Activation of morphemic meanings in processing opaque words

Tsang, Yiu-Kei; Chen, Hsuan-Chih

Published in:
Psychonomic Bulletin and Review

DOI:
10.3758/s13423-014-0589-2

Published: 01/10/2014

Document Version:
Peer reviewed version

Citation for published version (APA):
Tsang, Y.-K., & Chen, H.-C. (2014). Activation of morphemic meanings in processing opaque words. *Psychonomic Bulletin and Review*, *21*(5), 1281-1286. https://doi.org/10.3758/s13423-014-0589-2

Running Head: OPAQUE WORD PROCESSING

Activation of morphemic meanings in processing opaque words

Yiu-Kei Tsang[1]

Hsuan-Chih Chen[2]

1: Department of Education Studies, Hong Kong Baptist University

2:Department of Psychology, The Chinese University of Hong Kong

Address for correspondence:

Yiu-Kei Tsang

Department of Education Studies

Hong Kong Baptist University

Kowloon, Hong Kong

Phone: +852-34115325

Email: yktsang@hkbu.edu.hk

Word count: 3995

Abstract

Two masked priming experiments were conducted to examine the activation of morphemic forms and meanings during opaque word processing. In Experiment 1, opaque primes significantly facilitated the recognition of transparent targets, which was consistent with previous results. However, transparent primes did not influence the recognition of opaque targets. This asymmetry could not be explained solely by morpho-orthographic processing, but it was consistent with models that assumed early morpho-semantic activation. Experiment 2 directly tested whether the meanings of the constituent morphemes in opaque words were activated. In the critical condition, targets were unrelated to the opaque primes at the lexical level but were semantically related to their morphemes (e.g., “butterfly-bread”). Facilitation was observed in this condition, providing strong evidence of morpho-semantic activation during opaque word recognition. These findings indicate that although initial morphological decomposition is determined by surface morphological form, it does not necessarily imply that morphemic meanings are activated at later stages of processing. Rather, the morphemic meanings may be available automatically once segmentation is complete.

Keywords: Morphological processing, semantic transparency, morpho-semantics, Chinese

Introduction

Morphology is crucial to word formation. For example, “plays”, “player”, and “playground” can be constructed from “play”. The role of morphemes in complex word recognition has been studied extensively (Amenta & Crepaldi, 2012). In the last decade, considerable evidence has been accumulated to support the proposal that morphemic form alone is sufficient to trigger morphological decomposition (Rastle & Davis, 2008). Specifically, in a masked priming experiment, stem word recognition was facilitated not just by transparent primes (morphemes related to word meanings; e.g., cleaner-CLEAN), but also by opaque/pseudo-complex primes (morphemes unrelated to word meanings; e.g., corner-CORN), while letter-sharing had no effects (e.g., brothel-BROTH; “-el” is not an English suffix; Rastle, Davis, & New, 2004). Opaque word priming was also observed in Chinese (Tsang & Chen, 2013a) and French (Longtin, Segui, & Hallé, 2003), supporting morpho-orthographic decomposition across different languages.

Although it is widely accepted that morphemic forms are activated to trigger rapid morphological decomposition, it remains equivocal whether morpho-semantics is available early. Longtin et al. (2003) and Rastle et al. (2004) argued against early morpho-semantic activation based on their findings that transparent and opaque primes facilitated word recognition equally. In contrast, Diependaele, Sandra and Grainger (2005; 2009) and Feldman, O’Connor and Moscoso del Prado Martín (2009) observed stronger masked priming by transparent words than opaque words, which was taken as evidence for fast morpho-semantic activation. Other researchers studied the issue with ambiguous morphemes and discovered stronger masked priming when primes and targets shared morphemic forms and meanings (e.g., *in*valid-*in*correct), as compared to form-sharing only (e.g., *in*side-*in*correct; Zhou, Marslen-Wilson, Taft, &

Zhu, 1999). Moreover, the early stage of morphemic ambiguity resolution was sensitive to various morpho-semantic variables, such as meaning frequency and contextual constraints (Taft & Nguyen-Hoan, 2010; Tsang & Chen, 2013a; 2013b).

To accommodate early morpho-semantic activation, some models incorporate explicit morpho-semantic representations. For instance, Taft and Nguyen-Hoan (2010) proposed that morphemes are represented not just at the form level, but also at the lemma level, an abstract layer of representations coding consistent form-meaning linkages. Thus, morpho-semantic priming can be attributed to repeated activation of the same lemmas. Crepaldi, Rastle, Coltheart and Nickels (2010) also adopted the lemma idea, although they restricted lemma sharing only to inflected words (e.g., “fall-fell”, “cat-cats”), but not to derived words (and by extension, compound words), because the latter cases often involve subtle changes in meanings and word classes (e.g., “critic-critical”; “baseball-baseline”). In the hybrid dual-route model, Diependaele et al. (2009) proposed that morpho-orthographic decomposition and holistic processing operate simultaneously. Morphemic meanings can be activated postlexically and rapidly via the morphological route and lexical route, which send excitatory feedback to influence morphological processing, accounting for the morpho-semantic effects in masked priming experiments.

While these models assume different mechanisms of morphological processing, they are consistent in suggesting the possibility that morphemic meanings can be activated automatically and rapidly, not just for transparent but also for opaque words. For instance, the meanings of “corn” and “clean” can be activated once “corner” and “cleaner” are decomposed based on surface morpho-orthography. Although for opaque words, the activated morphemic meanings must eventually be inhibited by whole word meanings to avoid miscomprehension, the inhibition might be ineffective in previous masked priming experiments for several reasons. First, stem words were used as targets, which completely matched with the decomposed morphemes, and typically had higher frequency than the opaque primes. This strengthened the facilitation from morphemic meanings and comparatively, the inhibition from whole words might be too weak, especially given a short stimulus-onset-asynchrony (< 50 ms). Thus, it is possible that within the temporal window reflected by masked priming, morphemic meanings could be highly active for both transparent and opaque words, which means that the absence of semantic transparency effect (Longtin et al., 2003; Rastle et al., 2004) could not be taken as indisputable evidence against early morpho-semantic activation. In this study, we reexamined early morpho-semantic activation during opaque word processing in two masked priming experiments.

In Experiment 1, we compared the masked priming effects of opaque primes on transparent targets against those of transparent primes on opaque targets. If only morphemic form was activated, the strength of facilitation should be identical across the two conditions because there was equal amount of morpho-orthographic sharing. In contrast, if early morpho-semantic activation occurred, facilitation of opaque targets should diminish or disappear, as compared to transparent targets, because the morphemic meanings activated by the constituent morphemes in prime words were related only to transparent targets, but not to opaque targets. This should strengthen the inhibition from whole words in the opaque target condition. In Experiment 2, we used target words that were unrelated to the whole opaque primes, but semantically related to the initial constituent morphemes. Any facilitation observed in this condition would provide direct evidence for morpho-semantic activation even in opaque words.

Experiment 1

Participants

Forty-eight undergraduates from The Chinese University of Hong Kong were recruited. They were native Cantonese speakers and had normal/corrected vision.

Materials

Twenty-four Chinese morphemes were used to construct pairs of transparent and opaque bimorphemic words (critical morphemes always at the initial position). For transparent compound words, the critical morphemes contributed to word meanings (e.g., “雷雨” *thunderstorm*, meaning “thunder-rain” literally). Opaque words were either loanwords from other languages (e.g., “雷達” *radar*, meaning “thunder-arrive” literally) or words used only in highly specific context (e.g., “點心” *Dim Sum*, meaning “dot-heart” literally). Twelve loanwords bore phonological similarity to source English words. Although this might increase phonological salience, it could not explain any morpho-semantic effects observed because phonological sharing, just as moprho-orthographic sharing, was identical across conditions. Twenty-four bimorphemic control words were also created with morphemes not used in the transparent and the opaque conditions. These control words were fully transparent (e.g., “飯盒” *lunch box,* meaning “rice-box” literally). Words in different conditions were matched in log-transformed word frequency (Cai & Brysbaert, 2010), frequency of the second morphemes (Research Centre for Humanities Computing, 2003), and number of strokes (Table 1).

[Insert Table 1 about here]

Four conditions were formed by crossing target type (transparent vs. opaque) and prime type (form related vs. unrelated) as independent variables (when transparent words were targets, opaque words served as form-related primes; similarly, for opaque targets, transparent words served as form-related primes). This design prevented frequency difference between primes and targets. The unrelated primes were Chinese bimorphemic words that were unrelated to the targets at both morphological and lexical levels. To avoid item repetition, four lists were constructed such that each target appeared only once within a list and all possible prime-target pairings were exhausted across lists. There were six items per condition in a list. For the lexical decision task, 24 nonword targets were created by combining Chinese morphemes in a non-interpretable way (e.g., “河亮”, meaning “river-bright” literally). Thus, meaning retrieval was necessary to perform lexical decision. All nonwords were preceded by real word primes, half of which shared morphemes with the targets such that morpheme-sharing was not informative to the lexical status of targets. The same set of nonwords was added to each experimental list (i.e., 48 items in each list).

Procedure

There were five to eight participants in each experimental session. They were arranged to their computer booths for presenting materials individually and to minimize interference from other participants. Each trial began with a fixation cross in the center of the screen for 500 ms, which was replaced by a random stroke pattern as the forward mask. The prime word (in PMingLiU font) was then presented for 40 ms. The target (in DFKai-SB font) appeared immediately after the prime and stayed on the screen until participants responded or for 2000 ms when no responses were made. Participants were instructed to decide as quickly and as accurately as possible whether the target was a real Chinese word by pressing corresponding keys on keyboard. They were not informed about the presence of the primes but were told that they might see a "flash of symbols" before the targets. The combination of forward mask and short presentation duration ensured that participants were unaware of the primes. Twelve practice trials were provided. Participants were randomly assigned to the four lists (12 participants in each list). Items within a list were presented randomly. The experiment lasted for about 15 minutes.

Results and Discussion

Trials with incorrect responses (9.2%) or extreme reaction times (±2.5 S.D.; 1.3%) were discarded from further analyses. Table 2 displays the mean reaction times and error rates in each condition for the remaining data. A linear mixed-effect model (lme; Baayen, Davidson, & Bates, 2008) and a mixed logit model (Jaeger, 2008) were used to analyze the reaction time data and error rates, respectively. Target type (transparent vs. opaque) and prime type (form related vs. unrelated) were treated as fixed effects, and subject and item were treated as random effects. A treatment coding was adopted such that opaque targets were compared against transparent targets, and related primes were compared against unrelated primes. Following Barr, Levy, Scheepers, and Tily (2013), random intercepts, random slopes, and their correlations were included in the random effect structure. For lme, given a relatively large dataset (over 1000 valid observations), the *t*-distribution should approximate the normal distribution. Thus, any effects with $t > 2$ were considered to be significant at the .05 level. For mixed logit model, we reported the Wald Z values and p values obtained by Laplace approximation.

[Insert Table 2 about here]

For error rates, only the main effect of target type was significant (*Wald* $z = 3.11$, $p < .005$). There were fewer errors for transparent targets. The prime type effect and the interaction were non-significant (*Wald z*s = 1.22, *n.s.*). For reaction times, responses were faster for transparent than opaque targets ($b = 95.36$, $S.E. = 29.87$, $t = 3.19$, $p < .01$). The main effect of prime relatedness was non-significant ($b = 6.88$, $S.E. = 23.72$, $t < 1$). However, the main effects were characterized by a significant interaction between target and prime types ($b = 56.55$, $S.E. = 23.83$, $t = 2.37$, $p < .05$). To further specify the nature of this interaction, a separate lme test was conducted for each target type. A significant prime type effect was obtained for transparent targets ($b = 49.23$, $S.E. = 14.75$, $t = 3.34$, $p < .01$), but not for opaque targets ($b = 8.65$, $S.E. = 23.90$, $t < 1$).

While opaque primes facilitated transparent target recognition, which was consistent with previous findings with stem word targets (Longtin et al., 2003; Rastle et al., 2004), transparent primes failed to influence the processing of opaque targets[1]. Similar results were recently obtained in an ERP experiment by Morris, Grainger and Holcomb (2013), in which complex nonwords facilitated the recognition of transparent targets (e.g., “farmity-farmer”), but had no effects for opaque targets (e.g., “cornity-corner”). This asymmetry can be readily explained if we assumed fast morpho-semantic activation once decomposition based on surface morphemic form is complete. For opaque primes, the morphemic meanings activated were related to meanings of the whole transparent targets, producing strong facilitation. However, morphemic meanings of the transparent primes were irrelevant to the opaque targets. Instead, they might be more strongly connected to other transparent words containing the same morphemes because many transparent words were more frequent than the

[1] An anonymous reviewer suggested that the nonwords used in Experiment 1 were too difficult, which might have artificially encouraged participants to rely more on morpho-semantics. To test this idea, we replicated Experiment 1 with nonwords that were constructed by fake characters. This should greatly reduce task difficulty because perceptual analysis would be sufficient for lexical decision. Results of this additional experiment were consistent with the original ones, indicating that task difficulty could not explain the current findings (see Supplemental Material).

opaque ones, creating competition with opaque target activation that might cancel out the facilitation due to sharing of morphemic forms. This explains why morphological priming was non-significant for opaque targets even though morpho-orthographic sharing should still be at work.

The idea of fast morpho-semantic activation also implies that the constituent morphemes should influence the recognition of semantically related targets at the early stage of processing reflected by masked priming (e.g., facilitation of "bread" by "butterfly"). This was tested in Experiment 2.

Experiment 2

Participants

Thirty participants from the same population as in Experiment 1 were recruited. None of them had participated in other experiments or pilot testing.

Materials

The transparent, opaque, and unrelated words in Experiment 1 were used as primes in Experiment 2. Targets were transparent bimorphemic Chinese words that were semantically related to the initial morphemes, but not to the whole opaque words. Therefore, facilitation by opaque primes could only be attributed to morpho-semantic activation but not to lexical semantics. Given that morphemes contribute to meanings of transparent words, targets were also related to the transparent primes. Semantic relatedness was rated by 20 to 27 pilot participants on a 6-point Likert scale (1 = strongly unrelated; 6 = strongly related). For example, the target word "閃光" *flash* was related to the morpheme "雷" *thunder* (mean rating = 4.78), and also the transparent prime "雷雨" *thunderstorm* (mean = 4.41). But it was unrelated to both the opaque “雷達” *radar* (mean = 2.47) and the unrelated primes “飯盒” *lunchbox* (mean = 2.42). Three experimental lists were created to prevent target repetition. All prime-target combinations were exhausted across lists. There were eight items per condition. Eight fillers with unrelated primes and targets were added to balance the number of related and unrelated trials. Thirty-two nonword items similar to those in Experiment 1 were added for lexical decision.

Procedure

The procedure was identical to that of Experiment 1. There were 10 participants in each list.

Results and Discussion

Trials with incorrect responses (5.1%) or extreme reaction times (±2.5 S.D.; 1.5%) were discarded from further analyses. Table 3 displays the mean reaction times and error rates in each condition. Data were analyzed as in Experiment 1. Prime type (transparent vs. opaque vs. control) was treated as fixed effect. Subject and item were treated as random effects while maintaining a maximal random effects structure.

[Insert Table 3 about here]

In the first analysis, a simple effect model was used to compare performance in the two morpheme-sharing conditions against unrelated control. Reaction times were significantly faster in both the transparent ($b = 57.02$, *S.E.* = 19.55, $t = 2.92$, $p < .05$) and the opaque conditions ($b = 39.65$, *S.E.* = 15.92, $t = 2.49$, $p < .05$). In the second analysis, a linear contrast (transparent vs. opaque; opaque vs. control) was set up to examine the pairwise differences across conditions. Reaction times were comparable in the transparent and the opaque conditions ($b = 17.38$, *S.E.* = 16.76, $t = 1.04$), while a significant difference emerged between the opaque and the control conditions (b = 39.65, $S.E.$ = 15.92, t = 2.49, $p < .05$). There were no significant differences in error rates (Wald z = 0.36 to 1.60).

Masked morphological priming was produced by transparent and opaque primes, with non-significant difference between the two conditions. Most importantly, the effects in the opaque prime condition could only be attributed to morpho-semantic activation because they were unrelated to targets at the lexical level. These results provided direct evidence for early morpho-semantic activation for opaque words.

General Discussion

Previous masked priming experiments that compared transparent and opaque words (Diependaele et al., 2005; Longtin et al., 2003; Rastle et al., 2004) typically considered non-significant semantic transparency effects as evidence against early morpho-semantic activation. However, as discussed in the Introduction, it is possible that opaque words could temporarily activate morphemic meanings as strongly as transparent words did because of the masked priming procedure and the choice of materials. In other words, both morphemic form and meanings are activated at the early stages of processing. In light of this possibility, we reexamined masked morpho-semantic priming by opaque word in two experiments. Experiment 1 showed that masked morphological priming cannot be explained solely by the sharing of morphemic forms, as the priming effect was non-significant in the transparent prime-opaque target condition (despite a typical opaque prime-transparent target effect was found). In Experiment 2, opaque primes could facilitate the recognition of targets that were related to morphemic meanings but unrelated to whole words, providing direct evidence of early morpho-semantic activation for opaque words.

The issue of early morpho-semantic activation is not trivial because it provides insights to how quickly language users can retrieve meanings from linguistic inputs (Feldman et al., 2009). Together with our studies on morphemic ambiguity (Tsang & Chen, 2013a; 2013b), we suggest that morphemic meanings can be activated very quickly, even before the involvement of conscious awareness. For transparent words, the morphemic meanings activated contribute to whole words and morphological integration will not interfere with lexical access. In contrast, for opaque words, although integration is attempted, the outputs are non-interpretable, causing troubles in word recognition (Ji, Gagné, & Spalding, 2011). Lavric, Rastle and Clapp (2011) further suggested that failure of morphological integration would trigger a semantic reanalysis based on whole words, as evidenced by a stronger N400 for opaque than for transparent words. This reanalysis is costly and time-consuming, cancelling out the morpho-orthographic facilitation at later stages of processing reflected by cross-modal priming (Marslen-Wilson, Tyler, Waksler, & Older, 1994). It also explains why the morphemes in opaque words could facilitate the recognition of semantic targets in masked priming (Experiment 2), but not in unmasked priming (Sandra, 1990). On the other hand, the limits of morpho-semantic activation require further investigation. In particular, it remains to be tested whether morpho-semantic effects persists when the morphemes were presented in isolation (i.e., as individual words), given that masked priming was usually weaker when primes and targets were related in lexical semantics (Rastle, Davis, Marslen-Wilson, & Tyler, 2000).

The morpho-semantic effects observed in this study are consistent with models that assume separate morpho-semantic representations. Judging which model best fits the empirical data is not easy, but our findings can provide important constraints for model selection. First, morphemic meanings are activated even for opaque words, suggesting automatic morpho-semantic activation after morpho-orthographic decomposition. Second, quick morpho-semantic activation has been observed for compound (this study) and derived words (Diependaele et al., 2005). Therefore, the model by Crepaldi et al. (2010) might need to be extended to accommodate morpho-semantic relationships other than inflections. On the other hand, the lemma model by Taft Nguyen-Hoan (2010) and the dual-route model (Diependaele et al., 2009) are general enough to account for the present findings. However, the dual-route model may need further justifications to explain why morphological effects emerged earlier than lexical ones (Tsang & Chen, 2010; Zhou et al., 1999) despite the assumption of a parallel lexical route of word recognition. Further experiments are needed to verify these models

Future research is also needed to investigate why early semantic transparency effect was found in some studies (Feldman et al., 2009; Diependale et al., 2005; 2009) but not in others (Longtin et al., 2003; Rastle et al., 2004). As briefly mentioned in the Introduction, it may be related to the frequency of constituent morphemes. For high frequency morphemes, the strongly activated morphemic meanings in opaque words can temporarily resist inhibition from whole words. The strength of morpho-semantic activation will be comparable in transparent and opaque conditions, resulting in non-significant differences between the two conditions. In contrast, for low frequency morphemes, strong competitions between morphemic meanings and whole words occur for opaque words, but not for transparent words. In this case, transparent primes will lead to stronger facilitation than opaque primes, creating the semantic transparency effect observed.

Finally, it is important to replicate the present findings in other languages. Written Chinese has unique properties that may have strengthened morpho-semantic effects. For instance, the linkage between form and meaning may be stronger in Chinese than alphabetic scripts (Zhou et al., 1999). The physical spaces separating individual morphemes may also simplify morpho-orthographic decomposition and accelerate morpho-semantic processing. Yet, early morpho-semantic activation has also been demonstrated in other languages (Diependale et al., 2005; Feldman et al., 2009; Taft & Ngyen-Hoan, 2010), which led us to believe that morpho-semantic activation during opaque word processing is language-universal.

References

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology*, 3.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59,* 390-412.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, *68,* 255-278.

Cai, Q., & Brysbaert, M. (2010). SUBTLEX-CH: Chinese Word and Character Frequencies Based on Film Subtitles. *PLoS ONE, 5*, e10729.

Crepaldi, D., Rastle, K., Coltheart, M., & Nickels, L. (2010). 'Fell' primes 'fall', but does 'bell' prime 'ball'? Masked priming with irregularly-inflected primes. *Journal of memory and language, 63*, 83-99.

Diependaele, K., Sandra, D., & Grainger, J. (2005). Masked cross-modal morphological priming: Unravelling morpho-orthographic and morpho-semantic influences in early word recognition. *Language and Cognitive Processes, 20,* 75-114.

Diependaele, K., Sandra, D., & Grainger, J. (2009). Semantic transparency and masked morphological priming: The case of prefixed words. *Memory & cognition*, *37,* 895-908.

Feldman, L. B., O'Connor, P. A. & Moscoso del Prado Martín, F. (2009). Early morphological processing is morphosemantic and not simply morpho-orthographic: A violation of form-then-meaning accounts of word recognition. *Psychonomic Bulletin & Review, 16*, 684-691.

Jaeger, T. F. (2008). Categorical data analysis: Away from ANOVAs (transformation or not) and towards logit mixed models. *Journal of Memory and Language, 59*, 434-446.

Ji, H., Gagné, C. L., & Spalding, T. L. (2011). Benefits and costs of lexical decomposition and semantic integration during the processing of transparent and opaque English compounds. *Journal of Memory and Language, 65,* 406–430.

Lavric, A., Rastle, K., & Clapp, A. (2011). What do fully visible primes and brain potentials reveal about morphological decomposition? *Psychophysiology, 48,* 676–686.

Longtin, C.-M., Segui, J., & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes, 2003*, 313-334.

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

Morris, J., Grainger, J., & Holcomb, P. J. (2013). Tracking the consequences of morpho-orthographic decomposition using ERPs. *Brain Research, 1529*, 92-104.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes*, *15*, 507-537.

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review, 11*, 1090-1098.

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes, 23*, 942-971.

Research Centre for Humanities Computing (2003). *Chinese Character Database: With Word-formations*. Retrieved from http://humanum.arts.cuhk.edu.hk/Lexis/lexi-can/

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

Taft, M., & Nguyen-Hoan, M. (2010). A sticky stick? The locus of morphological representation in the lexicon. *Language and Cognitive Processes, 25*, 277-296.

Tsang, Y.-K., & Chen, H.-C. (2010). Morphemic ambiguity resolution in Chinese: Activation of the subordinate meaning with a prior dominant-biased context. *Psychonomic Bulletin & Review, 17*, 675-881.

Tsang, Y-K., & Chen, H.-C. (2013a). Early morphological processing is sensitive to morphemic meanings: Evidence from processing ambiguous morphemes. *Journal of Memory and Language, 68*, 223-239.

Tsang, Y.-K., & Chen, H.-C. (2013b). Morpho-semantic processing in word recognition: Evidence from balanced and biased ambiguous morphemes. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. doi: 10.1037/a0033701

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

Acknowledgement

We thank Matt Goldrick, Davide Crepaldi, Joanna Morris, and an anonymous reviewer for constructive comments and suggestions on an earlier version of the manuscript. This research was supported by the Start-up Grant (#38-40-090) from Hong Kong Baptist University.

Table 1. Sample materials and their properties.

	Transparent	Opaque	Control
Examples	雷雨	雷達	飯盒
Literal meanings	thunder – rain	thunder – arrive	rice – box
Translations	thunderstorm	radar	lunchbox
Word frequency (log)	1.58	1.56	1.66
Number of strokes	21.04	20.67	21.67
1st character frequency (log)	3.53	3.53	3.39
2nd character frequency (log)	3.48	3.39	3.34

Table 2. Mean reaction times (standard error of means in parentheses) and error rates in Experiment 1.

Target type	Transparent			Opaque		
Prime type	Related	Unrelated	Effect	Related	Unrelated	Effect
Reaction times (ms)	670 (10.32)	720 (12.38)	50	762 (13.92)	749 (12.38)	-13
Error rates (%)	5.21	7.29	2.08	11.81	12.50	0.69

Table 3. Mean reaction times (standard error of means in parentheses) and error rates in Experiment 2.

Prime type	Transparent	Opaque	Control
Reaction times (ms)	611 (7.22)	628 (6.63)	664 (9.16)
Error rates (%)	4.58	5.42	5.42