The effect of priming direction on reading Chinese compounds

James Myers*, Bruce Derwing†, and Gary Libben†
*National Chung Cheng University and †University of Alberta

Abstract

This paper reports the first priming experiment on Chinese compounds to manipulate direction of priming, conducted in order to provide new data on the different stages, or at least aspects, of compound processing. The results parallel those found in other languages: first components prime compounds and second components do not, an effect that is also sensitive to semantic transparency, while compounds prime both of their components regardless of transparency. These results are consistent with a model in which compounds are accessed left-to-right, followed by a more thorough decomposition.

INTRODUCTION

Repetition priming paradigms have played an important role in the search for the effects of morphological components on word recognition in many languages, including Chinese (see reviews in Taft, Liu, and Zhu, 1999; Myers, 2002). Parameters that have been explored using such paradigms include task, particularly lexical decision vs. naming (e.g., Feldman and Prostko, 2002), modality (orthographic, auditory, or mixed; e.g., Zhou and Marslen-Wilson, 1995, and Zhou, Marslen-Wilson, Taft, and Shu, 1999, use the same Chinese stimuli but vary modality; see also Drews, 1996, for further references in other languages), time lag between prime and target (immediate repetition priming, without masking or with forward or backwards masking, in which trials consist of prime-target pairs typically separated by less than one second, or long-term repetition priming, in which earlier items in a list of single-stimulus trials act as primes for later items; studies comparing time lag and masking include Feldman, 2000, and Feldman and Prostko, 2002, for English; Zhou, et al., 1999, for Chinese; see also Feldman, 2003, for a review of long-term priming studies), semantic transparency (examined in most studies, e.g., Zwitzerlood, 1994, for Dutch compounds; Jarema, Busson, Nikolova, Tsapkini, and Libben, 1999, for French and Bulgarian compounds; Taft, Liu, and Zhu, 1999, for Chinese compounds; see also review in Stolz and Feldman, 1995), type of morphological operation, such as prefixation vs. suffixation (e.g., Feldman and Soltano, 1999), derivation vs. inflection (e.g., Raveh and Rueckl, 2000), and affixation vs. compounding (Andrews, 1986, represents the classic study of this factor, though it did not use priming paradigms), and for compounds, the position of the relevant morpheme (e.g., Jarema, et al., 1999, for French and Bulgarian; Taft, Liu, and Zhu, 1999, and Zhou, et al., 1999, for Chinese).

This paper will focus on immediate repetition priming in lexical decision tasks with written Chinese compounds varying in transparency, and is particularly concerned with yet another commonly examined parameter in priming studies, namely what Drew (1996) calls the direction of morphological relation, and what we will call priming direction, namely, whether (a) prime and target are both morphologically complex (sharing a

morpheme), or (b) the prime is a morpheme and the target a complex word containing this morpheme, or (c) the reverse of (b) (for lack of a more parsimonious description, we will term these three directions MM-MM, M-MM, and MM-M, respectively). This manipulation was a key factor in Marslen-Wilson, Tyler, Waksler, and Older (1994), with the often-discussed finding that priming was only found between suffixed forms and bases (both directions), not between two suffixed forms sharing a base (but cf. Pastizzo and Feldman, 2002).

One reason to be interested in direction of priming for research on compounds in particular is that the different directions seem, on the face of it, to probe into different stages or aspects of the processing of compounds. If the response latencies for compounds are affected by the prior presentation of morphological components (M-MM priming), this implies that the activation of components can affect the processing of words (though it doesn't require that compounds are *normally* accessed via their components, nor even that the effect necessarily relates to access itself and not some postlexical process). If the response latencies for target components are affected by compound primes (MM-M priming), this would seem to provide a diagnostic of morphological decomposition (though, again, we can't be sure about the timing of decomposition relative to access). Finding that priming effects are the same for both directions would imply that compound processing is essentially morpheme processing: components become active at some early stage and simply remain active. Alternatively, if differences are found in the pattern of priming effects across directions, this could potentially open a window into the time-course of morphological processing. For example, if M-MM priming is stronger than MM-M priming, this would imply that the processing of compounds is affected by component activation but does not involve obligatory decomposition, whereas if the reverse is found, this would imply that compounds are initial accessed without reference to their components, which are only parsed out later (though with important caveats that we spell out below). Any differences involving position or transparency would add important nuances to the picture.

Priming direction has in fact been found to make a difference in the processing of compounds. When a transparent compound is the target, it is typically better primed by its first constituent (a result found for Greek and Polish by Kehayia, et al., 1999, and for Bulgarian by Jarema, et al., 1999, and for Dutch by Sandra, 1990). By contrast, when the compound is used as the prime, priming by the second component may be stronger if it is the head (as found for Dutch by Zwitzerlood, 1994). This pattern implies that the processes probed in M-MM priming operate from left to right, while in the (presumably later) processes probed in MM-M priming, both morphemes have become active.

Curiously, however, it appears that priming direction has never been manipulated as an experimental factor in Chinese. All priming experiments of which we are aware involve primes and targets that are both compounds (MM-MM). Such experiments show component priming effects that are sensitive to both position and transparency: priming is greater when compounds share the first character than when they share the second or when the matching character appears in opposite positions (e.g., Zhou, et al., 1999), and priming is more reliable with semantically transparent compounds, only showing priming with opaque compounds when primes and targets are separated by longer time intervals

(as shown by Liu and Peng, 1997, in an immediate repetition priming paradigm).

While such experiments do imply that components are active at some point in the processing of Chinese compounds, they do not allow us the ability to probe into the time course of processing (nor, by its very nature, does long-term repetition priming, in spite of the useful property that it is less sensitive to mere form and semantic similarity than immediate repetition priming, thus allowing true morphological priming to stand out more unambiguously; see discussions in Zhou and Marslen-Wilson, 1994; Feldman and Prostko, 2002; Raveh and Rueckl, 2000). By contrast, manipulating priming direction in immediate repetition priming paradigms does seem to offer us some ability to probe into the time course, given that in an M-MM condition the response time measure is collected at an earlier point, relative to the onset of the compound display, than in an MM-M condition. In addition, of course, there is the fact that priming direction has been manipulated in languages with alphabetic orthographies, with theoretically interesting results, making it useful to know what happens with the very different orthographic system of Chinese. In particular, a naive model in which compound processing reduces entirely to character processing has a greater prima facie plausibility in Chinese than in a language whose orthography clearly separates words and does not use morphemes as fundamental units, and it would be good to add differences in priming direction effects to the collection of evidence that argues against such a model (see reviews in Taft, Liu, and Zhu, 1999; Myers, 2002).

There are, however, some quite legitimate reasons why the manipulation of priming direction may have been neglected in Chinese up until now, difficulties that we must also understand and attempt to solve in our study. First, theoretical linguistic and corpus-based arguments both support the claim that the typical Chinese word is bimorphemic: a number of phonological and morphological processes conspire to expand or reduce Chinese words into a disyllabic template, which are thus morphologically complex (Chinese morphemes are virtually always monosyllabic) and orthographically composed of two characters (Duanmu, 2000). The result is that about 74% of all word types in running text are two-character compounds (cited from Zhou and Marslen-Wilson, 1994). This may make any experiment that uses both one-character and two-character words somewhat disconcerting to the Chinese word processor: the former may seem atypical, especially in the context of the latter.

Second, a lexical decision made on a compound is not the same as one made on a single character, as is highlighted by the sort of nonlexical foils that are available for each. With MM targets, the nonwords can be either nonlexical combinations of real characters (analogous to *blinkflap* in an English experiment, except with an unambiguous orthographic separation between the clearly morphemic components) or combinations of nonlexical characters (analogous to *blickflass*). By contrast, with M targets, the nonwords can only be nonlexical characters (analogous to *blick* or *flass*). If only the M-MM direction were at issue, it would clearly be preferable to use only noncompounds with real components as foils, since this would force participants to parse the stimuli morphologically before making a decision, but if one wants to compare this direction with MM-M, it is necessary to use noncharacter compounds as well.

Third, the key problem of distinguishing component priming from whole-word

semantic priming and form priming becomes more difficult in M-MM and MM-M paradigms, as opposed to compound-compound priming. In a MM-MM paradigm, it is relatively straightforward to match primes on their degree of semantic relatedness to a target, thus allowing morphological relatedness to be manipulated separately (as was done, for example, in Zhou and Marslen-Wilson, 1995). If, however, one member of a prime-target pair is monomorphemic, it is less clear how the relatedness judgments themselves are being processed, since the morpheme and word levels may be confused in the judges' minds. For example, if one asks judges to rate the semantic similarity of the words *bedroom* and *house*, one would like to be sure that they are comparing the word *house* with the word *bedroom* as a whole, and not just with *bed* or *room*, but it seems impossible to be sure. Lacking solid semantic controls, finding alternative arguments that M-MM or MM-M priming are truly morphological and not merely due to word-level semantics becomes more difficult. The only source of evidence would involve the interaction (or lack thereof) between component priming and semantic transparency of the compound: if priming effects are found with an opaque component, this cannot be due to priming via whole-word semantics. At the same time, however, to distinguish morphological priming from mere form priming, we would have to look for some role of semantics in the overall priming pattern as well.

A final problem closely related to the previous two is that for M-MM priming to occur, the prime character must activate the same abstract morpheme found in the target compound, but ambiguity of the character may make this difficult, whereas in MM-M priming, prior presentation of the character in a compound context may result in only one of its associated morphemes becoming activated. The problem of how to identify morphemes outside of compound contexts is notorious in Chinese (see Packard, 2000, for much discussion). Assuming that the multiple meanings of a character compete with one another rather than simply becoming active in parallel, this would result in stronger MM-M priming than M-MM priming, obscuring any difference due to stage of processing.

To some degree, of course, all of these problems arise for the morphological priming experiments that have been conducted on other languages, and there is no overwhelming reason not to follow their precedent and simply find out what happens in Chinese, with some care taken to face the known challenges. The difference in typicality between monomorphemic words and compounds in Chinese is not something that can be easily modified experimentally, but we have made some attempt to deal with the other problems listed above. Thus we include foil type as an experimental factor (i.e., noncompounds like *blinkflap* vs. noncharacter compounds like *blickflass*) and have manipulated semantic transparency of the compounds, both to investigate the relevance of this widely recognized factor in our paradigm, but also to allow for an alternative route into the question of the source of priming (i.e., morphology vs. word-level semantics or form). Specifically, following works such as Jarema, et al. (1999) and Libben, Gibson, Yoon, and Sandra (2003), our categorization of transparency was morpheme-based rather than word-based to allow us to localize the effect, giving four categories rather than two, similar to the following English examples from Libben, et al. (2003): OO (opaque in both positions, as in *deadline*), OT (transparent only in second position, as in *chopstick*), TO (as in *cardshark*), and TT (as in *bedroom*). Priming involving pairs like *card* and

cardshark may be due to whole-word semantics, but if it is found with pairs like *shark* and *cardshark*, it cannot be. To distinguish morpheme priming from mere form priming, we must also pay attention to interactions with the position of the repeated character. Character position is a form-based property, and so may be expected to be relevant in form priming (even monomorphemic words are presumably read left-to-right). Yet if semantic effects vary depending on character position, this cannot be due to form priming, which should operate independently of semantics. It also cannot be due to word-level semantics (assuming the materials have been selected properly). The simplest explanation would be that morpheme-level semantics is relevant, and that morphemes are processed differently depending on position. Finally, the problem of the ambiguity of characters was addressed (though perhaps not solved) by using only compounds formed of characters representing free words, and pretesting component-compound pairs for their degree of relatedness, the same pretest used to divide compounds into the above four semantic categories.

EXPERIMENT

Method

Materials

The procedure for choosing materials was as follows. We began with the approximately 25,000 two-character nouns in the Academia Sinica Balanced Corpus of Chinese (Chen, Huang, Chang, and Hsu, 1996), and then restricted our attention to the approximately 900 whose log frequencies were within 1 SD of the mean (due to rightward skew of word frequency distributions, this procedure is biased towards the selection of somewhat higher-frequency words). All noun-noun and adjective-noun compounds composed of free morphemes were extracted, and 30 examples each of OO, OT, TO, and TT compounds were selected by two native-speaking assistants. 136 naive native speakers were then asked to judge the semantic relatedness of each component character to the whole compounds in a paper-and-pencil task with four lists (34 judges per list) counterbalancing order of items (random or the reverse of this) and position of the component; judgments were made on a six-point scale, with 6 representing most related. This gave two mean judgment scores for each of the 120 compounds (first-position transparency and second-position transparency). These two scores were then used to calculate the Euclidean distance from a point representing the two median scores, which in turn allowed us to choose the 20 items most representative of the four transparency categories (e.g., items with high first-position scores but low second-position scores were classified as TO).

Each compound was paired with four single character words, coded as follows: char1 (the first character of the compound), char2 (the second character of the compound), semrel (semantically related to the whole compound), and unrel (judged as semantically unrelated to the whole compound by native-speaking assistants). Because the semantically related controls were one-character words, we were unable to use Chinese

synonym dictionaries for selection of materials, which list only the bimorphemic compounds more typical of the Chinese lexicon. Thus these items were generated by ten naive native speakers from the compounds given to them, the most common of whose proposals were then selected and modified by two native-speaking assistants.

The four sets of compounds (OO, OT, TO, TT) were matched for frequency (each around 50 tokens per million). The frequencies of the four characters associated with each compound were also matched (around 400 tokens per million), as were their number of strokes (a measure of visual complexity). ANOVAs found no significant differences in log compound frequency across the four types (F < 1, $p > 0.9$), and for log character frequency, no main effect of position (F < 1, p > 0.6) and no interaction with compound type (F < 1.8, $p > 0.18$). However, there was a significant main effect of compound type on log character frequency ($F(3, 76) = 4.09$, MSE = 0.245, $p = 0.0095$), with a Tukey/Kramer posthoc test showing that TT compounds had significantly lower mean log character frequency (3.466) than OO compounds (3.797) or TO compounds (3.788). A two-way ANOVA (semantic relatedness × position) naturally found a main effect of semantic relatedness on judgment scores ($F(1, 156) = 718.28$, MSE = 0.319, $p < 0.0001$), with transparent components having an average score of 4.5 and opaque ones 2.1, but no main effect of position (F < 0.03, p > 0.8). However, there was a significant interaction between these two factors ($F(1, 156) = 4.24$, MSE = 0.319, $p = 0.041$), with characters in first position showing a greater difference in transparency scores (4.63 vs. 2.05, a difference of 2.58) than characters in second position (4.43 vs. 2.22, a difference of 2.21).

In addition to these 80 lexical compounds, 160 nonlexical compounds were created. 80 of these were noncompound foils, i.e., genuine characters combined in nonlexical ways (judged as clearly impossible by native-speaking assistants). The remaining 80 were noncharacter foils, i.e., two-character compounds composed of nonlexical characters, each created by nonlexical combinations of genuine subcharacter components (e.g., semantic radicals and phonetic components) using Microsoft Paint. No fillers were used.

Participants

96 students at National Chung Cheng University (southern Taiwan) were paid to participate in the experiment. All were native speakers of Mandarin with normal or corrected-to-normal visual acuity.

Design and procedure

The task was a visual-visual immediate priming lexical decision task. Each participant was arbitrarily assigned to one of three conditions (32 participants each): M-MM-noncomp (character primes, compound targets, nonlexical combinations of real characters as foils), M-MM-nonchar (character primes, compound targets, combinations of nonlexical characters as foils), and MM-M-nonchar (compound primes, character targets, nonlexical characters as foils). There were four types of prime-target relationships (abstracted from order): char1, char2, semrel, unrel, as defined above. To prevent participants from seeing any given compound more than once, a Latin square design was

used, necessitating the creation of four separate prime-target lists for each condition, with 8 (=32/4) participants receiving each list. The materials were designed around the compounds, not the characters, which meant that only in the M-MM conditions was there no confound between target and prime-target relationships; in the MM-M condition, target characters were not identical across prime-target relationships.

The experiment was controlled by E-Prime (Version 1.0; Schneider, Eschman, & Zuccolotto, 2002) running in Windows 98 on IBM-compatible personal computers in a sound attenuated room. All stimuli (lexical and nonlexical) were presented as BMP files. In each trial, a fixation point ("+") first appeared in the center of the screen for 300 ms. This was then replaced by the prime word, written as a horizontal (left to right) string of black characters 1.1 cm high on a white background, which was displayed for 200 ms. Finally, the prime was replaced by the target word, also in black but in a different and somewhat larger font (1.4 cm), which was displayed until the participant's response or until the end of the trial (2 sec). Responses were measured by means of keys labeled *zhenci* ("real word") and *feici* ("non-word") on (respectively) the right and left sides of a standard computer keyboard; participants were asked to press these keys as quickly and accurately as possible. If a participant failed to respond within two seconds, no time was recorded and the next trial began. After the practice session with 16 items, the experimental session ran with all items (for that participant's list) presented in random order. The experiment took approximately 10 minutes per participant.
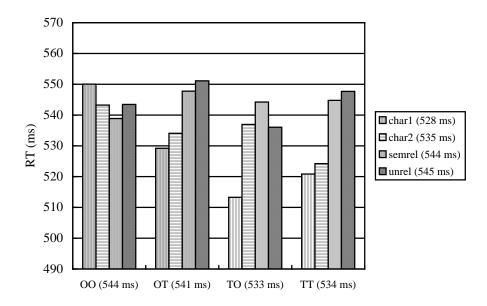
Results

Separate by-participant (F1) and by-item (F2) analyses were conducted on the accuracy rates and reaction times for the real word targets, not modified to take account of the Latin square design. RTs for erroneous responses and RTs more than 2 SDs from each participant's mean were removed prior to analysis.

The M-MM results were analyzed with three-way ANOVAs (Foil Type [noncomp, nonchar] × Character Type [char1, char2, semrel, unrel] × Compound Type [OO, OT, TO, TT]); for F1, Foil Type was a between-group factor and Character Type and Compound Type were within-group factors, while for F2, Foil Type and Character Type were within-group factors and Compound Type was a between-group factor. Responses were faster in the condition with noncharacter foils (noncharacter mean RT was 529 ms, noncompound mean RT was 547 ms; all reported means are from the by-participant analyses), though this was only significant in the by-item analyses ($F1(1, 62) = 0.63$, MSE = 133,998, $p = 0.43$; $F2(1, 76) = 27.18$, MSE = 2,038, $p < 0.0001$). This difference in significance was presumably due to the different treatments of the Foil Type factor (between-group in the by-participant analysis, within-group in the by-item analysis), and was reflected in the much higher standard deviations and standard errors in the condition with noncharacter foils (F1 noncomp: SD = 67.70, SE = 3.00; F2 nonchar: SD = 124.53, SE = 5.50; F2 noncomp: SD = 47.39, SE = 2.65; F1 nonchar SD = 61.97, SE = 3.46). In neither analysis did any other factor interact significantly with Foil Type (Fs < 1.2, ps > 0.3).

The mean RTs for M-MM, averaged across the two foil conditions, are shown in Figure 1. The effect of Character Type was highly significant by participant and

Myers, J., Derwing, B., & Libben, G. (2004). The effect of priming direction on reading Chinese compounds. Mental Lexicon Working Papers, 1, 69-86. University of Alberta, Canada.

marginally so by item (F1(3, 186) = 7.60, MSE = 2,048, $p < 0.0001$; F2(3, 228) = 2.50, MSE = 4,033, $p = 0.06$). A Tukey/Kramer posthoc test on the by-participant ANOVA showed that first character RT was significantly different (lower) from semantically related RT and from unrelated RT, but no other pairs of RTs were different from each other. The effect of Compound Type was also highly significant by participant, but not so by item (F1(3, 186) = 5.01, MSE = 1,416, $p = 0.002$; F2(3, 76) = 1.27, MSE = 3,430, $p = 0.29$). A Tukey/Kramer posthoc test on the by-participant ANOVA showed that OO RT was significantly different (higher) than both TO and TT RTs, but no other pairs of RTs were different from each other. There was also an interaction between Character Type and Compound Type that was highly significant by participant, but not by item (F1(9, 558) = 2.62, MSE = 2,110, $p = 0.006$; F2(9, 228) = 0.785, MSE = 4,033, $p = 0.63$). As Figure 1 makes clear, this interaction primarily involved different RTs for char1 and char2 across the four compound types relative to the two controls (semrel and unrel): no priming with OO targets, priming for both positions with TT, priming only for first position with TO, and priming for both positions with OT, though not quite as great as with TT.

Figure 1. Character type and compound type effects on RT in M-MM (averaged across foil type conditions). Mean RTs are shown for the levels of each factor.
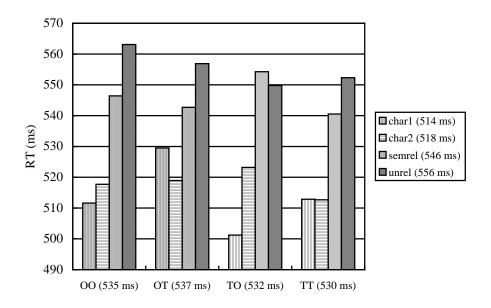

Accuracy rates neared ceiling and so only revealed marginal effects for Character Type (F1(3, 186) = 2.55, MSE = 0.006, $p = 0.06$; F(3, 228) = 2.11, MSE = 0.003, $p = 0.10$); all other main effects and interactions had Fs < 1.6, ps > 0.19. Means averaged across foil types are given in Table 1.

Myers, J., Derwing, B., & Libben, G. (2004). The effect of priming direction on reading Chinese compounds. <u>Mental Lexicon Working Papers, 1</u>, 69-86. University of Alberta, Canada.

Table 1. Accuracy rates in M-MM.

	OO	OT	TO	TT	Means
char1	0.981	0.978	0.984	0.959	0.976
char2	0.988	0.978	0.981	0.988	0.984
semrel	0.978	0.978	0.981	0.988	0.981
unrel	0.975	0.959	0.981	0.963	0.97
Means	0.98	0.973	0.982	0.974	

The MM-M results for RT and accurate rates were analyzed with two-way ANOVAs (Character Type × Compound Type) for F1 only (since target characters were not the same across the four prime-target relationships), with both factors as within-group factors. The RT results are shown in Figure 2. The only significant result for RT was a main effect of Character Type ($F1(3, 93) = 24.35$, MSE = 2,214, $p < 0.0001$); a Tukey/Kramer posthoc test showed that both char1 and char2 RTs were significantly different (lower) than both controls (semrel and unrel), with no other significant comparisons. There was no significant effect of Compound Type and no interaction ($Fs < 1.2$, $ps > 0.3$).

Figure 2. Character type and compound type effects on RT in MM-M. Mean RTs are shown for the levels of each factor.

However, accuracy rates for MM-M, given in Table 2, did show significant main effects for both Character Type ($F1(3, 93) = 2.94$, MSE = 0.004, $p = 0.04$) and Compound Type ($F1(3, 93) = 3.79$, MSE = 0.003, $p = 0.013$), though there still was no interaction; Tukey/Kramer posthoc tests showed that the char2 accuracy rate was significantly

Myers, J., Derwing, B., & Libben, G. (2004). The effect of priming direction on reading Chinese compounds. Mental Lexicon Working Papers, 1, 69-86. University of Alberta, Canada.

different (higher) than unrel, and that the OT accuracy rate was significantly different (lower) than TT.

Table 2. Accuracy rates in MM-M.

	OO	OT	TO	TT	Means
char1	0.988	0.975	0.975	0.994	0.983
char2	0.994	0.969	0.988	0.994	0.986
semrel	0.981	1	0.969	0.981	0.983
unrel	0.975	0.938	0.963	0.988	0.966
Means	0.984	0.97	0.973	0.989	

In order to examine the effect of priming direction more fairly (the M-MM condition had twice as many participants as the MM-M condition), we also conducted three-way ANOVAs on just M-MM-nonchar and MM-M-nonchar (Direction [M-MM, MM-M] × Character Type × Compound Type); only by-participant analyses were done (targets were not the same for the different priming directions), in which Direction was a between-group factor and Character Type and Compound Type were within-group factors. There was no main effect of Direction for either RT (M-MM 529 ms, MM-M 533 ms) or accuracy rate (both 0.979) (Fs < 0.04, ps > 0.8). The main effect of Character Type on RT seen in the previous two sets of analyses remained (F1(3, 186) = 18.17, MSE = 2,365, p < 0.0001). Tukey/Kramer posthoc tests showed that, as in the MM-M analysis, char1 and char2 RTs were each significantly different (lower) than each of the controls (semrel, unrel). The main effect of Compound Type did not quite reach significance (F1(3, 186) = 2.16, MSE = 1,822, p = 0.09), though as in the M-MM condition, OO was slowest (535 ms) and TT the fastest (528 ms). The interaction between Character Type and Compound Type also failed to reach significance (F1(9, 558) = 1.50, MSE = 2,138, p = 0.14). Even though the previous analyses had found an effect of Compound Type in M-MM but not MM-M, there was no significant interaction between Direction and Compound Type (F < 0.6, p > 0.6), as can also be seen in Figure 3. However, the nature of the Character Type effect did vary by direction of priming, as shown by the significant interaction between these two factors (F1(3, 186) = 7.41, MSE = 2,365, p = 0.0001). As can be seen in Figure 4, this interaction primarily reflected the much greater degree of character priming in the MM-M condition, but also, perhaps, the fact that a character position effect appears in M-MM but not in MM-M.

Figure 3. Compound type and direction of priming effects on RT. Mean RTs are shown for the levels of each factor.
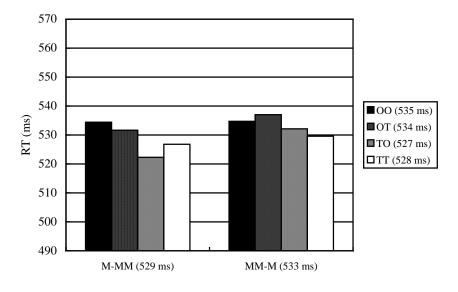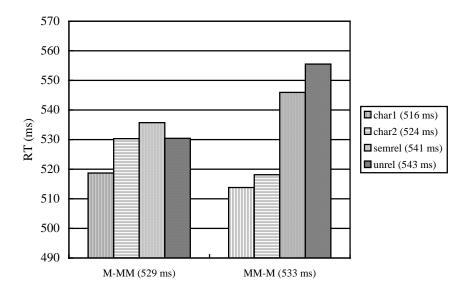

Figure 4. Character type and direction of priming effects on RT. Mean RTs are shown for the levels of each factor.

The analysis of accuracy rate only revealed one significant effect, that of the main effect of Character Type ($F1(3, 186) = 2.91$, MSE = 0.004, $p = 0.035$), with a Tukey/Kramer posthoc test showing that only the accuracy rates for char2 and unrel were significantly different from each other (see Table 3).

Table 3. Accuracy rates averaged across M-MM-nonchar and MM-M.

	OO	OT	TO	TT	Means
char1	0.984	0.969	0.981	0.978	0.978
char2	0.994	0.981	0.984	0.988	0.987
semrel	0.975	0.988	0.972	0.988	0.98
unrel	0.981	0.956	0.972	0.975	0.971
Means	0.984	0.973	0.977	0.982	

DISCUSSION

Because of the complexity of the results, we begin by summarizing the effects of characters and compounds and their interactions separately for each priming direction, before we address the question of what, if anything, the manipulation of priming direction has revealed about compound processing in Chinese.

The first observation that must be dealt with is that, for both M-MM and MM-M priming, no pure semantic priming was demonstrated: the two control types of semantically related and semantically unrelated characters never differed from each other in any analysis. The simplest interpretation of this state of affairs is that the semantically related characters were poorly selected, and did not in fact relate sufficiently strongly with their associated compounds. This null hypothesis cannot be ruled out at present, since we have not yet collected semantic relatedness scores on these items due to a concern over how best to accomplish this. Given the bimorphemic bias in Chinese, it was already hard enough for pilot participants to come up with free one-character words that seemed related to the whole-word meaning of two-character compounds. The collection of semantic judgments may also be influenced by morphological relationship, which is hardly invisible even to naive judges (see the end of the introduction for a similar point). Thus the process involved in rating the relationships of compound-character pairs may greatly depend on whether there is any morphological overlap in the stimulus items: rating only morphologically unrelated pairs would likely involve quite a different scale from rating only morphologically related pairs (which is what we did for calculating semantic transparency). In any event, we have evidence that the semantically related controls we chose were less than ideal, since many involved associative rather than truly semantic relationships (e.g., *huoche* "train" was linked with *kuai* "fast"), and all were selected to match given compounds, rather than the other way around (though these putatively semantically related items did not prime in the MM-M condition either). However, even if the semantically related items were close semantic matches with their morphological counterparts, priming would not have been a necessary consequence. In spite of the robustness of the semantic priming effect, it can be weak or absent on occasion, even in immediate repetition priming paradigms (e.g., Feldman, 2000, found morphological priming but no semantic priming with short primes durations, though admittedly these were over 100 ms shorter than ours). Erring on the side of caution, however, in the remainder of this section we treat both controls together.

Beginning now with M-MM priming, the most notable observation is that the character effect, while robust, was restricted to the first position: matching the character prime with the second character of the target did not affect responses relative to the controls. This result parallels what has been found in a variety of other languages, as noted in the introduction (e.g., Kehayia, et al., 1999, for evidence from Greek and Polish; Jarema, et al., 1999, for Bulgarian; Sandra, 1990, for Dutch), and suggests that a left-to-right process is involved.

The main effect of compound semantics, in which TT compounds were responded to more quickly than OO compounds, is also a common finding, though it is not consistent across studies. For example, Jarema, et al. (1999) found that French TT compounds were responded to more quickly than OO compounds, while Bulgarian TT compounds showed longer response latencies than OO compounds. In Chinese, some have found that semantically transparent compounds are responded to more slowly (and less accurately) than semantically idiosyncratic or opaque compounds (including Su, 1998; Liang, 1992; Lee, 1995), while others have found the reverse pattern (C.-H. Tsai, 1994; Lü, 1996) or no difference (S.-T. Chen, 1993). In fact, in a pilot version of this experiment using the same materials and the same number of participants but displaying the target compounds for only 400 ms instead of 2000 ms (following the procedure used in the immediate repetition priming experiments in Zhou, et al., 1999), the magnitude of the compound effect was the same as in the present version (around a 10 ms difference between TT and OO RT), but greater cross-participant variability greatly reduced its significance. Given our careful semantic controls and semantic pretesting, however, we believe that our positive effect on RT is truly related to ease of processing due to semantic transparency.

Crucially, the nature of the semantic effect also highlights the importance of the first component in M-MM priming: fully opaque OO compounds were responded to more slowly than TO and TT compounds, but the posthoc analyses did not find a significant difference between OO and OT compounds. The positive effect of transparency on response times is thus localized to the first component, not to the second component or to the compound as a whole. Due to the localization of the semantic effect, the priming cannot simply be dismissed as whole-word semantic priming (especially since, as nouns, the second component is often the head and may thus be expected to be more semantically similar to the meaning of the whole word than the first component). At the same time, moreover, the fact that semantics plays a key role here implies that the priming cannot be purely form-based either, suggesting that our priming effects did involve morphological priming.

This claim is strengthened by an examination of the significant interaction between the character and compound factors. From Fig. 1, it appears that character position only matters in TO compounds, with first position characters priming and second position characters not (posthocs unfortunately cannot legitimately be performed here to test this impression); in OO compounds neither character primes, in TT compounds both characters prime, and in OT compounds it seems that both prime as well, but to a lesser extent. This pattern cannot be interpreted as word-level semantic priming, since we would then have found that only second position characters prime OT compounds. The precise way in which this behavior of OT compounds should be interpreted, however, is not fully

obvious. Taking the approximately 20 ms advantage for components over controls in OT compounds as a genuine effect, along with the lack of any priming in OO compounds, we are led to the curious inference that the effect of the prior presentation of an opaque first component can be modified by the transparency of the second component: its mere presence in the compound can speed up response times even when it is not itself primed. While supporting the claim that our results demonstrate true morphological priming, then, we must also conclude that the process by which the prime affects decision latencies involves more than merely speeding up initial access of the compound in memory.

The final aspect of the M-MM analysis that we must discuss briefly is the effect of foil type. As one might have expected, using noncompound foils composed of real characters made the task harder (resulting in slower response times) than noncharacter foils composed of fake characters. Importantly, however, there was no interaction between foil type and the morphologically relevant factors of character and compound type. This suggests that it is legitimate to use noncharacter foils in morphological experiments, since use of such foils appears not to trigger a dramatically different sort of processing (e.g., a greater focus on form with noncharacter foils). Moreover, the foil type effect only appeared in the by-item analyses, apparently since the manipulation of foil type had inconsistent effects across participants.

Turning now to the MM-M results, we again found quite a robust character priming effect, but this time, character position made no overall difference. This is roughly comparable to studies in other languages that failed to find a first-position bias in MM-M priming (e.g., in Dutch by Zwitzerlood, 1994). Moreover, there was no main effect of compound type on reaction time, though OT compound primes resulted in a significantly greater number of errors than TT primes. There was also no significant interaction between character and compound types in either RT or accuracy, though examination of Fig. 2 suggests a trend in which the first component of TO compounds was primed more than the second component (with possibly the reverse trend for OT compounds). The lack of a clear effect of compound type is not overly surprising, given the difficulty of establishing it even in the M-MM condition, with twice as many participants. At first the presence of a strong character effect may not seem surprising either, given that the targets in this condition were characters, but one must recall that this effect was already quite robust in the M-MM condition, where the isolated characters were merely primes. Hence the major observations that come out of the analysis of the MM-M condition is that component priming remains, and that it is relatively insensitive to semantics or to position.

If correct, this pattern is clearly different from what was observed in the M-MM condition. The analyses explicitly comparing direction of priming provide further information regarding such differences (controlling for foil type and number of participants, i.e., using only the M-MM results that involved noncharacter foils). Most fundamental was the interesting finding (replicating what we had also found in the pilot) that overall reaction times were not affected by priming direction: mean response times to character targets and compound targets were not significantly different. Nevertheless, the interactions with priming direction showed that the character effect was significantly stronger in the MM-M condition than in the M-MM condition, while the compound effect

was not significantly affected by direction of priming (no obvious pattern stands out in Fig. 3). The latter observation implies that the stronger character effect in MM-M was not due solely to this task's requiring attention to be focused on character targets rather than compounds, since otherwise the compound effect would have been significantly stronger in the M-MM condition when the number of participants was matched. Moreover, examination of Fig. 4 suggests that character position was only relevant in the M-MM condition.

Although, as we pointed out in the introduction, it is not necessary to interpret the direction of priming effect as relating to stages rather than merely aspects of processing, the stage interpretation is nevertheless consistent with the fact that responses in the M-MM condition occurred around 530 ms after presentation of the compound, while in the MM-M condition, responses occurred around 730 ms after presentation of the compound (i.e., 530 ms + 200 ms, the duration of the compound prime). Taken together, then, these results are consistent with a compound processing model which begins with the first morpheme (form/meaning pairing) acting as the key into the lexical entry, and which eventually leads to the compound's being decomposed, making all components of the compound available regardless of their contribution to the compound's word-level semantics. This is precisely the behavior that would be expected of the model developed in Libben (1994, 1998) and Libben, et al. (2003), in which a morphological parser searches for morphemes in an input string in a left-to-right fashion, and which sees semantic transparency as the degree to which the lexical entry for a compound is linked to the lexical entries for its components. Hence if this left-to-right parser hits upon a character-sized word that happens to be linked to the compound that must be decided upon (i.e., a TO or TT compound), processing will proceed more smoothly than if the first character is not semantically linked to the compound as a whole. Yet after this process has found the compound in the lexicon, its components do not remain invisible, perhaps particularly in a language like Chinese, where these components are orthographically so salient.

ACKNOWLEDGEMENTS

REFERENCES

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

Chen, S.-T. (1993). *Hanyu gouci zai yuedu licheng zhong dui yuyi chufa xiaogai de yingxiang* [The influence of semantic activation effects on Chinese morphology during reading]. Unpublished master's thesis, National Chung Cheng University, Chia-Yi, Taiwan.

Myers, J., Derwing, B., & Libben, G. (2004). The effect of priming direction on reading Chinese compounds. <u>Mental Lexicon Working Papers, 1</u>, 69-86. University of Alberta, Canada.

Chen, K.-J., Huang, C.-R., Chang, L,-P, & Hsu, H.-L. (1996). SINICA CORPUS: design methodology for balanced corpora. *Language, Information and Computation, 11*, 167-176.

Drews, E. (1996). Morphological priming. *Language and Cognitive Processes, 11* (6), 629-634.

Duanmu, S., (2000). *The phonology of Standard Chinese*. Oxford: Oxford University Press.

Feldman, L. B. (2002). Graded aspects of morphological processing: Task and processing time. *Brain and Language, 81*, 12-27.

Feldman, L. B. (2003). What the repetition priming methodology reveals about morphological aspects of word recognition. In J. S. Bowers & C. J. Marsolek (Eds.), *Rethinking implicit memory* (pp. 124-138). Oxford: Oxford University Press.

Feldman, L. B., & Soltano, E. G. (1999). Morphological priming: The role of prime duration, semantic transparency, and affix position. *Brain and Language, 68*, 33-39.

Jarema, G., Busson, C., Nikolova, R., Tsapkini, K., & Libben, G. (1999). Processing compounds: A cross-linguistic study. *Brain & Language, 68*, 362-369.

Kehayia, E., Jarema, G., Tsapkini, K., Perlak, D., Ralli, A., & Kadzielawa, D. (1999). The role of morphological structure in the processing of compounds: the interface between linguistics and psycholinguistics.   *Brain and Language, 68*, 370-377.

Lee, C.-Y. (1995). *Hanyu zuheci yu chengyuci zai xinli cidian zhong de biaozheng fangshi* [The representation of compounds and idioms in the Chinese mental lexicon]. Unpublished master's thesis, National Chung Cheng University, Chia-Yi, Taiwan.

Liang, M. Y. (1992). *Recognition processing in reading compositional and idiomatic words.* Unpublished master's thesis, National Tsinghua University, Hsinchu, Taiwan.

Libben, G. (1994). How is morphological decomposition achieved? *Language and Cognitive Processes, 9*, 369-391.

Libben, G. (1998). Semantic transparency in the processing of compounds: Consequences for representation, processing, and impairment. *Brain and Language, 61*, 30-44.

Libben, G., Gibson, M., Yoon, Y. B., & Sandra, D. (2003). Compound fracture: The role of semantic transparency and morphological headedness. *Brain and Language, 84*, 50-64.

Liu, Y., & Peng, D.-L. (1997). Meaning access of Chinese compounds and its time course. In H.-C. Chen (Ed.), *Cognitive processing of Chinese and related Asian languages* (pp. 219-232). Hong Kong: The Chinese University Press.

Lü, C.-C. (1996). *Zhongwen yuci renzhi licheng* [Chinese word recognition]. Unpublished doctoral thesis, National Tsinghua University, Hsinchu, Taiwan.

Marslen-Wilson, W., Tyler, L., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review, 101*, 3-33.

Myers, J. (2002). Processing Chinese morphology: A survey of the literature. Unpublished ms., National Chung Cheng University.

Packard, J. L. (2000). *The morphology of Chinese: A linguistic and cognitive approach.* Cambridge: Cambridge University Press.

Pastizzo, M. J., & Feldman, L. B. (2002). Does prime modality influence morphological

Myers, J., Derwing, B., & Libben, G. (2004). The effect of priming direction on reading Chinese compounds. <u>Mental Lexicon Working Papers, 1</u>, 69-86. University of Alberta, Canada.

processing? *Brain and Language, 81*, 28-41.

Raveh, M., & Rueckl, J. G. (2000). Equivalent effects of inflected and derived primes: Long-term morphological priming in fragment completion and lexical decision. *Journal of Memory and Language, 42*, 103-119.

Sandra, D. (1990). On the representation and processing of compound words: automatic access to constituent morphemes does not occur. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 42*, (3-A), 529-567.

Stolz, J. A., & Feldman, L. B. (1995). The role of orthographic and semantic transparency of the base morpheme in morphological processing. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 109-154). Hillsdale, NJ: Lawrence Erlbaum.

Su, Y.-C. (1998). The representation of compounds and phrases in the mental lexicon: evidence from Chinese. *University of Maryland Working Papers in Linguistics, 6*, 179-199.

Taft, M., Liu, Y., & Zhu, X. (1999). Morphemic processing in reading Chinese. In J. Wang, A. W. Inhoff, & H.-C.Chen (Eds.), *Reading Chinese script: A cognitive analysis* (pp. 91-113). Mahwah, NJ: Lawrence Erlbaum Associates.

Tsai, C.-H. (1994). *Effects of semantic transparency on the recognition of Chinese two-character words: Evidence for a dual-process model*. Unpublished master's thesis, National Chung Cheng University, Chia-Yi, Taiwan.

Zhou, X., & Marslen-Wilson, W. (1994). Words, morphemes, and syllables in the Chinese Mental lexicon. *Language and Cognitive Processes, 9* (3), 393-422.

Zhou, X., & Marslen-Wilson, W. (1995). Morphological structure in the Chinese mental lexicon. *Language and Cognitive Processes, 10* (6), 545-600.

Zhou, X., Marslen-Wilson, W., Taft, M., & Shu, H. (1999). Morphology, orthography, and phonology in reading Chinese compound words. *Language and Cognitive Processes, 14* (5/6), 525-565.

Zwitserlood, P. (1994). The role of semantic transparency in the processing and representation of Dutch compounds. *Language and Cognitive Processes, 9* (3), 341-368.