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Morphological Structure in the Chinese Mental Lexicon

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This paper investigates the role of morphological structure in the representation and processing of Mandarin Chinese compounds. A series of 12 experiments, all using disyllabic compounds in a variety of auditory–auditory priming tasks, contrast the effects of four different types of prime–target relationship (identical, morphological, homophonic, homographic), while varying the constituent position of the related syllables in primes and targets. These priming effects were evaluated both in paired priming tasks, with a 150-msec inter-stimulus interval (ISI) between prime and target, and in delayed repetition tasks, using short, medium and long lags (intervening items ranging from 1 to 40). The results provide evidence against single-layer, morpheme-based models of the Chinese mental lexicon, pointing instead to a two-layer, whole-word and morphemic model (the Multi-Level Cluster Representation Model).

INTRODUCTION

A central issue in the study of human language is the properties of the mental lexicon; the problem of how listeners and speakers use and represent their knowledge of the words and morphemes in their language. In the research reported here, we approach these questions cross-linguistically, developing a model of the mental lexicon for one of the world's major languages, Mandarin Chinese, which differs in several fundamental ways from the Indo-European languages (in particular English and its West Germanic relatives), which have been the main focus of psycholinguistic research into

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lexical representation and process. To do this we focus on the predominant word-type in modern Mandarin Chinese—the disyllabic compound—and concentrate on two closely related questions: Are these compound words represented in the lexicon as whole words or as separate morphemes, and how are these representations accessed from the speech input? In answering these questions we will conduct 12 experiments, using a mixture of immediate and delayed repetition priming tasks, leading to the postulation of a Multi-Level Cluster Representation Model of the Chinese mental lexicon.

Background

A number of theories have been proposed to address the issue of lexical representation of polymorphemic words. These theories can be broadly differentiated into word-based and morpheme-based approaches. While morpheme-based approaches assume that the lexicon is composed of unanalysable morphemes, word-based approaches argue that the lexical entries of polymorphemic words correspond to whole words, with (or without) morphological marking within each lexical entry. These approaches to representation are coupled with answers to the question of how the proposed representations are accessed in word recognition. While morpheme-based approaches normally assume a morphologically decomposed access process, word-based approaches can accommodate both morphologically decomposed and whole-word access processes.

Psycholinguists have collected abundant experimental evidence for or against these approaches since the original work of Taft and Forster (1975; 1976). Unfortunately, the previous research has at least three limitations. The first is that the experimental work is mainly on a few European languages, encompassing a narrow range of morphological types. Human language covers a wide spectrum of morphological type and complexity, ranging from isolating languages like Chinese, whose only productive morphological process is compounding, to agglutinative languages like Finnish or Turkish, which have complex derivational and inflectional morphological systems. The data collected from English or French cannot be taken, without examination, as evidence of how Chinese words or Finnish words are represented in the lexicon.

The second limitation is that most previous research has concentrated on derivational and inflectional morphology. Compounding and other morphological processes have been relatively neglected. This is partly because compounding is less important than derivation in forming new words in most European languages, and partly because of *a priori* assumptions about the uniformity with which different types of polymorphemic words are represented. However, given its different morphological properties, compounding may have different representational and processing consequences. In Chinese, since compounding is effectively the only way of forming polymorphemic words, compound words have to be the focus of morphological research.

The third limitation is that previous studies on morphology, with a few recent exceptions (Marslen-Wilson, Tyler, Waksler, & Older, 1994; Schriefers, Zwitserlood, & Roelofs, 1991; Taft, Hambly, & Kinoshita, 1986; Tyler, Marslen-Wilson, Rentoul, & Hanney, 1988), have focused on written words. This relative neglect of the spoken domain is partly due to the assumption that there is a modality-independent lexical representation subserved in the same way by auditory and visual access routes. In Chinese, given that morphemes are almost entirely unambiguous in the logographic written system but are highly ambiguous in their spoken form, the two access routes may well reflect underlying structure in different ways.

These three limitations provide three incentives for the present research. We will study Chinese, representing a morphological type outside the mainstream of current research. We will concentrate on compound words, which have been relatively neglected in previous research. And we will focus on the recognition of spoken as opposed to written polymorphemic words. We hope that the present research will not only deepen our understanding about the lexical processing of spoken Chinese, but also provide insight into the universality of morphological structure in the organisation of the lexicon.

Some Characteristics of Chinese Words

Compared with Indo-European languages, one striking fact about Chinese is that derivational and inflectional morphology play a minor role in word formation (Li & Thompson, 1981). It is often referred to as an "isolating" language in which each word consists of just one morpheme. According to a recent statistical analysis of modern Chinese (Institute of Language Teaching and Research, 1986), monomorphemic, monosyllabic words are about 12.0% by type and 64.3% by token in a corpus of 1.31 million words. However, Chinese does have richly developed compound forms: disyllabic words make up about 73.6% by type and 34.3% by token in use. The majority of disyllabic words are compound words, though there are a few affixed and monomorphemic words. Compounding is the most effective way of constructing new words in Chinese.

Syllable, Character and Morpheme

Morphemes in Chinese are usually free, meaning that they can stand alone as monomorphemic words. Except in a few cases, the phonological form of a morpheme in Chinese is a syllable; that is, a CVC, CVVC or CVVV segmental arrangement or template accompanied by a suprasegmental tone. Tone is the linguistic abstraction of phonetic pitch carried by the vocalic part (mainly the vowel) of a syllable (Gandour, 1978). It is used to convey lexical information. In Mandarin Chinese, which is our focus here, there are four different tones: high-level (Tone 1), high-rising (Tone 2), low-dipping (Tone 3) and high-falling (Tone 4). Because of historical accidents, some segmental templates are not accompanied by all of the four tones. Consequently, there are only about 1300 different syllables in Chinese.

Because there are over 5000 morphemes in Chinese, each syllable corresponds, on average, to 4 different morphemes (Yin, 1984), with some syllables representing as many as 40 morphemes. A distinctive characteristic of Chinese, therefore, is that there are very many homophonic morphemes. The phonological form (a syllable) of a morpheme or monomorphemic word is usually ambiguous in the sense that a morpheme cannot be specified merely from the form. A corresponding English example would be [taim], which could refer to either *time* or *thyme*, though this kind of ambiguity is much less common for English morphemes.

In contrast, there is, with few exceptions, a one-to-one correspondence between a morpheme and its *orthographic* form, which, in Chinese, is a character. In effect, the character has the function of differentiating homophonic morphemes. Figure 1 exemplifies the relations between morphemes and their phonological and orthographic forms. As can be seen, there do exist cases where two or more different morphemes may have the same orthographic form (i.e. a character), which may have just one pronunciation.

Disyllabic Words

The majority of disyllabic words in Chinese are compounds. They are formed by concatenating morphemes from virtually every form class, and can be classified into various categories according to internal structure (Chao, 1968; Li & Thompson, 1981). The same morpheme may take part in several kinds of compounding and have different functional relations with other constituent morphemes. In most cases, the word meanings are not the simple composition of morpheme meanings, but the relations between them are, to native speakers, usually clearly traceable. In other words, the meanings of compound words are the result of interactions between the meanings of constituent morphemes. Fully opaque words, such as "ma(3) hu(0)" (where two morphemes meaning *horse* and *tiger* combine to form a compound meaning *careless*) are rare in Chinese and are excluded from the present research.

The dominance of compounding in Chinese and the salience of individual morphemes make these disyllabic compounds an important and novel

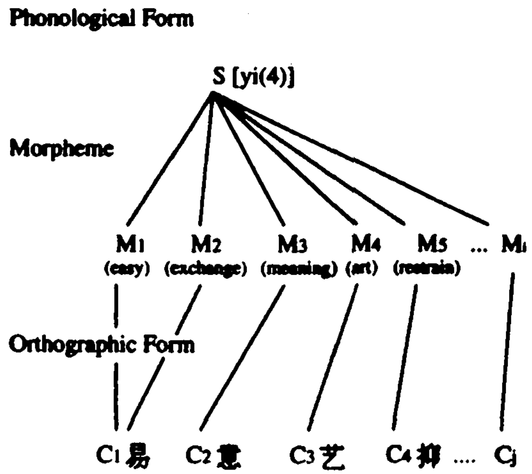

FIG. 1. The relations between Chinese morphemes and their phonological and orthographic forms. The syllable "yi(4)" is given in Pinyin (the phonetic transcription of Chinese characters), where (4) represents the tone of the syllable. English translations of the meanings of morphemes are given in parentheses. S, syllable; M, morpheme; C, character.

cross-linguistic test case for different models of lexical structure. We will focus here on the contrast between two principal types of model. Each model has a morphemic level of representation—this seems inescapable given the status of syllables as free morphemes in Chinese—but they differ in whether or not they also assume a separate "whole-word" level of representation. The most plausible single-layer morphemic model for Chinese is a morpheme network model, which represents all morphemes—whether free morphemes, affixes or other bound morphemes—as individual entries in the lexicon. These entries are linked together in a network, where links between morphemes indicate their status as parts of a compound, disyllabic or otherwise. An example of this approach for Indo-European languages is the Augmented Addressed Morphology (AAM) model (Caramazza, Miceli, Silveri, & Laudanna, 1985; Caramazza, Laudanna, & Romani, 1988). Zhang and Peng (1992) have proposed a version of this model for Mandarin Chinese. The intuitive appeal of a morpheme network approach for Chinese is that it captures straightforwardly the greater individuality of the constituent parts of Chinese multimorphemic words, and is consistent with the ambiguity of the notion "word" for the Chinese speaker (Hoosain, 1992).

At the same time, there are also good arguments for including a whole-word level of representation. The semantic properties of disyllabic compounds are rarely fully predictable from the composition of their constituent morphemes, and this is difficult to capture in a single-layer morphemic model where lexical status is indicated by stronger links between morphemes. Furthermore, in earlier research using a differential frequency technique (Zhou, 1992; Zhou & Marslen-Wilson, 1994), we found clear evidence for a whole-word level of representation. The second type of model we will examine, therefore, is a combined whole-word and morphemic model, reflecting both the evidence for whole-word representations and the salience of individual morphemes in the language. This is a two-layer model, separating a word level from a morpheme level, with compounds that share common morphemes being linked *via* their constituent morphemes. Clearly, there are many degrees of freedom in deciding how these different levels might be organised and linked. A major goal of the research here is not just to discriminate single- and dual-layer models of the Chinese mental lexicon, but also to place much stronger constraints on the architecture and processing properties of the model best fitting the data we will be reporting.

Experimental Considerations

The priming paradigm is a preferred method of addressing the representation of morphological properties in the lexicon and of morphological relations between lexical entries. In this paradigm, target words are preceded, either immediately or at a variable delay, by sets of prime words to which they may or may not be morphologically related. If the morphological properties of polymorphemic words are indeed represented in the lexicon, the presence of morphologically related prime words should activate those properties that are shared in one way or another by target words. Different patterns of priming effects, as assessed against a baseline, should tell us how these properties are accessed in lexical processing and help us to choose between the different approaches to lexical representation discussed above. On the other hand, if the morphological properties of polymorphemic words are not explicitly represented in the lexicon, these words should be represented in the same way as monomorphemic words and there should be no independent morphological priming effects.

The present research applies this paradigm and rationale to issues of lexical representation and processing in Chinese disyllabic compound words, using intra-modal auditory–auditory repetition priming tasks. We will focus on two goals: first, to identify and isolate any morphological priming effect from possible semantic and phonological priming effects, as well as any strategic, non-lexical effects; second, to differentiate, on the basis of this new research, between different approaches to lexical representation.

We take three measures to achieve the first goal. First, we set up a number of priming conditions in which a target word is primed not only by a morphologically related word but also by phonologically related words. These serve in part as a phonological control. Second, we conduct a number of pre-tests on the stimulus words, which enable us to carry out *post hoc* analyses to differentiate morphological priming effects from semantic effects. Third, we apply to the same set of stimuli two different versions of the priming paradigm: the paired (or immediate repetition) priming task and the delayed repetition priming task. Because different priming effects have different time-courses and different sensitivities to the influences of stimulus environment and strategic factors, the comparison between the two tasks will give a clearer separation of morphologically based priming effects, and provide a clearer picture of morphological organisation in the lexicon.

To achieve the second goal, we not only examine the priming effects from different priming conditions and from different tasks, but also systematically vary the constituent positions of critical morphemes in primes and targets—that is, whether they occur in first or second syllable position. Different models of lexical representation make contrasting predictions about morphological priming when critical morphemes are in different constituent positions, especially when the morpheme is phonologically ambiguous. To do this, we take advantage of the fact that the same morpheme in Chinese can often appear at different constituent positions in different compound words. Three sets of experiments, addressing priming effects in different constituent positions, are included in this research. We now turn to a more detailed consideration of the specific contrasts in each experiment, and the motivation for their inclusion in the research.

Experimental Design

Similar designs are adopted in all the three sets of experiments, all using auditory–auditory repetition priming. In general, a target disyllabic compound word is preceded by one of a quintet of disyllabic priming words: (1) by the word itself (the IDENTity condition); (2) by a word sharing a morpheme (and its phonological and orthographic form) with the target word (MORPH condition); (3) by a word sharing a character (and its pronunciation) with the target (CHAR condition); (4) by a word sharing only a homophonic syllable with the target (HOM condition); (5) by an unrelated control word (BASEline condition). Figure 2 gives a sample quintet. The response latency to a target primed by a BASE word serves as a baseline against which the possible facilitatory or inhibitory effects in other priming conditions are assessed.

MORPHological Priming Condition. In this condition, a target is preceded by a word which shares a constituent morpheme with the target; in the first set of experiments, the shared morpheme always occurs in first constituent position in both prime and target (as illustrated in Fig. 2). These shared morphemes always have the same phonological and orthographic

Prime Type	Prime	Target
1. IDENT	ju(4) ben(3) 剧本 (play script)	
2. MORPH	ju(4) chang(3) 剧场 (theatre)	
3. CHAR	ju(4) lie(4) 剧烈 (violent, acute)	ju(4) ben(3) 剧本
4. HOM	ju(4) pa(4) 惧怕 (fear, dread)	
5. BASE	chuang(4) li(1) 创立 (originate, create)	

FIG. 2. Experiment 1: Sample prime–target pairs for IDENT(ical), MORPH(ological), CHAR(acter), HOM(ophone) and BASE(line) conditions. Related constituents in MORPH, CHAR and HOM are the first syllables in primes and targets. Words are given in Pinyin as well as in characters (with English translations in parentheses).

forms. Both morpheme-based approaches and a whole-word representation approach can predict a facilitatory priming effect, by assuming either that the same morpheme representation is repeatedly accessed in the processing of a prime and the target, or by assuming that the activation of the whole-word representation for the prime spreads to the whole-word representation for the target through a morphological link.

The primary issue for the MORPH condition is to determine whether any priming effects in this condition are indeed morphologically based, and cannot be reduced instead to simple semantic or form priming effects. We take several measures related to this issue. The first concerns the choice of stimuli, where we exclude associatively related prime–target pairs from the final stimulus sets, in order to simplify the interpretation of any priming effects. A second pre-test elicits judgements about the semantic relatedness between the meanings of prime and target disyllabic compounds. This will enable us to determine in *post hoc* tests whether the magnitude of priming effects varies as a function of the semantic relatedness between primes and targets.

The second measure, designed to isolate morphological effects, evaluates the role of form priming in the MORPH condition. In two further test conditions (the CHAR and HOM conditions described below), the primes and targets are orthographically and/or phonologically related but not morphologically or semantically related. The third measure, involving contrasts between different experimental tasks, we discuss shortly.

CHARacter and HOMophonic Priming Conditions. In these two conditions, the prime and target share a common syllable which stands for different morphemes in the prime and target (see Fig. 2). The main purpose of including these conditions is to provide phonological controls for the possible form priming effect in the MORPH condition. In addition, the CHAR and HOM conditions may also provide us with information about phonological priming in Chinese. However, in considering the characteristics of Chinese morphemes and words, any priming effect found in the CHAR and HOM conditions cannot be unambiguously attributed to the *formal* relations between primes and targets. This is because of the homophony of the Chinese syllable. The shared syllables in primes and targets in the CHAR and HOM conditions not only create phonological overlap between primes and targets, but also represent differences between primes and targets at the morphological level. Parallel examples can be found in English, where the shared sequence WATCH in the two compounds WATCHDOG and WATCHSTRAP creates both phonological overlap and two different morphemes. Thus, although we will generally refer to the CHAR and HOM conditions as involving phonological priming, any priming effect obtained may not come just from the phonological relations between primes and targets. It may also reflect morphological relations between homophonic morphemes [see Laudanna, Badecker, & Caramazza (1989; 1992) for priming effects between homographic stems in Italian].

A final point here is why both the CHAR and HOM conditions are included, since the only difference between them is in the orthographic form of the critical prime, with the CHAR prime sharing orthographic and phonological form with the target, and the HOM prime only phonological form. Why should this variation in the orthographic similarity of prime–target morpheme pairs play a role in spoken word recognition? There have been some suggestions for alphabetic scripts that orthographic information is automatically activated and exploited in spoken word processing (e.g. Donnenwerth-Nolan, Tanenhaus, & Seidenberg, 1981; Jakimik, Cole, & Rudnicky, 1985; Seidenberg & Tanenhaus, 1979). If so, then there may be systematic differences between the two priming conditions, with possibly stronger effects here than for other languages, given the salience of orthographic form in Chinese in disambiguating the intended morpheme.

IDENTity Priming Condition. We also include an identity priming condition, primarily to allow a comparison of the relative size of priming effects in the MORPH and IDENT conditions. This comparison is often taken as evidence of whether the same lexical entries have been accessed (e.g. Fowler, Napps, & Feldman, 1985; Stanners, Neiser, Hernon, & Hall, 1979). If the morphological priming effect is *full* (i.e. statistically not different from the identity priming effect), it is argued that primes and targets are represented in the same lexical entries. If the priming effect is *partial* (i.e. statistically less than the identity priming effect but still different from the control baseline), it may be concluded that primes and targets have separate but connected representations in the lexicon (Stanners et al., 1979; but see Fowler et al., 1985; Feldman & Fowler, 1987).

Our second interest in including the identity priming condition is to evaluate possible strategic contributions to the priming effects in these studies. To do this, we manipulate the stimulus environment in which the repeated items appear. In Experiment 1, for example, all the related pairs of words in the experiment have in common the property that they share the same initial syllables. But in Experiment 2, where we look at priming between second constituents, only repeated words (the IDENT stimuli) share initial syllables between prime and target. Other pairs of words are related only on the final syllables. In the latter case, repeated words are more prominent in the stimulus environment and therefore more likely to be vulnerable to the influences of response strategies and episodic factors. To the extent that such effects are found for identity priming, we can estimate how far strategic effects may be contributing to priming effects in other text conditions.

Experimental Tasks

As indicated earlier, the choice of experimental task is important in isolating a pure morphological priming effect. Here we will run the same stimuli in both paired (immediate) priming tasks and in delayed repetition priming tasks, with repetition lags varying over experiments from zero (in the paired priming studies) to one or two intervening items in the "short lag" delayed repetition studies, and up to 40 or more in the "long lag" studies. Although semantically but not associatively related words were found to prime each other in experiments using a paired-word priming lexical decision task (Lupker, 1984; Moss, Ostrin, Tyler, & Marslen-Wilson, 1995; Seidenberg, Waters, Sanders, & Langer, 1984), this effect was not observed in experiments using a repetition priming task (Bentin & Feldman, 1990), even when no intervening items were inserted between primes and targets (Napps, 1989; Shelton & Martin, 1993; but see Bentin & Feldman, 1990). It has been claimed that the pure semantic priming lasts only a short time (Henderson, Wallis, & Knight, 1984; Shelton & Martin, 1993). Words which are only phonologically related do not seem to prime each other in the repetition priming task (Marslen-Wilson et al., 1994). Therefore, if a priming effect is still found for the MORPH, CHAR or HOM condition in repetition priming experiments, especially at medium or long lags, this effect can be more confidently attributed to the morphological relations between primes and targets.

Constituent Positions

The final major factor in this research is the manipulation of the constituent positions of critical morphemes in primes and targets. This is intended to help us to choose between different approaches to lexical representation, since single-layer, morpheme network models make different predictions from two-level models that separate morphemic from whole-word levels of representation. Because the spoken form of Chinese morphemes is usually homophonous, the first syllable of an auditorily presented compound word will almost always be ambiguous between a number of different morphemes (and disyllabic compounds). The second syllable, however, will be heard in the context of the cohort of word candidates activated by the initial syllable, and this may immediately constrain its interpretation. Consequently, the variation of the constituent position of critical morphemes in primes and targets may induce different priming effects.

We report three variations in constituent position here. In Experiments 1A–D, the related syllables are in the first constituent position in both primes and targets (as shown in Fig. 3). In Experiments 2A–D, the related syllables are the second constituents of both primes and targets, and in Experiments 3A–D, we examine the effects of second constituent primes on first constituent targets.[1]

EXPERIMENT 1A

We begin this research with an immediate repetition (paired) priming study, where a disyllabic compound target is responded to under the five conditions discussed above and summarised in Fig. 2. Apart from the IDENT condition, the priming relationship here is always between the first constituent of the prime and the first constituent of the target. This will allow us to make our first steps towards determining whether there are independent morphological priming relations between Chinese compounds,

[1]We also conducted a fourth set of experiments, in which the related syllables were the first constituents of the prime and the second constituent of the target (Zhou, 1992). In the interests of space we do not report these studies here, since they did not provide additional information about the organisation of the Chinese lexicon, over and above the three sets of experiments already included here.

and whether the pattern of effects discriminates single-level morpheme network models from two-level models that include a whole-word level of representation.

Method

Design

The experimental design followed the general considerations laid out above. A spoken compound target word was paired with five types of spoken prime words (see Fig. 2). In the related conditions, a target shared either the initial morphemes (the IDENT and MORPH conditions) or the initial syllables (CHAR and HOM conditions) with its primes.

Materials

The critical stimuli were 45 compound words, each primed by five words from the five experimental conditions. These priming words were matched on word frequency (cf. Zhou & Marslen-Wilson, 1994) and, if possible, on word class and tone pattern. The final set of word stimuli was selected from a larger pool of potential targets and primes. Three pre-tests were conducted on these words.

Pre-test 1: Free Association. Eighty Chinese students and visiting scholars in Cambridge were divided into four groups of 20. Each group was asked to give associates to 93 potential targets, or to their MORPH, CHAR or HOM primes. The subjects were requested to write down the first words which came to mind when they read the stimulus words. If one or more subjects gave the prime as the associate of the corresponding target (or vice versa), the target and its primes were if possible excluded from the stimulus lists. Because of other constraints on the stimuli, six MORPH prime–target pairs that were weakly associatively related (average associative strength of 11%) were included in the final set.

Pre-test 2: Morpheme Meaning Similarity Judgement. To make sure that the shared initial syllable in a paired MORPH prime and target represented the same morpheme, and that the shared initial syllable in a paired CHAR prime and target represented different morphemes, 40 subjects were asked to judge the similarity of the basic meanings of the related constituents on a 9-point scale. The MORPH or CHAR primes were presented in pairs with corresponding targets in booklets. Twenty subjects in one group saw half of the MORPH prime–target pairs and CHAR prime–target pairs, while another 20 subjects saw the other half. In the final set of 45 targets and their primes, the average similarity of morpheme meanings between MORPH primes and targets was 8.4 (range 7.5–9.0), while the mean for the CHAR primes and targets was 1.8 (range 1.0–3.0).

Pre-test 3: Word Meaning Relatedness Judgement. Finally, a word meaning relatedness judgement pre-test was conducted on the MORPH prime–target pairs and the CHAR prime–target pairs. Forty subjects, none of whom had participated in pre-test 2, were divided into two groups and requested to make judgements on a 9-point scale about the relatedness of the whole-word meanings of prime–target pairs. Twenty subjects in each group judged half of the MORPH prime–target pairs and half of the CHAR prime–target pairs, which were presented in booklets. The CHAR primes were not semantically related to their targets—average relatedness was 1.5 for the final test set. For the MORPH prime–target pairs, word meaning relatedness covered a wide range, from 2.0 to 8.9, with a mean of 6.4.

Besides the 45 quintets of word stimuli, 48 sets of word–nonword pairs were constructed, which were modelled in structure on the word stimuli and designed to act as foils. In the analogue to the IDENT condition, a nonword target was preceded by the word from which it was derived (usually the nonword target differed from the IDENT prime in the tone or the initial consonant of the second syllable). In an analogue of the MORPH and HOM conditions, a nonword target was primed by a word which either shared its initial morpheme or the phonological form of its initial constituent with the word from which the nonword was derived.

As further fillers, we used another 45 word–word pairs and 42 word–nonword pairs. Primes and targets in these pairs were neither semantically nor phonologically related. None of the syllables in the filler primes and targets were used twice or had been used in critical primes and targets.

A Latin square design was used to assign critical primes to the five test versions. For the words in each version, there were nine primes from each of the five priming conditions. The same filler prime–target pairs were used in all five versions. Within each version, all the primes and half the targets were compound real words and half the targets were compound nonwords. No syllables were used twice within a version except when the primes and targets were related. Forty percent (72/180) of the prime–target pairs were related in some way. Among them, 16 (8.9%) pairs were both semantically and phonologically related.

The same pseudo-random order was used throughout, so that, across test versions, the same target appeared in the same position in the testing sequences. The only difference between versions was that the critical primes for a particular target were different. No more than four consecutively presented targets were words or nonwords.

Procedure

All the stimuli were recorded by a male native speaker of Mandarin Chinese and digitised at a sampling rate of 20 kHz. The stimuli were then transferred to tape, using Marantz cassette tape-recorders, which were used later to run the experiments. The transfer of stimuli from the computer to tape was controlled by a program which specified time intervals between trials as well as the inter-stimulus interval (ISI; 150 msec for paired priming experiments) between primes and targets.[2] A warning signal was added 250 msec before the onset of each prime word. Another pulse to trigger a reaction timer was also added to the second channel of the tapes, aligned with the onset of the target word. The interval between the offset of each target word and the onset of the next warning tone was set at 5 sec.

The subjects were tested in groups of one or two in quiet rooms. They were told that the targets were both words and nonwords and were requested to make lexical decisions to the targets as quickly and as accurately as possible. The forefingers were used to press "yes" or "no" response keys. The dominant hand was used for the "yes" keys.

Each subject first heard a list of 40 pairs of practice words. The primes and targets had the same relations as in the pairs in the formal test, with 20 prime–target pairs related. There was a break after the practice and a break in the middle of the main test session. The first three item pairs after each break were always dummies (i.e. fillers). The complete testing session for each subject lasted about 35 min.

Subjects

Fifty-two native speakers of the Beijing dialect of Mandarin Chinese were tested, 50 of whom were second-year undergraduate students at Beijing Teachers' College, and 2 of whom were Chinese students in London. All the subjects were paid for their participation.

Results

Ten subjects were tested for each version. The data from two subjects were discarded and replaced by those of the London subjects because their responses failed to meet the predetermined accuracy criterion (80% for both critical word and nonword targets). The data of four word targets and one nonword target were also deleted because response errors on them were over 50%. The overall percentage of missing data was 7.6%. Mid-mean

[2]The ISI is defined here as the time interval between the acoustic offset of the prime word and the acoustic onset of the target word.

TABLE 1
Experiment 1A. Paired Priming/First Constituents: Mean Lexical Decision Times (msec) and Error Rates (%)

	IDENT	*MORPH*	*CHAR*	*HOM*	*BASE*
Mean RT	731	758	825	832	793
Percent error	4.9	3.7	9.6	8.9	5.5

reaction times were then computed for each remaining item and subject. The mean reaction times, based on mid-means, are reported in Table 1. Priming effects, as assessed against the baseline, are plotted in Fig. 3.

Reaction times (RTs) were entered into one-way ANOVAs with subjects and items as random variables. There was a significant main effect of prime type [$F_1(4,196) = 38.71$, $P < 0.01$; $F_2(4,160) = 33.68$, $P < 0.01$]. Compared with the baseline, reaction times to targets were faster when they were primed by themselves (IDENT) or by morphologically related words (MORPH). Reaction times to these targets were slower, however, when they were primed by phonologically related words (in the CHAR and HOM conditions). Newman-Keuls *post hoc* tests confirmed the significance of these differences.

It is clear that morphological priming was effective in facilitating the recognition of the test words. Targets were responded to 35 msec faster in the MORPH condition than in the BASE control condition ($P < 0.01$, Newman-Keuls). However, compared with identity priming, morphological

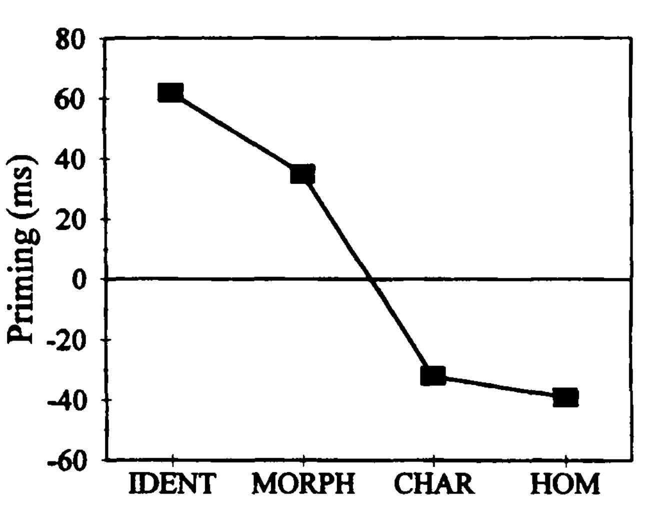

FIG. 3. Experiment 1A: Priming effects (test *vs* baseline) for four test conditions (IDENTical, MORPHological, CHARacter and HOMophone).

priming was only partial. The 27-msec difference between the IDENT and MORPH conditions was significant on both the subject ($P < 0.05$) and item ($P < 0.01$) tests. In comparison, phonological priming in the CHAR and HOM conditions was inhibitory. Responses to targets were slower than in the BASE conditions ($P < 0.01$). The CHAR and HOM conditions themselves did not differ ($P > 0.1$).

The error data are consistent with the RT results. The arcsine transformed error rates were entered into one-way ANOVAs. A significant main effect of prime type was observed [$F_1(4,196) = 4.614$, $P < 0.005$; $F_2(4,160) = 3.633$, $P < 0.01$]. Newman-Keuls analyses showed that there were no significant differences between the error rates in the IDENT, MORPH and BASE conditions (all $P > 0.1$). Errors increased markedly in the CHAR and HOM conditions (which did not themselves differ), where targets were primed by phonologically related words. These differences were either significant ($P < 0.01$ or $P < 0.05$) or marginally significant ($P < 0.1$) in the subject and item tests, respectively.

Discussion

Morphological and Identity Priming

Morphological priming in this experiment was only partial, relative to identity priming. This is inconsistent with most repetition studies on morphological complex words, whether using visual (Feldman & Fowler, 1987; Fowler et al., 1985; Napps, 1989) or auditory (Fowler et al., 1985) presentation. Full morphological priming effects were observed in those studies. The present finding is also inconsistent with the full priming effect found in some paired priming experiments (e.g. Forster, Davis, Schoknecht, & Carter, 1987). Nonetheless, the partial priming effect found here is potentially consistent with both the whole-word representation view and the morpheme network approach.

For the whole-word representation approach, it could be assumed that morphologically related words—in this experiment, words sharing the same initial constituents—are connected, either directly or via their common morphemes. In the priming paradigm, the activation of a priming word spreads to morphologically related words and enhances their activation level. When the target is presented a short time after the prime, the already activated representation reaches more quickly the criterial difference of activation level from other words (Marslen-Wilson, 1990), resulting in faster recognition of the target. Indirect morphological priming, mediated via morphological links, is less effective than direct access to the same lexical entries in identity priming. The awkward assumption equating activation through morphological connections with activation produced by direct access, as assumed in some studies (Fowler et al., 1985; Grainger, Colé, &

Segui, 1991) in order to explain full morphological priming within the whole-word representation framework, is not necessary here.

The morpheme network approach can also handle partial morphological priming. In identity priming, two morpheme nodes and the connections between them are repeatedly activated in the processing of a prime and the target, while in morphological priming, only one of the morphemes used in the target is pre-activated in the processing of the prime. This makes morphological priming less effective than identity priming.

However, there exists a quite different kind of account for the priming effects in the MORPH condition, in terms of the semantic rather than the morphological relations between primes and targets. Semantically but not associatively related words have been shown to prime each other in a number of paired priming experiments, all using morphologically simple words (Fischler, 1977; Lupker, 1984; Moss et al., 1995; Shelton & Martin, 1993). Although the prime–target pairs in Experiment 1A were generally not associatively related, they were semantically related, as demonstrated in pre-test 3. Furthermore, we found a significant correlation between the size of morphological priming effects and the degree of semantic relatedness ($r = +0.33$, $P < 0.05$). This suggests that semantic relations between primes and targets did play a role here in producing the facilitatory effect in the MORPH condition, although it does not mean that these effects can be attributed solely to these semantic relations. It is also unclear what the mechanism for any semantically mediated effect might be. Such an effect could be caused by the automatic spread of activation in the semantic network, but it could also come from strategic processes, such as post-lexical semantic coherence checking. These possibilities will be followed up in Experiments 1B–D.

Phonological Priming

Three interesting results emerged from the CHAR and HOM conditions. The first was that the priming effect was in the opposite direction to the priming effect in the MORPH condition. This is convincing evidence that, whatever the source of the MORPH priming effect, it cannot be reduced simply to the phonological relationship between prime and target. The second is that there was no significant difference between the magnitudes of the priming effect in the two conditions. Orthographic information seems not to affect priming effects between phonologically related spoken words in Chinese.

The third result is that the "phonological" priming effect in the present experiment was inhibitory. Words are more difficult to recognise if they are preceded by phonologically related words. This result is consistent with findings in some previous studies (Brown, 1990; Radeau, Morais, & Devier, 1988), but contradicts data from other research (Jakimik et al., 1985; Slowiaczek & Pisoni, 1986). In the following discussion, we will concentrate on the inhibitory effects.

These priming effects could take place at a number of different processing levels. First, they could involve low-level perceptual processing of the speech input, possibly at a featural level (Lahiri & Marslen-Wilson, 1991; Warren & Marslen-Wilson, 1987; 1988). However, if phonological priming is located at this level, we should expect facilitation, instead of inhibition, for the processing of words sharing parts of phonological forms with their priming words. The subsequent processing of the same features should be facilitated. Alternatively, phonological priming could involve the lexical level effects on the processing of a word target that arise from the phonological relations between primes and targets. Just as the orthographic priming effect may not arise from the low-level orthographic representation (e.g. Segui & Grainger, 1990), phonological priming could operate lexically, instead of pre-lexically.

Evidence supporting the idea that phonological priming comprises both pre-lexical facilitation and lexical interference has come from a number of recent studies. Slowiaczek and Hamburger (1993) found that the processing of target words could be facilitated or inhibited depending on the amount of initial phonological overlap between targets and primes. Brown (1990) also found that the processing of cohort competitors could be facilitated or inhibited depending on whether the priming words have been fully processed. These data suggest that there is both a pre-lexical facilitatory component and a lexical inhibitory component in phonological priming, and that the final priming effect depends on the balance of these components. Other studies by Marslen-Wilson (1993; Marslen-Wilson, Gaskell, & Older, 1991) also suggest that cohort members compete with each other in lexical processing. In the priming task, the activation of a target has to overcome the competition from the already activated prime to reach the criterial difference of activation levels and be recognised.

The prime–target pairs in the CHAR and HOM priming conditions could well produce inhibitory phonological priming effects at the lexical level. Primes and targets are cohort competitors; there is substantial initial phonological overlap between them, and primes are fully processed before targets are heard. However, it is also possible that morphological factors play a role here. As we pointed out previously, the boundaries of phonological units (the syllables) in Chinese compound words coincide with the boundaries of morphological units (morphemes). Sharing the initial phonological forms between primes and targets also means that the initial constituents of primes and targets are homophonic morphemes. Although the inhibitory effects observed in the CHAR and HOM conditions could arise from competition between cohort members, it could also come from competition between homophonic morphemes which may or may not be inhibitorily linked (Bard, 1990). If we assume that there is a level of morphemic representation in the lexicon, then homophonic morphemes may compete with each other when they are activated by an input syllable.

When the prime word is processed, the initial morpheme becomes more highly activated than its homophonic morphemes after the input of the second constituent. This is either because of the spread of activation from the word level to morpheme representations for the whole-word representation approach, or because of the backward spread of activation from the second constituent for the morpheme network approach. The competing homophonic morphemes are at the same time being deactivated. When the initial syllable of the target is then heard, the morpheme used in the prime and those homophonic morphemes are once again activated. It takes more time for the activation of the homophonic morpheme actually used in the target to overcome this competition and reach a criterial difference of activation from the homophonic morpheme used in the prime. The recognition of the target is hence delayed.

Experiment 1A does not allow us to choose among these various alternative accounts. The morpheme-based representation approaches would attribute the inhibitory effects in the CHAR and HOM conditions primarily to morpheme level competition, whereas the word-based approach assuming a level of morphemic representation would attribute the effects to both word level and morpheme level competition. The following experiments will help us in differentiating these accounts.

EXPERIMENTS 1B–D

In Experiment 1A, we obtained robust priming effects in all the critical experimental conditions. However, it is not clear if these effects, whether facilitatory or inhibitory, are due to morphological relations between primes and targets or to semantic and phonological relations. This obscurity is partly a consequence of the experimental task, which does not directly discriminate priming effects from morphological as opposed to semantic and phonological sources. In the following experiments, we readdress these issues using a series of delayed repetition priming tasks. As we argued above, previous research suggests that morphological priming effects decay less rapidly than semantic or phonological effects. Experiments 1B, 1C and 1D, all using priming between first constituents, examine the pattern of priming for the same five conditions (IDENT, MORPH, HOM, CHAR, BASE) across short, medium and long repetition delays.

Method

Materials

The design was the same as in Experiment 1A. All the critical primes and targets were split into five testing versions such that the same primes and targets appeared in the same versions across all four experiments (1A–D). To balance the proportions of words and nonwords, a further 38 nonwords were created, in addition to 52 nonword filler targets taken from Experiment 1A. These nonword fillers were used in every test version. Consequently, as in the paired priming experiment, the stimuli of each repetition priming experiment were fully counterbalanced across the five test versions. In each version, 26% (72/276) of the total items were related (morphologically and/or phonologically). Because no syllable appeared twice in a specific version unless intended, 540 different syllables (including syllables from 40 practice items) were presented to each subject.

Experiment 1B was a "short lag" repetition priming experiment in which all the critical targets and their corresponding primes were separated by one or two intervening items. Experiments 1C and 1D were "medium lag" and "long lag" repetition priming experiments, respectively. The same stimuli were used in all these experiments. The only difference was that the order of the appearance of items was rearranged so that there were 8–10 intervening items between a prime and target in the medium lag experiment and 40–45 items in the long lag experiment. The delay between a prime and the targets was, on average, 15 sec in the short lag experiment, 72 sec in the medium lag experiment and 340 sec in the long lag experiment.

Procedure

The preparation of stimuli followed the procedure in Experiment 1A. The subjects were tested in groups of one or two and asked to make lexical decisions to each item as quickly and as accurately as possible. The interval between the offset of an item and the onset of the next item was about 6 sec. There was a warning tone before each item.

Before the main test, the subjects received 40 practice items. Among them, 20 were related in ways specified in the experimental design.

Subjects

Altogether, 160 first- and third-year students at Beijing Teacher's College were tested. Ten subjects were run for each version except in Experiment 1D, where 12 subjects were tested. Five more subjects, all native speakers of Mandarin Chinese, were tested in London as replacements for the discarded Beijing subjects.

Results

Five subjects who averaged more than 20% response errors were discarded and replaced by new subjects tested in London. Four word targets in Experiment 1B, four in Experiment 1C and three in Experiment 1D were also excluded from the analyses because more than half of the subjects classified them or their primes as nonwords in one or more testing versions. In general, if a subject's response to a prime was incorrect, the reaction time for the corresponding target was not included in the analyses.

Mean reaction times and error rates are reported in Table 2. Priming effects relative to baseline are presented in Fig. 4. In the following paragraphs, we first report the analyses of the overall priming effects, treating the short, medium and long lags as three levels of a between-subject factor. We then analyse each experiment separately.

Overall Analyses

There was a significant main effect of lag [$F_1(2,157) = 5.11$, $P < 0.01$; $F_2(2,121) = 32.90$, $P < 0.01$]. The subjects in the medium lag experiment (1C) responded to word targets more quickly than the subjects in the short and long lag experiments. There was also a significant main effect of prime type [$F_1(4,628) = 166.91$, $P < 0.01$; $F_2(4,484) = 123.68$, $P < 0.01$]. There was strong facilitation, averaging 82 msec, in the IDENT condition ($P < 0.01$ in *post hoc* tests). Morphological priming was also effective in facilitating the processing of targets, although the overall effect was much smaller (19 msec, $P < 0.01$). In contrast, the phonological priming effect (in both the CHAR and HOM conditions) continued to be inhibitory, with significant 19-msec

TABLE 2
Experiments 1B, 1C and 1D. Delayed Repetition Priming/First Constituents: Mean Lexical Decision Times (msec) and Error Rates (%)

	IDENT	*MORPH*	*CHAR*	*HOM*	*BASE*
Experiment 1B					
Mean RT	717	781	827	846	803
Percent error	1.7	5.6	9.0	8.5	7.3
Experiment 1C					
Mean RT	693	768	812	827	792
Percent error	1.5	3.2	6.3	8.5	5.4
Experiment 1D					
Mean RT	753	804	827	819	815
Percent error	2.9	6.7	7.9	10.0	9.8

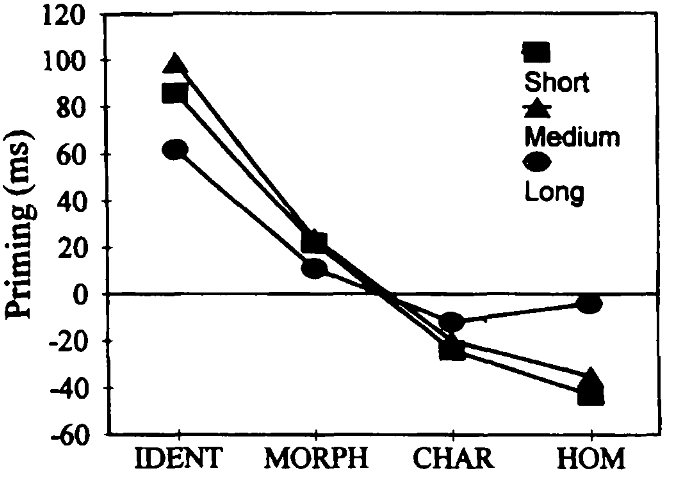

FIG. 4. Experiments 1B–D: Priming effects (test *vs* baseline) for four test conditions (IDENTical, MORPHological, CHARacter and HOMophone) at three different repetition lags (short, medium and long).

effects in the CHAR condition and 27-msec effects in the HOM condition. But these conditions did not themselves differ.

Finally, there was a significant interaction between prime type and lag (experiment) [$F_1(8,628) = 6.06$, $P < 0.01$; $F_2(8,484) = 4.61$, $P < 0.01$]. This interaction indicated that the effectiveness of primes in facilitating or inhibiting the processing of targets varied across experiments. Figure 4 suggests that this effect was chiefly due to a general reduction in all priming effects in the long lag experiment (1D). We will explore this and other effects in more detail below.

The analyses of the overall error data showed a slightly different pattern. There were no significant differences in error rate between experiments ($P > 0.1$); nor was there a significant interaction between prime type and experiment ($F < 1$). The only significant differences were between the error rates in the IDENT and MORPH conditions and rates in other conditions. Newman-Keuls tests revealed that targets in the IDENT condition were responded to more accurately than in any other condition (all $P < 0.01$). The error rate in the MORPH condition was also significantly lower than in the baseline control condition ($P < 0.01$), although it was only marginally different from the rates in the CHAR and HOM conditions in the item tests ($0.05 < P < 0.1$; but $P < 0.05$ in the subject tests). The differences between the error rates in the CHAR, HOM and BASE conditions did not reach significance (all $P > 0.1$).

Experiment 1B: Short Lag

The main effect of prime type was highly significant in the one-way ANOVAs on mean reaction times [$F_1(4,196) = 80.19, P < 0.01; F_2(4,160) = 59.30, P < 0.01$]. Newman-Keuls tests showed that repetition priming in the IDENT condition was significantly greater (86 msec) than in any other condition, and also somewhat larger than the 62-msec effect in Experiment 1A. The priming effect in the MORPH condition (22 msec), although reduced relative to the 35-msec effect in Experiment 1A, was also significant ($P < 0.05$) against the baseline.

The priming effects in the CHAR (−24 msec) and HOM (−43 msec) conditions remained inhibitory, and of approximately the same magnitude as in Experiment 1A (−32 and −39 msec, respectively). However, the size of the effect in these conditions was now significantly different ($P < 0.05$).

The outcome of the error analysis was generally consistent with the findings for RTs. There was a significant main effect of prime type on response accuracy [$F_1(4,196) = 5.05, P < 0.01; F_2(4,160) = 4.05, P < 0.01$]. *Post hoc* tests showed that this was because the error rate was significantly lower in the IDENT condition than in any other condition. Although the error rate was slightly elevated relative to BASE in the CHAR and HOM conditions, this did not approach significance.

Experiment 1C: Medium Lag

As Fig. 4 shows, the results for Experiment 1C were very similar to those for Experiment 1B, suggesting that the increase in lag, from a few seconds to over a minute, had little effect on processing.

There was a significant main effect of prime type [$F_1(4,196) = 66.58, P < 0.01; F_2(4,160) = 49.14, P < 0.01$], with *post hoc* tests showing differences in response time between all conditions except CHAR and HOM. As before, the strongest effects were in the IDENT condition, where the priming effect (99 msec) was even larger than in Experiment 1B (86 msec). The MORPH priming effect, at 24 msec, was also comparable to that in Experiment 1B. The inhibitory effects in the CHAR and HOM conditions also remained intact, with the effects for the two conditions (−20 and −35 msec, respectively) similar to those in Experiment 1B. But unlike in Experiment 1B, the difference between the CHAR and HOM conditions did not reach significance ($P > 0.1$).

The error rate analyses were in line with the RT results. There was a main effect of prime type [$F_1(4,196) = 7.85, P < 0.01; F_2(4,160) = 5.05, P < 0.01$], with the fewest errors in the IDENT and MORPH conditions, and with the CHAR and HOM conditions tending to have elevated error rates relative to baseline. The only differences that were reliable on *post hoc* tests, however, were between the IDENT and MORPH conditions on the one hand and the CHAR and HOM results on the other.

Experiment 1D: Long Lag

Compared with the first three experiments, the priming effects in Experiment 1D were greatly reduced. The main effect of prime type was still significant in the analyses of the word RT data [$F_1(4{,}236) = 32.71$, $P < 0.01$; $F_2(4{,}164) = 21.66$, $P < 0.01$], but this was almost entirely due to the IDENT condition. Priming here was 62 msec relative to baseline, which was reduced relative to the short and medium lag experiments, but comparable to the effect in Experiment 1A with no intervening lag. Priming in the other conditions, although still in the same direction as before, now fell well short of significance—there was 11 msec facilitation for the MORPH primes, and 12 and 4 msec interference for the CHAR and HOM primes. These patterns are mirrored in the error analyses, where the reduced error rate for the IDENT targets was reflected in a significant main effect of prime type [$F_1(4{,}236) = 6.07$, $P < 0.01$; $F_2(4{,}164) = 3.86$, $P < 0.01$].

Discussion

In the three repetition priming experiments, the identity priming effect was consistently observed, but morphological and phonological priming were effective only in the short and medium lag experiments. The results of these two experiments clearly mirrored the findings in the paired priming experiment, even though different priming tasks were involved. The disappearance of morphological and phonological priming effects in the long lag experiment is almost certainly the result of the much greater delay, and much larger number of intervening items, between prime and target.

Morphological and Identity Priming

Consistent with Experiment 1A, the morphological priming effect in Experiments 1B and 1C was only partial, relative to the identity priming effect. Moreover, the magnitude of the priming was constant (about 23 msec) in the short and medium priming experiments. Again, these effects are, by themselves, consistent with both the two-layer, whole-word representation approach and the morpheme network approach.

The more immediate issue is whether the priming effects in the MORPH condition can be reduced to pure semantic priming. In Experiment 1A it seemed likely that semantic relations between primes and targets did play a role in producing the facilitatory effect. However, considering the nature of the repetition priming task and the data from Experiments 1B–1D, it is unlikely that semantic factors are the sole source of the priming effect in the MORPH condition.

Earlier research has found semantic priming to be relatively short-lived, at least for visually presented, morphologically simple English words. Interposing an unrelated word between the prime and target can reduce or eliminate the associative semantic priming effect (e.g. Dannenbring & Briand, 1982; Gough, Alford, & Holley-Wilcox, 1981). Although Napps (1989) did find associative priming effects in a zero to 10 lag visual repetition priming study, she did not find any effect between synonyms in the same study. Other studies also suggest that the non-associated semantically related words do not always prime each other even at zero lags (Shelton & Martin, 1993; but see Moss et al., 1995), or at least in medium or long lag conditions (Bentin & Feldman, 1990). In the present study, only a few MORPH targets were associatively related to their primes, and the time intervals between primes and targets were quite long (about 72 sec in the medium lag experiment).

Two considerations suggest that MORPH priming effects in the current research cannot be reduced to semantic priming. First, the size of the effect in the MORPH condition remained constant across short and medium lag conditions. If the priming effect were purely semantic, and if the effectiveness of semantic priming is time-dependent, we would expect a decrease in the medium lag experiment. Second, although the correlation between the size of priming effect and semantic relatedness approached significance in the short lag experiment ($r = 0.29, P = 0.07$), it did not do so in the medium lag experiment ($r = 0.17, P = 0.29$).

It is likely that the MORPH priming effects in these four experiments reflect, to varying degrees, both semantic and morphological relations between primes and targets. The facilitatory effect in the paired priming experiment, and possibly in the short lag experiment, was the joint outcome of semantic and morphological priming. Because of the different time-course of semantic and morphological priming, the semantic effect seemed to have dissipated in the medium lag experiment, with the morphological relationship between primes and targets now primarily responsible for the priming effect. Note that semantic and morphological priming may be not additive, but interactive (Bentin & Feldman, 1990). This morphological effect, in turn, had dissipated sufficiently in the long lag experiment for no significant effects to be obtained in the MORPH condition.

Phonological Priming

As in Experiment 1A, the CHAR and HOM primes slowed down subsequent responses to their targets, with these effects dissipating at very long repetition delays. The fact, however, that significant effects were obtained in the short and medium lag conditions almost certainly rules out an account of these effects in terms of low-level phonetic or phonological analysis processes. Instead, we need to look to lexical or morphological accounts of the type we discussed earlier. On a lexical account, the inhibitory effects in Experiments 1B and 1C reflect the long-term consequences of competition between cohort members when the prime is first heard. This leaves the original prime word relatively more activated than competitor words sharing the same initial (and homophonic) syllable. When the initial syllable of the target is subsequently heard, this gives an early advantage to the original prime word. Through the mechanisms of competition between cohort members, this leads to a slowing in the recognition of the target word, relative to the baseline condition, where the target has been preceded only by unrelated words.

The second type of account, also compatible with the results so far, attributes the inhibitory effects primarily to the morphological relations between primes and targets. For the morpheme-based representation approaches, the effects are due to competition between homophonic morphemes. For the whole-word approach, the inhibitory effect is due to both the competition between homophonic morphemes and the word level competition between cohort members. Competition at these two levels could reinforce each other through spread of activation, leading to the delay in the recognition of target words.

Non-lexical and Strategic Effects

So far we have discussed our data in terms of lexical organisation and automatic lexical processing mechanisms. In recent years, however, a number of studies have identified other types of contributions to priming effects in lexical decision experiments (e.g. Becker, 1980; de Groot, 1984; Radeau et al., 1988; Seidenberg et al., 1984; Tweedy, Lapinski, & Schvaneveldt, 1977). These effects can be classified into three types; pre-lexical expectancy, post-lexical coherence checking and episodic memory. Can any of these explain the priming effects observed so far?

For the facilitatory effect in the MORPH condition, all the alternative explanations would assume that this effect arises from attentional processes and response strategies based on semantic relations between primes and targets. The pre-lexical account assumes that when a prime is presented, subjects generate a set of words which are semantically related to the prime (Becker, 1980; 1985). If the target is in this set, a quick "yes" lexical decision can be made. If the target is not in this set, a further search in the lexicon is needed. A post-lexical account locates the effect after lexical access for the target but before the explicit decision about its lexical status (de Groot, 1984; Neely, Keefe, & Ross, 1989). There are a number of accounts of this type, but they all postulate that the subject uses the semantic relatedness between primes and target as a cue to lexical status, which can speed reponse times.

Although both types of account could be invoked to explain the facilitatory effect in Experiment 1A, they have difficulties in explaining the same effects in Experiments 1B and 1C. If subjects generated an expectancy set for each word (Becker, 1980; 1985; Neely, 1991), in most cases they would not find targets in the expected sets, since only 18 of 138 word targets were semantically related to words preceding them. Furthermore, since the items were not presented in prime–target pairs, subjects would have no way of knowing which prime a target was related to. Consequently, if they were to search expectancy sets for targets, they would have to search all the sets generated from previously presented words. This cannot be an effective mechanism for producing the observed facilitatory effects in the MORPH condition.

Post-lexical semantic checking mechanisms face essentially similar problems. To which previous word should the meaning of the present target be related and checked? The mechanism would have to backtrack several words before the decision is made. Furthermore, if such a process were a major contributor to facilitatory effects, the size of the effect should decrease as more intervening items are inserted between primes and targets. We found instead that the MORPH effect did not change between the short and medium lag experiments.

Radeau et al. (1988) appealed to similar strategic mechanisms to account for inhibitory phonological priming effects. They argued that if subjects are exposed to identical prime–target pairs, they will come to expect a repetition whenever the initial phonological form of a word matches the initial part of the prime. This will lead to slower responses in the CHAR and HOM cases, where there will be a conflict between the actual word and the expected word. However, in a recent paired priming experiment in which there was no identity priming condition and indeed no morphological priming condition, we still observed a 27-msec inhibitory effect between compound words sharing initial syllables. This suggests that strategic anticipation is not responsible for the inhibitory effects in the CHAR and HOM conditions. It is in any case unclear how these effects would operate at longer repetition delays.

The third alternative account is in terms of episodic memory factors, where priming is based on access to the episodic memory trace established when the prime was encountered. Although an account in these terms might be put forward for the IDENT condition, where the same word is repeated, it is hard to see how this could account for the differential priming effects in the MORPH, CHAR and HOM conditions. The finding that priming is facilitatory in one case and inhibitory in another seems to require recourse to the properties of *lexical* representations and structures. The purpose of episodic accounts is precisely to avoid reference to the mental lexicon in explaining priming effects.

EXPERIMENTS 2A–D

The results of Experiments 1A–D suggest that the morphological structure of Chinese compound words is explicitly represented in the lexicon. They do not tell us, however, how this structure is represented. Both two-layer, whole-word representation approaches and a single-layer morpheme network approach can accommodate these data equally well. The aim of the present experiments is to provide evidence that will discriminate between these alternative accounts. To do this, we put the critical morphemes at the final constituent position of disyllabic primes and targets, instead of the initial position as in Experiment 1.

Figure 5 is a schematic representation of the design. A compound word target is primed either by the word itself (the IDENT condition) or a completely unrelated word (the BASE condition). These two conditions are the same as in Experiment 1. The same target is also primed by a morphologically related word (MORPH condition), a phonologically and orthographically related word (CHAR condition), and a phonologically related word (HOM condition). Because the related morphemes or syllables here are both the second constituents of the prime words and target words, this means that the prime and target words are not in the same cohort, contrary to Experiment 1. Only the prime–target pairs in the IDENT condition share the same initial phonological form.

In the MORPH condition, again both whole-word and morpheme network approaches do predict priming, either because words sharing constituent morphemes are morphologically connected, whatever the position of the shared morpheme, or because these compounds share common morpheme representations in the lexicon. The CHAR and HOM conditions, in contrast, should discriminate between the two approaches. The morpheme network approach attributes the inhibitory effects in these conditions to competition between homophonic morphemes in the lexicon. Accordingly, a change in the constituent positions of the critical morphemes in primes and targets should not affect priming effects, so that we should still observe an inhibitory effect. The whole-word representation approach makes different predictions. Because primes and targets are not cohort members, there should not be word level competition between lexical representations. Moreover, because morpheme representations are connected to the whole-word representations, word level activation may affect the competition between homophonic morphemes and so change the pattern of priming effects. We pursue these possibilities in more detail in the Discussion below.

Prime Type	Prime	Target
1. **IDENT**	jian(3) yi(4) 简易 (simple, unsophisticated)	
2. **MORPH**	qing(1) yi(4) 轻易 (easily, rashly)	
3. **CHAR**	mao(4) yi(4) 贸易 (trade)	jian(3) yi(4) 简易
4. **HOM**	ya(1) yi(4) 压抑 (inhibit, constrained)	
5. **BASE**	wu(1) xian(4) 污陷 (frame a case against)	

FIG. 5. Experiment 2: Sample prime–target pairs for IDENT(ical), MORPH(ological), CHAR(acter), HOM(ophone) and BASE(line) conditions. Related constituents in MORPH, CHAR and HOM are the second syllables of primes and targets. Words are given in Pinyin as well as in characters (with English translations in parentheses).

Method

As with Experiment 1, Experiment 2 consisted of four sub-experiments. Experiment 2A was a paired priming lexical decision experiment, whereas Experiments 2B–D were repetition priming experiments with different lags between primes and targets.

Materials

The critical word stimuli were chosen from 110 quintets of primes and targets which were pre-tested according to the procedures specified in Experiment 1. All the words underwent three pre-tests: free association, morpheme meaning similarity judgement, and word meaning relatedness judgement. Eighty Chinese students and scholars in Cambridge were asked to give free associates to the MORPH, CHAR and HOM priming words, and to the targets used in this experiment and in Experiment 3. Forty of these subjects were then asked to participate in the morpheme meaning similarity pre-test. The MORPH prime–target and CHAR prime–target pairs were presented in two booklets, with half of the stimuli from the MORPH pairs and another half from the CHAR pairs in each booklet. The two kinds of prime–target pairs were counterbalanced across two groups of subjects so that no subject would see the same target twice. The order of appearance of stimuli pairs was also randomised. Another 40 subjects, also from the first pre-test, were required to make word meaning relatedness judgements to the same word pairs.

The final 45 quintets of primes and targets had the following properties. Only seven prime–target pairs (six in the MORPH condition) had either forward or backward associative relations (14.3% average associative strength). The average morpheme meaning similarity was 8.4 for the MORPH primes and targets and 2.0 for the CHAR primes and targets, indicating that the critically related morphemes were the same morphemes in the MORPH prime–target pairs and different morphemes in the CHAR prime–target pairs. The mean semantic relatedness between the MORPH primes and targets was 5.6 (range 2.8–8.8). The CHAR primes were not semantically related to the targets: the mean was only 1.6. The five priming words for a specific target were matched on word frequency and, if possible, on word class and tone pattern.

As in Experiment 1, 48 word–nonword pairs were constructed along the lines of the test stimuli, with analogues of the IDENT, MORPH and HOM conditions. In the IDENT analogues, the nonword target differed from the prime in the tone or the initial consonant of the first syllable. In the MORPH and HOM analogues, the prime and target had different first syllables but had second syllables that were either morphologically or phonologically related. For Experiment 2A, a further 45 word–word fillers and 42 word–nonword fillers were constructed, in which the primes and targets in the filler pairs were not related either semantically or phonologically. For Experiments 2B–D, the 42 nonword filler targets used in Experiment 2A were retained and 46 new nonwords were generated by changing the tones or initial consonants of the first syllables of real words.

The 45 quintets of test primes were assigned, along with their targets, to five test versions, using the same procedure as for Experiment 1. In Experiment 2A, 72 (40%) prime–target pairs were related in one way or another (phonologically and/or semantically). For Experiments 2B–D, with a higher proportion of nonword fillers, only 26% of items in a version were related.

Procedure

The preparation of stimuli and the procedures for testing subjects were the same as in Experiment 1.

Subjects

In total, 200 undergraduate students at Beijing Normal University were invited to participate in the experiment, 10 in each version. They all were native speakers of Mandarin Chinese. A further nine subjects were tested in London as replacements for discarded Beijing subjects.

Results

The data were analysed in the same way as in Experiment 1. Nine subjects were replaced because they made more than 20% response errors to either critical word or nonword targets (one in Experiment 2A, two in Experiment 2B, two in Experiment 2C and four in Experiment 2D). Four word targets in Experiment 2A and three word targets in each of the repetition priming experiments were also deleted from the analyses because more than 50% of the subjects in a test version responded to them or to their primes incorrectly. Mid-means of reaction times and response error rates were then computed for each item and each subject. The mean reaction time and error rate for each condition are reported in Table 3 for the paired priming experiment (2A) and in Table 4 for the repetition priming experiments (2B–D). The priming effects for the word targets, expressed as difference scores, are shown in Figs 6 and 7.

Experiment 2A: Paired Priming

The mid-mean reaction times were entered into one-way ANOVAs with subjects and items as random variables. A significant main effect of prime type was observed in both the subject and item tests [$F_1(4,196) = 74.24, P < 0.01$; $F_2(4,160) = 75.45, P < 0.01$]. Reaction times to targets were shorter overall in the critical priming conditions than the baseline. Individual analyses of the experimental conditions (Newman-Keuls) showed several differences from the results of Experiment 1A. However, as the comparison between Figs 3 and 6 shows, the main overall change was an across-the-board facilitatory shift in the size of the priming effects, averaging 90–100 msec.

The strongest effects were again in the IDENT condition, where the identity priming effect was 157 msec (versus 62 msec in Experiment 1A). The MORPH priming effect was also much stronger (139 msec versus 35 msec in Experiment 1A) and, unlike Experiment 1A, no longer significantly different from the IDENT effect. This means that priming in the

TABLE 3
Experiment 2A. Paired Priming/Second Constituents:
Mean Lexical Decision Times (msec) and Error Rates (%)

	IDENT	*MORPH*	*CHAR*	*HOM*	*BASE*
Mean RT	682	700	773	786	839
Percent error	2.4	2.2	8.0	9.8	10.2

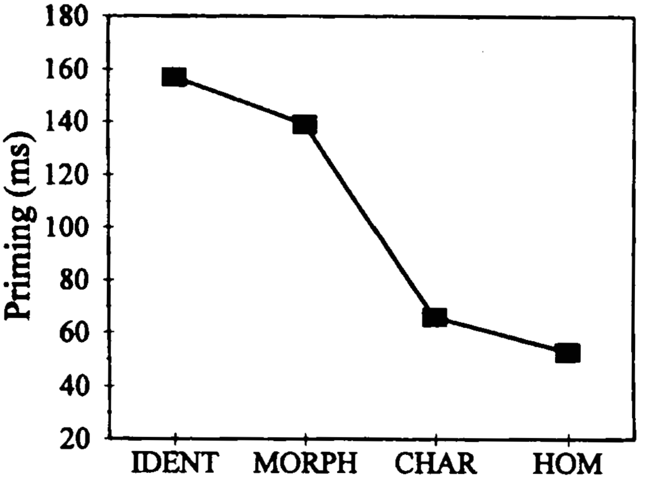

FIG. 6. Experiment 2A: Priming effects (test *vs* baseline) for four test conditions (IDENTical, MORPHological, CHARacter and HOMophone).

morphological condition was statistically "full" (although the numerical difference, 28 msec, was very close to the 27-msec difference between MORPH and IDENT in Experiment 1A).

The CHAR and HOM conditions both showed a striking and significant shift from inhibitory effects throughout Experiment 1 to facilitatory effects of 66 and 53 msec, respectively. Words were responded to more quickly when they were preceded by words sharing the last syllables with them than when they were preceded by unrelated words (all $P < 0.01$). The difference between the CHAR and HOM conditions remained non-significant.

The analyses of the error data show largely parallel effects. The main effect of prime type was significant [$F_1(4,196) = 11.71, P < 0.01; F_2(1,160) = 10.18, P < 0.01$], and *post hoc* tests showed significantly lower error rates in the IDENT and MORPH conditions, with the other conditions not differing from each other.

We now turn to the three repetition priming experiments, Experiments 2B–D (see Table 4 and Fig. 7).

Experiment 2B: Short Lag

The effects in the short lag repetition priming experiment with second constituent primes and targets showed essentially the same pattern as in Experiment 2A, but with reduced effects all round. There was a significant main effect of prime type [$F_1(4,196) = 21.19, P < 0.01; F_2(4,160) = 19.63, P < 0.01$], with an overall facilitatory effect of 47 msec. The strongest effect was

TABLE 4
Experiments 2B, 2C and 2D. Delayed Repetition Priming/Second Constituents: Mean Lexical Decision Times (msec) and Error Rates (%)

	IDENT	*MORPH*	*CHAR*	*HOM*	*BASE*
Experiment 2B					
Mean RT	752	778	801	804	831
Percent error	3.2	3.2	7.1	6.3	4.6
Experiment 2C					
Mean RT	730	805	823	821	837
Percent error	1.4	2.6	3.0	7.0	4.0
Experiment 2D					
Mean RT	772	818	826	827	831
Percent error	2.9	5.5	5.2	7.6	7.1

in the IDENT condition: at 79 msec, it was about the same size as that in Experiment 1B (85 msec) and almost half that in Experiment 2A (157 msec). The MORPH priming effect was also robust (53 msec) and significantly less than the IDENT effect, making morphological priming statistically partial. The CHAR and HOM effects (30 and 27 msec, respectively) were also significant, and remained facilitatory.

The error rate analysis showed marginal main effects of condition, but no significant differences between individual priming conditions.

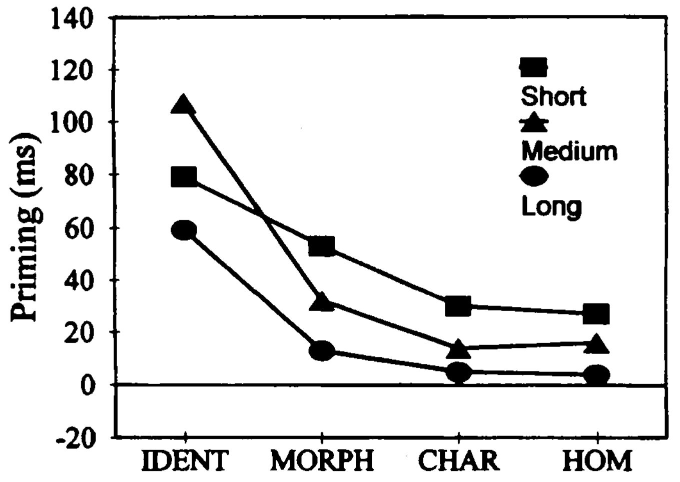

FIG. 7. Experiments 2B–D: Priming effects (test *vs* baseline) for four test conditions (IDENTical, MORPHological, CHARacter and HOMophone) at three different repetition lags (short, medium and long).

Experiment 2C: Medium Lag

The main effect of prime type was again highly significant [$F_1(4,196) = 30.03, P < 0.01$; $F_2(4,164) = 44.35, P < 0.01$]. Much the strongest effect here was the 107-msec identity priming in the IDENT condition; stronger, in fact, than in Experiment 2B. For the other three conditions, as Fig. 7 brings out, the priming effects were much weaker, although still facilitatory. The 32-msec effect in the MORPH condition was still significant ($P < 0.01$, Newman-Keuls), but not the 14- and 16-msec effects in the CHAR and HOM conditions, respectively.

The error rate analysis revealed a main effect of prime type ($P < 0.01$), shown in *post hoc* tests to be due to the elevated error rate in the HOM condition.

Experiment 2D: Long Lag

There was a main effect of prime type [$F_1(4,196) = 11.54, P < 0.01$; $F_2(4,164) = 12.39, P < 0.01$], which, as in Experiment 1D, was entirely due to the identity priming effect of 59 msec ($P < 0.01$). Consistent with this, error rates were reduced in the IDENT condition relative to baseline ($P < 0.05$).

Discussion

The change from first constituent to second constituent in the prime–target pairings had two prominent effects. The first was that priming in the phonological conditions was no longer inhibitory but facilitatory. Responses to word targets were facilitated when they were preceded by words sharing last syllables with them, whether or not the common syllables corresponded to the same morphemes. The second was that there was a large increase, relative to Experiment 1, in the priming effects in the paired priming experiment; however, these effects, especially for the nonword targets, were drastically reduced in the repetition priming experiments. These data may reflect not only lexical processing and the organisation of morphological structure, but also the strategic processes induced by the change of stimulus environment.

Morphological and Identity Priming

The facilitatory effect between second constituents in the MORPH condition can be straightforwardly accounted for by the morpheme network approach and the word-based representation approach. The prime activates a morphemic representation, and this facilitates the subsequent recognition of a target containing the same morpheme. Alternative accounts would look either to the semantic or phonological relations between primes and targets, or to strategic processes. The phonological explanation is inadequate, since the effect in the MORPH condition was much larger than in the CHAR or HOM conditions. The semantic account is not viable either, because (1) there were no correlations between the size of priming effect and the degree of semantic relatedness in any of the four experiments, and (2) the priming effect was still significant in the medium lag experiment, beyond the point at which semantic priming effects are typically obtained.

A strategic account may have a role to play in explaining the much larger morphological and identity priming effects in Experiment 2A than in Experiment 1A. This increase may in part reflect changes in the stimulus environment, and the non-lexical response strategies this could have induced. In Experiment 1A, all the related prime–target pairs shared the same initial phonological forms. In Experiment 2A, only the prime–target pairs in the IDENT condition shared exactly the same initial syllables (the nonword foils had different, though similar, first syllables). In principle, this would permit subjects to make a "yes" decision as soon as they detected that the targets began with the same syllable as the prime. On the other hand, only 9 of the 180 (5%) stimulus pairs were of this type, so the subjects would have limited opportunities for developing this strategy.

It is less clear how strategic processes could have contributed to the increased strength of the morphological priming effect in Experiment 2A, since there were not the same potential cues from first syllable overlap—primes and targets in this condition had completely different first constituents (see Fig. 5). Note that there were still robust MORPH priming effects in the short and medium lag experiments, where, we have argued, strategic factors do not play a role.

Phonological Priming

The finding of facilitatory effects in the CHAR and HOM conditions, where the prime syllable is only phonologically related to its target, is a challenge to the single-layer morpheme network approach, which seems to predict inhibitory priming effects between compound words sharing the last syllables. The activation of the critical morpheme in the prime should make it more difficult for the homophonic morpheme in the target to be discriminated from other competing morphemes, and consequently slow down the recognition of the target.

In contrast, a whole-word representation approach—so long as it incorporates a separate morphemic level of representation—can account for this result in terms of different activation effects at word and morpheme levels. The second syllable of a prime word will activate a set of homophonic morphemes. The results for the CHAR and HOM conditions suggest that the activation level of all these morphemes remains elevated, thereby contributing to the subsequent speed of recognition of a target word containing one of these morphemes as second syllable. The fact that there is no corresponding effect when the critical morphemes are word-initial (as in Experiment 1) is presumably connected to the fact that different homophonic morphemes in initial position will lead to word-level competition. When they occur in second syllable position, the cohort has already been established, so that new word candidates will have difficulty becoming established. However, the exact mechanism whereby a whole-word model would produce these effects requires a more detailed version of such a model. We will return to this in the General Discussion.

The alternative to an account along these lines is to postulate a level of *syllabic* representation in the system. Dell (1986) has proposed a network-based lexicon with these properties for sentence production, and Emmorey (1989) has made similar proposals to account for the priming effects she found between words sharing final syllables. She explained the facilitatory effect in pairs like *tango–cargo* in terms of repeated access to common syllable representations. A similar mechanism could be invoked to explain the effects in the current experiments, where the activation of the final syllable in the prime would facilitate the recognition of targets containing the same phonological syllables, independent of their morphemic identity. The inhibitory effects of phonological priming in Experiment 1 could be explained by appealing to the notion of word level competition. The competition between cohort members overrides the facilitation caused by the repeated access to common syllable representations in primes and targets. This syllable representation account, as well as the whole-word representation approach and the morpheme network approach, will be explored further below.

EXPERIMENTS 3A–D

In Experiments 1 and 2, the priming effects in the MORPH conditions were always facilitatory, independent of the constituent position of critically related morphemes in primes and targets. In contrast, these changes in constituent position drastically influenced the direction of priming in the CHAR and HOM conditions. This functional relationship between constituent position and the nature of priming effect is problematic for a single-layer, morpheme-based approach to explain. In this experiment, we take advantage of the fact that a morpheme in Chinese can appear at different constituent positions in different compound words and manipulate further the positions of the critical morphemes in primes and targets. As we will argue below, this should provide additional evidence to discriminate among alternative theories.

As shown in Fig. 8, we now place the target syllable in first constituent position (as in Experiments 1A–D) and the priming syllable in second

Prime Type	Prime	Target
1. **IDENT**	rong(2) ren(3) 容忍 (tolerate, put up with)	
2. **MORPH**	kuan(1) rong(2) 宽容 (tolerant, lenient)	
3. **CHAR**	xiao(4) rong(2) 笑容 (smiling expression)	rong(2) ren(3) 容忍
4. **HOM**	fan(2) rong(2) 繁荣 (flourishing, prosperous)	
5. **BASE**	fan(2) mang(2) 繁忙 (busy)	

FIG. 8. Experiment 3: Sample prime–target pairs for IDENT(ical), MORPH(ological), CHAR(acter), HOM(ophone) and BASE(line) conditions. Related constituents in MORPH, CHAR and HOM are the second syllable in the prime and the first syllable in the target. Words are given in Pinyin as well as in characters (with English translations in parentheses).

constituent position (as in Experiments 2A–D), across the same five conditions as before. The issue for the IDENT conditions is whether the change in stimulus environment will affect the priming results. In Experiment 2, the only stimulus pairs that shared their initial syllables were the IDENT pairs. In Experiment 3, this is still true of the word pairs, but it is now also true of the IDENT nonword foils as well, which only deviate from their primes in their second syllables. This should prevent subjects from developing the early response strategy they might have adopted in Experiment 2A.

Note that this provides a test of our claims about the conditions under which strategic attentional processes emerge. If these processes are sensitive to the stimulus environment within an experiment, the size of the identity priming effect should be larger than in Experiment 1A but smaller than in Experiment 2A. But there should be no corresponding differences across the repetition priming experiments, if we are correct in our argument that the repetition priming task severely curtails the development of non-lexical response strategies.

Turning to the MORPH conditions, Experiment 3 is more like Experiment 2 than Experiment 1, since primes and targets are not in the same word-initial cohorts as they were in Experiment 1. This difference may have been one reason for the larger priming effects in Experiment 2, since potentially facilitatory morphemic priming effects could have been obscured, in Experiment 1, by word level competition between prime words and target words. If so, then the size of the priming effect in the MORPH condition should also be larger in Experiment 3 than in Experiment 1. This should be especially evident in the short lag experiments, where potential strategic conditions are minimised and lexical priming effects are still robust.

Turning to the CHAR and HOM conditions, these should help us to choose between syllable representation and whole-word representation accounts. If the syllable representation account is correct, we should continue to observe facilitation in the present experiment because, like Experiment 2 but unlike Experiment 1, the prime–target pairs in the present CHAR and HOM conditions are not in the same word-initial cohorts. No word level competition should obscure the facilitatory effects originating at the syllable representation level. The whole-word representation account, without a syllabic level, makes different predictions, which we will discuss later.

Method

Materials

Most of the MORPH, CHAR and HOM primes were already pre-tested for Experiment 1. For other primes and targets, the three pre-tests as described in Experiment 1A were carried out. Forty-five quintets of primes and targets were finally selected. They all conformed to the requirements laid out previously. The average morpheme meaning similarity was 8.3 for the MORPH prime–target pairs and 1.9 for the CHAR prime–target pairs. Eight pairs of the MORPH primes and targets had associative relations, with an average associative strength of 12.5%. The average semantic relatedness beteween the MORPH primes and targets was 6.2. The CHAR primes and targets were not semantically related, with an average relatedness score of 1.4.

As before, 48 sets of word–nonword pairs were constructed as specific foils to the experimental conditions. For the IDENT analogues, the nonword targets now shared the same first constituent as the prime but diverged in the second syllable. In the paired priming experiment, an additional 45 unrelated word–word pairs and 42 word–nonword pairs were selected for use as fillers. A Latin square design was used to assign critical primes of word targets into five versions. All 45 targets appeared in each version with 9 primes from each of five priming conditions. The prime–target pairs in the first version were randomised with the restriction that no more than four word or nonword targets appeared successively. This pseudo-random order was then used in the other four versions, such that the same targets appeared at the same positions across five versions.

In the repetition priming experiments, all the critical word targets used in Experiment 3A were retained together with their primes. These stimuli were split into five testing versions in which the critical prime–target pairs in each version were the same as in the corresponding version in Experiment 3A. To add as many fillers as possible, to minimise possible strategic effects in the repetition priming experiments and to balance the proportion of words to nonwords, the 42 nonword filler targets used in Experiment 3A and a further 46 nonword targets constructed in the same way as other nonwords were added to each version. Consequently, 72 (26%) items were related in each test version. As in the above repetition priming experiments, a pseudo-random sequence was used for the five versions in each experiment so that the critical targets and fillers were presented in the same positions across versions.

Procedure

The preparation of stimuli and the testing of subjects were carried out in the same way as in Experiment 1.

Subjects

For Experiment 3A, the subjects were 50 Chinese students and visiting scholars in London. Most were native speakers of Mandarin, but some were from the northern part of China and were fluent speakers of Mandarin. Ten subjects were assigned at random to each testing version. For Experiments 3B–D, the subjects comprised 150 undergraduate students at Beijing Teachers' College. They were all native speakers of Mandarin. A further four subjects in London were also tested as replacements for the discarded Beijing subjects. All subjects were paid for their participation.

Results

Four Beijing subjects (two in Experiment 3B and one each in 3C and 3D) in the repetition priming experiments were replaced because of error rates to critical word or nonword targets above 20%. Two word targets in Experiment 3A, four in Experiment 3B, one in Experiment 3C and three in Experiment 3D were deleted because of error rates over 50%. For the same reason, two nonword targets in Experiment 3A, four in Experiment 3B, one in Experiment 3C and two in Experiment 3D were also discarded. Item and subject mid-means were computed for each remaining item and subject. The mean reaction times and error rates for each condition are reported in

TABLE 5
Experiment 3A. Paired Priming/Second–First Constituents: Mean Lexical Decision Times (msec) and Error Rates (%)

	IDENT	*MORPH*	*CHAR*	*HOM*	*BASE*
Mean RT	712	764	825	841	832
Percent error	3.0	1.9	6.3	10.7	9.5

Tables 5 and 6. The priming effects, relative to baseline, are shown in Figs 9 and 10.

Experiment 3A: Paired Priming

There was a significant main effect of prime type [$F_1(4,196) = 87.94$, $P < 0.01$; $F_2(4,168) = 69.65$, $P < 0.01$], with responses faster overall (by 47 msec) in the priming conditions than in the baseline condition. Priming was again strongest in the IDENT condition (120 msec), and significantly larger than the sizeable 68-msec effect ($P < 0.01$) in the MORPH condition. However, in contrast to the previous experiments, there were no effects, either inhibitory or facilitatory, in the CHAR and HOM conditions, neither of which differed significantly from BASE. The 16-msec difference between CHAR and HOM conditions was not significant either.

The errors followed a similar pattern, with the significant effect of prime type [$F_1(4,196) = 13.65$, $P < 0.01$; $F_2(4,168) = 9.61$, $P < 0.01$] reflecting the reduced error rates, relative to baseline, in the IDENT and MORPH

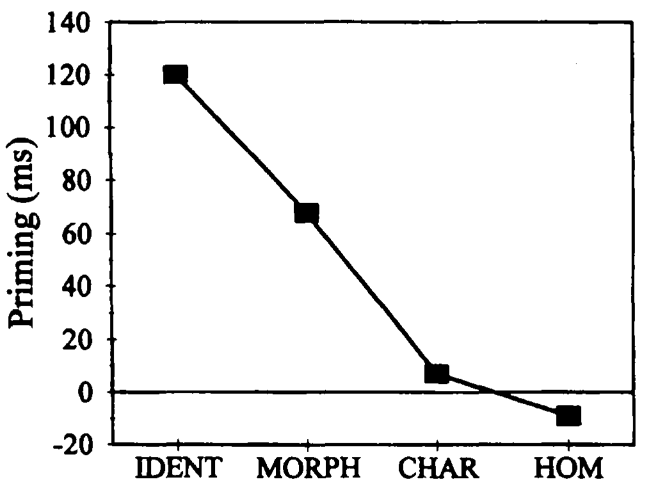

FIG. 9. Experiment 3A: Priming effects (test *vs* baseline) for four test conditions (IDENTical, MORPHological, CHARacter and HOMophone).

conditions. Error rates did not differ in the HOM and BASE conditions, but were significantly lower in the CHAR condition.

We now turn to the three repetition priming experiments (see Table 6 and Fig. 10).

Experiment 3B: Short Lag

The results here largely parallel those for Experiment 3A. There was a significant main effect of prime type [$F_1(4,196) = 41.54, P < 0.01$; $F_2(4,160) = 39.63, P < 0.01$], with faster responses in the IDENT and MORPH conditions. Identity priming, at 86 msec, was strongest, and significantly greater than the 58 msec in the MORPH condition. The CHAR and HOM conditions, in contrast, did not differ from BASE or from each other. The error rate analyses were consistent with this, with the effect of prime type [$F_1(4,196) = 5.30, P < 0.01$; $F_2(4,160) = 5.24, P < 0.01$] again reflecting a tendency to lower error rates in the IDENT and MORPH conditions.

Experiment 3C: Medium Lag

There was again a main effect of prime type [$F_1(4,196) = 59.15, P < 0.01$; $F_2(4,172) = 59.12, P < 0.01$], with a facilitatory 94-msec effect in the IDENT condition, which was considerably greater ($P < 0.01$) than the reduced but still significant 35-msec effect in the MORPH condition. There were no effects in the CHAR condition, but slowed responses in the HOM condition. Responses here were significantly slower than in the CHAR condition ($P < 0.01$), and marginally so relative to BASE (by subjects, $P < 0.01$; by items, $P < 0.01$).

TABLE 6

Experiments 3B, 3C and 3D. Delayed Repetition Priming/Second–First Constituents: Mean Lexical Decision Times (msec) and Error Rates (%)

	IDENT	*MORPH*	*CHAR*	*HOM*	*BASE*
Experiment 3B					
Mean RT	740	768	815	832	826
Percent error	2.2	4.4	6.6	5.9	9.0
Experiment 3C					
Mean RT	717	776	805	830	811
Percent error	1.3	2.2	6.0	6.6	7.2
Experiment 3D					
Mean RT	761	809	817	820	822
Percent error	1.4	4.5	7.6	6.9	7.6

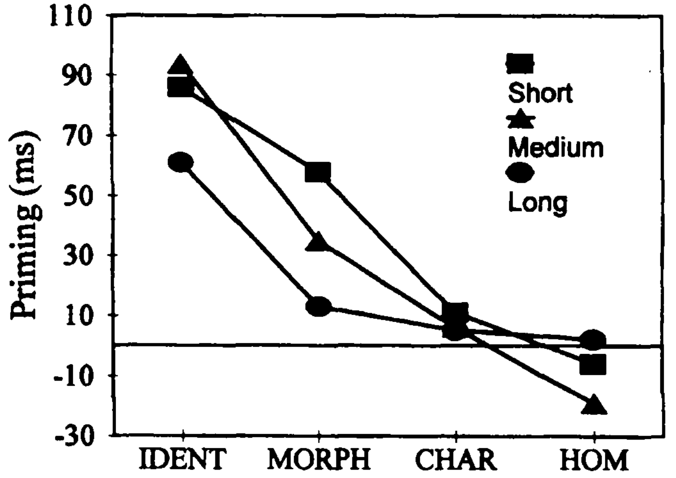

FIG. 10. Experiments 3B–D: Priming effects (test *vs* baseline) for four test conditions (IDENTical, MORPHological, CHARacter and HOMophone) at three different repetition lags (short, medium and long).

The error analyses again provided a main effect of prime type [$F_1(4,196) = 6.31$, $P < 0.01$; $F_2(4,172) = 6.26$, $P < 0.01$], reflecting reduced error rates in the IDENT and MORPH conditions relative to the other three.

Experiment 3D: Long Lag

As in the earlier long lag experiments, priming effects were minimal here, with the exception of significant identity priming (61 msec), leading to a main effect of prime type [$F_1(4,196) = 17.97$, $P < 0.01$; $F_2(4,164) = 18.65$, $P < 0.01$], with parallel results for the error analysis, where the effect of prime type [$F_1(4,196) = 6.79$, $P < 0.01$; $F_2(4,164) = 4.42$, $P < 0.01$] reflected lower error rates in the IDENT condition. The small facilitatory effects in the MORPH condition, visible in both response time and error rate measures, did not approach significance.

Discussion

In this third series of experiments, the critical morphemes occurred in different but adjacent constituent positions, as second syllable of the prime and as first syllable of the target. For the IDENT condition, this led to strong facilitatory effects of 120 msec in Experiment 3A, which was larger than the 62-msec effect in Experiment 1A, but less than the 157-msec effect in Experiment 2A. These differences plausibly reflect strategic responses to the different stimulus environments in the three paired priming experiments, where, as we discussed earlier, the phonetic identity of the initial syllables of the prime and the target varies in its salience and reliability as a response cue.

The effects in the MORPH condition were again robust, though throughout less than the identity priming effects, and reduced, in Experiment 3A, relative to the effects in Experiment 2A. Morpheme network and whole-word approaches would both explain these facilitatory effects in terms of repeated access to the same morpheme representations.

Turning to the CHAR and HOM conditions, here we find yet a third pattern of responses, where the overall null effect differed both from the inhibitory effects in Experiment 1 and the facilitatory effects in Experiment 2. This new pattern is inconsistent with a morpheme network approach, which predicts an inhibitory priming effect between homophonic morphemes. It is also inconsistent with the syllable representation account we advanced as a possible explanation of the facilitatory results in Experiment 2, since this would predict facilitatory effects here as well. In each case, there was repeated access to a common syllable representation in the processing of CHAR or HOM prime–target pairs.

As before, an account of the null effect can be constructed under the whole-word approach, in terms of the time-course and nature of the activation processes at word and morphemic levels. Such an account would pit the effects of the residual acivation of homophonic morphemes (as in Experiment 2's facilitatory effects) against the inhibitory effects, at the word level, of competition between the same morphemes when subsequently reactivated by the initial syllable of the target word. These conflicts would come into play either immediately, as in the paired priming experiment, or at variable delays, as in the repetition priming experiments. We will postpone discussion of the details of this until the presentation of the full model in the next section.

GENERAL DISCUSSION

In three sets of experiments, using both the paired priming and repetition priming tasks, we consistently obtained priming effects between words sharing common morphemes, irrespective of the position of these morphemes in primes and targets. In contrast, the priming effect between words having just common syllables but homophonic morphemes could be either inhibitory, facilitatory or null, depending on the position of related morphemes. In the following discussion, we first summarise the data, by priming condition, across the 12 experiments. We then move to a model of lexical representation for Chinese disyllabic words. Finally, we discuss the implications of the model and the results for studies of lexical representation in the human mental lexicon.

Identity Priming

Figure 11 presents in summary form the priming effects for the IDENT condition across the 12 experiments, grouped according to experimental task—paired priming, and the three levels of delay (short, medium, long) in the repetition priming experiments. There were strong effects throughout, even in the long lag experiments where all other priming effects were absent. There was considerable variation in the magnitude of the facilitatory effect across the paired priming experiments but very stable effects across the repetition priming experiments. With the exception of Experiment 1, the size of the identity priming effect in each experiment was largest in the paired priming experiments, decreased in the short and medium lag repetition experiments—with a consistent tendency to stronger priming at the medium lag—and fell off further in the long lag experiments.

These observations are confirmed in four sets of ANOVAs conducted on the paired priming and the repetition priming experiments, with size of priming effect as the dependent variable and experiment (Experiments 1, 2, 3) as a nested factor with three levels. In the paired priming experiments, the significant effect of experiment [$F_1(2,147) = 23.38$, $P < 0.01$; $F_2(2,122) = 116.83$, $P < 0.01$] indicated that the size of the priming effect varied across experiments. However, this effect disappeared in the analyses on the short, medium and long lag experiments, where the amount of identity priming was strikingly similar across experiments.

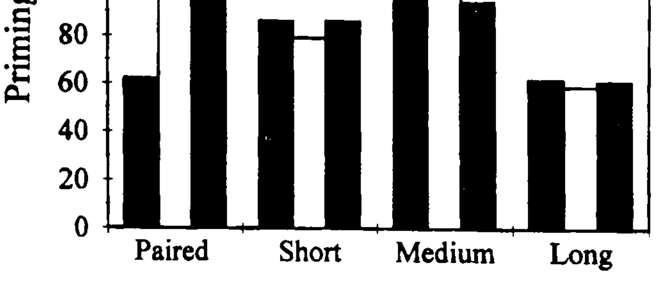

FIG. 11. Priming effects in the IDENTical condition across Experiments 1–3, grouped by experimental task (paired priming *vs* short, medium and long lag repetition priming).

A major reason for including the identity priming condition was to evaluate the potential contribution of strategic processes to the priming effects. This seems to have been achieved, since the size of the priming effect in the paired priming task was clearly influenced by the changing stimulus environment in the three experiments. The word targets in the IDENT condition were most prominent and predictable in Experiment 2A, less so in Experiment 3A, and least in Experiment 1A. Correspondingly, the identity priming effect—although significant throughout—was smallest in Experiment 1A, largest in Experiment 2A and intermediate in Experiment 3A. This variation in the prominence of identity priming can be seen as similar in its effects to variation in the proportion of semantically related prime–target pairs (de Groot, 1984; Keefe & Neely, 1990; Tweedy et al., 1977). Both prominence and higher predictability induce strategic expectancies, and change the bias of lexical decision (Farah, 1989).

The most important point for the interpretation of the current results is that, although identity priming effects were apparently strategically modulated in the paired priming experiments, it is clear from Fig. 11 that there were no such effects in the repetition priming experiments, where primes and targets were not explicitly paired and there were intervening items between primes and targets. At a given lag, the size of the effect was constant across experiments, even at the short lag, where the differences in the prominence of identity prime–target pairs should still have been readily apparent. This suggests that strategic attentional processes had minimal influence on performance in the repetition priming task. The implication of this is that the priming effects in the morphological and phonological conditions are unlikely to be due to strategic processes. It is hard to imagine that subjects did not take advantage of the obvious relations between the IDENT prime–target pairs in Experiments 2B and 2C but could still exploit some other, more subtle relations between primes and targets. We can confidently attribute the priming effects in the MORPH, HOM and CHAR conditions to the linguistic relations between primes and targets and not to response strategies.

Morphological Priming

The overall pattern of priming effects in the MORPH condition is plotted in Fig. 12, again grouped according to experimental task. Morphological priming effects were observed in all the sub-experiments except in long lag repetition priming.[3] However, the magnitude of the effect varied across experiments, with significant effects of experiment in the paired priming [$F_1(2,147) = 40.85$, $P < 0.01$; $F_2(2,122) = 24.47$, $P < 0.01$] and short lag

[3]Collapsing across experiments, the overall MORPH priming effect at long lags was in fact significant.

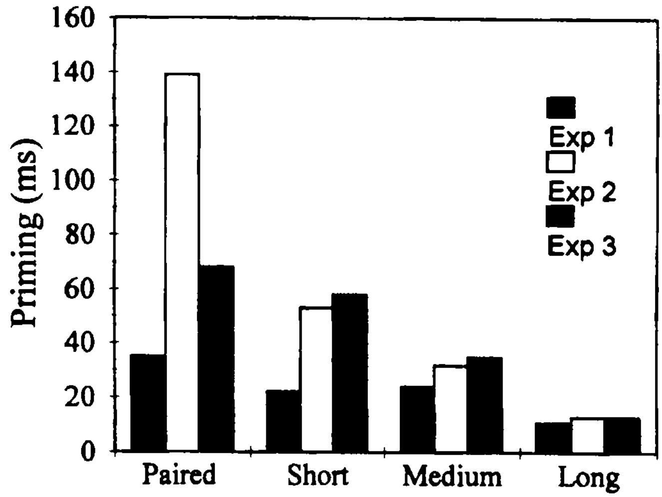

FIG. 12. Priming effects in the MORPHological condition across Experiments 1–3, grouped by experimental task (paired priming *vs* short, medium and long lag repetition priming).

experiments [$F_1(2,147) = 6.03$, $P < 0.01$; $F_2(2,121) = 4.32$, $P < 0.05$]. In general, there was least morphological priming in Experiment 1, where prime and target syllable were both in first constituent position, and approximately the same amount of priming in Experiments 2 and 3, with the exception of paired priming in Experiment 2, where the priming effect was exceptionally strong.

The purpose of these various manipulations of constituent position and of experimental paradigm was to enable us to distinguish among different approaches to lexical representation in Chinese. As we noted in the earlier discussions of the various experiments and sub-experiments, the general pattern of results is problematic for a single-layer, morpheme network approach, which has difficulties in explaining why the size of morphological priming effects varies as a function of these manipulations in position.

To account for these variations, we need to look to more complex models, where a word level layer of representation is distinguished from a morphemic level. The presence of the morphemic level allows for priming irrespective of prime–target constituent position, and the presence of a word level allows the model to discriminate Experiment 1 from Experiments 2 and 3—where priming was greater throughout in the MORPH condition. In Experiment 1, the morphological priming effect due to repeated access to the same morphemic representations was partly obscured by word level competition between cohort members. This competition was reduced in the repetition priming experiments, while at the same time the size of the morphological priming effect decreased over time, leading to the relative stability of morphological priming in the short and medium lag experiments. For Experiments 2 and 3, because primes and targets in the MORPH conditions were not in the same cohort, morphological priming effects could surface without being obscured, leading to larger MORPH effects than in Experiment 1. Indeed, if we measure the morphological priming effect in Experiment 1 not from the control baseline but from the phonological control—compensating for the word level competition triggered by the initial constituent phonological overlap between primes and targets—the priming effect in the MORPH condition was about 70 msec in the paired priming experiment and 55 msec in the short lag experiment, comparable to the MORPH priming effects in Experiments 2 and 3.

Phonological Priming

A striking aspect of the research was the variation in the direction of the HOM and CHAR priming effects as a function of constituent positions of prime and target syllables. These effects are summarised, for the two priming conditions separately, in Figs 13 and 14. The pattern is very clear. In Experiment 1, where the homophonic syllables occurred in word-initial position in both prime and target, the effects were inhibitory throughout, but declined in strength as the delay between prime and target increased. In Experiment 2, where both prime and target syllable occurred in second constituent position, the effects were facilitatory throughout, and again declined in strength as a function of delay. In Experiment 3, where the prime occurred in second position but the target in word-initial position, the effects were more or less null throughout, even in the paired-priming task. The other aspect of Experiment 3 is a consistent difference between CHAR and HOM, not observed in the other experiments, such that the CHAR primes had a weakly facilitatory effect throughout, while the HOM primes were weakly inhibitory, except in the long lag case. This difference between CHAR and HOM was significant in the individual analysis of the medium lag experiment (3C), as well as in the overall analysis of Experiment 3.

As we have argued at several points in this paper, this complex pattern of results can only be explained in terms of a model which specifically includes both morphemic and whole-word levels of representation. Any account in terms of a single-level model cannot explain the shifts in the directionality of the priming effects as a function of the constituent positions of prime and target syllables. Specifically, as we will lay out in more detail below, we argue that homophonic morphemes excitatorily link to whole-word representations that contain them. The interactions between the word level activation and morpheme level activation during lexical access then lead to different patterns of phonological priming effects across the three experiments. In Experiment 1, the inhibitory priming effect is likely to

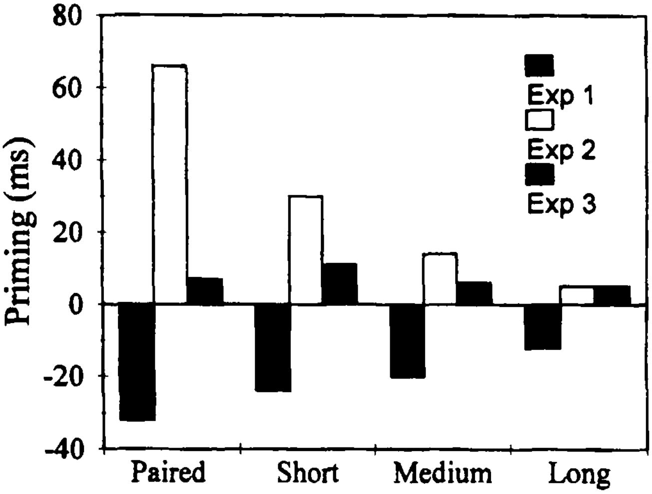

FIG. 13. Priming effects in the CHARacter condition across Experiments 1-3, grouped by experimental task (paired priming *vs* short, medium and long lag repetition priming).

reflect word level competition between cohort members, where the residual higher activation of the word corresponding to one reading of the homophonic initial syllable will interfere with recognition of a word requiring a different reading of the same homophonic syllable. In Experiment 2, the same word level effects do not come into play, since the

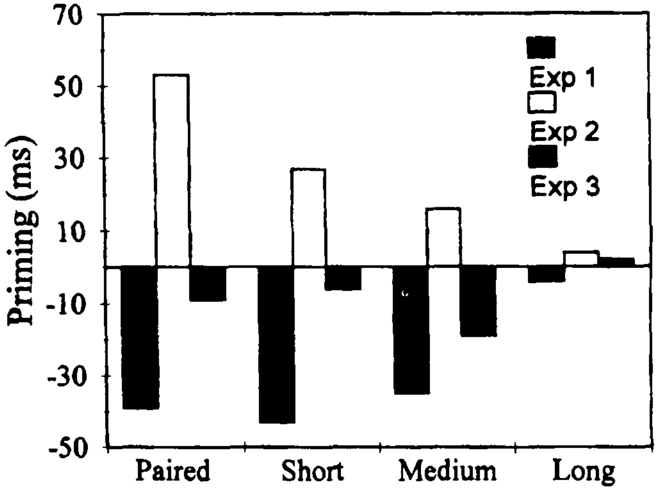

FIG. 14. Priming effects in the HOMophone condition across Experiments 1-3, grouped by experimental task (paired priming *vs* short, medium and long lag repetition priming).

homophonic syllable, now in word-second position, does not generate competition at the word level to the same extent. This allows the facilitatory effects due to the pre-activation of the critical homophonic morphemes to show through and speed the recognition response. In Experiment 3, we can attribute the overall null effects to the conflict between these two sets of facilitatory and inhibitory factors: the morpheme level facilitation due to the position of the prime syllable in word-second position, and interference effects generated at the word level by competition between different words beginning with the same word-initial critical morphemes.

A MODEL OF LEXICAL REPRESENTATION FOR CHINESE DISYLLABIC WORDS

The pattern of results across the 12 experiments reported here, and summarised in the preceding section, point to a model of the Chinese mental lexicon, which assumes both whole-word lexical entries and the explicit representation of morphological structure in the lexicon. We now describe in more detail a preliminary two-level model for the representation of Chinese disyllabic words. This is a localist model, based on the interactive-activation framework (McClelland & Elman, 1986; McClelland & Rumelhart, 1981; Taft, 1991; 1994), and incorporating some basic concepts of the Cohort model (e.g. Marslen-Wilson, 1987).

In this model, the lexicon is a multi-level hierarchical network, in which different representation levels correspond to basic linguistic units, such as features, syllables, morphemes and words. The morphological structure of Chinese disyllabic words is represented at both the morpheme level and the word level (see Fig. 15 for a schematic representation of the model). At the morpheme representation level, different morphemes are represented as different nodes. Nodes having the same phonological form (i.e. homophonic morphemes), constitute a morpheme cluster in which members compete with each other in lexical processing. These morphemic nodes connect excitatorily to whole-word representations for compounds which contain these morphemes. That is, a specific morpheme is linked to *all* the compound words containing this morpheme, whether at first or second constituent position. It is not only words sharing their initial syllables which are activated and compete with each other in spoken word recognition, but also words ending with these shared syllables.[4]

[4]In a previous version of the present model (Zhou, 1992), we assumed, in common with most other interactive-activation models (e.g. Dell, 1986; McClelland & Elman, 1986), that members of the same word or morpheme cluster connect with each other in the lexicon and inhibit each other laterally in lexical processing. However, if we assume that word recognition takes place when the activation level of a particular representation reaches a criterial difference from the activation levels of other competing representations (Marslen-Wilson, 1990), this usual assumption of intra-level lateral inhibition is not necessary (see Bard, 1990, for a discussion).

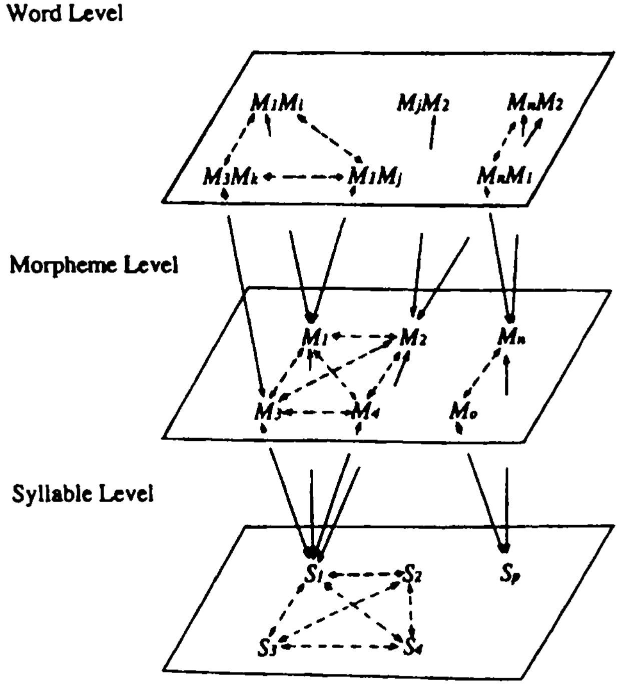

FIG. 15. A Multi-level Cluster Representation Model for Chinese disyllabic compound words. Broken lines within levels indicate the competition between cluster members; continuous lines between levels indicate excitatory connections between corresponding members.

The basic processing mechanism in the model is spreading activation through the relevant part of the lexicon. Each word or morpheme node has a normal resting level, which is partly determined by its frequency of use in the language, and a "firing" threshold. The speech input activates all the nodes that are consistent with the input. More frequently used nodes are activated more quickly and hence reach threshold more rapidly. The activation state of a node in real time is influenced by the input from the nodes connected to it at the other representation level. When the activation level of a node reaches its threshold, it sends some proportion of the activation level to all nodes connected to it. Because we assume that there are only inter-level bidirectional excitatory connections between word representations and morpheme representations, we expect only bottom-up and top-down effects in lexical processing. When the activation sent out by the activated node reaches the destination node, it adds to that node's current activation level. When the activation level of the latter node reaches a threshold, it sends out activation to the nodes it is connected to as well, including the node from which it receives spreading activation. The spreading of activation takes place only during the processes of word recognition. After the recognition process is completed, the activation levels of those nodes fall back to their normal resting states.

Lexical representation in this model is word-based. Chinese disyllabic words are represented as wholes in the lexicon. In lexical access, the speech input ultimately projects onto a level of word representation. However, morphological structure is also explicitly represented in the model, in two different ways. One of these, clearly, is the level of morpheme representation itself. The other is the marking of morphological structure at the word level. To connect a whole-word representation with a morpheme node, the morphological structure of the whole word has to be marked or bracketed.

An important property of the model is that words sharing common morphemes do not connect directly with each other. Rather, they connect via common morpheme representations at the morpheme level. For example, in Fig. 15, the two word representations M1Mi and M1Mj are not connected at the word level (the broken lines joining them indicate that they are cohort competitors, not that they are morphologically or lexically linked at this level). They connect indirectly via the common morpheme node M1 at the morpheme representation level. The word level relationship between M1Mi and M1Mj, which share initial morphemes, is no different to the relationship between M1Mi and M3Mk, whose initial morphemes are different but homophonic. This allows the system to capture explicitly the relationship between words having homophonic morphemes. Words like M1Mi, M3Mk and MjM2 are usually assumed not to be morphologically related. The relationship between M1Mi and M3Mk (*watchdog* and *watchstrap* are a corresponding pair of English examples) is regarded as similar in kind to the relationship between two monomorphemic words beginning with the same syllable (e.g. *random* and *ransack*). In the present model, these two kinds of words are treated differently. In addition to word level competition, pairs like M1Mi and M3Mk are also competitors at the morphological level. The inhibitory priming effect between words sharing initial homophonic morphemes (Experiment 1) is thus due to both word level competition between cluster members and morpheme level competition between homophonic morphemes. The facilitatory priming effect (Experiment 2) or null effect (Experiment 3) between words sharing homophonic morphemes reflect the interactions between word level and morpheme level activation, and the way these change as a function of target and prime constituent position.

When the critical syllable in a prime occurs in second constituent position, it activates all the corresponding homophonic morphemes, including the morpheme used as the first or second constituent of the target. Because of the spread of activation from the word representation, the activation of the critical morpheme (M2) used in the prime (MjM2) is elevated to a higher level than other homophonic morphemes (M1, M3). However, the homophonic morpheme (M1) used as the second constituent in the target is still activated, and hence the target word (MnM1). This residual activation is clearly highly facilitatory. Even though the morpheme encountered in the prime (M2) will have a higher residual activation, it will not be able to affect processing, because the words with which it connects will not have been activated by the initial syllable of the target. This is the reason for the facilitatory effect in Experiment 2.

In contrast, when, as in Experiment 3, the critical syllable is the first syllable of the target, then these residual differences in the activation level of the homophonic morpheme used in the prime will slow recognition of the target word. The higher activation level of the critical morpheme (M2) used in the prime (MjM2) will tend to interfere with the recognition of the target word beginning with the morpheme M1. This conflict between, on the one hand, the pre-activation of the target by the prime and, on the other, the competition from words beginning with the critical morpheme (M2) used in the prime, leads to the cancellation of the priming effect. To account for the null effect in the repetition priming experiments as well as in the paired priming task, it must be assumed that these small differential increments in the activation of different words and morphemes have a long half-life.

CONCLUDING REMARKS

We motivated this research in the context of cross-linguistic questions about the human mental lexicon, looking at a language type that had previously been relatively neglected, and at a morphological process where previous research had led to inconclusive results. What can we now say about lexical representation across different morphological categories and across different language types?

The clearest conclusion we can draw is that purely morphological accounts of lexical representation do not hold universally. In a language like English, there is now considerable evidence for a morphologically decomposed representation of derivationally complex forms (e.g. Marslen-Wilson et al., 1994). Words such as *happiness* or *unhappy* seem to be represented in stem + affix format, where the stem morpheme {happy} is linked to the affixes {-ness} and {-un}. The evidence for Chinese, in contrast, is that disyllabic compounds are represented as whole-word units, without direct links at the lexical level between words sharing the same morphemes. This is on the face of it surprising, given the salience of individual syllables as morphemes in the Chinese language, but it is consistent with our results elsewhere using differential frequency techniques (Zhou & Marslen-Wilson, 1994), showing the dominance of whole-word frequency over frequency effects related to individual syllables or morphemes.

This difference between English and Chinese may reflect genuine cross-linguistic differences, or it may reflect universal differences between compounding and affixation as procedures for word formation. In Chinese, as in English, the interpretation of a compound is not reliably predictable from the composition of its components; a *flourmill*, for instance, is a mill that produces flour, but a *windmill* does not produce wind, nor a *watermill* water. In contrast, derivational affixes have regular compositional consequences. The affix {-ness}, for example, applies to adjectives to form abstract nouns, and the interpretation of the resulting complex form (as in *sadness*, *quietness*, *hopefulness*, *sugariness*, etc.) is much more predictable. This would allow for the on-the-fly computation of the meaning of a derived form in a way which was not possible for compounds, with their more idiosyncratic meanings. The meanings of transparent derived forms, therefore, would not need to be stored separately in the way that may be necessary for compounds.

To resolve these issues, we need to develop a much clearer picture of the representation of compounds in languages like English (cf. Monsell, 1985; Sandra, 1990; Zwitserlood, 1994), as well as to introduce variations in semantic predictability in future research into Chinese compounds. But the important point is that we need to pursue these issues in typologically different languages—differing, for example, in the ways that English and Chinese contrast in their morphological systems. Only in this way can we separate out the idiosyncracies reflecting the quirks of individual languages from the more general principles governing the mental representation of lexical knowledge and how this knowledge is deployed in language processing. The research reported here is a step in this direction. Our interest is not just in Chinese, or indeed English, but in the global properties of human language as a cognitive phenomenon.

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