MORPHOLOGICAL PROCESSING OF CHINESE COMPOUNDS:

The time course of semantic transparency effect

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DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

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TABLE OF CONTENTS

LISTS OF TABLES & FIGURES

ABBREVIATIONS

ANOVA	analysis of variance
L2	second language
OO	fully opaque compounds
SOA	stimulus onset asynchrony
TO/OT	partially opaque compounds
TT1	fully transparent compounds paired with fully opaque compounds
TT2	fully transparent compounds paired with partially opaque compounds

SUMMARY

Using masked priming and short-term priming paradigms, this research investigated the effect of semantic factors in Chinese compound processing. We have three types of primes: 1) morphologically related and semantically transparent, 2) morphologically related but semantically opaque, and 3) morphologically unrelated (i.e. baseline). For related primes, we paired each fully transparent compound prime (abbreviated as TT1) (e.g., *lao ren* old man, lit. 'old + man') with a truly opaque compound prime (OO) (e.g., *lao ban* boss, lit. 'old + board') that shares one morpheme with the transparent prime. And the target is the English translation of the shared morpheme (e.g., *lao* in this case). Apart from comparing the semantic transparency effects between fully transparent and fully opaque primes, we also contrasted this effect between fully transparent and partially opaque primes. Similarly, each fully transparent compound prime (TT2) (e.g., *you tian* oilfield, lit. 'oil+ field') was paired with a partially opaque prime (TO/OT) (e.g., *you cai* a type of vegetable, lit. 'oil + vegetable') which shares a common morpheme with the transparent compound. And the target is the English translation of the shared morpheme (e.g., *oil* in this case).

In the comparison between TT and OO compounds, progressive impact of semantic transparency on morphological processing while the prime exposure duration increased is observed in this study. To be more specific, the facilitation data under each priming condition showed that semantically transparent primes significantly boosted their targets' identification across all the three SOAs. Opaque primes however started to show robust priming effects only at the SOA of 150ms and marginally significant priming effects at the SOA of 250ms. At an SOA of 50ms, the difference between transparent and fully opaque effects was smallest. When SOAs were increased to longer scales (150ms and 250ms), transparent facilitation effects showed a trend to be stronger than effects for opaque primes, although only marginally significant by item analysis. We documented a U shape pattern of semantic transparency effects between completely transparent and partially opaque compounds. Namely, at a brief SOA of 50ms, transparent compounds revealed robust constituent priming effects and partially opaque compounds demonstrated marginally significant facilitation effects. Magnitudes of priming effects after these two types of compounds did not differ from each other. At the SOA of 150ms, the magnitude of facilitation for transparent primes was robust whereas priming effects under the partially opaque condition were absent. Facilitation differences between transparent and partially opaque compounds were significant. When the SOA was of 250ms, both transparent and partially opaque compounds significantly reduced target decision latencies and the effect of semantic transparency was not reliable.

Taken together, the results suggest that semantic transparency modulate the magnitude of morphological segmentation in reading Chinese compounds. More critically, this influence is time-constrained. The results were interpreted within both the traditional and the connectionist approach to morphological processing. It seems that for results we observed, the connectionist approach provides better accounts according to which morphological processing results from the interactive activation of form and meaning of the morpheme and intercorrelations of morpheme and whole words.

CHAPTER ONE: INTRODUCTION

The role of morphological structure in the human language processing system has become an important topic in psycholinguistic research. One goal in morphological processing is to determine how morphemes are stored in the mental lexicon and how morphological information is computed in lexical processing. One important source of evidence comes from studies employing the priming paradigm. Using this paradigm, studies in a variety of languages have shown that processing of a target word (e.g., *hunt*) is facilitated by the prior presentation of a morphologically related word (e.g., *hunter*) relative to an unrelated word (e.g., *clever*) (e.g., English: Marslen-Wilson, Tyler, Waksler, & Older, 1994; Hebrew: Frost, Foster, & Deustch, 1997; Dutch: Zwiserlood, 1994). Morphological facilitation as a result of a shared morpheme was not restricted to the visual presentation condition. For example, these facilitation effects were obtained when the prime or target is presented auditorily (e.g., Marslen-Wilson & Tyler, 1997) or when primes are auditorily presented and targets are visually presented (e.g., Marslen-Wilson et al., 1994). The results of the above morphological priming experiments suggest that morphological representations (shared by primes and targets) are activated in the process of visual word recognition.

Because morphological relatives are formed from a common base morpheme (e.g., *reappear* and *disappear* are morphological relatives that share the same base stem *appear*) morphological relatedness is naturally bound with meaning and form similarity to some extent (Raveh, 1999). Therefore, recent studies have taken a more nuanced approach, contrasting effects of shared morphology with effects of pure form or meaning similarity in the absence of morphological relatedness. In a seminal study, Rastle, Davis, Marslen-Wilson and Tyler (2000) compared semantic, orthographic, and morphological priming in a masked priming procedure. They used masked primes with three prime exposure durations: 43, 72 and 250ms. They found significant priming effects for morphologically related prime-target pairs that are also semantically related (e.g., *hunter-hunt*). And these facilitation effects are as strong as repetition priming effects at all stimulus onset asynchronies (SOAs). Moreover, these morphological effects were greater than those found for purely semantically related (e.g., *cello-violin*) or purely orthographically related (e.g., *electrode-elect*), suggesting that morphological priming effects cannot be attributed to pure formal or semantic similarity.

The morphological effects provide strong evidence for morphology as an important level of analysis of linguistic structure and psycholinguistic behavior.

Although current models generally consent to the critical role morphemes play in the mental lexicon, they differ as to the locus of the morphological effects. There are three major models explaining the representational structures that underlie morphological effects on word recognition. Taft and Forster (1985) postulated ‘sublexical’ models of morphological processing, in which they assume that morphological information is explicitly represented in the mental lexicon, represented at the sublexical form level. When a polymorphemic word is recognized, it is first of all decomposed into its constituent morphemes, which then act as the basis to the meaning activation of this whole word. Because these models advocate that morphological effects on lexical processing are results of orthographic decomposition of morphologically complex words, they are also characterized as 'pure form' accounts of morphological processing (Rastle & Davis, 2003).

Dual-route models of morphological processing (e.g., Caramazza, Laudanna, & Romani, 1988; Schreuder & Baayen, 1995) argue that both morphemes and whole word forms are explicitly stored in the long-term memory. In terms of processing, there exist two distinct mechanisms for the identification of polymorphemic words: the parsing route (morphological decomposition) and the direct route (whole word retrieval). Various properties of words may influence in which route a complex word is processed. For example, when a complex word is of low frequency (Caramazza et al., 1988) or a novel word (Schreuder & Baayen, 1995), the word is recognized by being parsed into its constituent morphemes.

These abovementioned two models, 'sublexical' and 'dual-mechanism', share a core principle of the traditional approach to morphological processing, i.e., an independent level of morphological representation is located somewhere in the lexicon, and in real time processing morphological decomposition takes the form of an all-or-none phenomenon.

An alternative approach to morphological processing is proposed in recent parallel-distributed processing (PDP) theories (Plaut & Gonnerman, 2000; Ruckel, Mikolinski, Raveh, Miner, & Mars, 1997; Raveh, 1999). According to this approach, word recognition involves the establishment of stable activation states (attractors) over distributed processing units that represent orthographic (spelling), phonological, and semantic properties of a word. The recognition network captures the degree of similarity in the mappings among these processing units and the time for activation states to stabilize. Similarly, in a morphological complex word, although morphological regularities are not explicitly represented, they constituent fundamental parts in the internal structure of polymorphemic words, registering the consistency in mapping between the surface forms of words and their meanings. When a particular surface pattern occurs in many words and maps consistently to certain aspects of meaning, the internal representations will register this regular mapping and weigh the connection strength among the form and meaning units (e.g., let us assume a language that only has six words: *appear*, *reappear*, *disappear*, *casual*, *casualness*, and *casualty*. The surface pattern *appear* occurs in all the three words *appear*, *reappear* and *disappear* and connects systematically to the sense *to show up.* Similarly, the form *casual* appears in all these words *casually, casualness,* and *casualty.* However out 2 of these 3 words, the form *casual* maps to the same meaning *informal.* Therefore, the network system will register a stronger connection strength between the form and meaning units of *appear* relative to that of *casual*). In this way, morphemes are implicitly represented in the internal structures of polymorphemic words. Accordingly, this approach to morphology makes the contradictory argument to traditional models. The degree of systematicity in the mapping between form and meaning of morphological relatives varies along a continuum and thus the magnitudes of behavioral effects that reflect morphological processing should show graded differences (Plaut & Gonnerman, 2000).

Previous research on semantic transparency

Morphologically related words naturally overlap in word meaning and according to different degrees. For instance, the meaning of a semantically transparent word (e.g., *hunter*) is typically obtained by the semantic combination of its constituent morphemes. However, if we simply compute the meaning of other words (e.g., *casualty*) in the same way as we do with transparent words, it would be misleading because for these words, meanings of the whole are diverged from the semantic computation of its morphemes. We name these words as opaque words. As a consequence, the extent to which the meaning of the whole word can be composed from that of its morphological constituents is defined as semantic transparency.

The issue about the impact of semantic transparency in morphological processing is crucial in that it may determine to what extent morphological complex words undergo decomposition and further determine the locus of morphological representations within the lexicon (Libben, 1998). Using priming paradigm, many studies have been conducted to contrast facilitation effects for transparent and opaque words. All these studies used a morphological complex word as the prime (e.g., *conditional*) and its base morpheme as the target (e.g., *condition*). Researchers also varied the semantic relation between the prime and the target so that in the transparent condition the prime is a semantic relative to the target (e.g., *conditional-condition*) whereas in the opaque condition the prime is not semantically related to the target (e.g., *casualty-casual*). Among the initial investigators, Marslen-Wilson et al. (1994) employed auditory-visual cross-modal priming experiments to probed semantic transparency effects in English morphology. They found that a semantically transparent and morphologically complex word like *government* primes its base *govern*, while a semantically opaque word like *apartment* does not prime its etymological base *apart*. Based on this finding, Marslen-Wilson came to the hypothesis that semantic transparency is a factor determining whether or not there is morphological segmentation. Specifically, semantically transparent words are identified via morphological decomposition while opaque items are processed as a whole. When the transparent prime word is parsed, priming arises as a result of the fact that the same access representation (i.e., the base morpheme) is employed in the recognition of both the transparent prime and the base-form target. In contrast, opaque words do not produce facilitation because they are accessed as a whole and thus no shared access representation exists between primes and targets.

Frost, Forster and Deutsch (1997) however questioned the role of semantic transparency in morphological processing reported in Marslen-Wilson and others' study. Using a masked priming technique they found that the role of semantic transparency was not crucial in Hebrew. Both opaque and transparent morphological relatives in Hebrew reduced target decision latencies. Accordingly, Deutsch, Frost and Forster (1998) proposed a model in Hebrew morphology arguing that morphological complex words sharing a same morpheme are clustered via the representation of the same root and "this organization is independent of semantic factors"(p.1250).

The two different results in these two experiments could be due to the fact that they used two different experimental designs. Recall that Marslen-Wilson et al. (1994) used a cross-modal priming paradigm, in which primes are processed auditorily and perceived consciously. In contrast, Frost et al. (1997) employed the masked priming paradigm which does not permit subjects consciously perceive the prime. Feldman, Soltano, Pastizzo, & Francis (2004) summarized the experimental literature that contrasts the priming effects of transparent and opaque words and found that semantic transparency effects are more evident under short-term priming conditions but in the masked priming or long-term priming techniques, opaque and transparent relatives did not differ from each other in terms of the effect size. Based on this review, they argued that experimental contexts are not all sensitive to semantics (see also Raveh, 1999 for a similar view). Namely, semantic transparency effects in morphological facilitation are evident under the conditions in which semantic priming is typically revealed as well. In those contexts where semantic priming effects are not usually evident, researchers also failed to find to an effect of degree of semantic transparency among morphological relatives. To address the issue of variation in patterns of facilitation over experimental tasks, Feldman et al. (2004) used different experimental tasks (i.e., short-term priming with SOAs of 250ms and 48ms and forward masked priming) to systematically investigate the contribution of semantic transparency to morphological processing. Within each experiment, there were three types of semantic relationship (opaque, transparent and unrelated) and a shared target was primed by each dimension. They found that the difference in target (e.g., *casualness*) decision latencies following semantically transparent (e.g., *casually*) and semantically opaque (e.g., *casualty*) morphological relatives were modulated by SOAs. Specifically, at the SOA of 250ms, targets that followed transparent and opaque primes differed significantly (40ms) be it in cross-modal or purely visual presentation condition. However when the SOA is reduced to 48ms, such robust differences disappeared. These findings were consistent with another study by Feldman (2000) in which she contrasted morphological effects with effects of either semantic or orthographic similarity. In one experiment, she found that divergence between morphological and orthographic target decision increased as processing time for the prime increased. Specifically, differences between morphological effects and orthographic effects were largest at the long SOA (300ms) and smallest at the brief SOA (66ms). Given all morphological and orthographic primes were matched for similarity to the target, their differentiation is originated from different degree of semantic relatedness between the prime word and the target and therefore the divergence is consistent with the claim that the influence of semantic similarity on decision latencies to the target increases as a function of processing time for the prime (see also Feldman & Prostko, 2002). Taken together, the above results indicate that semantic effects are temporally constrained (Feldman, 2000). When processing time for the prime is limited (i.e., masked priming at the SOA of 50ms), effects of semantic similarity are generally absent, however under those conditions in which morphological and semantic effects are evident, the magnitude of morphological facilitation is sensitive to the degree of semantic similarity.

To sum up, these studies reviewed above showed semantic transparency effects are dependent on the amount of time that a prime is presented to a participant in morphological priming tasks. Therefore, any workable models on morphological processing must accommodate this time-varying pattern of semantic transparency effects.

Alternative explanation for why the role of semantic transparency in the study of Marslen-Wilson et al. (1994) and Frost et al. (1997) was observed to be different is that these two experiments used two different languages.

Indeed, subsequent studies done by Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson (2000) used the same experimental paradigm as Marslen-Wilson et al. (1994), cross-modal priming, and they found significant priming effects for morphologically related prime-target pairs regardless of whether the semantic relationships were transparent or opaque. However, transparent words demonstrated larger effect sizes of facilitation relative to opaque words. Frost et al. (2000) further argued that the reason why morphological priming effects were found under semantically opaque condition is that Hebrew morphological decomposition and analysis are compulsory in the Hebrew language processing and this rich morphological environment gave rise to strong priming effects for opaque primes.

To summarize, there are still some inconsistencies in the empirical data concerning the relative strength of facilitation for transparent and opaque morphological words and the different time courses of these priming effects. But one thing ascertained is that both linguistic and experimental differences should be considered when we probe the question how the degree of semantic transparency modulates morphological processing.

Models and semantic transparency studies in reading Chinese compounds

In Chinese, a character virtually always represents one syllable and also almost always one morpheme (Packard, 2000). According to the Lexicon of common words in contemporary Chinese (Han, 2009), which includes 56,008 words, 6% are one-character words, 72% are two-character words, 12% are three-character words, and 10% are four character words. Despite of the fact that most Chinese words are two morphologic compounds, the distinction between morpheme and words is in fact blurry in Chinese (Pinker, 2000).

Huang (1984) provided a most cited example *danxin* (worry, lit. ‘carry + heart’) (as cited in Myers 2010). It sometimes act as a word in sentences, like *ta hen dan xin ni* (he much worries about you). However, some syntactic operations slip it up and thus each morpheme in the compound ends up as a word. For instance, *ta dan le ni wu nian de xin* (he has been worried about you for 5 years).

Although Chinese morphemes are more often used within two character compounds than by themselves, Chinese permits two-character words slip up into two morphemes, each of which can be reused in another compound. In this sense, most Chinese morphemes develop to obtain meanings even if they are binding morphemes. Take the bound morpheme *hao* as an example. It cannot be used alone. However, it can combine with the free morpheme *da* (lit. big) to build up the compound *haoda* (broad and wide, lit. ‘broad + big’). In other cases, it can combine with another bound morpheme *han* and they together construe the compound *haohan* (vast, lit. ‘broad + wide’). As such, even the bound morpheme *hao* develops a sense over time indicating breadth (Taft & Zhu, 1997). Indeed, Packard (2000) reasoned that it may be a confusion which morpheme can stand alone as a word (i.e., a free morpheme), and which cannot (i.e., a bound morpheme). Productive process occurs also in situations where a compound is truncated to one morpheme and then recombines with others. Take the compound *jichang* (airport, lit. ‘machine + area’) as an example. The fact that this compound takes the meaning of ‘airport’ instead of its literal meaning is because the first character of this word is truncated from the compound *feiji* (airplane, lit. ‘fly + machine’). Truncation in this way gives more meanings to one morpheme, making it polysemous (Myers, 2010).

The issue of semantic transparency is also relevant to Chinese words because semantic relations between two morphemes and the word can be sometimes transparent but sometimes opaque. Literature on the role of semantic transparency in reading Chinese compounds is rich and ever growing. Following we will attempt to provide a general overview of this literature and to review two particular models.

Studies investigating the representations of Chinese compound words were primarily morphological priming studies, in which the primes and targets are both two-character strings. Zhou, Marslen-Wilson, Taft and Shu (1999) provided strong evidence showing morphological activation in compound recognition. They examined the time course of visual compound processing in a complex series of primed visual lexical decision experiments. They used two-character primes and targets (most of them are transparent) which were put into two SOA conditions (57ms, 200ms) and masked priming. Each target (e.g., *huagui* luxurious, lit. 'splendid + valuable') was primed by three types of related compounds: 1) those shared the same morpheme, i.e. the morpheme condition (e.g., *huali* magnificent, lit. 'splendid + beautiful'), 2) those shared the same form with a different meaning, i.e. the character condition (e.g., *huaqiao* overseas Chinese, lit. 'China + bridge'), or 3) those shared a homophone (including same tone) of a different character (e.g., *huaxiang* glide, lit. 'slide + soar'). The positions of the key characters were also varied in one experiment. Specifically, all the critical morphemes in primes were the second constituents and all the critical morphemes in targets were the first constituents of compounds. The results showed that the morpheme priming effect was consistently greater than character priming, and there was no homophone priming at all. Morphological priming effects maintained even if the position of the key characters changed except that this facilitation effect was markedly reduced using the masked priming paradigm in which the shared morphemes did not occupy the same spatial position. This morphological activation pattern is not a result of word level semantic priming in that they have controlled whole word semantic relatedness between prime and target beforehand.

To understand the activation of morphemes in Chinese compounds, other studies examined the effect of morpheme frequency on reading two character words. Taft, Huang and Zhu (1994), in a visual lexical decision task, matched the whole-word frequency of two-character compounds while manipulating character frequency of the first and second character respectively. Participants were faster to judge compounds as real words if both characters were common than if one of them was rare. This pattern suggests that word recognition of Chinese compounds does involve access of the component characters (as cited in Myers, 2006).

Morpheme activation predicts that semantically opaque compounds should be processed different from transparent compounds, since only in the former do the meanings of the component morphemes compete with that of the whole word. To clarify the role of semantic transparency, some studies take the approach of examining component frequency. Peng, Liu and Wang (1999) first held semantic transparency constant and varied word and character frequency in a visual lexical decision experiment. They found positive word and character frequency effects. In other words, higher word and character frequency resulted in quicker word responses. Character frequency effects however were found to interact with semantic transparency, when they held word frequency constant. For transparent words the character frequency effect was positive, but for opaque words participants responded slower to those containing higher frequency characters. Peng et al. (1999) explained these results based on the argument that component characters were activated in opaque compounds. As a result, activation at the compound level was inhibited due to the competition between the meaning of a compound and that of the component characters (as cited in Myers, 2006). Mok (2009) found further evidence for the competition view of compound processing. They employed a character detection task in reading Chinese compounds and observed a stronger word superiority effect in compounds that contained at least one semantically opaque morpheme as compared with fully transparent compounds. This suggests that both morphemes and words are activated in compound processing but the word-level activation of opaque compounds is more strongly than that of morphemes and wins eventually in the semantic competition.

Priming paradigms also shed light on the role of semantic transparency in reading Chinese compounds. Peng et al. (1999) used two character compounds as primes and targets in the visual priming task. They manipulated the factor of semantic transparency by dividing primes into two categories: transparent and opaque. They also manipulated the priming conditions so that in the experimental condition the first character of prime and target were identical whereas in the control condition they were entirely unrelated. To rule out the possibility of whole-word semantic priming, they controlled that the meanings of primes and targets were unrelated. In this case, the same character in the identical condition contributed different meanings to prime and target. So for transparent prime-target pairs, the example would look like: prime *anning* (quiet, lit. 'peace + peace') and target *anzhuang* (install lit. 'put on + install'). For opaque pairs, the example would be: the prime *kuaihuo* (happy, lit. 'happy + glad') and the target *kuaisu* (speed, lit. 'fast + speed'). Only transparent primes show facilitation effects. The priming effect for transparent compounds is consistent with the hypothesis that the components of compounds are activated in transparent compounds and the nonsigicant effect for opaque compounds is brought about by the semantic competition between morphemes and whole words (as cited in Myers, 2006).

To further investigate the time course of semantic activation of morphemes in opaque compounds, Liu and Peng (1997) used semantic priming paradigm with varying SOAs. There were three testing conditions: (1) the opaque prime word was semantically related to the target whole-word (e.g., *caoshuai* sloppy, lit. 'grass + command'-- *mahu* careless, lit. 'horse + tiger' related to *caoshuai*); (2) the first character of the opaque word was semantically related to the target whole word (e.g. *caoshuai* sloppy, lit. 'grass + command'-- *shumu* tree, lit. 'tree + wood' related to *cao*); (3) the second character of the opaque priming word was semantically related to the target whole-word (e.g., *caoshuai* sloppy, lit. 'grass + command'-- *lingdao* lead, lit. 'lead + guide' related to *shuai*). At the shortest SOA (43ms), only the whole-word condition shows priming effect. However, when SOA increases to 143ms, all three conditions were facilitated by the opaque primes, showing that both whole words and constituent morphemes in these words are activated. In another experiment, they compared transparent and opaque primes at an intermediate SOA of 86ms, and priming effect was found only with transparent compounds. Combining the results of these two experiments, we can see that morphemes in opaque compounds don't reveal their activation until late.

Now results from the literature can be summarized that morphemes are activated when native speakers read Chinese compounds but their activation is dependent on the degree of semantic transparency as well as time course of processing. Currently, two models on Chinese morphological representation have been proposed and we will review them respectively.

Taft and Zhu (1997) proposed a multilevel activation model for morphological processing in Chinese. Framed within the ‘sublexical’ theories (Taft & Forster, 1975), this multilevel activation model assumes that morphemes are represented one layer lower than whole word level. When a compound word is presented, the bottom-up activation starts. Namely, the orthography activates morphemes that in turn activate word units. When processing ascends to semantic levels, a semantic check will be carried out to confirm whether meanings of constituent morphemes are consistent with meanings of whole words. If there is no semantic overlap between morphemes and whole words, activation in the morphemic unit is reset to baseline.

Zhou, Marslen-wilson, Taft, & Shu (1999) postulated a model in Chinese compound recognition and later Zhou proposed its realization in distributed connectionist theories (Zhou & Marslen-wilson, 2009). In this framework, compound words and their morphemes are both represented at orthographic, phonological and semantic levels. More critically, representations of morphemes are not independent from those of compounds because of overlapping representations shared by whole words and morphemes at these levels. In real time processing of compounds, they promoted the view that processing Chinese compounds is critically an interactive process between constituent morphemes and whole words. Therefore, the initial orthographic analysis of the visual input of the morpheme would not only lead to the activation of orthographic, phonological and semantic representations of its own but also the activation of form and meaning properties of whole words. Transparent and opaque words differ in how close constituents are semantically related with whole words and hence this difference would affect how the recognition system processes these words. If morphemes and whole words overlap to a large degree at the semantic level, such as transparent compounds, their respective activation would boost the activation of each other. For example, the mapping of the morpheme *hua* (flower) is very similar when it appears by itself and when it is embedded in the transparent word *huayuan* (garden lit. 'flower + yard'). The activation of *hua* sends excitory forces to the activation of *huayuan*, accelerating the transparent word processing. In the meantime, whole word activation sends facilitatory feedback to morphological activation, accelerating constituent processing. In contrast, when meanings of morphemes are not consistent with those of whole words, the interactive action would trigger semantic competition between them, which then slows down their activations.

The purpose of current study

Semantic transparency proves to be a test stone for the scientific debate between traditional approaches and connectionist approaches to morphological representations and processing. For those traditional models, their primary consensus is that morphologically related words are clustered via a base root morpheme that shared by all these words. Morphological decomposition takes place whenever connection exists for a morphological complex word and the constituent morpheme. Semantic transparency is one primary factor determining whether whole words are linked to their morphemes. In alignment with this logic, morphological decomposition is an all-or-none phenomenon, in which semantic transparency plays a critical role. In contrast, the connectionist models take morphology as a characterization of the learned mapping between the surface forms of words and their meanings and thus they make the strong prediction that the magnitudes of behavioral effects that reflect morphological processing should vary continuously as a function of the degree of semantic transparency (Plaut & Gonnerman, 2000). The main goal of the study is to examine whether the degree of semantic transparency modulates the extent to which morphemes are activated in Chinese compound recognition and whether this morphological activation is modulated by time.

In this paper, we focus on semantic transparency effects in reading Chinese compounds and clarify this question from two perspectives. First, the semantic relatedness of the base morpheme to the meaning of the complex form can vary according to different degrees. In other words, besides the traditional category of semantic transparency into fully transparent and fully opaque, there are in fact many intermediate cases between the two poles (Plaut & Gonnerman, 2000). Nevertheless, most studies investigating semantic transparency effects did not include these intermediate cases. As Chinese compounds dominantly consist of two morphemes, semantic relationship between whole words and morphemes can thus have situations as follows. In the current study, we define completely transparent compounds (TT) as those in which meanings of the two morphemes both contribute to the semantic computation of the whole word (e.g., *huayuan*, garden lit. ‘flower+park’). Partially transparent compounds are words whose meaning is only determined by one morpheme of the word (e.g., *xigua*, watermelon, lit. ‘west+melon’). So there will be two subcategories within partially transparent compounds: 1) those in which only the left morpheme is related to the compound (TO) and 2) those in which only the right morpheme is related to the compound (OT). Finally, completely opaque compounds are items whose meaning cannot be interpreted from either of its morphemes (OO) (e.g., *laoban*, boss, lit. ‘old+board’). The inclusion of three levels of semantic transparency (i.e., TT, TO/OT, and OO) permits us a more comprehensive understanding of the influence of semantic transparency in morphological segmentation. Second, as Feldman et al. (2004) argued semantic transparency effects are sensitive to time course and it is misleading to interpret the influence of semantic transparency within one time frame. In fact, determining the temporal order of full words and their constituents is crucial to discriminate competing models of morphological processing. In the present study, the effects of priming across these types of semantic transparency are examined in each of the three SOA conditions: 50ms, 150ms, and 250ms so that we can examine the temporal course in which semantic similarity contributes to morphological processing in a systematic way.

In search of an experimental method

The priming paradigm has provided a particularly useful way by which to study morphological effects in language processing. Facilitation in target recognition when it was preceded by a morphologically related word is taken as evidence that morphological representations shared between prime and target are activated in the recognitions of both the prime and the target. However, this morphological facilitation effect account still cannot provide a completely straightforward explanation of morphological processing because priming between morphologically related words normally involves partial repetition of form as well as of semantic information and all these factors could cofound the size of morphological effects. To investigate effects that are semantic in nature, we need to adopt a priming procedure that taps into pure semantic effects in morphological processing. To avoid the form level confounding effects, we use a cross-language translation priming provides a way out here. In this priming paradigm, primes are presented in a language and followed by translation- equivalent targets presented in another language. Word stimuli can also be created so that language of the prime is the dominant language for participants while language of the target is not or we can manipulate the two languages the other way around. In this way, priming effects can be measured in L1-L2 or L2-L1 directions.

Like within language priming, cross-language priming effects are usually interpreted in terms of activation models of word recognition (Forster, Mohan & Hector, 2003). Put simply, the representations that are activated by the prime may have residual activation when the target is presented. If the prime and target share representational overlap, then the target may already be partly activated even before the input is perceived. Thus, its recognition time will be faster than if an unrelated prime had been presented. In the current cross linguistic context, shared activation can be thought of as the result of an overlap in lexical representations between prime in one language and target in another. For example, if two words sound alike, both may be activated by the same phonetic input; if two words mean the same thing, both will be activated by the same conceptual node. In the bilingual lexicon, words from two languages are stored in a shared manner so that the semantic access to the English word *dog* will partially activate other words that share the same conceptual node such as the Frequency translation *Chien* (e.g., Finkbeiner, Forster, Nicol, & Nakamura, 2004). In real time processing within this paradigm, it occurs like this if the semantic node that corresponds to *dog* is activated when the English prime *dog* is presented, the time needed to identify that subsequent presentation of the French target *Chien* may be reduced if there is any residual activation left from the presentation of the prime. The residual activation results in speeded recognition of a word or priming. This cross linguistic paradigm used in studying Chinese compounds can reveal us morphological activation at the semantic level. Chinese and English translation equivalents are more likely to be coded at the level of semantics as the two languages are of distinctive orthographic systems (Jiang & Forster, 2001; Wang & Forster, 2010). In the current study, we will take the L1-L2 priming direction in which Chinese, the focused language, is in the prime position. This direction is taken to satisfy our goal of examining time course of Chinese morphological activation. In the priming paradigm, we can manipulate the time frame within which the prime is displayed.

Our logic is that if the prime significantly reduces the reaction time of target recognition, it would suggest that semantic representation of the shared morpheme in this prime-target pair is activated in the recognitions of both the target and the target and we can further deduce that this shared morpheme is processed in the recognition of the prime compound. In this study we set three conditions of prime words: fully transparent (TT), partially opaque (TO/OT) and fully opaque (OO). And we contrast priming effects under these three conditions at three different SOAs: 50ms, 150ms and 250ms. If we find differences in terms of priming effects between TT condition and OO condition or TO/OT condition, we can take this pattern of results as evidence that semantic transparency effects modulate morphological segmentation in Chinese compounds. If we also observe that facilitation differences among these three condition increase as the SOA increases, we can further provide support for the fact that semantic transparency influence in Chinese compound processing is time-constrained.

CHAPTER TWO: EXPERIMENTS 1-3

Experiment 1: Semantic transparency effects in the semantic priming paradigm with an SOA of 250ms

Evidence from several studies using the short-term paradigm indicates that semantic transparency is a factor influencing morphological priming effects (e.g., Marslen-Wilson et al., 1994; Frost et al., 2000; see also Feldman et al., 2004 for a review). In this procedure, a short time lag is inserted between the presentation of the prime and the target words. Relative to a semantically unrelated control, the significant facilitation after semantically related words has been shown by numerous studies (for a review see Neely, 1991), suggesting that this procedure is sensitive to activations at the level of semantic information. Studies on English, French and other alphabetic languages have shown that in the immediate priming paradigm, morphologically related and semantically transparent primes significantly reduced reaction latencies to their targets whereas such robust priming effects were absent for morphologically related but semantically opaque primes (e.g., Feldman & Soltano, 1999; Feldman, Soltano, Pastizzo & Francis 2001; Longtin et al., 2003). The findings from Frost et al. (2000) however reveal that there is a contrast between Hebrew and English morphological processing. In a study using immediate cross-modal priming, they observed that both semantically transparent and opaque words produced reliable priming effects, although transparent words facilitated their target recognition to a greater extent relative to opaque words. These results indicated that whether morphologically related yet semantically opaque words may or may not show priming effects is a language-specific issue. As Frost et al. (2000) argued, in languages where morphological combination plays an obligatory part in reading, morphemes are represented explicitly even for semantically opaque words and it is these explicit morphological units in opaque words that lead to facilitation effects for these words. Similar to Hebrew, morphemes are orthographically distinct in a compound. This would imply that readers of Hebrew and Chinese can "see" morphemes explicitly and thus morphological analysis is also compulsory in reading Chinese. [1] The purpose of this experiment therefore is to examine whether transparent and opaque Chinese compounds are both able to generate reliable priming effects as in Hebrew.

In the current study, we selected transparent compounds whose meaning cannot be fully interpreted by either of its morphemes (e.g., *youtian*, oil field, lit 'oil + field'). Given this control, any differences obtained in the priming effect between transparent and opaque compounds cannot be attributed to differential effects of semantic similarity at the whole word level, but instead must reflect differences in the semantic processing of the morphemes in transparent and opaque primes.

Method

Participants

Thirty subjects studying at the National University of Singapore (NUS) were paid to participate in the experiment. All were native speakers of Chinese with English as their L2. All of them are from mainland China and had been studying English as a L2 during their school years in China for 6 years and

[1] This argument is based on the suggestion given by one anonymous reviewer of this thesis.

have lived in Singapore, an English speaking country for at least 1 year.

Materials

Tested items. Primes were Chinese compounds varied in the degree of semantic transparency. The targets were the English translations of shared morphemes of the Chinese compounds. Three priming conditions were designed: (a) morphologically related and fully transparent primes (e.g., *huayuan* garden, lit. ‘flower + yard’), (b) morphologically related but fully opaque primes (e.g., *huasheng* peanut, lit. ‘flower + birth’), and (c) morphologically and semantically unrelated primes (e.g., *learn*, lit ‘study + acquire’). Ninety prime-target pairs were constructed, consisting of fully transparent and fully opaque words, so that each condition consisted of 30 pairs. We selected our primes from the Modern Chinese Frequency Dictionary (1986), matching their mean frequencies. One way ANOVA showed that there is no main effect of frequency ($F(2, 87) = 1.97$, $p > .1$) and we found no difference between every two conditions in Tukey multiple comparisons ($ps > .1$). All targets were the English translations of the shared morphemes in morphologically related conditions. They were all free morphemes. As for the English translations of the critical Chinese morphemes, we asked 10 English-Chinese bilinguals in NUS to translate these shared morphemes from Chinese to English. Although their first language is English, they are highly proficient in Chinese, their second language. Targets were always presented in English (L2) and prime in Chinese (first language, L1). For each Chinese morpheme, we selected its translation that was conceded by more than 5 of these English-Chinese bilinguals.

As Plaut and his associate (Plaut & Gonnerman, 2000) have argued that morphologically complex words vary along a continuum of semantic transparency, we thus not only selected completely opaque compounds but also partially opaque compounds to investigated whether graded priming differences between fully transparent, partially opaque, and fully opaque compounds can be observed. Due to the design of the current study, we are limited to select enough primes to compare all three types of compounds within one contrast. Therefore, based on the principles of contrast between transparent and opaque primes, we selected another group of contrastive primes: fully transparent and partially opaque compounds. There were three morphological priming conditions in this case: (a) morphologically related and fully transparent primes (e.g., *xibei* northwest, lit 'north+ east'), (b) morphologically related but partially opaque priming (e.g., *xigua* watermelon lit 'west + melon'), and (c) morphologically and semantically unrelated primes (e.g., *daolai* arrival lit 'arrive + come'). Again, the former two conditions share a morpheme which is the opaque constituent (i.e., the morpheme that is semantically inconsistent with the meaning of a partially opaque compound). The target word is the English translation equivalent of this shared morpheme. In the set of partially opaque items, half of the words are TO compounds (i.e. partially opaque compounds whose second constituent was opaque) and the half are OT compounds (i.e. partially opaque compounds whose first constituent was opaque) compounds. Ninety prime-target pairs were thus selected. The mean frequencies of Chinese primes in these three conditions were matched. One way ANOVA showed that there is no main effect of frequency ($F(2, 87) = .528$, $p > .1$) and Tukey multiple comparisons showed no difference between every two of these conditions ($ps > .1$). A rating study was conducted after the experiment on the same population of subjects to discriminate the semantic contrast between fully opaque primes and fully transparent primes as well as partially opaque primes and fully transparent primes. The difference was rated on a 7 point scale. Those pairs scored higher than 3.5 were selected. As a result, responses to three items (*矛盾*, *红颜*, *耳光*) in the fully opaque condition were deleted from all analyses because they were rated not significantly different from corresponding transparent primes.

The mean log frequency and length of primes and targets are summarized in Table 1 (see Appendix A). Log frequencies of Chinese primes were measured against Modern Chinese Frequency Dictionary (1986) and log frequencies of English targets were measured against CELEX English Lexical Database (1996). Experiment stimuli are listed in Appendix B.

Fillers. In order to minimize the likelihood that participants would develop response strategies based on the relationship between the prime and the target words, filler materials were added. The inclusion of 75 word-word trials reduced the relatedness proportion for word-word trials to 30%. The Chinese primes in these filler trials were selected from the Modern Chinese Frequency Dictionary (1986). They were all transparent in terms of semantics and resemble the test primes in base frequency. English word targets were selected from the English Lexicon Project (Balota, Yap, Cortese, Hutchison, Kessler, Loftis, Neely, Nelson, Simpson, & Treiman, 2007) developed by the Cognitive Psychology Lab at Washington University in St. Louis to match the test targets in terms of log frequency and length. In addition, 135 word-nonword trials were included. This set of fillers ensured that there were equal numbers of word and nonword targets. Again, the Chinese primes in these filler trials were selected from the Modern Chinese Frequency Dictionary (1986) to match test primes in terms of base frequency. Nonwords were constructed by changing one or two letters in a real word and matched words with length.

Design

Three experimental lists were created by rotating the targets across the three priming conditions, using a Latin-Square design, so that each target appeared only once for a given participant. Each experimental list consisted of 270 prime-target pairs: 60 test pairs and 210 filler pairs (the latter were the same in all the lists). These pairs were presented in a different random order for each participant.

Procedure

The participants were tested individually or in groups of two in a quiet room. The experiment was conducted on a PC using DMDX software (Forster & Forster, 2003). They were instructed to silently read the Chinese prime and decide as quickly and accurately as possible whether the target was an English word. The experiment began with a short practice session (20 pairs) followed by 3 experimental blocks, with each block containing items from each condition. The order of the items within each block was then randomized as were the blocks. The participants took a break of one to two minutes between the two blocks. The experimental session lasted approximately 20 minutes.

Each trial began with the presentation of a visual fixation signal (‘+’) in the middle of the screen for 300ms followed immediately by the prime word printed in SimSun 14 point. It remained on the screen for 200ms and was followed by a blank of 50ms. Then the target letter strings, which was printed in Courier New 18 point, appeared and remained on the screen for 500ms.

Responses were made by pressing the ‘yes’ button with the right hand, or the ‘no’ button with the left hand. And the response deadline was set to 4000ms. After each response, feedback message was presented indicating the speed and accuracy of the response.

Results

Incorrect responses and outliers (defined as reaction times slower than 1500ms or faster than 300ms) were excluded from the response time analysis. The mean response times and error rates for each experimental condition are shown in Table 2 (see Appendix A).

The data were analyzed separately for fully transparent vs. fully opaque comparison and fully transparent vs. partially opaque comparison. We run repeated ANOVAs on the RT data for correct responses, and the error rates, with Prime Type (fully transparent—fully opaque—unrelated or fully transparent—partially opaque—unrelated) as main independent variables.

<u>OO and TT words</u>

Response times. The overall ANOVA on the latency data revealed the main effect of prime types in subject analysis [F1 (2, 51) =5.56, MSE=2645.29, p<.01] but not in item analysis [F2 (2, 41) =2.40, MSE=4590.23, p=.11], indicating that lexical decisions for the targets were faster when these targets were preceded by the morphologically related primes than by an unrelated prime. Planned comparisons showed that priming effects were reliable for fully transparent primes [F1 (1, 29) =16.78, MSE=1533.51, p<.01; F2 (1, 26) =4.60, MSE=3771.78, p<.05]. The planned comparison between fully opaque vs. unrelated primes was marginally significantly only by participants [F1 (1, 29) =3.43, MSE=2438.98, p=.074; F2<1]. The difference between transparent and opaque conditions was not reliable by subject analysis [F1 (1, 29) =1.58, MSE=3010.36, p=.22] but approached significance by item analysis [F2 (1, 26) =2.98, MSE=1991.67, p=.094], indicating fully transparent compounds showed a trend to produce stronger priming effects than opaque compounds.

Error rates. ANOVAs revealed that the overall effect of priming type mirrored that in the analysis of reaction times [F1 (2, 57) =3.36, MSE=.00, p<.05; F2 (2, 45) =1.62, MSE=.00, p>.1]. This suggests that subjects made fewer errors if they were primed by Chinese compounds. A series of planned comparisons showed that the priming effect was significant in the transparent condition by subject analysis [F1 (1, 29) =5.38, MSE=.01, p<.05] but not by item analysis [F2 (1, 26) =2.31, MSE=.01, p=.33]. The significance of the priming effect in the opaque condition was reliable by subjects [F1 (1, 29) =5.25, MSE=.01, p<.05] but was missed by items [F2 (1, 26) =.04, MSE=.01, p>.1]. Differences between transparent and opaque conditions were not significantly different from each other [F1 (1, 29) =.01, MSE=.01, p>.1; F2 (1, 26) =.04, MSE=.01, p>.1].

TO/OT and TT words

Response times. ANOVAs were conducted on the response times and showed that prime type were significant effect in both subject and item analysis [F1 (2, 53) =8.20, MSE=22709.33, p<.01; F2 (2, 52) =6.97, MSE=8.25, p<.01]. Reaction latencies to targets were faster when targets were preceded by morphologically related primes than unrelated ones. Planned comparisons revealed that transparent primes produced significant priming compared to unrelated primes in both subject and item analysis [F1 (1, 29) =18.60, MSE=1183.57, p<.01; F2 (1, 29) =12.63, MSE=2674.47, p<.01]. The partially opaque compounds demonstrated similar patterns relative to unrelated primes [F1 (1, 29) =7.28, MSE=1950.75, p<.05; F2 (1, 29) =8.19, MSE=2846.76, p<.01]. The difference in reaction times between fully transparent and partially opaque primes was not significant [F1 (1, 29) =.62, MSE=1385.65, p>.1; F2 (1, 29) =.64, MSE=1520.29, p>.1], indicating that in this experiment, fully transparent and partially opaque primes yielded priming effects of similar magnitude.

Error rates. ANOVAs revealed that the overall effect of priming type was not significant [F1 (2, 46) =1.50, MSE=.01, p>.1; F2 (2, 47) =1.64, MSE=.01, p>.1]. A series of planned comparison showed that the priming effects were robust in the fully transparent condition [F1 (1, 29) =4.46, MSE=.01, p<.05; F2 (1, 29) =3.38, MSE=.01, p=.076], indicating that subjects made less errors when being primed by transparent compounds compared to unrelated compounds. For partially opaque primes, no effect was found [F1 (1, 29) =.34, MSE=.01, p>.1; F2 (1, 29) =.39, MSE=.01, p>.1]. The fully transparent and partially opaque priming conditions were not significantly different from each other [F1 (1, 29) =1.20, MSE=.01, p>.1; F2 (1, 29) =1.87, MSE=.01, p>.1].

Discussion

A critical question we addressed in experiment 1 is whether transparent and opaque compounds can both significantly facilitate their targets recognition as their counterpart in Hebrew and whether differences between transparent and opaque compounds are processed differently. An advantage of the present design is that we could assess the effect of semantic transparency by comparing latencies to the same target, which was the translation of the shared morpheme either encoded in a transparent or opaque prime. We found that semantically transparent compounds produced significantly larger priming effects than semantically opaque compounds, although these differences were only marginally significant by item analysis. The present results seem to be compatible with the dual-mechanism models, which postulate that semantic transparency is an important factor determining whether a complex word decomposes or not in processing. Our priming pattern replicated what Frost et al. (2000) demonstrated in Hebrew morphology: similar to Hebrew, constituent priming effects were observed for both semantically transparent and opaque Chinese compounds. When an embedded base morpheme (e.g., ‘hua’) is activated in a compound prime, the subsequent processing of the target (e.g., ‘flower’, the English translation of ‘hua’) then benefits from the previous processing of the stem morpheme (e.g., ‘hua’) because of the semantic overlap between the target and the stem morpheme. In alignment with this logic, the robust facilitation effects observed here suggest that morphemes in both transparent and opaque compounds are decomposed in compound recognition. This provides counterevidence to the dual-route model proposed by Marslen-Wilson et al. (1994), which predict that only transparent compounds undergo morphological decomposition whereas opaque compounds were processed as a whole.

For both fully transparent and partially opaque compounds, we found robust priming effects. This finding is consistent with what we observed for completely transparent and completely opaque compounds. The pattern of semantic transparency effects in the comparison of fully transparent vs. partially opaque primes takes on yet another type. We observed equivalent levels of robust priming effects for both types of primes despite the fact that semantic transparent primes are related to the meaning of the tested shared morpheme to a greater extent than partially opaque primes. We reanalyzed the semantic weight (i.e., the extent to which a morpheme can semantically contribute to a compound) of the two morphemes in partially opaque compounds. Recall that in these compounds, half of them are OT noun compounds, the head of which is on the right morpheme and transparent. Out of all these 30 partially opaque compounds, the transparent morpheme in 23 compounds contributes to the meaning of the whole word to a great extent that the compound can be understood well merely by decoding the meaning of the transparent compound. Therefore, the degree of semantic transparency in this type of compound is closer to completely transparent compound than to completely opaque compounds along the continuum of semantic transparency. Although the target is not semantically related to the partially opaque prime, we might assume that it is this closer distance between truly transparent and partially opaque compounds that leads to a nonsignificant semantic transparency effect in the contrast between completely transparent and partially opaque compounds. We will discuss this in detail in the general discussion.

To conclude, the pattern of somewhat significant divergence in target recognition following completely transparent and completely opaque primes was particularly informative. This differentiation is consistent with the claim that semantic transparency of morphological complex words affects the processing of its constituent morphemes in short-term priming (e.g., Marslen-Wilson et al., 1994; Feldman et al., 2004). However, the fact that opaque and partially opaque compounds yielded comparable significant priming effects poses a challenge to the dual – route models which propose that opaque words are retrieved as whole words.

Although using a method that is sensitive to semantic similarity is perhaps necessary to reveal processing differences between transparent and opaque compounds, the present experiment is evidently not sufficient to answer whether the semantic transparent effect in morphological processing is a general fact about complex word recognition or is evident only under short-term priming paradigm. Similarly, we are still not in a position to conclude whether morphological activation in opaque compounds is a general fact about lexical representation, or are apparent only under experimental situations (such as short-term priming we employed).

Experiment 2 thus set out to investigate by varying SOAs to assess the time course of morphological decomposition in opaque compounds. In experiment 2, we used masked priming paradigm, in which the prime is complete invisible to participants. We aim to investigate whether morphological decomposition in transparent and opaque compounds could occur even when subjects were not aware of the primes.

Experiment 2: Semantic transparency effects in the masked priming paradigm with an SOA of 50ms

The results of experiment 1 revealed a marginally significant semantic transparency effect between fully transparent and fully opaque compounds. Differential priming effects for truly opaque and transparent primes were observed: fully transparent primes reliably facilitate the reaction times to their targets whereas fully opaque primes failed. In recent expositions of morphological facilitation, however, some studies using a forward-masking paradigm with a visual lexical decision task, did not find an effect of semantic relatedness (e.g., Feldman et al. 2004; Frost et al., 1997; Rastle et al., 2000). To be more specific, transparent and opaque items generated an equivalent magnitude of facilitation in these studies. This outcome is consistent with the traditional accounts of morphology, which claim that morpheme is an independent level of representation in the lexicon and thus morphological processing is not affected by orthographic and semantic properties of a morphologically complex word (e.g., Frost, et al., 1997; Frost et al., 2000). Although the above studies overall showed that the effect of semantic transparency in morphological processing is still not a clear-cut picture, findings of Feldman et al.（2004）suggested that the contribution of meaning to morphological processing appeared to magnify as processing time for the prime increased. They have reported the difference in target (e.g., *casualness*) decision latencies following semantically transparent (e.g., *casually*) and semantically opaque (e.g., *casualty*) morphological relatives is dependent on SOAs. Specifically at 250-ms SOA targets that followed transparent and opaque primes differed significantly but at 48-ms SOA this difference was not significant.

In addition, robust priming effects we observed under partially opaque and opaque conditions are problematic for the dual mechanism theories of morphological processing. One may refute these effects on the ground that it is the awareness of the prime in short-term priming procedure rather than the lexical structure of opaque compounds that gave rise to the significant facilitation effects.

The goal of experiment 2 was to examine the time course of contribution of semantics to morphological processing and that of morphological activation in opaque compounds along word recognition. Following from the findings of Feldman et al. (2004), we hypothesize that if the extent to which semantics contribute to Chinese compound processing increases as prime exposure time increases, semantic transparency effects will be less reliable as SOA is reduce from 250ms to 50ms.

Method

Participants

Thirty students participated in this experiment. All were selected from the same population as in the previous experiment.

Design and materials

The experimental materials and design were the same as in experiment 1 with several items changed to have a better representation of fully and partially opaque compounds.

The mean log frequency and length of primes and targets are summarized in Table 3 (see Appendix A). Experiment stimuli are listed in

Appendix B.

<u>Procedure</u>

The sequence of events in each trial was identical to that in experiment 1, except for the different SOA. In the present experiment, a visual mask (‘贔贔贔贔贔’) of 500ms duration preceded the prime which appeared for 50ms. The SOA in this experiment was then 50ms.

Results

Incorrect responses and outliers were excluded from the response time analysis. Outliers were defined as response times that were above 1500ms or below 300ms. Outliers accounted for less than 1% of all responses. The data from one participant were excluded from the analysis because of a high error rate (over 25%). The data from completely and partially opaque pairs were analyzed separately. The mean response times and error rates for the morphological priming conditions are shown in Table 4(see Appendix A).

<u>OO and TT words</u>

Response times. ANOVAs on the latency data revealed that the effect of Prime Type was not significant by subject analysis, but approaching significance by item analysis [$F1\ (2, 54) = 2.29$, $MSE = 1888.59$, $p > .1$; $F2\ (2, 57) = 2.87$, $MSE = 1707.30$, $p = .066$]. Planned comparisons revealed a robust priming effect only in truly transparent condition [$F1\ (1, 29) = 3.84$, $MSE = 2081.01$, $p = .060$; $F2\ (1, 29) = 5.34$, $MSE = 1803.43$, $p < .05$]. The opaque and unrelated condition did not differ from each other [$F1\ (1, 29) = .96$, $MSE = 1898.83$, $p > .1$; $F2\ (1, 29) = 1.66$, $MSE = 1452.14$, $p > .1$]. Neither significant difference between the transparent and opaque conditions was observed [$F1\ (1, 29) = 1.73$, $MSE = 1260.47$, $p > .1$; $F2\ (1, 29) = 1.35$, $MSE = 1775.41$, $p > .1$].

Error rates. ANOVAs revealed that the overall effect of Prime Type was not significant by either subject or item analysis [F1 (2, 58) =.79, MSE=.00, p>.1; F2 (2, 50) =.90, MSE=.00, p>.1]. A series of planned comparisons showed that error rates did not differ across conditions of different prime types (both Fs<1). The planned comparison for differences between transparent vs. opaque primes were not significant (both Fs<1).

TO/OT and TT words

Response times. The overall ANOVA on the latency data revealed that the priming effect was not significant by subject analysis but approaching significance by item analysis. [F1 (2, 55) =1.38, MSE=2650.25, p>.1] but approached significance by items [F2 (2, 56) =2.81, MSE=2613.85, p=.07]. Planned comparisons revealed the priming effect only for completely transparent primes compared to unrelated primes by item analysis, not by subject analysis [F1 (1, 29) =2.13, MSE=2649.92, p=.16; F2 (1, 29) =4.59, MSE=2552.72, p<.05]. No priming effect was observed for the partially opaque condition compared to the unrelated condition, except that the item analysis was approaching significance [F1 (1, 29) =1.62, MSE=2937.44, p=.21, F2 (1, 29) =3.30, MSE=2910.00, p=.080]. The difference between completely transparent and partially opaque conditions was not significant [F1 (1, 29) =.02, MSE=1987.01, p>.1; F2 (1, 29) =.05, MSE=2152.64, p>.1].

Error rates. ANOVAs revealed that the overall error rates did not differ across different priming conditions [F1 (2, 56) =.39, MSE=.00, p>.1; F2 (2, 53) =.82, MSE=.00, p>.1]. A series of paired comparison showed that the error rates did not differ across conditions: completely transparent primes vs. unrelated primes [F1 (1, 29) =.08, MSE=.00, p>.1; F2 (1, 29) =.31, MSE=.00, p>.1];

partially opaque primes vs. unrelated primes [F1 (1, 29) =.71, MSE=.00, p>.1; F2 (1, 29) =1.94, MSE=.00, p>.1], the completely transparent vs. partially opaque conditions [F1 (1, 29) =.41, MSE=.00, p>.1; F2 (1, 29) =.49, MSE=.00, p>.1].

Interim Discussion

Experiment 2 did not reveal robust semantic transparency effect with a prime duration of 50ms across different prime conditions. The absence of semantic transparency effect is in line with the data from previous studies in different languages (e.g., English: Feldman et al., 2004; Hebrew: Frost et al., 1997; French: Longtin et al., 2003). Our findings from Experiment 2, together with results from other studies imply that at a SOA as short as 50ms, morphological processing appeared to be hard to occur. Moreover, the masked priming paradigm has been argued as a tool tapping the unconscious processes (Forster et al., 2003), in which whether semantic decoding can occur has been fiercely debated.

Adopting the masked priming procedure, Frost et al. (1997) contrasted morphological priming effects in Hebrew for semantically transparent and semantically opaque words. When the orthographic similarity was controlled across prime-target pairs, equivalent priming effects were found for both transparent and opaque primes. They thus hypothesized that morphological effects are independent from semantic effects. A possible limitation of masked priming as a means for probing semantic transparent effects is that it is relatively insensitive to semantic processing (Frost et al., 2000; Feldman et al., 2004). Weak or nonexistent semantic priming effects were constantly reported by researchers like Perea, Gotor, Rosa, & Algarabel (1995) using this paradigm. (as cited in Frost et al., 2000). In alignment with this logic, this insensitivity raises the possibility that it may not be an effective experimental context to measure semantic contributions to the morphological effect.

Indeed, experiment 1 and 2 has shown that semantic transparency effects are apparent at the longer SOAs (250ms) but not in the masked priming task (50ms). Therefore, employing short-term priming with an SOA of 150ms, we will examine semantic transparency effects in a systematic way whether the semantic difference between transparent and opaque compounds can indeed contribute to morphological processing in Experiment 3.

Experiment 3: Semantic transparency effects in the short-term semantic priming with an SOA of 150ms

Results from the above two experiments combined to unfold a picture that semantic transparency effects magnified if the prime was allowed more time to be processed. In order to improve our understanding of the time course of morpheme processing, we used a SOA between 50ms and 250ms: 150ms.

Method

Participants

Thirty students who met the characteristics described in Experiment 1 and 2 were paid to participate in the experiment.

Design and materials

The design of this experiment was identical to that of Experiment 2.

Procedure

As in Experiment 1, all subjects were instructed to pay attention to everything they saw on the screen and make a lexical decision on the string of letters on each trial. The sequence of events in each trial was the same as Experiment 1, except for the different duration of the prime and the blank that followed it. In the 150ms SOA condition, the prime was presented for 120ms and the blank for 30ms.Thus across Experiment 1and 3, the relative duration of the prime and the blank was held constant.

Results

Data analysis procedure was the same as in Experiment 1 and 2. One participant was excluded from analysis because of high error rate (above 20%). The mean response times and error rates for the morphological priming conditions are shown in Table 5 (see Appendix A).

<u>OO and TT words</u>

Response times. ANOVAs revealed that there were significant priming effects in both participant and item analysis [F1 (2, 49) =12.23, MSE=1533.54, p<.01; F2 (2, 48) =8.26, MSE=3011.43, p<.01]. Planned comparisons revealed that latencies to visual targets proceeded by completely transparent compounds were significantly faster than those unrelated primes in both subject and item analysis [F1 (1, 26) =20.64, MSE=1636.10, p<.01; F2 (1, 29) =13.73, MSE=2918.23, p<.01]. The same pattern was observed opaque primes, compared to unrelated primes by both participant and item analysis [F1 (1, 26) =14.38, MSE=1056.56, p<.01; F2 (1, 29) =5.3, MSE=3199.78, p<.05]. The planned comparison did not show a significant difference between completely transparent and completely opaque compounds in subject analysis [F1 (1, 26) =2.28, MSE=1609.40, p=.14], but the item analysis demonstrated a trend towards significance [F2 (1, 29) =3.53, MSE=1379.34, p=.07].

Error rates. ANOVAs revealed that the error rates did not differ across different priming conditions [F1 (2, 49) =.53, MSE=.00, p>.1; [F2 (2, 58) =.63, MSE=.00, p>.1]. A series of paired comparison showed that none of the priming conditions differed from one another in error rates: transparent vs. unrelated [F1 (1, 26) =1.42,msE=.00, p>.1; F2 (1, 29) =1.20, MSE=.00, p>.1]; opaque vs. unrelated [F1 (1, 26) =.64, MSE=.00, p>.1; F2 (1, 29) =.22, MSE=.00, p>.1]; transparent vs. opaque [F1 (1, 26) =.29, MSE=.01, p>.1; F2 (1, 29) =.43, MSE=.00, p>.1].

<u>TO/OT and TT words</u>

Response times. The overall ANOVA on the latency data revealed significant priming effects across conditions in both participant and item analysis [F1 (2, 52) =4.80,msE=2044.02, p<.05; F2 (2, 45) =3.43,msE=8677.65, p=.053]. Lexical decisions on targets were faster when these targets were preceded by the morphologically related primes than when preceded by unrelated primes. Planned comparisons revealed that reliable priming effects only existed for completely transparent primes, compared to unrelated primes [F1 (1, 26) =8.74, MSE=3120.03, p<.01; F2 (1, 29) =5.75, MSE=7807.62, p<.05]. The partially opaque compounds did not show priming at all [F1 (1, 26) =.67, MSE=3134.57, p>.1; F2 (1, 29) =.70, MSE=9123.10, p>.1]. There was a significant difference between the completely transparent compounds and the partially opaque compounds [F1 (1, 26) =5.02, MSE=2841.48, p<.05; F2 (1, 29) =5.62, MSE=3103.85, p<.05], indicating that only completely transparent compounds demonstrated meaning-based morphological processing, but not for partially opaque primes.

Error rates. ANOVAs revealed that error rates were significantly lower in the morphologically related priming condition only in subject analysis [F1 (2, 49) =4.33, MSE=.00, p<.05], but not in item analysis [F2 (2, 47) =2.79, MSE=.00, p=.082]. A series of paired comparison showed that the error rates differ between completely transparent compounds and unrelated compounds [F1 (1, 26) =6.01, MSE=.00, p<.05; F2 (1, 29) =6.42, MSE=.00, p<.05]. Namely, transparent compounds helped subjects recognizing the targets, compared to unrelated compounds. Similarly, the completely transparent condition significantly reduced error rates compared to the partially opaque condition [F1 (1, 26) =5.77, MSE=.00, p<.05; F2 (1, 29) =4.36, MSE=.01, p<.05]. However, error rates did not differ between the partially opaque condition and the unrelated condition [$F1 (1, 26) = .28$, $MSE = .00$, $p > .1$; $F2 (1, 29) = .10$, $MSE = .02$, $p > .1$].

Interim Discussion

Experiment 3, in which an SOA of 150ms was adopted, provided us another time window to understand the morphological processing in Chinese compounds, in relation to the prime durations of 50ms and 250ms. The priming pattern in both completely transparent and opaque conditions replicated what we found in Experiment 1. Namely, in short-term priming paradigm, both transparent and opaque compounds can give rise to robust facilitation effects to their target recognition. These findings can be interpreted as evidence showing morphological processing in both transparent and opaque compounds. In addition, at both SOA of 150ms and 250ms, completely transparent compounds generated slightly larger priming effects than opaque compounds.

One interesting finding across Experiment 1 and 3 is that partially opaque compounds behaved similarly to transparent compounds at the SOA of 250ms, but not at the SOA of 150ms. That is, at the SOA of 150ms, partially opaque compounds did not producing any priming effects. This suggests that the time at which morphological decomposition takes place is influenced by the degree of semantic transparency. In other words, morphological processing is time-sensitive. This result is in accordance with Feldman et al. (2004), in which they found that semantic transparency effects are temporal-constrained. Our time-sensitive pattern of results then are hard to be accommodated in traditional approaches to morphological processing, in which they failed to visualize graded morphological processing along the time line of complex word recognition.

Discussion

The results of experiment 2 and 3 suggest that differences between transparent and opaque facilitation effects, believed to reflect different morphological processing mechanisms (e.g., Marslen-Wilson et al., 1994) are in fact constrained by the processing time for the prime. To be more specific, whereas transparent and opaque words produced comparable levels of priming at the SOA of 50ms (23ms and 11ms, respectively), at the SOA of 150ms transparent words produced a priming effect that was larger than that produced by opaque words (50ms and 34ms, respectively).

Effects of SOAs and Semantic transparency

The critical question here is whether there is statistically significant decrease of semantic contribution to morphological processing as SOA decreases. We ran analysis combining Experiment 1, 2 and 3. The results revealed no interaction between prime type and SOA (Fs <1) in both comparisons (i.e. transparent vs. opaque and transparent vs. partially opaque). Planned comparisons were conducted for SOAs and only interaction between prime type and SOA was marginal significant in the transparent vs. partially transparent from 50ms and 150ms ($F1\ (1, 55) = 2.84$, $MSE = 2390.94$, $p = .097$; $F2\ (1, 58) = 2.82$, $MSE = 2628.25$, $p = .098$).

We found that the difference in target decision latencies following semantically transparent and semantically opaque morphological relatives depended on SOA. Specifically, whereas in the 50 SOA condition, opaque and transparent words produced comparable levels of priming with only a 12ms difference between their priming effects (23ms vs11ms respectively), in the

150ms SOA condition, transparent priming effects was 16ms larger than those for opaque primes (50ms vs. 34ms, respectively). And at an SOA of 250ms, facilitation difference between transparent and opaque primes increased to 18ms.

The relative priming between transparent and partially opaque compounds is resonant with what we found in the comparison between transparent and completely opaque compounds. To be more specific, at the brief SOA of 50ms, the priming differences between transparent and partially opaque compounds were 2ms in the 50ms condition and increased to 33ms in the 150ms condition. However, when SOA was of 250ms, the difference decreased to an unreliable level (3ms) again.

Stated succinctly, the present study showed that semantic transparency effects are time-varying (Priming effects of Chinese compounds varying in the degree of semantic transparency across different SOAs were shown in Figure 1, 2 and 3 in Appendix A). As SOA increased, there was greater divergence among decision latencies for targets whose primes varied along a semantic dimension of similarity. The pattern of divergence between transparent and opaque target decision primes was particularly informative. Insofar as transparent and opaque primes were paired with the same target, they are only different in terms of the degree of semantic transparency. Their differentiation is consistent with the claim that semantic contribution to morphological processing latencies increases with processing time for the prime (Feldman et al., 2004). The pattern of results of Experiment 1 and 2 is difficult to reconcile with those traditional models of morphological processing by which morphological segmentation is not affected by semantic relations (e.g., Frost et al., 1997; Taft & Forster, 1975). The semantic transparency effects over time we observed here showed contradictory evidence against their argument that morphological processing is specifically morphological in nature (e.g., involve a separate morphological level of representations) and thus should be independent of semantic transparency.

CHAPTER THREE: GENERAL DISCUSSION

The main purpose of this study was to investigate the contribution of semantic transparency to morphological segmentation in reading Chinese compound words. In the study, we primarily compared reaction times to the same target following a fully transparent prime and fully opaque prime. Apart from this comparison, we also used the same material design to prime the same target with fully transparent or partially opaque compounds to compare priming differences. To understand the time course of semantic contribution to morphological processing, we examined the patterns of facilitation for the various types of semantic similarity in the short- term priming paradigm over a range of SOAs.

Fully transparent vs. *fully opaque compounds*

Progressive impact of semantic transparency on morphological processing while the prime exposure duration increased is observed in this study. To be more specific, the results under each priming condition showed that semantically transparent primes significantly facilitated their targets' identification across all the three SOAs. Opaque primes however started to show robust priming effects only at the SOA of 150ms and marginally significant priming effects at the SOA of 250ms. At the SOA of 50ms, the difference between transparent and fully opaque effects was smallest. When SOAs increased (150ms and 250ms), transparent facilitation effects were stronger than effects for opaque primes, although only marginally significant by item analysis.

Fully transparent vs. partially opaque compounds

We observed a U shape pattern of semantic transparency effects between completely transparent and partially opaque compounds. Namely, at a brief SOA of 50ms, transparent compounds revealed robust constituent priming effects and partially opaque compounds demonstrated marginally significant priming effects. Magnitudes of priming effects did not differ between these two types of compounds. At the SOA of 150ms, the magnitude of facilitation for transparent primes was robust whereas priming effects under the partially opaque condition were absent. Facilitation differences between transparent and partially opaque compounds were significant. When the SOA was 250ms, both transparent and partially opaque compounds significantly reduced target decision latencies and the priming effects did not differ between these two conditions.

Two aspects of the data have implications for our general understanding of morphological processing. The first relates to the time course over which different types of compounds are processed in relation to their morphological constituents. The summarized results suggest that semantic effects are temporally constrained. When processing time for the prime is limited, effects of semantic transparency are generally absent whereas under those conditions in which prime exposure time is relatively long, semantic transparency effects are evident. The second pertains to cross-linguistic difference in facilitation effects for opaque or partially opaque words. In the present study, we documented significant priming effects for partially opaque and opaque compounds in the immediate priming conditions and marginally significant facilitation effects in the masked priming conditions. This pattern of results indicates that morphemes are processed even in those semantically opaque Chinese compounds at some point of word recognition.

One may argue that the reason morphologically related primes significantly reduced reaction times of their target recognition when compared to unrelated primes is that the prime word and the target have overlapping semantic features. This then means that facilitation effects found in the current study could arise purely at the semantic activation of whole words without any involvement of morphemes. However, we observed marginally significant priming effects for partially opaque compounds as well as numerical facilitations for opaque compounds in the masked priming condition. And also we found significant priming effects for these two types of primes under the short-term priming paradigm. All these findings support our argument that these priming effects could not be the result of semantic overlap at the compound level, because partially opaque and fully opaque compounds are not semantically related with their targets. The pattern of facilitation effects across fully transparent, partially opaque and fully opaque compounds suggests that in the compound word recognition, constituent morphemes are activated.

Sublexical account and the modified versions

As described in the introduction, advocates of ‘sublexical’ theories of morphological processing proposed that morphological constituents are explicitly represented at one level lower than the whole word representation (Taft & Forster, 1985; Taft & Zhu, 1997). In real time processing, constituent morphemes are first automatically stripped off from polymorphemic words for lexical access in order to successfully access the complex words. They further postulated that the morphological parsing is only a process of segmenting the surface form of a complex word into its constituents, independent of semantic factors. Accordingly, we would expect a purely form-based morphological segmentation of Chinese compounds, regardless of semantic transparency in the early stage of word recognition. Although the unreliable semantic transparency effects observed at the SOA of 50ms (Experiment 2) were consistent with the claim that the morphological processing in the early stage is independent of semantic transparency, our results of significant facilitation effects for transparent primes indicate that facilitation does not rise solely from morphological segmentation at the orthographic level because Chinese-English translation equivalents do not share representations at this level. The results imply that semantic processing of morphemes is engaged only in the early stages of compound recognition for transparent compounds.

These results might be better explained by later modifications (e.g., Taft, 2003; Taft & Nguyen-Hoan, 2010; see also Taft, Liu & Zhu 1999 for Chinese compound processing) made to the previous ‘sublexical’ model on morphological processing. Within a localist interactive activation framework, these models proposed that morphological information is stored at an intermediate level between form level and semantic level of the whole word. This level (called ‘lemma’) is in essence an abstract level because it captures the correlation between orthographic and semantic knowledge during the processing of the whole word. They also postulated that morphemes and whole words are connected both through the orthographic and semantic links for transparent compounds and that only morphological-orthographic links exist between constituents and the whole word for opaque compounds. The co-occurrence of form and semantic activations at the ‘lemma’ level can explain why we observed semantic processing of morphemes in all three types of primes at different SOAs. However, in these modified models, processing of morphemes is sensitive to the degree of semantic transparency of a compound when processing ascends up to the semantic level. If the meaning of a morpheme is not consistent with the meaning of the whole word, they hypothesized that the recognition system suppresses the morphological activation to an inactive level. The fact that significant priming effects were found under truly opaque conditions at later stages of processing are indicative of semantic links between morphemes and compounds and thus poses a challenge to these models. Alternatively, if we consider facilitation effects for opaque compounds in short-term priming as post-lexical effects, then this account would have problems explaining why at the SOA of 150ms, we observed significant priming effects for fully opaque compounds in the absence of robust priming effects for partially opaque compounds.

Dual-route mechanism

Dual-route models of morphological processing postulate that both lexical representation of whole words and morphological constituents exist in the lexicon. In real time processing, these models depict two distinct mechanisms for the processing of morphologically complex words: rule-governed computation (parsing route) and lexical look-up (direct route). Some variants of this view assume that choosing which route for lexical access is dependent on semantic transparency of a polymorphic word (Marslen-Wilson et al., 1994). On the one hand, for words whose morphemes are explicitly represented, such as semantically transparent words, lexical access is based on automatic parsing of morphologically complex words into their constituent morphemes. On the other, for words that do not have explicit morphemic representations, like semantically opaque words, they are not decomposable and therefore the visual stimulus of a complex word directly activates the access representation of the whole-word. Other versions of dual route model hold that the two routes are activated in parallel and "race" to achieve identification (e.g., Schreuder & Baayen, 1995).

The dual route mechanism (Marslen-Wilson et al., 1994) is concerned in particular with the role of morphological and semantic relationships in determining the properties of lexical representations. According to Marslen-Wilson et al. (1994), all transparent compounds are stored in a decomposable manner and processed compositionally whereas opaque compounds are represented as whole words and accessed as unanalyzed wholes. Consistent with this theory, they found robust priming effects in the cross-modal priming technique for transparent derivationally complex primes and nonexistent priming effects for semantically opaque derivationally complex primes. Significant priming effects for transparent primes are a result of activation of the same lexical stem shared in the prime-target pairs. By contrast, semantically opaque prime-target pairs do not share a common lexical stem and hence the prime cannot facilitate decision latencies to its target. Following this claim, we would also hypothesize that if semantically transparent compounds are decomposed, the overlapping semantic representations that are shared by primes and their targets in the current study should generate significant priming effects. For semantically opaque compounds, as they are processed as indecomposable whole words, unreliable priming effects should be observed. Therefore, stronger priming effects for transparent items than opaque items are to be expected. Although at SOAs of 150ms and 250ms, the pattern that semantic transparent primes gave rise to stronger priming effects than matched opaque primes appears to be interpretable within theories of two distinct mechanisms for compound processing, the significant priming effect for opaque words at these time lags meanwhile poses a challenge to dual-route models. Robust facilitation to target decisions after opaque primes suggest that instead of stored as a whole in the lexicon, opaque compounds were processed via the parsing route at later stage of processing. This is in fact in accordance with findings from a recent similar study performed by Myers and his colleagues (Myers, Derwing, & Libben, 2004a); although the main purpose of this study is to investigate the effect of priming direction in reading Chinese compounds. Using the short-term priming paradigm, in one experiment, they manipulated a Chinese morpheme target primed by a Chinese compound differing in the degree of semantic transparency. Like our results, at the SOA of 200ms, both transparent and opaque primes generated significant facilitation effects on the targets. Similarly, our findings for partially opaque compounds are also problematic for this dual-route model. At the SOA of 250ms, we found that partially opaque primes significantly facilitated the target recognition compared to unrelated primes. These findings together suggest that the traditional divide between regulars (processed by online computation) and irregulars (processed by direct retrieval from the mental lexicon) in dual-route models must be too simplistic.

The results may be accommodated with other versions of dual-route hypothesis. The time course of semantic transparency observed in this experiment is more in agreement with the model of Schreuder and Baayen

(1995). According to this account, morphologically complex words can be represented at the morpheme and/or word level. In the identification of a morphologically complex word, the direct route (i.e. direct lexical retrieval of the whole representation) will be activated simultaneously with the morphological route (i.e. computing the meaning of the whole by adding the meanings of constituents together). The winner of the two routes is the one whose access representation is more highly activated. Semantic transparency is one factor determining the activation level of the access representation and therefore it also determines which route will be most efficient and win the "race" in the end (Raveh, 1999). We interpret the results that opaque compounds did not show priming effects till at the later stages by hypothesizing that in the early stage of word recognition, whole-word and morphemic representations are activated in parallel and compete for the access route. As a result, no facilitation effect was found. In the later stage of processing, the morphological parsing route races over the direct retrieval route and reliable priming effects unfolded. The pattern of results observed in the partially opaque condition across three SOAs, however, cannot be readily explained within this dual-route model. It could not explain the fluctuated wave of the competition within partially opaque compounds. In particular, it is unclear why the parsing route has the upper hand in the beginning but loses the race in the middle stage of the processing and gains the upper hand again later.

The connectionist models of morphological processing

The connectionist models of morphological processing would provide a more successful account for the results we observed. From a connectionist perspective, morphemes are not explicit representation units in the lexicon. Rather, they are abstract learned regularities emerging in the mapping between the forms of polymorphemic words and their meanings (Plaut & Gonnerman, 2000). In repeated exposure to morphologically related words (e.g., *attention*, *attentive*, *attend*), the network would automatically detect that a particular surface pattern consistently appear in these words and it systematically maps onto certain aspects of meaning. Gradually, these morphologically related words develop a very similar internal representation reflecting the statistical regularities of the form and meaning match of the shared morpheme. As the degree of the form and meaning association is graded, the model predicts that when orthographic overlap is held constant, semantic factors should contribute to morphological processing in a graded manner. And the converse is true (Plaut & Gonnerman, 2000; Raveh, 1999).

The other characteristic one can observe in connectionist models is that morphological behavior is interactive. As Zhou and Marslen-Wilson (2009) proposed, morphological representations and word representations are activated in parallel in Chinese compound word recognition. In real time processing, the activations of morphemes and whole words affect and are affected by each other, resulting in competition and cooperation between them at orthographic, phonological and semantic levels. In alignment with this logic, we can argue that semantic transparency determines the processing speed of a morphologically complex word. Semantically transparent words are processed faster and more accurately than less transparent words because "the activation of semantic representations of constituent morphemes would partially active representations of whole words" (p. 1015). Indeed, there is evidence that semantically transparent Chinese compounds are responded to more quickly than semantically opaque compounds (e.g., Myers et al., 2004a; Peng et al., 1999).

Having described the characteristics of the activation dynamics of morphologically complex words, we will now turn to discuss the how these characteristics affect the effectiveness of transparent and opaque words as primes. In particular, I will explain how the magnitude of priming effects changed as a function of the time available for their processing (SOA) and the semantic transparency of the primes. As in Chinese compound processing, morphemes and compounds are activated simultaneously and interactively, the activation status of the critical morpheme is not only dependent on how systematic its form matches its meaning but also on how similar its meaning is with the meaning of the whole word. Therefore, the activation levels of the prime word and its morpheme are results of this interactive process. If the activation status of the prime is consistent with that of the target word, the presence of the prime will produce facilitation effects. If the residual states of the prime are in contradiction with the activation status of the target, the prime states then serve as hindering forces in target processing and thus result in negative or no priming effects (Raveh, 1999). Next I examine how our results can be interpreted based on this line argument within connectionist models.

First, we consider the results from the masked priming paradigm. Significant facilitations were obtained for fully transparent primes (23ms), whereas fully opaque primes generated numerical facilitation effects (11ms). These results showed that semantic activation of morphemes in transparent compounds occurred in the early stage of processing, and this morphological activation should not be considered as simple morphological parsing at the form level because Chinese-English translation equivalents are unlikely to share orthographic representations. In the meantime, we did not find a significant semantic transparency effect in the contrast between transparent and fully opaque words or transparent and partially opaque words at the SOA of 50ms. The failure to find semantic transparency effects has also been reported in many studies (e.g. English: Rastle et al., 2000; Feldman et al., 2004; Hebrew: Frost et al., 1997; French: Longtin et al., 2003). This pattern of results seems to conflict with the connectionist proposal that morphology emerges from learned regularity among the mapping of forms and meanings of words and therefore morphological processing is not independent of orthographic or semantic factors. To have a better understanding of what the connectionist approach actually predicts throughout word recognition, Ruckel and Raveh (1999) trained recurrent networks to simulate the contribution of semantic similarity to morphological processing (as cited in Raveh, 1999). They found that when semantic transparent and opaque words are processed in the early stage of recognition, although their processing is influenced both by semantic and orthographic units, orthographic similarity of the input plays a more determining role at this initial level of processing. Therefore, when the effects of transparent and opaque words are examined under experimental conditions that tap into the form-based level of processing (e.g., masked priming with a brief SOA), these words should behave with no difference so long as their form structures are similar. We can the hypothesize that at the SOA of 50ms in Experiment 2, processing of the prime word is still at the very early stage of word recognition and accordingly meanings of a word is not fully activated, we therefore do not expect significant facilitation differences between fully transparent and fully opaque primes and between completely transparent and partially opaque primes.

However, their simulation also revealed that when given more processing time, the recognition pattern of transparent and opaque compounds starts to diverge. In Experiment 3, the results showed that priming differences between transparent and opaque primes started to magnify and approached significance at the SOA of 150ms. Specifically, we found robust priming effects for both transparent and opaque primes but priming effects for transparent primes were stronger than those for opaque primes. Because Chinese compound recognition is an interactive process between morphemes and whole words and because this interaction in transparent compounds is a beneficial process, we can assume that the morphological processing in transparent primes takes place earlier relative to partially opaque and opaque compounds, and therefore we found significant priming effects for transparent words at the SOA of 50ms. Although morphemes are processed more quickly in transparent compounds, this does not mean that at the SOA of 50ms, the activation of the whole word has reached a full stage of recognition. In fact, we argue that it is quite possible at such an early stage; meaning of the whole transparent word is activated to some extent but not to the full status. When the SOA increases to 150ms, the full compounds should reach a richer level of activation and as a result, morphological activation should benefit more from the stronger activation states of a transparent compound at this stage and pass more positive feedback to whole word activation. As a result, when the target is presented at the SOA of 150ms, we get a larger magnitude of priming effects in transparent prime words (47ms) compared to those in the masked priming condition (22ms). Unlike transparent primes, opaque primes are recognized relatively slowly and thus their activation levels are not as strong as that of transparent compounds at the SOA of 150ms. In the meantime, morphemes are activated as well. One can imagine that there will be semantic competition between morphemes and the whole word but we can assume that the partial activation of the whole word is not overwhelming enough to override the activation of the morphemes. Therefore, when the target is presented, the residual status of the prime compound still matches that of the target. This explains why we found reliable facilitation effects in opaque words at the SOA of 150ms. As reviewed previously, Liu and Peng (1997) tested morphological activation in opaque compounds at a closer SOA (143ms). They found that decision to target were significantly facilitated by the opaque prime relative to an unrelated control, indicating that morphemes in opaque compounds are activated in the short-term priming paradigm. Combined with their study, our significant priming effects in opaque condition were not so surprising and spoke to the fact that morphological activations in opaque words are available at shorter SOAs. In terms of the marginally different facilitation effects we got for transparent and opaque compounds at the SOA of 150ms, we can explain the effects based on the following argument. In opaque compounds, semantic competition between the morphemes and the whole word takes place at the SOA of 150ms. By contrast, the activation of the full word and morphemes in transparent compounds strengthen the activation level of each other. It is the mutually fortified activation between the morphemes and the transparent compound leads to stronger priming effects in transparent compounds relative to opaque compounds. As time increases, the advantage of this mutual relationship in transparent compounds becomes more evident. Indeed, at the SOA of 250ms (Experiment 1), difference scores between truly transparent and opaque priming effects increased further from 16ms to 18ms. In addition, we observe strong priming effects for both transparent and opaque compounds. We can explain the facilitation effect in transparent primes based on similar argument we proposed at the SOA of 150ms. Interestingly, although priming effects for opaque words were strong, we observe a numerical change in the magnitude of this facilitation effect. To be more specific, the priming effects at the SOA of 250ms were smaller (23ms) compared to those at the SOA of 150ms (34ms), although the decrease was not significant statistically. We can hypothesize that at the SOA of 250ms, the activation of the whole opaque compound magnifies compared to that at the SOA of 150ms. Indeed, at the SOA of 250ms, we found that the magnitude of priming effects for opaque words (23ms) was 11ms smaller than that at the SOA of 150ms (34ms). Given more time, the lexical processor is more likely to suppress the semantic activation of morphemes. The increased activation strength of the whole word at the SOA of 250ms implies a more intense semantic competition between morphemes and the opaque compound. Therefore, compared to the SOA of 150ms, the residual status of the prime compound at this time less consistently matches the activation status of the target word. As a result, priming effects in the opaque condition decreased at the SOA of 250ms relative to that at the SOA of 150ms. Despite of the fact that whole word was activated more strongly, at the

SOA of 250ms, we can hypothesize that its activation level has not yet reached a full status, because its activation is not overwhelming enough to override the activation of morphemes at this time. Therefore, we can still observe the significant facilitation effects from opaque compounds, compared to unrelated primes.

In the comparison between fully transparent and partially opaque compounds, at the SOA of 50ms, to the same extent fully transparent and partially opaque primes reduced reaction times to their shared targets. We can account for this result following the same logic discussed above. In the early stage of word recognition, processing at the semantic level receives little activation and therefore semantic transparent effects are not able to contribute significantly to morphological processing. In the meantime, morphemes in partially opaque compounds are activated relatively slower compared to transparent compounds and as a result, we only observed a marginally significant priming effect in the partially transparent condition. At the SOA of 150ms, however, we found the degree of semantic transparency strongly influenced morphological processing in fully transparent and partially opaque compounds. Namely, fully transparent items yielded robust priming effects whereas such effects were absent in partially opaque condition. We can assume that the recognition system has processed semantics of transparent compounds to their full at the onset of the target. As these compounds are semantically similar to the targets, truly transparent words strongly reduced reaction times to their targets relative to unrelated primes. In contrast, we hypothesize that the nonsignificant priming effects in partially opaque primes are the result of semantic competition between the whole compound and its morphemes as well as the semantic competition between the transparent morpheme and the opaque morpheme. In chapter 2, we analyzed that in our testing material, meanings of partially transparent compounds can be largely or even utterly derived from their transparent morphemes. Therefore, based on the interactive account of Chinese compound processing, we can assume that once transparent morphemes started being processed, recognition of the partially opaque compound as a whole starts immediately as well. Therefore, at the SOA of 150ms, like fully transparent compounds, a partially opaque word has already been processed to its full and correct states. This then indicates that the semantic competition between the whole word and the critical opaque morpheme reached asymptote so as to override the semantic similarity between the tested morpheme and the target. That is why we found a small and unreliable priming effect for partially opaque compounds.

The fact that truly transparent and partially opaque compounds gave rise to equivalent levels of priming effects at the SOA of 250ms was unexpected. Given enough time, it is plausible that morphemes are activated semantically regardless of semantic transparency. That is why we observed priming effects for all three types of primes: transparent, opaque and partially opaque compounds. But we would also expect that transparent compounds should produce more priming effects compared to opaque and partially opaque compounds. Similar findings were also reported by Frost et al. (2000) studying Hebrew morphology in which opaque words gave rise to robust priming effects in the cross-modal priming paradigm. The strong opaque facilitation effects in their study were resonant with what they previously found in a masked priming experiment (Frost et al., 1997). Seemingly, it is difficult to reconcile these two studies within the PDP model in that the reliable priming effects obtained under opaque condition were reflective of the fact that Hebrew morphological activation is independent of semantic factors of the whole word (Frost et al., 2000). Plaut and Gonnerman (2000) responded to the challenge by claiming that “morphological processing is far more subtle than is often assumed, and that the degree to which morphologically related items without semantic similarity should exhibit priming on a connectionist account depends on the degree of morphological structure of the entire language” (p.456). They simulated the effects of the overall degree of morphological richness of the language and semantic transparency on the behavior of connectionist networks. In these simulations, three-layered (input, hidden, and output) connectionist networks were trained on morphological richness of a language by varying “the frequency and extent to which the structure of words within the language—both in terms of their surface forms and their meanings—could be systematically decomposed into components that participate in the construction of many other words” (Plaut & Gonnerman, 2000, p.464). The results revealed that morphological richness of a language had a substantial impact on the simulated behavior of lexical decision task. Specifically, targets produced faster RTs in the morphologically rich language when compared with the impoverished language. Furthermore, they found that targets were significantly facilitated by morphologically related but semantically opaque primes in the morphologically rich language whereas such robust priming effects were absent in the morphologically impoverished language. They proposed that the processing of constituents in opaque items is strongly dependent on the degree of morphological richness in a language. The concept of morphological richness is particularly relevant to the *componentiality* principle underlying the connectionist approach. The notion of "componentiality" is defined as "the degree to which parts of the input can be mapped independently from the rest of the input" (p.459). The ability of connectionist networks to develop componential internal structures is in accordance to the degree of morphological richness of a language like Hebrew. In morphologically rich language, due to the fact that morphological complex words are highly componential in the majority of the language's vocabulary, even the small amount of opaque items develop decomposable morphological structures and exhibit robust priming effects. The concept of "componentiality" applied to Chinese has something to do with the fact that written Chinese marks morpheme boundaries prominently. As indicated previously, a large percent of Chinese compounds are composed of two morphemes, with each morpheme mapping almost perfectly to one character. Different from English, the Chinese writing system does not mark word boundary, but morphemes. We can then hypothesize that this unique morphological structure makes morphemes more explicitly "seen" in a word and that Chinese readers compulsorily compose these isolated small chunks (i.e. morphemes) into a word in reading[2]. This would imply that it is particularly easy for the network to develop componential internal structures in Chinese compound processing. Therefore, when the processing time was extended to longer SOAs (150ms and 250ms), fully opaque compounds significantly facilitated their target recognition.

Now let us return to the unreliable differences in semantic transparency

[2] This argument is based on the suggestion given by one anonymous reviewer of this thesis.

effects between fully transparent and partially opaque primes at the SOA of 250ms. We can then hypothesize the internal structures of the partially opaque compounds in our study are componential to the similar degree as that of fully transparent compounds. We came to this hypothesis based on the claim that connectionist networks can apply the ability to learn componentiality not only across languages but also across classes of words within a language (Plaut & Gonnerman, 2000). Therefore, the extent to the internal representation of a word is componential is accordance to the degree of its semantic transparency. In Chapter 2, we have analyzed that meanings of partially transparent compounds in our study can be large or utterly derived from meanings of their transparent morphemes. In this sense, partially opaque compounds should behave more like completely transparent compounds than opaque compounds. And thus the network captures their internal structures as almost componential as those of fully transparent words. If this is so, then why did we still observe significant differences between transparent and partially opaque facilitations at an SOA of 150ms? This change over time in fact falls naturally from the dynamics of the network learning to develop such componential internal structure. Plausibly, due to the semantic competition between the opaque morpheme in partially opaque compounds and the whole word, it takes longer for the network to stabilize the componentiality of their internal structures relative to fully transparent compounds. That is why we observed unstable patterns of morphological activation under partially opaque condition at the short SOA (50ms) and the intermediate SOA (150ms). Namely, in the masked priming paradigm, facilitation effects for these words were marginally significant and were non-significant in short-term priming with an SOA of

150ms. However, given long enough time of processing (250ms), reliable priming effects were observed for partially opaque compounds, which were of the same magnitude of fully transparent compounds.

Finally, the dynamics of the development of “componentiality” can also explain the time course of priming effects for fully opaque primes. As these words are at the farthest end along the semantic transparency continuum, they take the longest time to stabilize componential internal structures. Therefore, at the SOA of 50ms, fully opaque compounds failed to facilitate their target recognition. They did not start to produce strong priming effects until the SOA was increased to 150ms. However, at an SOA of 250ms, we also observed an attenuation of the facilitation effect size for these words. That is, at this time lag, completely opaque compounds only gave rise to marginally significant priming effects. In the same vein, we may hypothesize that stable and strong facilitation to fully opaque targets would take place beyond 250ms.

In sum, connectionist models of morphological processing provide a fine-grained account for the changes we observed in morphological processing in Chinese compounds as a function of semantic transparency at different time courses. However, a potential limitation of the present study is that may be misleading to investigate the time course of semantic contributions to morphological processing with the lexical decision task. Requirements of the lexical decision task may dilute the degree of which semantics is analyzed in the task. This concern arises because this task is that semantics may not play a significant role when subjects decide whether a letter string is a real word or not mainly based on a familiarity check of the orthographic information of the targets (Balota & Chumbley, 1984). Therefore, one question remains interesting and worthy to tap into in our current study: can we obtain a robust semantic transparency effect in other tasks that emphasize semantic processing more than LDT like semantic categorization task?

Limitations

This thesis has some limitations. A general limitation is the cross-language priming task we used in general and the interpretation scope of the results of the paradigm. As the Chinese words and characters do not share phonology or orthography with the English targets, the results can detect morpheme activation of the prime at the semantic level. In other words, this cross-language translation priming in our study is more effective in revealing semantic activation of the morpheme in a compound. As reviewed in the first chapter, a major worry in morphological priming studies is how to distinguish morpheme priming from confounding semantic priming. Therefore the cross linguistic priming effects we obtained cannot be comparable to morphological priming effects studied previous in the within language priming paradigm. And this calls for cautious interpretation of our results. Another source of limitation derives from the partially opaque compounds we selected here. The original idea of including this type of compounds is to construct a graded spectrum of semantic transparency in our Chinese compounds. As analyzed previously, the compounds we selected are more transparent than opaque because to a larger extent transparent constituents contribute more than opaque ones to the meanings of full words. Further studies need a more delicate control of this type of compounds so that its semantic transparency is truly in between that of completely transparent and opaque compounds. In this case, it is interesting to see whether the pattern of facilitation effects we observed in the partially opaque condition can be replicated.

Concluding remarks

To conclude, the primary empirical contribution of the present study is to document the divergence of morphological facilitation effects between fully transparent and fully opaque compounds, as well as fully transparent and partially opaque compounds at various SOAs. At short SOAs, we found significant priming effects only for transparent compounds, whereas marginally significant priming effects were observed for partially opaque compounds and numerical positive facilitation effects observed for fully opaque compounds. Moreover, effect sizes between transparent and opaque primes as well as transparent and partially opaque primes were not significantly different. At longer SOAs, both transparent and opaque compounds significantly facilitated target decision latencies but the effect sizes for semantically transparent compounds were larger than those for semantically opaque compounds. Effects of semantic transparency that varies across experimental contexts pose a challenge to traditional models of morphological processing in which morphological processing is an all-or-none effect. Connectionist models of morphological processing provide a good account for our results, attributing the timely-constrained semantic transparency effects to the interactive meaning and form activation between constituent morphemes and whole words.

The most novel contribution of the present study is to use the cross-language priming paradigm to investigate language-internal morphological processing. In the literature of morphological priming, one long standing concern is to rule out form-based or semantics-based explanations of morphological priming. This cross-linguistic paradigm may turn out to be an effective way to circumvent possible objections again traditional within-language morphological priming, when applied to languages in which cognates in translation equivalents are constantly found. As for Chinese morphological processing, more creative modification of this paradigm is required to address the concern of pure semantic interpretation of morphemic activation we pointed out above and to examine the time course of this semantic transparency effect.

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APPENDIXES

APPENDIX A:
TABLES AND FIGURES

Table 1. Stimulus Characteristics of **Experiment 1**

	Log frequency(per million)	Length/Stroke
Transparent prime	1.78(1.61)	15.48 (4.38)
Opaque prime	2.00(1.94)	13.67 (4.61)
Unrelated prime	1.80(2.13)	15.74 (4.85)
English target	10.56(1.80)	5.74(2.03)
Transparent prime	1.71(1.71)	13.47(3.91)
Partially opaque prime	1.86(2.00)	14.33(4.14)
Unrelated prime	1.77(1.82)	14.2(3.17)
English target	10.87(1.24)	4.33(1.63)

Table 2. The mean response times (ms), error rates according to relation type and to priming relation, and priming effects in **Experiment 1**

		Priming conditions			**Priming effects**	
	Transparent	**Opaque**	**Unrelated**	**TT-U**	**OO-U**
	花园-- flower	花生-- flower	多少-- flower		
RT	580(75)	598(88)	621(83)	41**	23(*)
Error	.07(.09)	.07(.09)	.11(.10)		
	Transparent	**Partially opaque**	**Unrelated**	**TT-U**	**TO/OT-U**
	出门--door	专门--door	到来-- west		
RT	558(73)	565(76)	596(80)	38*	31*
Error	.04(.07)	.07(.09)	.08(.12)		

Table 3. Stimulus Characteristics of **Experiment 2/3**

	Log frequency(per million)	**Length/Stroke**
Transparent prime	1.70(1.67)	15.53(4.93)
Opaque prime	1.90(1.89)	14.13(4.35)
Unrelated prime	1.85(1.82)	16.17(3.83)
English target	10.54(1.50)	5.33(1.79)
Transparent prime	1.71(1.71)	13.47(3.91)
Partially opaque prime	1.86(2.00)	14.33(4.14)
Unrelated prime	1.77(1.82)	14.2(3.17)
English target	10.87(1.24)	4.33(1.63)

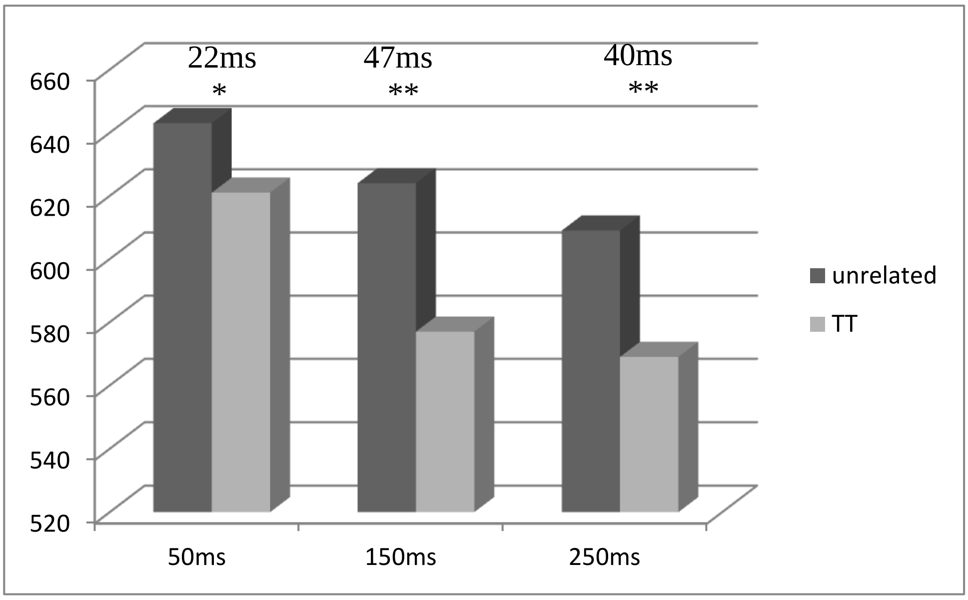
Table 4. The mean response times (ms), error rates according to relation type and to priming relation, and priming effects in **Experiment 2**

		Priming conditions		**Priming effects**	
	Transparent	**Opaque**	**Unrelated**	**TT-U**	**OO-U**
	花园--flower	花生-- flower	多少--flower		
RT	624(94)	636(106)	647(109)	23*	11
Error	.08(.07)	.08(.09)	.10(.11)		
	Transparent	**Partially opaque**	**Unrelated**	**TT-U**	**TO/OT-U**
	出门--door	专门--door	到来--west		
RT	618(64)	620(86)	638(99)	20*	18(*)
Error	.09(.11)	.08(.08)	.10(.12)		

Table 5. The mean response times (ms), error rates according to relation type and to priming relation, and priming effects in **Experiment 3**

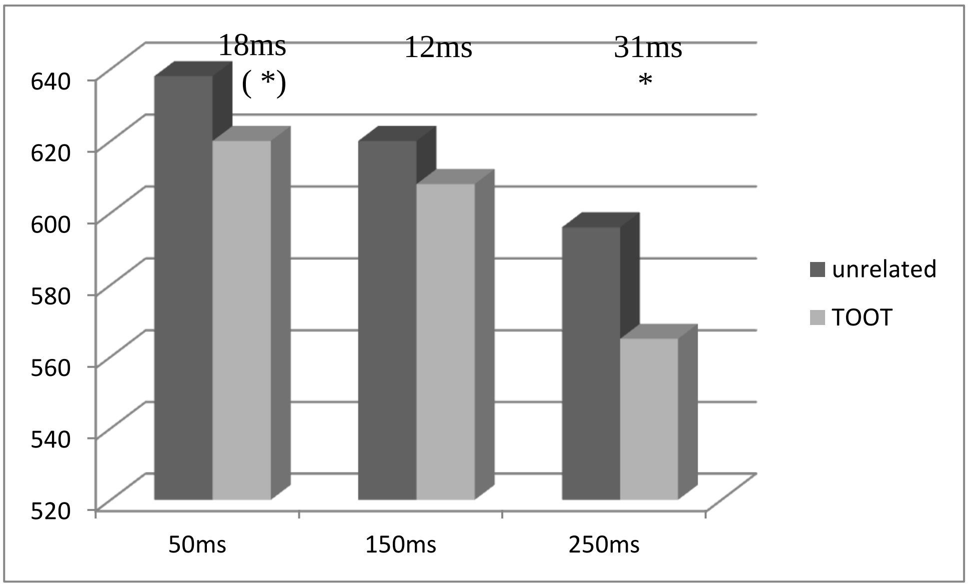
		Priming conditions		**Priming effects**	
	Transparent	**Opaque**	**Unrelated**	**TT-U**	**OO-U**
	花园--flower	花生-- flower	多少--flower		
RT	578(72)	594(74)	628(77)	50**	34*
Error	.07(.10)	.08(.10)	.09(.10)		
	Transparent	**Partially opaque**	**Unrelated**	**TT-U**	**TO/OT-U**
	出门--door	专门--door	到来--west		
RT	575(71)	608(88)	620(98)	45**	12
Error	.06(.07)	.12(.10)	.13(.10)		

Figure 1. Priming effects of completely transparent compounds (combined results of TT1 and TT2) over time



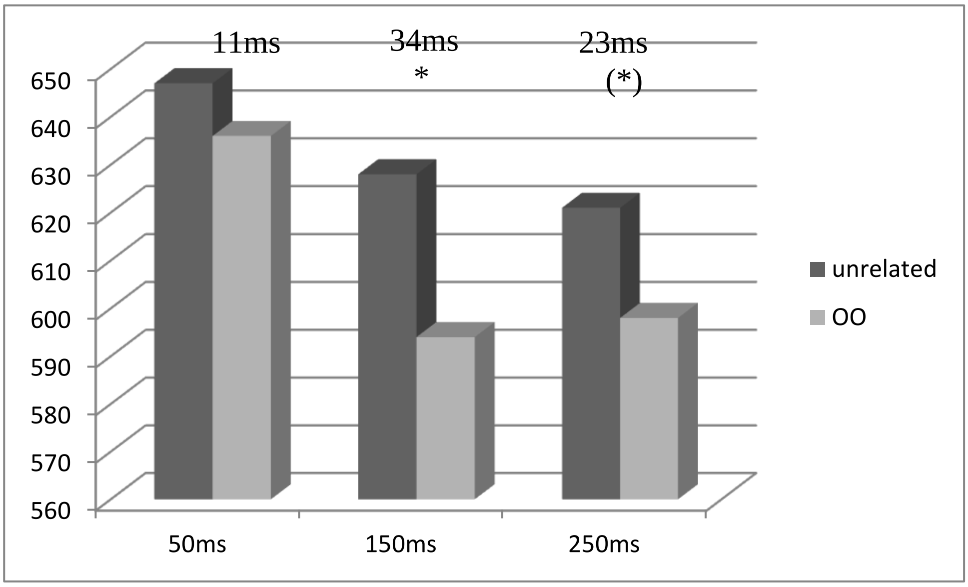
(*) marginally significant; * p<.05; ** p<.01.

Figure 2. Priming effects of partially transparent compounds over time



(*) marginally significant; * p<.05; ** p<.01.

Figure 3. Priming effects of completely transparent primes over time



(*) marginally significant; * p<.05; ** p<.01.

APPENDIX B

EXPERIMENT STIMULI

The sets of stimuli of the three priming conditions from **Experiment 1**

I) Completely transparent (TT) vs. completely opaque (OO) set

	PRIME	TARGET
Transparent	积雪 accumulated snow (lit. accumulate + snow)	accumulate
Opaque	积极 enthusiastic (lit. accumulate + pole)	
Unrelated	数学 math (lit. count + subject of study)	
Transparent	黑板 blackboard (lit. black + board)	board
Opaque	老板 boss (lit. old + board)	
Unrelated	起源 originate (lit. raise + origin)	
Transparent	估计 estimate (lit. estimate + calculate)	calculate
Opaque	伙计 employee (lit. partner + calculate)	
Unrelated	自由 liberty (lit. self + follow)	
Transparent	开关 switch (lit. open + close)	close
Opaque	机关 institution (lit. machine + close)	
Unrelated	病房 ward (lit. sickness + room)	
Transparent	造型 style (lit. create + form)	create
Opaque	造化 good fortune (lit. create + change)	
Unrelated	平整 even (lit. even + flat)	
Transparent	难过 sad (lit. difficult +pass)	difficult
Opaque	难道 could it be said that (lit. difficult+ way)	
Unrelated	遗留 leave over (lit. lose + leave behind)	
Transparent	尽力 try one's best (lit. use up + strength)	use up
Opaque	尽管 although (lit. use up + manage)	
Unrelated	目标 aim (lit. eye + target)	
Transparent	食指 index finger(lit. eat + finger)	finger
Opaque	发指 angry (lit. hair + finger)	
Unrelated	苦笑 forced smile (lit. bitter + smile)	
Transparent	电流 electricity (lit. electricity + flow)	flow
Opaque	风流 talented and romantic (lit. wind+ flow)	
Unrelated	共同 common (lit. together + same)	
Transparent	花园 garden (lit. flower + park)	flower
Opaque	花生 peanut (lit. flower + birth)	
Unrelated	畏惧 frighten (lit. fear+ dread)	
Transparent	主将 main general (lit. main + general)	general

Opaque	麻将 mahjong (lit. hemp + general)	
Unrelated	点名 call the roll (lit. point out + name)	
Transparent	神圣 sacred (lit. god + holy)	god
Opaque	神经 nerve (lit. god + pass)	
Unrelated	成就 achievement (lit. become + accomplish)	
Transparent	垂直 vertical (lit. hang + straight)	hang
Opaque	垂青 appreciate (lit. hang + green)	
Unrelated	到来 arrival (lit. arrive + come)	
Transparent	马路 street (lit. horse + road)	horse
Opaque	马虎 casual (lit. horse + tiger)	
Unrelated	身边 by one's side (lit. body+ side)	
Transparent	百货 general merchandise (lit. hundred + product)	hundred
Opaque	百合 lily (lit. hundred + together)	
Unrelated	配合 coordinate (lit. join in marriage + together)	
Transparent	夜里 in the night (lit. night + in)	in
Opaque	公里 mile (lit. common+ in)	
Unrelated	严格 strict (lit. strict + standard)	
Transparent	新生 newborn (lit. new + life)	life
Opaque	卫生 hygiene (lit. guard + life)	
Unrelated	观看 watch (lit. look + see)	
Transparent	眼光 foresight (lit. eye + light)	light
Opaque	耳光 slap (lit. ear+ light)	
Unrelated	车站 station (lit. car + stop)	
Transparent	指针 hand (lit. point + needle)	needle
Opaque	方针 policy (lit. square + needle)	
Unrelated	包装 wrap up (lit. wrap + pack)	
Transparent	红旗 red flag (lit. red + flag)	red
Opaque	红颜 a beauty(lit. red + color)	
Unrelated	富有 wealthy (lit. rich + have)	
Transparent	沙漠 desert (lit. sand + the massive land)	sand
Opaque	沙发 sofa (lit. sand + send)	
Unrelated	合作 cooperate (lit. together + work)	
Transparent	线段 line segment (lit. line + segment)	segment
Opaque	手段 trick (lit. hand + segment)	
Unrelated	占有 occupy (lit. take up + own)	
Transparent	分析 analyse (lit. separate +resolve)	separate
Opaque	分寸 appropriate (lit. separate + inch)	

Unrelated	照片 photo (lit. take a picture + thin piece)	
Transparent	影片 film (lit. shadow + slice)	shadow
Opaque	影响 influence (lit. shadow + sound)	
Unrelated	保温 keep warm (lit. keep + warm)	
Transparent	听说 hear (lit. listen + talk)	talk
Opaque	小说 novel (lit. small + talk)	
Unrelated	光滑 smooth (lit. light + slippery)	
Transparent	矛头 head of spear (lit. head + spear)	spear
Opaque	矛盾 contradiction (lit. spear + shield)	
Unrelated	骄傲 pride (lit. arrogant + proud)	
Transparent	物理 physics (lit. thing + theory)	thing
Opaque	物色 seek (lit. thing + color)	
Unrelated	呼吸 breath (lit. hale out +hale in)	
Transparent	万千 hundreds of thousands (lit. ten thousand + thousand)	thousand
Opaque	秋千 swing (lit. fall + thousand)	
Unrelated	骄傲 pride (lit. arrogant + proud)	
Transparent	楼上 upstairs (lit. building + up)	up
Opaque	马上 immediate (lit. horse + up)	
Unrelated	选民 voter (lit. elect + the mass)	
Transparent	噪声 noise (lit. noisy + voice)	voice
Opaque	相声 crosstalk (lit. mutual + voice)	
Unrelated	辽阔 broad (lit. distant + broad)	

II) Completely transparent(TT) vs. partially opaque (TO/OT) set

	PRIME	TARGET
Transparent	将军 general (lit. support + army)	army
Opaque(TO)	冠军 champion (lit. crown + army)	
Unrelated	富有 wealthy (lit. rich + have)	
Transparent	脸色 complexion (lit. face + color)	color
Opaque(TO)	角色 role (lit. role + color)	
Unrelated	地震 earthquake (lit. earth + quake)	
Transparent	处长 the head of a department (lit. department + chief)	department
Opaque(OT)	处女 virgin (lit. department + girl)	
Unrelated	电信 telecommunication (lit. electricity + communication)	

Transparent	出门 go out (lit. out + door)	door
Opaque(TO)	专门 specialized (lit. special + door)	
Unrelated	选择 choose (lit. choose + pick up)	
Transparent	消毒 disinfect (lit. eliminate + toxin)	eliminate
Opaque(OT)	消息 news(lit. eliminate + information)	
Unrelated	吸收 absorb (lit. inhale+ intake)	
Transparent	军备 armament (lit. army + equipment)	equipment
Opaque(TO)	责备 reprove (lit. blame + equipment)	
Unrelated	法制 legality (lit. law + system)	
Transparent	尽快 as soon as possible (lit. try one's best + quick)	quick
Opaque(TO)	外快 extra income (lit. external + quick)	
Unrelated	拨动 stir (lit. stir + move)	
Transparent	肥料 fertilizer (lit. fat + material)	fat
Opaque(OT)	肥皂 soap (lit. fat + soap)	
Unrelated	通知 notice (lit. inform + know)	
Transparent	毛线 knitting wool (lit. hair + thread)	hair
Opaque(OT)	毛病 defect (lit. hair + illness)	
Unrelated	询问 inquire (lit. inquire + ask)	
Transparent	动手 touch (lit. move + hand)	hand
Opaque(TO)	助手 assistant (lit. help + hand)	
Unrelated	明亮 bright (lit. light + shiny)	
Transparent	回头 turn one's head (lit. turn + head)	head
Opaque(TO)	骨头 bone (lit. bone + head)	
Unrelated	共同 common (lit. together + same)	
Transparent	决心 resolution (lit. determined + heart)	heart
Opaque(TO)	背心 underwaist (lit. back + heart)	
Unrelated	全部 whole (lit. whole + part)	
Transparent	打败 defeat (lit. fight + failure)	fight
Opaque(OT)	打算 plan (lit. fight + calculate)	
Unrelated	吉利 lucky (lit. fortune + benefit)	
Transparent	老家 hometown (lit. old + home)	home
Opaque(TO)	专家 expert (lit. special + home)	
Unrelated	严格 strict (lit. strict + standard)	
Transparent	学会 learn (lit. learn + know)	know
Opaque(TO)	机会 opportunity (lit. crucial point+ know)	
Unrelated	土壤 earth (lit. earth + land)	
Transparent	陆军 ground force (lit. ground + army)	ground

Opaque(OT)	陆续 successive (lit. ground + continue)	
Unrelated	因而 therefore (lit. because + so)	
Transparent	渔夫 fisherman (lit. fishing + person)	person
Opaque(TO)	功夫 time (lit. work + person)	
Unrelated	出产 produce (lit. out + produce)	
Transparent	午饭 lunch (lit. noon + meal)	noon
Opaque(OT)	午夜 midnight (lit. noon + night)	
Unrelated	感叹 sign (lit. feel + sign)	
Transparent	油田 oilfield (lit. oil + field)	oil
Opaque(OT)	油菜 rape (lit. oil + vegetable)	
Unrelated	默默 silent (lit. silent + silent)	
Transparent	老人 old man (lit. old + person)	old
Opaque(OT)	老师 teacher (lit. old + teacher)	
Unrelated	行为 behavior (lit. behave + do)	
Transparent	掌握 grasp (lit. palm + hold)	palm
Opaque(OT)	掌故 anecdote (lit. palm + story)	
Unrelated	雪白 snow white (lit. snow + white)	
Transparent	记者 journalist (lit. keep note of + person)	person
Opaque(TO)	或者 or (lit. or + person)	
Unrelated	放心 relief(lit. put down + heart)	
Transparent	戒烟 quit smoking (lit. quit + smoking)	quit
Opaque(OT)	戒指 wedding ring (lit. quit + ring finger)	
Unrelated	忍心 be hardhearted enough to (lit. tolerate + heart)	
Transparent	海峡 strait (lit. sea + gorge)	sea
Opaque(OT)	海报 poster (lit. sea + newspaper)	
Unrelated	路程 journey (lit. road + distance)	
Transparent	立场 stand of point (lit. stand + field)	stand
Opaque(OT)	立刻 instant (lit. stand + time)	
Unrelated	真诚 sincerity(lit. true + honest)	
Transparent	笑话 joke (lit. laugh + talk)	talk
Opaque(TO)	像话 reasonable (lit. resemble + talk)	
Unrelated	年级 grade (lit. year + rank)	
Transparent	浪花 wave (lit. wave + flower)	wave
Opaque(OT)	浪费 waste (lit. wave + spend)	
Unrelated	无论 no matter what (lit. no + spoke of)	
Transparent	管道 tunnel (lit. tube + way)	way
Opaque(TO)	味道 taste (lit. taste + way)	

Unrelated	口袋 pocket (lit. month + bag)	
Transparent	西北 northwest (lit. west + north)	west
Opaque(OT)	西瓜 watermelon (lit. west + melon)	
Unrelated	多少 how much (lit. more + less)	

The sets of stimuli of the three priming conditions from **Experiment 2**

I) Completely transparent (TT) vs. completely opaque (OO) set

	PRIME	TARGET
Transparent	积雪 accumulated snow (lit. accumulate + snow)	accumulate
Opaque	积极 enthusiastic (lit. accumulate + pole)	
Unrelated	数学 math (lit. count + subject of study)	
Transparent	成熟 mature (lit. become + mature)	become
Opaque	成本 cost (lit. become + book)	
Unrelated	拼命 strive (lit. be ready to risk + life)	
Transparent	黑板 blackboard (lit. black + board)	board
Opaque	老板 boss (lit. old + board)	
Unrelated	起源 originate (lit. raise + origin)	
Transparent	改建 rebuild (lit. change + build)	build
Opaque	封建 feudalism (lit. seal + build)	
Unrelated	夺目 dazzling (lit. seize + eyes)	
Transparent	估计 estimate (lit. estimate + calculate)	calculate
Opaque	伙计 employee (lit. partner + calculate)	
Unrelated	自由 liberty (lit. self + follow)	
Transparent	开关 switch (lit. open + close)	close
Opaque	机关 institution (lit. machine + close)	
Unrelated	病房 ward (lit. sickness + room)	
Transparent	造型 style (lit. create + form)	create
Opaque	造化 good fortune (lit. create + change)	
Unrelated	平整 even (lit. even + flat)	
Transparent	耳机 headphone (lit. ear + machine)	ear
Opaque	耳光 slap (lit. ear + light)	
Unrelated	门口 entrance (lit. door + mouth)	
Transparent	尽力 try one’s best (lit. use up + strength)	use up
Opaque	尽管 although (lit. use up + manage)	
Unrelated	目标 aim (lit. eye + target)	
Transparent	花园 garden (lit. flower + park)	flower
Opaque	花生 peanut (lit. flower + birth)	
Unrelated	畏惧 frighten (lit. fear+ dread)	
Transparent	草原 prairie (lit. grass + land)	grass
Opaque	草率 careless (lit. grass + lead)	
Unrelated	合作 cooperate (lit. together + work)	

Transparent	手工 handmade (lit. hand + make)	hand
Opaque	手段 trick (lit. hand + segment)	
Unrelated	到来 arrival (lit. arrive + come)	
Transparent	马路 street (lit. horse + road)	horse
Opaque	马虎 casual (lit. horse + tiger)	
Unrelated	身边 by one's side (lit. body+ side)	
Transparent	百货 general merchandise (lit. hundred + product)	hundred
Opaque	百合 lily (lit. hundred + together)	
Unrelated	配合 coordinate (lit. join in marriage + together)	
Transparent	新生 newborn (lit. new + life)	life
Opaque	卫生 hygiene (lit. guard + life)	
Unrelated	观看 watch (lit. look + see)	
Transparent	指针 hand (lit. point + needle)	needle
Opaque	方针 policy (lit. square + needle)	
Unrelated	包裝 wrap up (lit. wrap + pack)	
Transparent	久经 long-experienced (lit. long + pass)	pass
Opaque	神经 nerve (lit. god + pass)	
Unrelated	占有 occupy (lit. take up + own)	
Transparent	起飞 depart (lit. raise + fly)	raise
Opaque	起草 make a draft (lit. raise + grass)	
Unrelated	照片 photo (lit. take a picture + thin piece)	
Transparent	爆发 burn out (lit. burn + send)	send
Opaque	沙发 sofa (lit. sand + send)	
Unrelated	成就 achievement (lit. become + accomplish)	
Transparent	影片 film (lit. shadow + thin piece)	shadow
Opaque	影响 influence (lit. shadow + sound)	
Unrelated	保温 keep warm (lit. keep + warm)	
Transparent	里面 inside (lit. in + side)	side
Opaque	体面 appropriateness (lit. body + side)	
Unrelated	车站 station (lit. car + stop)	
Transparent	听说 hear (lit. listen + talk)	talk
Opaque	小说 novel (lit. small + talk)	
Unrelated	光滑 smooth (lit. light + slippery)	
Transparent	物理 physics (lit. thing + theory)	thing
Opaque	物色 seek (lit. thing + color)	
Unrelated	呼吸 breath (lit. hale out +hale in)	
Transparent	万千 hundreds of thousands (lit. ten thousand +	thousand

	thousand)	
Opaque	秋千 swing (lit. fall + thousand)	
Unrelated	骄傲 pride (lit. arrogant + proud)	
Transparent	楼上 upstairs (lit. building + up)	up
Opaque	马上 immediate (lit. horse + up)	
Unrelated	选民 voter (lit. elect + the mass)	
Transparent	噪声 noise (lit. noisy + voice)	voice
Opaque	相声 crosstalk (lit. mutual + voice)	
Unrelated	辽阔 broad (lit. distant + broad)	
Transparent	走向 walk to (lit. walk + towards)	walk
Opaque	走狗 running dog (lit. walk + dog)	
Unrelated	苦笑 forced smile (lit. bitter + smile)	
Transparent	跑道 track (lit. running + way)	way
Opaque	难道 could it be said that (lit. difficult+ way)	
Unrelated	遗留 leave over (lit. lose + leave behind)	
Transparent	风雨 wind and rain (lit. wind + rain)	wind
Opaque	风流 talented and romantic (lit. wind+ flow)	
Unrelated	点名 call the roll (lit. point out + name)	

II) Completely transparent vs. partially opaque set
The same as **Experiment 1**.