1	議案 yi4-an4 ‘bill’	訝異 ya4-yi4 ‘surprised’
夕 xi4	袖 xiou4	西歐 xi1-ou1 ‘Europe’	修養 xiou1-yang3 ‘cultivation’
枯 ku1	誇 kua1	酷愛 ku4-ay4 ‘craze for’	跨入 kua4-ru4 ‘step into’
譁 hua2	踝 huay2	化驗 hua4-yan4 ‘lab test’	壞事 huay4-shi4 ‘evil deed’
渣 zha1	寨 zhay4	眨眼 zha3-yan3 ‘blink’	窄小 zhay3-xiao3 ‘narrow’
八 ba1	百 bay3	霸業 ba4-ye4 ‘superior enterprise’	敗類 bay4-lei4 ‘scum’

Figure Captions

Figure 1. Mean naming times for each of the prime by target conditions in Exp. 1. The critical prime was character.

Figure 2. Mean naming times for each of the prime by target conditions in Exp. 2. The critical prime was syllable, but in the context of shared tone between the prime and the target.

Figure 3. Mean naming times for each of the prime by target conditions in Exp. 3. The critical prime was the syllable, but in the context of different tones between the prime and the target.





