LANGUAGE AND COGNITIVE PROCESSES, 1994, 9 (3) 393–422

Words, Morphemes and Syllables in the Chinese Mental Lexicon

Xiaolin Zhou and William Marslen-Wilson
Centre for Speech and Language, Birkbeck College, University of London, London, UK

This research uses the differential frequency effect as a diagnostic tool to investigate the mental representation of disyllabic compound words in Mandarin Chinese. In three experiments, subjects made lexical decision responses to spoken disyllabic words and nonwords. In Experiment 1, word frequency, morpheme frequency and syllable frequency were covaried, with either the first or second constituent of the compound held constant. Only word-frequency effects were found for real words, although responses were slower to nonwords with high-frequency initial syllables. The results for real words were replicated in Experiment 2, where syllable and morpheme frequency were varied for pairs of words sharing common morphemes in first or second position. Experiment 3, however, showed that when both word frequency and morpheme frequency were held constant, high-frequency first syllables slowed responses to real words. Experiment 3 also verified that syllable frequency effects for nonwords cannot be reliably obtained for second constituent contrasts. These effects were attributed to competition between homophonic morphemes. The overall results were interpreted in terms of a multi-level cluster model, with separate syllabic, morphemic and whole-word levels of representation.

Requests for reprints should be addressed to Xiaolin Zhou, Department of Psychology, Birkbeck College, University of London, Malet Street, London WC1E 7HX, UK. E-mail: ubjtp70@ccs.bbk.ac.uk.

This research was supported by a postgraduate studentship awarded to Xiaolin Zhou by the Sino-British Friendship Scholarship Scheme, and by grants to William Marslen-Wilson and Lorraine Tyler from the British ESRC, MRC and SERC. We would like to thank Jianmin Cui for his help in testing subjects in Beijing. We are also grateful to Marcus Taft and two anonymous reviewers for their helpful comments on an earlier draft of the manuscript.

INTRODUCTION

The purpose of this research is to explore the role of morphological structure in the representation and access of disyllabic words in spoken Mandarin Chinese. We approach this question from two perspectives: on the one hand, current issues in the psycholinguistic study of lexical representation and process and, on the other, the special properties of morphological processes in Mandarin Chinese, with the dominance of compounding and the effective absence of the processes of derivational and inflectional morphology familiar from Indo-European languages.

Psycholinguistic research into the role of morphology in the mental lexicon has concentrated on two closely related issues: Are morphologically complex words represented in the lexicon as whole words or as separate morphemes, and is there an obligatory morphological decomposition in the access process? Roughly three kinds of answer to these questions can be distinguished in the literature, representing the main variations of morpheme-based and word-based approaches to the representation and access of polymorphemic words.

The most radical morpheme-based approach, the *morpheme listing* view, insists that only stems (for affixed words) or first constituent morphemes (for compound words) are represented in the mental lexicon as lexical entries. The affixes and second constituents are listed under the morpheme entries (Taft & Forster, 1975; 1976) and come into play after the lexical entries have been accessed. The processing consequence of this claim about representation is that access to polymorphemic words must be conducted on a morphemic basis. Whole-word input representations are obligatorily decomposed into morphemic units before being projected onto the lexicon. If the main morpheme which corresponds to a lexical entry is not at the beginning of a word, as in the case of prefixed words, the initial secondary morpheme has to be stripped off before access to the lexical entry can take place.

The alternative, *whole-word representation* view, assumes that all polymorphemic words are represented as wholes, with or without explicit morphological marking in lexical entries. There is no compulsory morphological decomposition before access, although morpheme-based access may be available as fall-back. The suggestion of whole-word representation without any morphological information is made by Seidenberg (1987; 1989; Seidenberg & McClelland, 1989), who argued that morphological effects observed in previous visual experiments were confounded with orthographic effects, such as the relative frequency of particular letter clusters (but see Rapp, 1992, for a direct test of this suggestion). More widely accepted whole-word views assume that polymorphemic words are represented independently in the lexicon but with cross-references between words comprising the same morphemes (e.g. Fowler, Napps, & Feldman, 1985; Zhou, 1992; Zhou & Marslen-Wilson, 1992). The morphological structure of each word has to be explicitly marked to allow these morphologically based connections to be established.

A third view that we consider, the *morpheme network* view, claims that all the morphemes, whether roots or affixes, are represented as individual entries (Caramazza, Laudanna, & Romani, 1988; Lieber, 1980). However, unlike the morpheme listing view, these entries are connected with each other if they comprise polymorphemic words, forming a network (Hoosain, 1992). A representative of the morpheme network view is the Augmented Addressed Morphology (AMM) model developed by Caramazza and his colleagues (Burani & Caramazza, 1987; Caramazza, Miceli, Silveri, & Laudanna, 1985; Caramazza et al., 1988). In this model, each stem is marked with the relevant grammatical features while (inflectional) suffixes are grouped by conjugation type (for Italian words). There are positive links and, for some stems, negative links as well, between stems and suffixes. One property that differentiates the morpheme network view from the morpheme listing view is that all the morphemes are represented at the same level, whereas on the listing view, morphemes classified as "main" and "secondary" are represented at different levels.

The research here investigates the applicability of these types of model to the representation and access of polymorphemic words in Mandarin Chinese. Compared with Indo-European languages, the processes of inflectional or derivational morphology play a minor role in word formation in Chinese (Li & Thompson, 1981). Instead, Mandarin Chinese has a massive number of compound words. Disyllabic compounds are about 73.6% by type and 34.3% by token in a large text corpus (Institute of Language Teaching and Research, 1986), while the rest are mainly monomorphemic words (12.0% by type and 64.3% by token). Compounding is the most common method for constructing new words. Moreover, because the number of morphemes is limited (to about 6000), most morphemes and monomorphemic words are repeatedly re-used as constituent morphemes in compounds.

With few exceptions, the phonological form of a morpheme is a syllable, defined as a CVC, CVVC or CVVV segmental arrangement to which a suprasegmental tone is attached. The same segmental template is usually attached by four different lexical tones, giving four different syllables.[1] However, because of historical accidents, some templates are not accom-

---

[1] Throughout this paper, when we talk about "syllables", we are referring to both segmental and tonal features. The same segmental template (e.g. "yi") attached by different tones will be treated as different syllables.

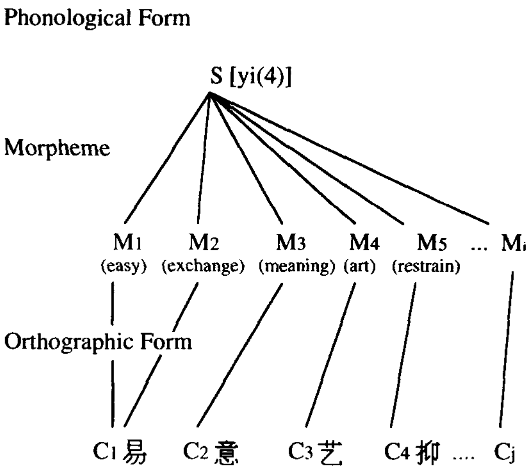

FIG. 1 The relationship between phonological form (syllables), morphemes, and orthographic form (characters) in spoken and written Chinese. S = Syllable, M = Morpheme, C = Character. The syllable "yi(4)" is given in Pinyin (the phonetic transcription of Chinese characters) while the number "4" in parentheses represents the tone of the syllable. English translations of the meanings of morphemes are also given in parentheses.

panied by all the four tones. Because only about 1300 different syllables are used in Mandarin Chinese, each syllable corresponds, on average, to four different morphemes (Yin, 1984). In extreme cases, one syllable may represent as many as 40 or 50 morphemes. A distinctive characteristic of Chinese, therefore, is the prevalence of homophonic morphemes. The phonological form (a syllable) of a morpheme or a monomorphemic word is ambiguous and does not uniquely specify the corresponding morpheme.

In contrast, there is usually a one-to-one correspondence between a morpheme and its orthographic form (a character).[2] In other words, the character has the function of differentiating homophonic morphemes. Figure 1 exemplifies the relations between morphemes and their phonological and orthographic forms in Mandarin Chinese, showing how the same phonological syllable (e.g. "yi(4)") corresponds to several different morphemes ("easy", "exchange", "meaning", "art", etc.), and where each morpheme has a unique character associated with it—with the exception of "easy" and "exchange", which share the same character.

---

[2] Occasionally, two different morphemes may have the same orthographic form. If a monomorphemic word is disyllabic, it is represented by two characters.

The dominance of compounding in Chinese, and the salience (and meaningfulness) of individual morphemes[3] as separate lexical items, make it an important test case from the perspective of the questions raised earlier. Are disyllabic compounds represented as whole words, or as linked morphemes? What is the role of individual morphemes in the access of these compounds from the speech stream? How will the results compare with those for Indo-European languages, where compounding plays a more minor role?

To investigate these questions, we will use the differential frequency effects as a diagnostic tool, where the frequency of a word's constituent morphemes is varied systematically. This diagnostic tool has been exploited in several previous studies, mostly using visual presentation (Andrews, 1986; Bradley, 1979; Burani & Caramazza, 1987; Colé, Beauvillain, & Segui, 1989; Taft, 1979). The research by Taft (1979), for example, manipulated the morpheme frequencies[4] of pairs of prefixed words (e.g. *reproach/dissuade*), which were matched on word frequency. Taft (1979) found that lexical decision times to words containing higher-frequency morphemes (e.g. the bound morph {*-proach*}) were faster than to words containing lower-frequency morphemes (e.g. the bound morph {*-suade*}). Comparable morpheme-frequency effects, usually accompanied by a whole-word frequency effect, have been observed for inflected words and for derived suffixed words (Burani & Caramazza, 1987; Colé et al., 1989; Taft, 1979), though not for French derivationally prefixed words (Colé et al., 1989).

When it comes to compound words, the results are conflicting. On the one hand, there were indications that frequencies of first constituent morphemes (Taft & Forster, 1976) or of both morphemes (Andrews, 1986) influenced lexical decision times to visually presented English compounds. On the other hand, after varying orthogonally the overall word frequency and the frequency of the first and second constituent words in Dutch compounds, van Jaarsveld and Rattink (1988) could find only whole-word frequency effects. The issue of word-based versus morpheme-based lexical representation is even more complicated when the data from experiments using priming techniques (e.g. Monsell, 1985; Sandra, 1990) are taken into consideration. In Chinese, given the saliency of all morphemes as discrete

---

[3] The salience of individual morphemes comes from the fact that morphemes in Chinese usually can stand alone as monomorphemic words. Each morpheme in the written form corresponds to a character which represents directly the meaning of the morpheme, and which, perceptually, has clear boundaries with adjacent characters.

[4] These frequencies were usually called cumulative root or cumulative stem frequencies, because they count over all the occurrences of the same roots or stems in any words.

elements in the language and its orthography, we would expect to find at least some effects of morpheme frequency in tasks tapping lexical access for spoken compounds. These effects should allow us to choose between different theories of lexical representation.

Given the relations between morphemes in Chinese and their phonological and orthographic forms (see Fig. 1), the issue arises of what is the appropriate measure of morpheme frequency for this language. There is not the same problem for languages like English, where most morphemes have a unique phonological form, so that counting the occurrences of a specific form is equivalent to counting the frequency of use of the corresponding morpheme. In Chinese, these counts do not usually coincide, giving two different measures of morpheme frequency. On one measure, morpheme frequency is determined by counting the occurrences of the morpheme, usually identified as a unique character, as a constituent morpheme in compounds and, occurring on its own, as a monomorphemic word. We still refer to this measure, which corresponds to the cumulative morpheme-frequency measure used in most research on Indo-European languages, as "morpheme frequency". The second measure is based on the phonological form of the morpheme, and counts all of the occurrences of the syllable which corresponds to the morpheme. Counting in this way, morpheme frequency includes all of the homophones of a given morpheme. This measure we will refer to as "syllable frequency".

This distinction between syllable and morpheme frequency suggests a stronger contrast between visual and auditory modalities for Chinese than for languages where morphemes are less likely to be homophonic. When a Chinese compound is presented visually, this should make syllable frequency much less relevant to the access process, because of the one-to-one relation between characters and specific morphemes. When it is presented auditorily, both syllable and morpheme frequency should be important factors in the access process—syllable frequency because the ambiguous phonological forms in the input may lead to the access of multiple morphemes and words, and morpheme frequency because at some point in processing, just as in the visual domain, the unique morpheme will have to be identified by the listener. This balance between syllable and morpheme frequency in the auditory domain is one reason for studying the access of spoken compounds here.

On different accounts of lexical representation, both types of morpheme frequency could affect recognition performance. On both morpheme listing and morpheme network accounts, where morphemes serve as lexical entries, the frequency of occurrence of the unique morpheme (morpheme frequency) should affect performance, with faster responses to compounds containing frequent morphemes. On the view that compound words are accessed via their first constituent, the frequency of the first morpheme in a disyllabic compound should have more influence on lexical decision time than the frequency of the second morpheme. On the other hand, if the morpheme frequency of either constituent of compounds does not affect performance (but whole-word frequency does), this will support the whole-word representation view—that the lexical entry for compound words cannot be reduced just to morphemes and the links between them.

The frequency of the phonological form of the morpheme (its syllable frequency) may also affect performance, but in a different way. There is some evidence from English that there is multiple access of the meanings of homophonic words (e.g. Small, Cottrell, & Tanenhaus, 1988; Swinney, 1979), so that hearing an ambiguous phonological form will initially activate all the lexical entries that correspond to that form. Analogously, presenting a syllable in Chinese may activate initially all the homophonic morphemes and/or whole-word entries in the lexicon. It is possible that the effects of this will be inhibitory, since morphemes with a higher syllable frequency will tend to have more competitor morphemes, and this could have the effect of slowing down recognition performance. If compound words are represented at both the morpheme and whole-word levels, this effect should be strongest for words with first constituents high in syllable frequency, since this will activate not only all homophonic morphemes but also all compounds which have these morphemes as first constituents. This is a possibility that we will look at specifically in Experiment 3.

EXPERIMENT 1

In the first experiment, we systematically varied the morpheme frequency (MF) and the syllable frequency (SF) of both the constituent morphemes of disyllabic compound words in Mandarin Chinese,[5] together with the word frequency (WF) of these compounds. Because of difficulty in finding enough stimulus words in which the morpheme and syllable frequencies of both first and second constituents could be varied simultaneously, we manipulated the syllable and morpheme frequencies of these constituents separately in two experiments. In Experiment 1A, we held the first constituent constant and varied the properties of the second constituent, and *vice versa* in Experiment 1B. As we noted above, morpheme-based theories predict effects of morpheme frequency, especially for the first constituent of a compound.

We also systematically manipulated the construction of nonwords in some of the experiments reported here. Nonword data have been widely

---

[5] Here, as elsewhere, we refer to the Beijing dialect of Chinese, on which the official language (Putonghua) is based.

adduced in theorising about the role of morphological structure in word recognition (Caramazza et al., 1988; Taft & Forster, 1975; 1976; Taft, Hambly, & Kinoshita, 1986), though some objections have been made to the use of nonword data in constructing a model of the processing of real words (Henderson, 1986). Both Taft and Forster (1976) and van Jaarsveld and Rattink (1988), for example, varied the morpheme frequency of the first constituents of compound nonwords to test the morpheme listing view, although with conflicting results (and interpretations). In Experiment 1B, we also varied the syllable frequency of the constituent morphemes in the nonword stimuli. Note that since these are spoken nonwords, the listener cannot establish which specific morpheme a syllable stands for, so that morpheme frequency cannot be systematically manipulated as well. If access to the lexicon is syllable by syllable (or morpheme by morpheme), there may be effects of syllable frequency on the time it takes to reject a nonword, especially for nonwords with high-frequency first constituents.

Method

Subjects. A total of 24 subjects who were graduate students or visiting scholars in Cambridge were tested in Experiment 1A and were paid for their participation. Fifteen of them were native speakers of Beijing Mandarin and the rest came from the northern part of China (i.e. native speakers of dialects of Mandarin).[6] Twenty-six subjects participated in Experiment 1B. Most subjects took part in both the experiments. However, the two tests for a specific subject were separated by an interval of at least 2 weeks.

Design and Materials. Both sub-experiments manipulated three independent variables (WF, SF and MF), each with two levels (high or low), giving a total of eight conditions for each experiment (2 × 2 × 2), ranging from high WF/high SF/high MF to low WF/low SF/low MF (abbreviated as HHH/LLL). In Experiment 1A, the syllable and morpheme frequencies of the second constituent morpheme were varied, while the frequencies of the first constituent were held constant. In Experiment 1B, the first constituent was varied and the second held constant.

In each experiment, 15 words were selected for each condition, giving a total of 120 critical words. All the words were well-formed and semantically transparent. In Experiment 1A, the average high and low word frequencies across relevant conditions were 88.5 and 5.4 respectively, whereas the values for the corresponding syllable frequencies were 5676

---

[6] We assume that these minor variations in the spoken form of Mandarin Chinese should not systematically bias the results here.

TABLE 1
Word, Syllable and Morpheme Frequency Counts in Experiment 1

	Experiment 1A					*Experiment 1B*				
		First Constituent		*Second Constituent*			*First Constituent*		*Second Constituent*	
	WF	*SF*	*MF*	*SF*	*MF*	*WF*	*SF*	*MF*	*SF*	*MF*
HHH	86	2467	1192	5681	1424	106	5649	1546	3462	1589
HHL	89	2596	1105	5906	210	104	5375	216	3247	1548
HLH	89	2568	1365	1433	1376	103	1501	1334	3209	1483
HLL	90	2163	1386	1243	200	107	1330	198	3644	1529
LHH	5.4	2456	1238	5490	1435	5.7	5490	1447	3428	1465
LHL	5.5	2274	1291	5626	194	5.9	5514	192	3181	1530
LLH	5.4	2294	1149	1500	1270	5.5	1452	1364	3367	1416
LLL	5.2	2376	1161	1315	196	5.5	1452	196	3451	1451

Note: In the condition labels (HHH to LLL), the first letter stands for WF, the second for SF and the third for MF. In Experiment 1A, the SFs and the MFs of the first constituents were held constant and in Experiment 1B those of the second constituents.

and 1373, and for the morpheme frequencies 1376 and 200. For Experiment 1B, the average high and low word frequencies were 105 and 5.6 respectively, whereas the corresponding high and low syllable frequencies were 5507 and 1434, and those of the morpheme frequencies 1423 and 200 (for further details of both experiments, see Table 1). All of these counts were extracted from a frequency dictionary (Institute of Language Teaching and Research, 1986),[7] which was based on a corpus of about 1.31 million Chinese words (1.81 million characters or syllables), of which most were written words. The relatively high syllable and morpheme frequency counts reflect the fact that there are few morphemes and even fewer syllables in Chinese and these syllables and morphemes are repeatedly used in different words.

To match the 120 test words, each experiment also contained 120 two-syllable nonwords. In Experiment 1A, the 120 nonwords were treated as fillers, and separated into four sets of 30. In the first two sets, nonwords were created by changing the tone of the first or second constituent of real words, such that the resulting syllables did not occur in the language. The second two sets contained nonwords formed by changing either the tone or the initial consonant of the second constituents in real words. Here, however, the resulting syllables were still existing morphemes in Chinese; they simply did not combine with their first constituents to form words.

In Experiment 1B, 80 of the nonwords were formed by combining syllables to create a 2 × 2 factorial design with the syllable frequencies of the first and second constituents as two independent variables. These variables had two levels (high and low), which combined with "constituent" (first or second) to give four conditions, ranging from high first/high second to low first/low second. The average high SF was 4100 and the average low SF was 68. The other 40 nonwords in Experiment 1B were constructed by changing the initial consonants of the second constituents of real disyllabic words. For each experiment, a further 30 words and nonwords were constructed for use as practice and dummy items.

In compiling the materials for the two experiments, every attempt was made to avoid the repeated use of the same syllables in different words and nonwords. The few stimuli that did use repeated morphemes or syllables were placed at intervals of at least 80 items in the test sequences. In parallel experiments, we found no priming effects at comparable delays between words or nonwords sharing common syllables or morphemes (Zhou, 1992).

---

[7] There was no direct syllable count in the dictionary. The syllable and morpheme frequencies used here were computed by the first author, on the basis of the character frequency count provided by the dictionary. The fact that a few characters may have two or more different pronunciations (i.e. corresponding to different syllables) was taken into account when SF and MF were computed.

All the words and nonwords were produced and recorded by a male native speaker of Mandarin and were then digitised at a sampling rate of 20 kHz. In each experiment, the word and nonword stimuli were arranged in quasi-random order, such that no more than three words followed each other and that words sharing common syllables were suitably separated. Two sequences were constructed, the second in the reverse order to the first. Half of the subjects were tested on each sequence.

Procedure. The subjects were tested in groups of four or less. They heard the stimuli played out from computer hard disk over headphones and were instructed to make a lexical decision to each presentation by pressing a "Yes" or "No" key as quickly and as accurately as possible. Reaction times were recorded automatically from the onset of words. After 26 practice trials, the subjects had 1 min rest and then continued with two dummy items and the testing stimuli. In the middle of the test, the subjects had a break and then continued with two other dummy items and the rest of the stimuli. The complete test session lasted for about 35 min.

Results

In Experiment 1B, two subjects were excluded from further analyses because their response times to both words and nonwords were much longer than for the other subjects. One nonword item in the high first/high second condition was also discarded because it had dubious lexical status and a high error rate (over 50%). No subjects or items were deleted in Experiment 1A. For the remaining data, response errors were removed and item and subject mid-means were then computed for words and nonwords, respectively. The missing data comprised about 6.0% in Experiment 1A and 5.4% in Experiment 1B. Tables 2 and 3 report the mean reaction times (based on item and subject mid-means) and error rates for word targets. The nonword data from Experiment 1B are reported in Table 4.

Experiment 1A: Second Constituent. In this sub-experiment, syllable and morpheme frequency were varied in the second constituent, with the first constituent held constant. Three-way ANOVAs were conducted on mean reaction times and error rates, with WF, SF and MF as factors and with subjects and items as random variables. Min F'-values were then computed. For responses to real word targets (see Table 2), only the effect of word frequency was significant [min $F'(1,144) = 14.52$, $P < 0.001$]. High-frequency words were responded to more rapidly (60 msec) than low-frequency words. Neither syllable nor morpheme frequency had any

TABLE 2
Experiment 1A: Second Constituent—Mean Reaction Times (msec) and Error Rates (%) for Words

	Morpheme Frequency	
	High	*Low*
High-frequency words		
High syllable frequency	778 (2.5)	784 (1.4)
Low syllable frequency	781 (5.0)	800 (1.4)
Low-frequency words		
High syllable frequency	848 (10.0)	855 (8.6)
Low syllable frequency	840 (5.6)	839 (13.7)

obvious influence on reaction times: the overall mean reaction times for high SF and low SF words were 816 and 815 msec respectively, while the average reaction times for high and low MF words were 811 and 819 msec respectively. Nor were there any significant two- or three-way interactions (min $F' < 1$ throughout). Analyses of the error data confirmed these findings. In the three-way ANOVAs, only word frequency had a significant influence on error rates, with low-frequency words more likely to be mistaken as nonwords [min $F'(1,134) = 10.86$, $P < 0.001$].

Experiment 1B: First Constituent. Here the second constituent was held constant and the first constituent varied. Despite the salience of the first constituent in morphemic access theories, we again found that only the effect of word frequency was significant [min $F'(1,134) = 10.40$, $P < 0.001$]. High-frequency words were generally responded to faster (50 msec) than low-frequency words. There were no significant main effects or interactions reflecting syllable frequency and morpheme frequency. The overall mean reaction times for high SF and low SF words were 842 and 841 msec respectively, while the average reaction times for high and low MF words were 839 and 843 msec respectively (min $F' < 1$ throughout). The results of three-way ANOVAs on error rates were consistent with the reaction time analyses. Only a word-frequency effect was observed [min $F'(1,106) = 9.51$, $P < 0.001$].

Nonwords: Turning to the nonwords (see Table 4), two-way ANOVAs were carried out on the mean reaction times, with the factors syllable frequency (high/low) and constituent (first/second). There was a main effect of syllable frequency, both for the first constituents [min $F'(1,93) = 9.03$, $P < 0.001$] and second constituents [min $F'(1,88) = 5.47$, $P < 0.05$]. However, as Table 4 shows, these effects (slower responses to nonwords

TABLE 3

Experiment 1B: First Constituent—Mean Reaction Times (msec) and Error Rates (%) for Words

	Morpheme Frequency	
	High	*Low*
High-frequency words		
High syllable frequency	828 (2.5)	795 (2.8)
Low syllable frequency	810 (1.7)	832 (2.2)
Low-frequency words		
High syllable frequency	873 (9.7)	870 (6.8)
Low syllable frequency	846 (5.3)	876 (9.2)

TABLE 4

Experiments 1B and 2A: Mean Reaction Times (msec) and Error Rates (%) for Nonwords

Constituent Syllable Frequency	*Experiment 1B*	*Experiment 2A*
High first/high second	968 (8.3)	916 (12.8)
High first/low second	901 (3.9)	876 (5.0)
Low first/high second	892 (7.1)	874 (4.3)
Low first/low second	882 (4.8)	833 (0.7)

containing high SF morphemes) are mainly due to the high first/high second condition, as reflected in the tendency towards an interaction between syllable frequency and constituent [$F_1(1,23) = 70.297$, $P < 0.001$; $F_2(1,75) = 3.644$, $P = 0.06$; min $F'(1,82) = 3.46$, $P = 0.06$]. It is clear from Table 4 that any frequency effect for the second constituent is mainly present in the high first/high second condition. Planned comparisons showed no significant differences between the other three conditions. The analyses of error rates did not show any significant differences.

Discussion

The presence of a robust word frequency effect in both experiments is consistent with many previous experiments in other languages, and is, furthermore, consistent with all three views of lexical representation we consider here (the morpheme listing, morpheme network and whole-word approaches). In the whole-word representation approach, this frequency effect reflects the activation level of word representations, while in the morpheme-based approaches the effect could be attributed either to stronger links between the constituent morphemes of higher-frequency compounds or to the earlier appearance of the second morpheme on frequency-ordered search lists (Taft & Forster, 1976). We will return to the word-frequency effect in the General Discussion and concentrate here on the absence of syllable and morpheme frequency effects in both Experiments 1A and 1B, the presence of syllable frequency effects for the nonwords in Experiment 1B, and the implications of this for the three approaches.

Note that the lack of syllable and morpheme frequency effects in these experiments cannot be attributed to the insensitivity of the lexical decision task to frequency effects in general, since a strong word-frequency effect was observed here, and because morpheme-frequency effects have been observed in other studies of affixed words (e.g. Burani & Caramazza, 1987; Colé et al., 1989; Taft, 1979) and of English compounds (Andrews, 1986; Taft & Forster, 1976). The absence of a morpheme-frequency effect here is most likely to be a consequence of how Chinese compound words are represented and accessed.

Both the morpheme listing view and the morpheme network view predict a morpheme frequency effect, either in terms of syllable frequency or in terms of morpheme frequency, for the first constituents of compounds. The network view also predicts a morpheme-frequency effect for the second constituent. The present data are inconsistent with these predictions. The most straightforward explanation for the absence of a morpheme-frequency effect would be that Chinese compound words are not represented in a morphemically decomposed form in the lexicon. Instead, each compound has a separate lexical entry which includes both constituent morphemes, as suggested for Dutch compound words (van Jaarsveld & Rattink, 1988).

This does not necessarily mean that morphological information is not encoded in the lexicon. Within a lexical entry, the morphological boundary could be marked to indicate morphemes comprising the compound. This could then allow the whole-word representation to be accessed in a morphemically—or, more precisely for Chinese, syllabically—decomposed way, allowing the lexicon to be accessed syllable by syllable as the input is heard. There is, in fact, some evidence to support syllabic access in the nonword data in Experiment 1B, where nonwords beginning with high SF syllables were generally more difficult to reject than nonwords beginning with low SF syllables.

However, before pursuing in detail the implications of the word and nonword results in Experiments 1A and 1B, we need to address two methodological criticisms that could be raised against these experiments. The first concerns the design decision to vary the syllable and morpheme frequencies of one constituent across two sub-experiments, while holding constant the average syllable and morpheme frequencies of the other constituent. The problem here is that any inaccuracy in the balancing of unvaried frequencies could obscure the possible effects of the variations in syllable and morpheme frequency in the other constituents. Second, due to constraints on the stimuli that could be used in this design, it is possible that the differences between high and low SF and MF in Experiments 1A and 1B were not large enough to allow frequency effects to be detected. Indeed, the ratios between high SF and low SF were only about 4:1, whereas the ratios between high WF and low WF were about 16:1. This would make any word-frequency effect much easier to detect.

In Experiment 2, we attempted to replicate the findings in Experiment 1 by using a paired-word design, which gives complete control of unvaried morphemes and which allowed us to increase the size of the differences between high and low MF and SF. Similarly, we retested our findings for the nonwords, using improved stimuli and experimental designs. In Experiment 3, we went on to investigate the further issue of possible inhibitory effects of high SF on response times.

EXPERIMENT 2

Experiment 2 asked the same questions as Experiment 1, and made the same predictions, with morpheme-based theories predicting effects of syllable and morpheme frequency, especially for first constituents. However, it used a different methodology to test these predictions, by selecting pairs of real words which share a common morpheme in either first (Experiment 2A) or second (Experiment 2B) position, and where the other morpheme is either low or high in SF and MF.

Consider a pair of words like "gan(3) dong(4)" and "gan(3) xie(4)". These words have similar word frequencies and the same initial morpheme (as indicated by the use of the same character in the two words). But their second constituents are different: while "dong(4)" has both high SF and MF (5782 and 5305, respectively), "xie(4)" has low SF and MF (657 and 317, respectively). Now consider another pair of words, "cheng(2) li(4)" and "du(2) li(4)". They have the same morpheme as their second constituents and their word frequencies are similar. But the SF and MF of the initial constituents "cheng(2)" and "du(2)" are different. The morpheme "cheng(2)" has both high SF and high MF (6815 and 4658, respectively), whereas the morpheme "du(2)" has both low SF and low MF (1034 and 312, respectively).

We also constructed new tests for syllable frequency effects in nonwords.

A possible criticism of the nonword stimuli in Experiment 1B was that the low SF syllables and their corresponding morphemes were rarely used in real compounds, and therefore might be more easily rejected. In Experiment 2A we corrected for this by using low SF syllables that do occur in real compounds, while in Experiment 2B we used the more powerful paired design for the nonwords, where a high-frequency syllable and low-frequency syllable were combined with the same syllable to form two nonwords. The common syllables here were always the second constituents.

Method

Subjects. Forty students at the China Institute of Political Science in Beijing were tested in Experiments 2A and 2B, with 10 subjects in each version. They were all native speakers of Mandarin Chinese.

Design and Materials. All the critical word pairs in each experiment were chosen from a larger set (about 90 pairs) of preselected potential stimuli. In addition to matching stimuli on word frequency as estimated in the conventional manner, we also matched stimuli on subjective familiarity. This was because many of the stimuli were low-frequency words, and corpus-based estimates can be unreliable. This meant that all the potential stimuli for the experiment underwent a familiarity judgement pre-test. In this pre-test, 18 subjects were asked to judge quickly (within 6 sec) on a 9-point scale (1 = very unfamiliar, 9 = very familiar) how familiar was a word they heard over headphones. Word pairs with a difference larger than 1.5 between their familiarity scores were not included in the final stimulus set.

For Experiment 2A, 60 pairs of words of the "gan(3) dong(4)" and "gan(3) xie(4)" type were chosen, and for Experiment 2B, 60 pairs of the "cheng(2) li(4)" and "du(2) li(4)" type. The words in each pair had similar word frequencies and the same first or second constituents. In Experiment 2A, the second constituent of one member of each pair had a high SF and high MF, whereas the second constituent of the other member of the pair had a low SF and low MF. In Experiment 2B, the variation was in the first constituents of each pair of words. High SF was defined here as over 2500 in the frequency count, high MF as over 2000, low SF as smaller than 1300, and low MF as smaller than 1000. The detailed frequency information for each condition is given in Table 5. Note that there is now a stronger contrast between high and low SF (ratio of 9:1) and between high and low MF (ratio of 13:1).

The 60 nonwords in Experiment 2A formed a 2 × 2 factorial design, replicating the nonword design for Experiment 1B, with syllable frequency

TABLE 5
Experiment 2: Mean Frequency and Familiarity of Word Stimuli

	Experiment 2A				Experiment 2B			
Condition	*WF*	*SubF*	*SF*	*MF*	*WF*	*SubF*	*SF*	*MF*
High SF/MF	25	6.2	5933	4017	21	6.1	5441	4075
Low SF/MF	26	6.2	584	266	19	5.9	648	367

Note: SubF, subjective familiarity.

and constituent as the two two-level factors. The average syllable frequency of the high SF and low SF constituents was 5236 and 121, respectively. All the low SF syllables are used in real compounds in the language. The two variables and two levels combined to give four conditions, ranging from high first/high second (HH) to low first/low second (LL) with 15 nonwords in each condition.

Experiment 2B used a paired nonword design, where high and low SF first constituents were paired with common second constituents to form nonwords, paralleling the real-word design for Experiment 2B. The syllable frequencies of the 60 high SF and the 60 low SF syllables averaged 5235 and 123, respectively. The syllable frequency of the common syllables, which served as the second constituents, averaged 862.

The word pairs in the two experiments were split into two versions and counterbalanced, so that half of the words in one version were from one condition, and half from the other condition. The nonwords in Experiment 2B were also split in the same way and combined with word stimuli to form two testing versions. In Experiment 2A, however, the same 60 nonwords were combined with the set of word stimuli to form two test versions. In both experiments, each version had 60 words and 60 nonwords. The few stimuli that did use repeated morphemes or syllables were placed at intervals of at least 60 items in the test sequences.

There were 40 practice items, half words and half nonwords. Another three items acted as dummies before the formal testing began.

Procedure. All the words and nonwords were produced and recorded by a female native speaker of Mandarin and were then digitised at a sampling rate of 20 kHz. In each experiment, the word and nonword stimuli were arranged in quasi-random order, such that no more than three words or nonwords were put together and words sharing one common syllable were placed at intervals of at least 60 items. All the practice and testing items were transferred onto cassette-tapes from the computer system. There was a warning signal 550 msec before the onset of an item and a 3 sec interval between the offset of an item and the onset of the next warning signal. Another signal in the second channel was synchronised with the onset of each item. This signal triggered a timer which was stopped by a subject's response. Hence, reaction times were recorded from the onset of each item.

The subjects were tested individually. They heard the stimuli played out from a tape-recorder over headphones and were instructed to make a lexical decision to each presentation by pressing a "Yes" or "No" key as quickly and as accurately as possible. After 40 practice trials, the subjects had 1 min rest and then continued with three dummy items and the rest of the testing stimuli. The complete test session lasted for about 15 min.

Results

Two nonwords and one word in Experiment 2A and two nonwords and two words in Experiment 2B were discarded because more than five subjects made mistakes when responding. Consequently, the matched words and nonwords were also deleted from the analysis. The mean reaction times and percent error rates for the word stimuli are given in Table 6. The mean reaction times and error rates for the nonword stimuli in Experiment 2A are presented in Table 4 together with the results for Experiment 1A.

Experiment 2A. There was no significant difference in reaction time between the high and the low word pairs [min $F'(1,120) < 1$]. If anything, the tendency was towards slower responses to the high SF/MF words (see Table 6). The analyses of the error rates were consistent with the reaction time data [min $F'(1,135) < 1$].

This absence of syllable and morpheme frequency effects is unlikely to be due to task insensitivity, since word frequency effects were obtained both in Experiment 1 and for the present stimuli. We partitioned the response times in Experiment 2A into high and low word-frequency groups, with mean word frequencies of 45 and 7 respectively, and found

TABLE 6
Experiment 2: Mean Reaction Times (msec) and Errors (%) for Word Stimuli

Experiment 2A		*Experiment 2B*	
High SF/MF	*Low SF/MF*	*High SF/MF*	*Low SF/MF*
722 (4.6%)	707 (3.4%)	794 (5.2%)	778 (7.4%)

a significant 36 msec advantage for the high WF group [$F_2(1,114) = 4.382$, $P < 0.05$].

Nonwords: The nonwords showed a significant main effect of syllable frequency for both the first constituent [min $F'(1,127) = 4.46$, $P < 0.05$] and the second constituent [min $F'(1,128) = 4.39$, $P < 0.05$], but no further effects. The difference between here and Experiment 1B is the clearer effect for the second constituent, with a high SF second constituent slowing down performance even when preceded by a low SF first constituent (see Table 4).

The nonword error rates manifested the same pattern with significant main effects for both the first constituent [min $F'(1,117) = 10.17$, $P < 0.01$] and the second constituent [min $F'(1,112) = 7.68$, $P < 0.01$], and no further significant effects. It is noteworthy that the error rate for the HH condition (12.8%) is now very much higher than the error rate for the LL condition (0.7%).

Experiment 2B. This sub-experiment varied the first constituent, while holding the second constant. This is where the morpheme-based theories would most strongly predict frequency effects. The results, however, were very similar to those obtained for Experiments 1 and 2A. Although the responses were 16 msec slower in the high SF/MF condition, this difference did not approach significance (min $F' < 1$). There were also no effects on error rate (min $F' < 1$).

Nonwords: Consistent with the preceding experiments, the nonwords showed a significant effect of syllable frequency [min $F'(1,120) = 5.01$, $P < 0.05$]. Nonwords beginning with high SF syllables (903 msec) were rejected significantly more slowly than the matched nonwords beginning with low SF syllables (862 msec). There was no significant difference in error rates (4.8 and 5.2% for high and low nonwords, respectively).

Discussion

For the most part, Experiment 2 confirmed the results of Experiment 1, and also replicated a preliminary experiment (Zhou & Marslen-Wilson, 1991) in which a similar paired design was used. Overall lexical decision response times to spoken disyllabic compounds do not seem to be affected by variations in the syllable or morpheme frequency of either constituent. Although there is a suggestion in Experiment 2B that words beginning with high SF and high MF morphemes are responded to more slowly than words beginning with low SF and low MF morphemes, this difference did not approach significance. Throughout, the only reliable effects for the word stimuli were those of word frequency. For the nonwords, a syllable frequency effect was consistently observed for the first constituent, and for the second constituent in Experiment 2A, with stimuli containing high SF constituents being slower to reject.

Before moving on to a fuller discussion of these results in the context of different theories of lexical representation, we need to investigate in more detail a possible complication arising from the high degree of homophony among Chinese morphemes. As we mentioned earlier in the paper, this may lead to inhibitory effects in tasks such as lexical decision. This is for the following reasons.

On conventional assumptions about the nature of lexical access (e.g. McClelland & Elman, 1986; Marslen-Wilson, 1987), a homophonic input syllable will activate a set of homophonic morphemes which compete with each other in the subsequent recognition process (Bard, 1990). Syllable frequency is correlated both with the number of homophonic morphemes associated with a given syllable, and with the frequency of occurrence of individual morphemes. For example, in Experiment 1B (where the first constituent was varied), the average number of homophonic competitors in the high SF/MF condition was larger than in the low SF/MF condition, and the average MF of these homophonic competitors was also higher. This makes it likely that the strength of competition between these activated morphemes is stronger in the high SF/MF condition than in the low SF/MF condition. If we assume that word recognition depends on the discrimination of the activation level of a critical word or morpheme from the activation level of its competing words or morphemes (Marslen-Wilson, 1987; 1990), it is clear that this increased competition will lead to slower recognition times, and therefore slower responses in the lexical decision task (Marslen-Wilson & Warren, in press). The upshot of this, especially for conditions where both syllable and morpheme frequency are high, is that a higher syllable frequency may be associated with processing conditions which counteract any facilitatory effects of a higher morpheme frequency. We address this possibility in Experiment 3.

EXPERIMENT 3

The purpose of this experiment was to establish whether higher syllable frequency is indeed associated with slower response times. To test this, we used the same paired design as in Experiment 2, but this time held both word and morpheme frequency constant, while varying syllable frequency. We restricted ourselves to first constituent variation, since it is here that all approaches would predict the strongest effects.

Consider a pair of words like "xian(4) hai(4)" and "sun(3) hai(4)". They share the same last morpheme and their word frequencies are similar. Moreover, the morpheme frequencies of the first constituents of the two words are also matched. The critical difference between the two words is the syllable frequencies of the first constituents. While "xian(4)" has a high SF (6627), "sun(3)" has only a low SF (165). If the higher syllable frequency leads to more morphemic and/or word level competition, then high SF words should be responded to more slowly than low SF words.

We also completed the re-examination of syllable frequency effects in nonwords using the more controlled paired design. In Experiment 2B, the second constituent was held constant and the syllable frequency of the first constituent was varied. Here we varied the syllable frequency of the second constituent. This allowed us to re-evaluate the finding in Experiment 2A of syllable frequency effects for the second constituent, which differs from the nonword results in Experiment 1.

Method

Subjects and Procedure. Another 20 subjects from the China Institute of Political Science participated in the experiment. The procedure was the same as in Experiment 2.

Design and Materials. The experiment was similar in design to Experiment 2B, except that the morpheme frequencies of critical morphemes were now held constant across paired words, not varied concurrently with the syllable frequencies. Sixty pairs of words like "xian(4) hai(4)" and "sun(3) hai(4)" were chosen in the same way as word pairs in Experiment 2. The average frequencies and subjective familiarities of the high SF words and low SF words are summarised in Table 7. All the syllable frequencies of high SF syllables were over 2300; all those of low SF syllables were below 800.

The nonword design adopted here also paralleled Experiment 2B, except that the common syllables of matched nonwords were now in first constituent position. Each pair of matched nonwords had the same initial constituent but different second constituents, which had either high or low SF (see Table 7).

TABLE 7
Experiment 3: Mean Frequency and Familiarity of Word and Nonword Stimuli

	Words				*Nonwords*
Condition	*WF*	*SubF*	*SF*	*MF*	*SF*
High SF	19	5.9	5463	171	5523
Low SF	19	5.8	360	158	122

Note: SubF, subjective familiarity.

TABLE 8
Experiment 3: Mean Reaction Times (msec) and Errors (%) for Words and Nonwords

Words		*Nonwords*	
High SF	*Low SF*	*High SF*	*Low SF*
778 (7.2%)	738 (7.2%)	845 (5.3%)	843 (4.0%)

Results

Two items and their matched words were discarded because more than five subjects classified them incorrectly. The mean reaction times and error rates for words and nonwords are reported in Table 8. Words beginning with high SF constituents were responded to significantly more slowly than the matched words beginning with low SF constituents [$F_1(1,19) = 8.498$, $P < 0.01$; $F_2(1,114) = 6.082$, $P < 0.05$; min $F'(1,82) = 3.54$, $P = 0.06$]. The error rates of the two types of words did not differ from each other.

Nonwords: Here there was no significant effect of syllable frequency (see Table 8). Nonwords ending with low SF constituents seemed to be rejected just as quickly and accurately as nonwords ending with low SF constituents ($F < 1$). This replicates findings in preliminary experiments reported by Zhou and Marslen-Wilson (1991), and is inconsistent with the effect found for second constituents in Experiment 2A. The present result is likely to be more reliable, because the paired design allowed better control over the processing environment in which the second constituents were encountered. Since paired nonwords have the same initial morphemes, the initial input will activate the same word and morpheme competitors, whereas in the factorial design, different morphemes occur in initial position for contrasting items.

Discussion

The results of Experiment 3 support the prediction that high SF can slow lexical decision responses to real words under the appropriate conditions. The view that this effect is due to competition between homophonic morphemes is supported by an analysis of the critical high and low SF first constituent syllables in this experiment. In the high SF condition, we estimate that there were 9.6 morphemes per syllable, as opposed to 3.3 morphemes in the low SF condition. Moreover, all the critical morphemes in the high SF condition had at least some higher-frequency competing morphemes (4.2 on average), while only 23 (out of 58) critical morphemes in the low SF condition had higher-frequency competitors (with an average of 0.6). A number of researchers have argued that higher-frequency competitors can slow identification time for a word (Grainger, 1990; Marslen-Wilson, 1990), and it is plausible that this was the source of the effect in Experiment 3.[8]

The implication of this is that in Experiments 2A and 2B, potential morpheme frequency results were being counteracted by the effects of competition between homophonic morphemes. Experiment 1, in which syllable frequency and morpheme frequency were covaried, did not give a clear answer to this, possibly because of the restricted range of the MF and SF contrasts in this experiment. Due to the impossibility of satisfactorily matching syllable frequencies, we were unable to test the facilitatory morpheme frequency effect using the paired-word design. A recently published experiment by Zhang and Peng (1992), which looked at frequency effects for visually presented words, suggests, however, that morpheme frequency effects can be obtained under conditions where syllable frequency (and homophonic competition) is less salient.

As we noted earlier, visual and auditory presentation may differ more markedly in their processing consequences for Chinese than for languages with fewer homophonic morphemes. The Chinese character is usually unique to a specific morpheme, so that morpheme frequency can be varied and tested more directly in the visual than in the auditory domain. Zhang and Peng (1992) found significant effects in lexical decision responses to visually presented words which were matched for whole-word frequency but which varied in the character frequency (defined by Zhang and Peng as "cumulative root frequency") of their first constituent.[9] Subjects were faster to respond to words with more frequent first characters. Zhang and Peng's results are not completely clear-cut, since the words were of low

---

[8] It could be argued that there is an alternative explanation for the slower reaction times to the words beginning with high SF syllables. Given that more syllables could follow high SF initial syllables to form compounds, words beginning with high SF syllables might have later uniqueness points (see Grosjean, 1980; Tyler & Wessels, 1983) than words beginning with low SF syllables. Since the rhyming part of a Chinese syllable can be treated as just one phoneme (You, Qian, & Gao, 1980), an earlier uniqueness point for a Chinese compound word can only be at the initial consonant position of the second syllable. Indeed, the number of words that become unique at this position is greater in the low SF condition than in the high SF condition (28 *vs* 18) in the present experiment. However, if this alternative explanation is viable, we should have observed similar effects in Experiment 2B, in which the number of words becoming unique at the initial consonant position of the second syllables is also greater in the low SF/MF condition than in the high SF/MF condition (30 *vs* 12).

[9] Zhang and Peng (1992) also report character frequency effects for second constituents, but there is possible speed–accuracy trade-off here, which suggests that this result needs replication.

frequency (2 per million) and the error rate was high (24%) for the low character frequency condition. Interpretation is further complicated by differences between coordinative compounds (e.g. noun–noun) and compounds with a modifier–head structure, with the latter not showing clear character frequency effects.[10] Nonetheless, the results are suggestive overall that morpheme frequency effects can be detected under conditions where syllable frequency, along with other variables associated with a morpheme's phonological form, has been neutralised.

GENERAL DISCUSSION

We will begin by summarising the results of the several experiments reported here, and then go on to consider in turn how these results can best be interpreted, in the light of the questions we asked at the beginning of this paper about the representation and access of disyllabic compounds. In doing so, we will take into account additional data about the mental representation of Chinese disyllables derived from a series of repetition priming experiments, also using spoken stimuli, and reported elsewhere (Zhou, 1992; Zhou & Marslen-Wilson, 1992).

The results of the current research show that the frequency of the entire disyllabic compound is the dominant factor in determining response time in a lexical decision task, and that this effect does not interact with variations in either the morpheme or syllable frequency of either of the constituent morphemes, despite the salience and discriminability of morphemes and syllables in Chinese, and despite the relative semantic transparency of the compounds being studied. At the same time, the results provide good evidence that the access process is not conducted in terms of unanalysed whole-word representations with no internal structure. The evidence for this is, first, the effects of syllable frequency on responses to nonword compounds, where the results are very consistent for the first constituent, and inconclusive for the second constituent—although the weight of the evidence suggests that syllable frequency is not reliably effective here. Second, the effects of high syllable frequency in slowing responses to real words also suggest an access process that is, at one level

---

[10] The authors concluded that modifier compounds are accessed only through their second stem. However, there is a logical problem here. Some morphemes in Chinese can be the constituents of both coordinative compounds and modifier compounds. If compound words are represented in a morpheme network, as the authors suggested, the same morpheme representation could be an "access code" for a coordinative compound but not for another modifier compound. Since the morphological structure of a compound is only known after lexical access is completed, when an orthographic input is available, how can the lexical access system decide to map the input onto the lexicon and activate this morpheme representation?

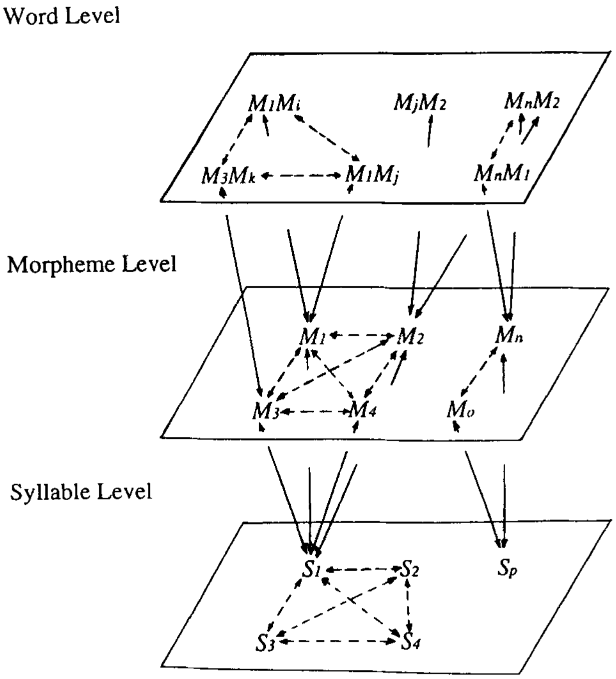

FIG. 2 A Multi-Level Cluster Representation Model for Chinese disyllabic compound words. Broken lines within levels indicate the competition between cluster members, while continuous lines between levels indicate excitatory connections between corresponding members.

or another, organised on syllabic and morphemic principles, and where morphemic and syllabic frequency may tend to have mutually cancelling effects.

We believe that these results can best be accommodated within a whole-word representation model (the Multi-Level Cluster Representation Model) of the type we have recently proposed elsewhere (Zhou, 1992; Zhou & Marslen-Wilson, 1992). This localist network model distinguishes a syllabic layer, a morphemic layer and a word layer, with competitive relations within clusters at each level, and with excitatory relations between levels (see Fig. 2). What is relevant here is the structure at the morphemic and word levels, and the relations between them. Clusters at the morphemic level are defined on phonological grounds, with morphemes sharing the same phonological form (and therefore connected to the same syllable node at the syllabic level) forming a cluster, competing with each other in lexical activation. Clusters at the word level are defined on syllabic rather than morphemic grounds, with words sharing the same first syllable competing with each other in spoken word recognition. Words sharing the same morpheme, irrespective of the constituent position of the morpheme, are not linked directly at the word level but indirectly via their connections with the morphemic level. This requires that word-level representations are internally structured in ways that reflect their morphological decomposition.

The detailed structure of this model is largely motivated by the pattern of facilitatory and inhibitory effects we found in the priming studies mentioned above (Zhou, 1992; Zhou & Marslen-Wilson, 1992). It was observed that while there is always a facilitatory priming effect between compound words sharing common morphemes, the priming effect between words having homophonic morphemes could be inhibitory, facilitatory or null depending on the position of critical morphemes in primes and targets. If homophonic morphemes are the initial constituents of both primes and targets, the priming effect is inhibitory. If homophonic morphemes are the second constituents of both primes and targets, the effect is facilitatory. If homophonic morphemes are the second constituents of primes and the first constituents of targets, however, there is no priming effect at all. The morpheme-based representation approaches have difficulties in explaining this pattern of priming effects. The model we propose, however, can handle the data by appealing to the time-course of lexical activation and the interaction between word-level and morpheme-level activation.

This model also reflects and explains the frequency effects in the present experiments. The whole-word frequency effects are directly explained, first of all, in terms of the effects of frequency on activation levels at the word level. The lexical decision task requires a decision in terms of word identity, and the relative speed of this decision reflects the timing with which the activation level for the word being heard diverges from the activation level of its competitors. The absence of clear morpheme-frequency effects in lexical decision to spoken disyllables is accounted for both in terms of competition between homophonic morphemes at the morpheme level and in terms of the salience of the word level in lexical decision responses. The syllable-frequency effects for the first constituents of real words and nonwords (with high SF slowing down "Yes" responses to real words and "No" responses to nonwords) are also explained in terms of clusters at the morpheme and word levels and their links to each other. High SF syllables will be correlated with more and stronger competitors at both the morpheme and word levels, and this will delay both types of decision. In the word case, as discussed earlier, the activation of higher-frequency competitors can delay identification, while in the nonword case, the stronger initial activation caused by the high SF initial syllable will take longer to drop back down to the criterial level for making the "No" response. Since clusters at the word level are organised on the basis of shared syllables in the first constituent, these effects of high SF should be stronger for the first than for the second constituent.

This approach to lexical representation has much in common with a morpheme network approach—it is also network-based, and includes a morphemic layer of representation—and makes many of the same predictions. We do not, however, favour a complete account in morpheme network terms. This is for two reasons: First, because of the difficulties such an approach will have in accounting for different effects for first and second constituents, which in the network approach should have almost equal status. In the experiments reported here, we found much stronger syllable frequency effects for the first than the second constituents of nonwords, and in the priming studies we found that priming effects of homophonic morphemes (facilitatory, inhibitory or null) depended on which constituents of the prime and target were priming each other, in ways that a network model cannot easily handle (Zhou, 1992; Zhou & Marslen-Wilson, 1992). Second, the network model does not give a uniform account of word-frequency effects. It explains word-frequency effects in different ways, depending on the word's morphological status. For monomorphemic words, frequency effects should reflect the activation level of different word representations, but for compounds (and other morphologically complex words), word-frequency effects are standardly attributed to variations in the strength of connections between constituents. A whole-word representation approach offers a more parsimonious single mechanism account of word frequency.

The other alternative, a strict morpheme listing view, seems less attractive on a number of grounds. It has problems with several aspects of the priming research (Zhou, 1992), especially the priming effects found between the second constituents of prime and target words, and it has difficulties with the absence of morpheme-frequency effects for the second constituent manipulations in Experiment 2A. The model assumes that the secondary morphemes of a compound are listed under the lexical entry headed by the primary morpheme (its first constituent). This listing may be organised in terms of morpheme frequency, since the morpheme-frequency effect has been observed for second constituents in English compound words (Andrews, 1986).[11] For Chinese, second constituent morphemes should not receive competition from their homophonic morphemes, because these homophonic morphemes are not listed under the same lexical entry. This would predict a facilitatory morpheme frequency

---

[11] In the original version of the morpheme listing model (Taft & Forster, 1976), the processing of the second constituent of a compound is not affected by the frequency or even the lexical status of that constituent (but see Andrews, 1986; Lima & Pollatsek, 1983; Monsell, 1985).

effect in Experiment 2A, even when syllable frequency was high as well. The finding of a null effect indicates that there is also competition between homophonic morphemes at the second constituent position.

In summary, we conclude that Chinese disyllabic words are represented as wholes in the mental lexicon. Nonetheless, the morphological structure of these disyllabic words is represented at both the word and morpheme levels, and this allows whole-word lexical entries to be accessed syllable by syllable as the word is heard. This is a picture of lexical representation that has more in common than we might originally have predicted with languages like English and Dutch (e.g. Inhoff, 1989; Monsell, 1985; van Jaarsveld & Rattink, 1988), where there is also evidence for whole-word representation of compounds and for the dominance of overall word frequency over morpheme frequency.

Manuscript received 24 March 1993
Revised manuscript received 16 December 1993

REFERENCES

Andrews, S. (1986). Morphological influences on lexical access: Lexical or nonlexical effects? *Journal of Memory and Language, 25*, 726–740.

Bard, E.G. (1990). Competition, lateral inhibition, and frequency: Comments on the chapters of Frauenfelder and Peeters, Marslen-Wilson, and others. In G.T.M. Altmann (Ed.), *Cognitive models of speech processing: Psycholinguistic and computational perspectives.* Cambridge, MA: MIT Press.

Bradley, D.C. (1979). Lexical representation of derivational relation. In M. Aronoff & M.L. Kean (Eds), *Juncture.* Sarasota, CA: Anma Libri.

Burani, C., & Caramazza, A. (1987). Representation and processing of derived words. *Language and Cognitive Processes, 2*, 217–222.

Caramazza, A., Miceli, G., Silveri, M.C., & Laudanna, A. (1985). Reading mechanisms and the organisation of the lexicon: Evidence from acquired dyslexia. *Cognitive Neuropsychology, 2,* 81–114.

Caramazza, A., Laudanna, A., & Romani, C. (1988). Lexical access and inflectional morphology. *Cognition, 28*, 297–332.

Colé, P., Beauvillain, C., & Segui, J. (1989). On the representation and processing of prefixed and suffixed derived words: A differential frequency effect. *Journal of Memory and Language, 28,* 1–13.

Fowler, C.A., Napps, S.E., & Feldman, L. (1985). Relations among regular and irregular morphologically related words in the lexicon as revealed by repetition priming. *Memory and Cognition, 13*, 241–255.

Grainger, J. (1990). Word frequency and neighbourhood frequency effects in lexical decision and naming. *Journal of Memory and Language, 29,* 228–244.

Grosjean, F. (1990). Spoken word recognition processes and the gating paradigm. *Perception and Psychophysics, 28,* 267–283.

Henderson, L. (1986). From morph to morpheme: The psychologist gaily trips where the linguist has trodden. In G. August (Ed.), *New trends in graphemics and orthography.* Berlin: de Gruyter.

Hoosain, R. (1992). Psychological reality of the word in Chinese. In H.-C. Chen & O.J.L. Tzeng (Eds), *Language processing in Chinese*. Amsterdam: North-Holland.

Inhoff, A.W. (1989). Lexical access during eye fixations in reading: Are word access codes used to integrate lexical information across interword fixations? *Journal of Memory and Language, 28*, 444–461.

Institute of Language Teaching and Research (1986). *A frequency dictionary of Modern Chinese*. Beijing: Beijing Language Institute Press.

Li, C.N., & Thompson, S.A. (1981). *Mandarin Chinese: A functional reference grammar*. Berkeley, CA: University of California Press.

Lieber, R. (1980). *On the organisation of the mental lexicon*. PhD dissertation, MIT.

Lima, S.D., & Pollatsek, A. (1983). Lexical access via an orthographic code? The basic orthographic syllable structure (BOSS) reconsidered. *Journal of Verbal Learning and Verbal Behavior, 22*, 310–332.

Marslen-Wilson, W.D. (1987). Functional parallelism in spoken word recognition. *Cognition, 25*, 71–102.

Marslen-Wilson, W.D. (1990). Activation, competition, and frequency in lexical access. In G.T.M. Altmann (Ed.), *Cognitive models of speech processing: Psycholinguistic and computational perspectives*. Cambridge, MA: MIT Press.

Marslen-Wilson, W.D., & Warren, P. (in press). Levels of perceptual representation and process in lexical access: word, phoneme and feature. *Psychological Review*.

McClelland, J.L., & Elman, J.L. (1986). The TRACE model of speech perception. *Cognitive Psychology, 18*, 1–86.

Monsell, S. (1985). Repetition and the lexicon. In A.W. Ellis (Ed.), *Progress in the psychology of language*. Hove: Lawrence Erlbaum Associates Ltd.

Rapp, B.C. (1992). The nature of sublexical orthographic organization: The bigram trough hypothesis examined. *Journal of Memory and Language, 31*, 33–53.

Sandra, D. (1990). On the representation and processing of compound words: Automatic access to constituent morphemes does not occur. *Quarterly Journal of Experimental Psychology, 42A*, 529–567.

Seidenberg, M.S. (1987). Sublexical structures in visual word recognition: Access units or orthographic redundancy? In M. Coltheart (Ed.), *Attention and performance XII: Reading*. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Seidenberg, M.S. (1989). Reading complex words. In G.N. Carlson & M.K. Tanenhaus (Eds), *Linguistic structure in language processing*. Dordrecht: Kluwer Academic.

Seidenberg, M.S., & McClelland, J.L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*, 523–568.

Small, S.L., Cottrell, G.W., & Tanenhaus, M.K. (Eds) (1988). *Lexical ambiguity resolution*. San Mateo, CA: Morgan Kaufmann.

Swinney, D.A. (1979). Lexical access during sentence comprehension: (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 18*, 645–660.

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory and Cognition, 7*, 263–272.

Taft, M., & Forster, K. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior, 14*, 638–647.

Taft, M., & Forster, K.I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior, 15*, 607–620.

Taft, M., Hambly, G., & Kinoshita, S. (1986). Visual and auditory recognition of prefixed words. *Quarterly Journal of Experimental Psychology, 38A*, 351–366.

Tyler, L.K., & Wessels, J. (1983). Quantifying contextual contributions to word-recognition processes. *Perception and Psychophysics, 34*, 409–420.

van Jaarsveld, H.J., & Rattink, G.E. (1988). Frequency effects in the processing of lexicalized and novel nominal compounds. *Journal of Psycholinguistic Research, 17,* 447–473.

Yin, B. (1984). A quantitative research of Chinese morphemes. *Zhongguo Yuwen, 5*, 338–347.

You, R., Qian, N., & Gao, Z. (1980). On the phonological system in Mandarin Chinese. *Zhongguo Yuwen, 5*, 328–334.

Zhang, B., & Peng, D. (1992). Decomposed storage in the Chinese lexicon. In H.-C. Chen & O.J.L. Tzeng (Eds), *Language processing in Chinese.* Amsterdam: North-Holland.

Zhou, X. (1992). *The mental representation of Chinese disyllabic words.* PhD dissertation, University of Cambridge.

Zhou, X., & Marslen-Wilson, W.D. (1991). The representation and access of Chinese disyllabic words. Paper presented at the *Experimental Psychological Society Meeting,* Sussex, July.

Zhou, X., & Marslen-Wilson, W.D. (1992). The morphological priming effects in Chinese compound words. Paper presented at the *25th International Congress of Psychology,* Brussels, July.