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Running Head: PROCESSING AMBIGUOUS MORPHEME

Morpho-orthographic and morpho-semantic processing in word recognition and
production: Evidence from ambiguous morphemes

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Abstract

Two sets of experiments were conducted to investigate the role of morphemes in word recognition and production. These experiments employed three priming procedures (i.e., masked, unmasked, and long lag) to study the relatively early to late stages of morphological processing. Targets were Chinese compound words containing an ambiguous morpheme (analogous to “*chair*” in “*chairman*” vs. “*armchair*”). Primes and targets shared the same ambiguous morpheme with the same interpretation (S), a different interpretation (D), or were completely unrelated (U). For word recognition, the facilitation by the S and the D primes was statistically identical in the masked priming procedure. But only the S primes continued to facilitate word recognition in the unmasked and the long lag priming procedures. In contrast, for word production, only the D primes produced significant facilitation in masked priming. In unmasked priming, both the S and D primes facilitated the naming reaction times, as compared with the unrelated baseline. But the facilitation was stronger in the S than in the D conditions. Finally, in the long lag priming procedure, both the S and the D primes produced facilitation of equal strength. These results indicate that the processing of ambiguous morpheme involves both morphemic form and meaning, and that the temporal dynamics of the two effects differ in recognition and production.

Keywords: Morphological processing, word recognition, word production, Chinese

Introduction

Since the seminal works by Taft and Forster (1975; 1976), the role of morpheme in lexical access has become one of the major theoretical inquiries in psycholinguistic research (Frost, Grainger, Carreiras, 2008; Frost, Grainger, & Rastle, 2005). After years of research and study, many researchers now agree that morphology must in some ways be introduced into the theories of language processing (e.g., Gonnerman, Seidenberg, & Andersen, 2007; Levelt, Roelofs, & Meyer, 1999; Taft, 1994; Taft, Liu, & Zhu, 1999). Yet, many details about morphological processing remain controversial, such as the processing of ambiguous morpheme (Bertram, Laine, Baayen, Schreuder, & Hyönä, 2000a), the relative importance of morphemic form and meaning (Rastle & Davis, 2008), and whether or not the morphological representation plays a different role in word recognition and production (Roelofs & Baayen, 2002). The main purpose of the present study is to compare the processing of Chinese ambiguous morpheme in word recognition and production. We are particularly interested in examining the time course of morpho-semantic activation across the two domains. We adopted the priming paradigm to examine the issue. If a reliable priming can be observed regardless of the intended interpretation of an ambiguous morpheme, the processing is likely driven by morphemic form. In contrast, if the effect occurs only when prime and target share an ambiguous morpheme with the same interpretation, we can conclude that morphemic meaning is involved.

In the following, we first review previous experimental evidence about the role of morphology in word recognition and production, and their implications on the development of language processing models (also see Lüttmann, Zwitserlood, & Bólte, 2011a). Next, we explain why it is important to consider the temporal dynamics of the activation of morphemic form and meaning in the present study. Finally, we

describe how the investigation of morphemic ambiguity can complement the research of semantic transparency in extending our understanding about morpho-semantic processing.

Morphological processing in word recognition

The role of morpho-orthography and morpho-semantics during word processing has been widely studied through the manipulation of semantic transparency. The primary difference between transparent and opaque words concerns the contribution of morphemic meaning to whole-word meaning. While the meaning of a transparent word can be constructed from the constituent morphemes (e.g., “departure” is semantically related to the stem “depart”), the morphemic meaning and the whole-word meaning are unrelated for opaque words (e.g., “department” and “buttercup”) and pseudo-complex words (e.g., “corner” and “brother”). Any difference between the processing of transparent and opaque or pseudo-complex words can thus be attributed to the involvement of morphemic meaning. In a series of cross-modal priming experiments, Marslen-Wilson, Tyler, Waksler, and Older (1994) demonstrated that the prior exposure to a derived word (e.g., “friendly”) could facilitate the subsequent recognition of its stem (e.g., “friend”). However, this effect was observed only after a transparent prime, but not after an opaque one (e.g., “casualty – casual”). In another study (Meunier & Longtin, 2007), morphological priming occurred for French pseudo-words that were interpretable by integrating the constituent morphemes (e.g., “rapidifier”, compared with non-interpretable combinations such as “sportation”). Given that there are no lexical representations for pseudo-words, the results appear to support a prelexical locus of morpho-semantic priming. Furthermore, the effect of semantic transparency could be observed in long

lag priming experiments (i.e., the prime and target were separated by 7 – 13 intervening trials; Rueckl & Aicher, 2008). A similar conclusion was reached when the semantic relation was defined between the prime word and a constituent morpheme in the target (e.g., “lightning – “thunder-stroke” and “bread – buttercup” for the transparent and the opaque conditions, respectively; Sandra, 1990). These findings provide support for the importance of morpho-semantic constraint in word recognition.

On the other hand, Libben, Gibson, Yoon, and Sandra (2003) studied morphological priming and arrived at a different conclusion with the visual-visual priming technique (Experiment 2). In their experiment, target words were fully transparent (e.g., “car-wash”), partially transparent (e.g., “strawberry” and “jailbird”), or completely opaque (e.g., “hogwash”). Prime words were either a constituent in the target word presented in isolation (e.g., “car”, “straw”, “jail”, and “hog”), or an unrelated word stem (e.g., “pen” for “car-wash”). Morphological priming was observed in all morpheme-sharing conditions compared with the unrelated baseline, although the strength of facilitation was the strongest for fully transparent words. Therefore, while the morphemic meaning is important, morpho-orthographic processing also appears to contribute to the size of morphological priming. Yet, as Libben et al. did not include a form-sharing condition (i.e., sharing only letters), their results might not be purely morphological in nature, but might also reflect the influence of orthographic sharing at the word level.

Interestingly, using the masked priming procedure, other studies have failed to find a morpho-semantic constraint in word recognition (e.g., Frost, Forster, & Deutsch, 1997; Longtin, Segui, & Hallé, 2003; Rastle, Davis, & New, 2004). Note that in masked priming experiments, participants are typically unaware of the prime because

it is presented very briefly (about 40 ms) and is forwardly masked. The common finding in masked priming experiments is that target word recognition is facilitated by transparent (e.g., “cleaner-clean”), opaque (e.g., “department-depart”), and pseudo-suffixed primes (e.g., “corner-corn”), as compared with both form-sharing (e.g., “brothel-broth”) or unrelated controls. In other words, morphological priming can be independent of morpho-semantics and relies solely on the overlapping of the morpho-orthographic structure between the prime and the target words. The absence of a priming effect in the form-sharing condition also suggested that the effect is morphological in nature, rather than due to letter sharing.

The available data are thus equivocal about the relative importance of morphemic form and meaning in word recognition. To resolve the discrepant findings, Rastle and Davis (2008) proposed a two-stage model of morphological processing. According to this model, results in masked priming experiments reflect the earliest stage of morphological processing, in which all words are segmented into their constituent morphemes based on the surface morpho-orthographic structure. In other words, not only transparent words but opaque ones like “department” and pseudo-complex ones like “corner” will be segmented because all of them appear to be morphologically complex on the surface. The facilitative priming observed in previous masked priming experiments (e.g., Rastle et al., 2004) can thus be attributed to the repeated activation of the same morphemic form. While this initial segmentation process is blind to morphemic meaning, the resulting constituents will be integrated for word meaning at the later morpho-semantic stage. If the integration is unsuccessful, as in the case of opaque or pseudo-complex words, a re-analysis that does not rely on morphemes will be needed for semantic retrieval (Lavric, Rastle, & Clapp, 2011). As a result, the constituents in an opaque word will create difficulty in

word recognition at this later stage when participants are fully aware of the primes, which cancel out the facilitation due to the activation of morphemic form at the earlier stage. In contrast, a transparent word will not trigger the re-analysis because word meanings are derived from combining the constituent morphemes. The morphological facilitation can thus survive [can survive not “can survives”] to the later stage.

Morphological processing in word production

Although empirical research of morphological processing in word production has lagged behind that of word recognition, increasing amount of evidence is now available in favor of the involvement of morphemes in this domain. For instance, Roelofs (1996) studied morphological processing in word production using the implicit priming paradigm, in which participants repeatedly produced words that share the initial morpheme (e.g., bypass, byway, and bylaw; the homogenous set) or words that are unrelated (e.g., bypass, indoor, and enrich; the heterogeneous set). The word production response was faster in the homogeneous set than in the heterogeneous set. This facilitative priming was attributed to the pre-activation of morpheme during the repeated production of morphologically related words because the effect of mere formal overlap (e.g., bypass, byte, and byre) was much weaker. In a subsequent study (Roelofs & Baayen, 2002), the strength of implicit priming was shown to be identical for both transparent (e.g., input, indoor, and inflow) and opaque words (e.g., insect, increase, invoice). The lack of sensitivity towards semantic transparency indicates that only the morphemic form, but not the morphemic meaning, plays a role in word production.

Similar results have been reported in experiments employing the picture-word interference (PWI) paradigm, which can be considered as a primed picture naming

task (Zwitserslood, Bölte, & Dohmes, 2000; 2002). In these experiments, the picture to be named was displayed together with the distractor word (i.e., the prime). Although participants were instructed to ignore the distractor, the relationship between the distractor word and the target picture could nevertheless influence picture naming latencies. In other words, the priming effect can originate from the repeated access of a representation that is shared between a pair of distractor and target. Zwitserslood et al. showed that picture naming was faster when the target picture was the root word of the distractor (e.g., “rose – rosebud”), as compared with a letter sharing or an unrelated control condition. More importantly, in line with the results of implicit priming, these experiments showed that the strength of facilitation was identical for the transparent and the opaque distractors, regardless of whether they immediately preceded the target picture, or there were 7 to 10 intervening trials between a distractor-target pair (i.e., the long-lag version of PWI; Dohmes, Zwitserslood, & Bölte, 2004; also see Koester & Schiller, 2008 for ERP data).

Lüttmann, Zwitserslood, Böhl, and Bölte (2011b) conducted two PWI experiments to further investigate morphological processing in German compound word production. A facilitation in picture naming was observed when the target and the distractor were compound words that shared the same morpheme (e.g., “handbag – travelling bag”; Experiment 1). The authors also successfully replicated the well-established semantic interference effect at the whole-word level (e.g., “cake – bread”). On the other hand, the facilitative effect disappeared when the distractor was semantically related to one of the constituents of the target but not related to the whole compound word (e.g., “cake – bread knife”). Their results provide further evidence that morphemic meaning is not activated during word production.

Results from both implicit priming and PWI experiments indicate that only the

morphemic form is involved in word production. The absence of a morpho-semantic effect is consistent with existing models of speech production, which typically consider individual morphemes as part of the word-form system (e.g., Roelofs & Baayen, 2002; Zwitserlood et al., 2000; 2002). For instance, in WEAVER++ (Levelt et al., 1999; Roelofs, 1996), a representative model of speech production, morphemes represent one of the major components in word-form encoding. To be specific, the concept of the word to be produced will activate its lemma, a linguistic unit that codes the syntactic properties of the word. The lemma will in turn activate a word-form representation called lexeme. Morphology is coded at the lexeme level such that for morphologically complex words, multiple lexemes will be activated and integrated for articulation. Morphological facilitation in implicit priming and PWI experiments can thus be attributed to the repeated activation of the same lexeme. In addition, given the feedforward architecture of WEAVER++, even when a morphemic meaning is available after word-form encoding, it will not influence word production because all semantic processes have been completed already at the earlier stages. Indeed, as Roelofs and Baayen (2002) explicitly suggested, “the process of form encoding operates on the word-form representations *regardless of whether or not the morphological constituents contribute systematically to the meaning of the whole word.*” (Italics added, p. 133)

Morphological processing in word recognition and production

As reviewed previously, morphemes are taken purely as structural units, instead of meaning units, in word production (Levelt et al., 1999). This stands in sharp contrast to word recognition, where morphological processing is both a morpho-orthographic and a morpho-semantic event (Rastle & Davis, 2008). While

Roelofs and Baayen (2002) attributed this discrepancy to the fundamental differences in the recognition and the production systems, this idea has not been extensively tested. There are only a few empirical studies that directly compared the role of morphology across processing domains. For instance, Baayen, Levelt, Schreuder, and Ernestus (2008) examined the processing of regularly inflected nouns and showed that morpheme (lexeme) frequency can modulate participants' response speed in both word recognition and production. Lüttmann et al. (2011a) tested the recognition and the production of derived German verbs with the cross-modal priming and the PWI paradigms. As compared with the unrelated baseline, a morphologically related distractor (prime) could facilitate target word processing significantly. However, semantic transparency failed to modulate the strength of facilitation in both word recognition and production.

Although it is not completely clear why cross-modal priming was insensitive to morphemic meaning in Lüttmann et al. (2011a; in contrast to Marslen-Wilson et al., 1994; Meunier & Longtin, 2007), their results do raise the possibility that the morphological system involved in word recognition and production is less distinct than Roelofs and Baayen (2002) proposed. Instead, both processes may operate on the same set of morphological representations. One important factor that may have contributed to the discrepant results in previous studies concerns the variation in experimental procedure. Previous research on word recognition (Marslen-Wilson et al., 1994; Rastle et al., 2004; Rastle & Davis, 2008) demonstrated that the relative importance of morphemic form and meaning depends critically on whether the experimental procedure reflects the relatively early stages (e.g., masked priming) or the later stages of processing (e.g., unmasked priming with a long SOA or long lag priming). For word production, researchers have relied mostly on the implicit priming

and the PWI paradigms. These procedures are useful in measuring the relatively late stages of processing, as the participants are fully aware of the distractor and the SOA between a target and a distractor is usually over 100 ms. Given that speech production goes from meaning to form (Levelt et al., 1999), word-form representations will play a dominating role at the later stages of the production processes. Yet, it seems reasonable to expect that the effects of morpho-semantics may become more readily observable at the earlier stages of processing, before a particular meaning is selected for production.

To the best of our knowledge, this hypothesis has not been empirically examined in the psycholinguistic literature. The present study was thus conducted to serve this purpose. We compared the relative importance of morphemic form and meaning in word production with the PWI paradigm. We also tested word recognition with the primed lexical decision task using the same set of materials to allow a direct comparison across processing domains. To evaluate the time course of morphological processing, prime/distractor words (context word hereafter) were presented with masked, unmasked (with a 100 ms SOA), and long lag priming procedures, which reflect the early to the late stages of processing. Based on the previous review, we hypothesized that during word recognition, morphological priming should be sensitive only to the morphemic form at the early stage of processing. The effect of morphemic meaning should emerge only at a relatively late stage. This pattern is expected to reverse for word production, such that the effect of morphemic meaning will precede the effect of morphemic form.

Morphemic ambiguity

In contrast to previous studies, we examined the effect of morpho-semantics with

morphemic ambiguity rather than semantic transparency. Many morphemes indeed have more than one meaning or function, such as “-er” (e.g., “teacher” vs. “higher”), “in-” (e.g., “input” vs. “invalid”), and “chair” (e.g., “chairman” vs. “armchair”). Our understanding of morphological processing will be incomplete without considering these ambiguous morphemes. However, morphemic ambiguity resolution is a relatively unexplored research area. The data available are also inconclusive. For instance, Bertram and colleagues demonstrated that the frequency of the base word did not influence lexical decision times of Finnish and Dutch inflected words (Bertram et al., 2000a; Bertram, Schreuder, & Baayen, 2000b). The authors thus concluded that words containing ambiguous morphemes are recognized holistically, presumably because the competition between the alternative meanings had made the morphemic route inefficient. On the other hand, sharing an ambiguous morpheme between a pair of prime and target facilitated Chinese compound word recognition (Zhou, Marslen-Wilson, Taft, & Shu, 1999), which supports the involvement of ambiguous morphemes in word recognition. Badecker and Allen (2002) also showed that the intended meaning of an ambiguous morpheme became available at the conscious stage of word recognition. Finally, in spoken word recognition, the meaning of a compound is constructed from the constituent morphemes, even when they are ambiguous (Tsang & Chen, 2010).

Research of morphemic ambiguity in word production is even scarcer. Obviously, more work is needed to clarify the role of ambiguous morphemes in word recognition and production. Although not much is known about ambiguity at the morphemic level, previous research on lexical ambiguity may provide important insights. For instance, Caramazza, Costa, Miozzo, and Bi (2001) were interested in testing whether the different meanings of a homophonic word (e.g., /nʌn/, which can be “nun” or “none”)

share a single representation or are represented separately. They showed that in picture naming, word translation, and lexical decision, the processing of homophonic words was affected by its meaning-specific frequency, but not by the cumulative frequency summed across all of its possible meanings. The authors thus concluded that homophonic words have independent representations. The same results were obtained in PWI experiments (Miozzo & Caramazza, 2005). Indeed, the separated representation of ambiguous words has become a fundamental assumption for theories of lexical ambiguity (e.g., Duffy, Morris, & Rayner, 1988; Rodd, Gaskell, & Marslen-Wilson, 2002).

The assumption of a distinct representation for each meaning of an ambiguous word may also apply to the morphemic level, such that an ambiguous morpheme will have a distinct representation for each morphemic meaning and a shared representation of the morphemic form (Badecker & Allen, 2002; Tsang & Chen, 2010). Accordingly, we hypothesized that if morphological priming can be observed when the context word and the target share an ambiguous morpheme regardless of its intended interpretation, the effect is likely due to morphemic form, just as when both transparent and opaque words affected target processing significantly (Rastle et al., 2004; Roelofs & Baayen, 2002). In contrast, if morphological priming occurs only when the ambiguous morpheme in the context word and the target share the same interpretation, the effect is morpho-semantic in nature, just as the presence of semantic transparency effect in word recognition (Marslen-Wilson et al., 1994; Rueckl & Aicher, 2008).

General method

Two sets of experiments were conducted to study morphological processing of

Chinese words that contain an ambiguous morpheme. In the first set (i.e., 1A, 1B, and 1C), participants performed a lexical decision task to examine the role of ambiguous morphemes in word recognition. The second set of experiments (i.e., 2A, 2B, and 2C) employed the PWI paradigm to examine the word production process. The relative timing between each pair of context word and target was manipulated by using three different priming procedures (i.e., masked, unmasked, and long lag priming). The same materials and experimental design were used to facilitate a comparison of results across experiments. A general description of the materials and design is presented in this section and the detailed procedure is provided under each experiment.

Materials and design

Fifty-two Chinese homonymic morphemes were prepared. Each morpheme has at least two distinctive dictionary meanings (e.g., “公” /gung1/, meaning “public” or “male”). In Chinese, there are also pseudo-complex words (e.g., “corner”) and compound-like words (e.g., “mushroom”), in which the constituent morphemes are unrelated to whole-word meanings. For example, the literal meaning of “背心” (“vest”) is “back – heart”. In addition, the constituents in many borrowed words in Chinese also have their own meanings, such as “曲奇” (“cookie”; the literal meaning is “song – strange”) and “雷達” (“radar”; the literal meaning is “thunder – arrive”). However, in the present study, only productive morphemic meanings were used to construct the materials. This indeed reflects an additional advantage for studying the effect of morphemic meaning with morphemic ambiguity. In studies of semantic transparency, opaque or pseudo-complex words can be considered as special cases. It is because the “opaque use” of a morpheme is unproductive, usually forming only one, or a few opaque words. For example, “depart” only appears in one opaque word

(“department”), but it can create many transparent words, such as “departing”, “departed”, and “departure”. In contrast, the alternative meanings of an ambiguous morpheme can be equally productive. For instance, the prefix “*in-*” can form “*input*”, “*indoor*”, and “*inland*” with the “position” meaning. It can also create “*invalid*”, “*incorrect*”, and “*infinite*” with the “opposite” meaning. Comparison can be made between two transparent words with productive constituent morphemes, allowing a better control over the material construction.

Two pilot tests were conducted to assess the relative frequency of usage (i.e., dominance) of the alternative meanings. First, 20 students at The Chinese University of Hong Kong, who did not participate in any of the main experiments, were asked to write down the first meaning that came to their mind when presented with each ambiguous morpheme in pilot test 1. Second, another group of participants (N = 16) was recruited to rate the familiarity of each alternative meaning in pilot test 2. They were shown the ambiguous morphemes together with their meanings and were asked to rate how frequently each meaning was used in daily life on a 7-point Likert scale (7 = very frequent). Based on these pilot tests, 36 ambiguous morphemes were chosen such that the more dominant meaning was written down at least 25% more often than the subordinate one in pilot test 1, and that the difference in the mean familiarity rating between the dominant and the subordinate meanings was larger than one in pilot test 2. The ambiguous morphemes chosen were thus “biased” in the sense that one interpretation clearly dominated over the other. Note also that while some morphemes chosen had an extreme ratings in the first pilot test (the dominant meaning was reported for 100%), none of the subordinate meanings was completely unfamiliar to the participants as indicated by the second pilot test (lowest rating = 2.85; see Table 1). The first pilot test might simply be less sensitive to subtle

differences on the low frequency end.

[Insert Table 1 about here]

Each of the 36 ambiguous morphemes chosen was used to construct a set of bimorphemic Chinese words as experimental items (see Appendix). The items were unambiguous at the whole-word level. The target word in each set was a concrete noun denoting common objects seen in daily life and was created based on the dominant meaning of an ambiguous morpheme (e.g., “公廁 – public toilet”, washroom). This allowed us to use the same targets in lexical decision and picture naming. The pictures for the naming tasks were simple line drawings of the target objects. There were three types of context word for all experiments. The same meaning context (S) was constructed with the dominant meaning (e.g., “公園 – public garden”, park) and shared both morpho-orthographic and morpho-semantic relationships with the target. In contrast, the different meaning context (D) was constructed with the subordinate meaning (e.g., “公雞 – male chicken”, rooster) and thus shared only in morpho-orthography with the target. Given that the target and the S context word shared morpho-semantics, it is likely that they were also more strongly related at the whole-word level than did the target and the D context word. The ambiguous morphemes in context words and targets always occupy the first morphemic position. Moreover, as mentioned previously, all words are transparent, as judged by 22 pilot participants who rated the contribution of morphemic meaning to whole-word meaning (pilot test 3; mean ratings = 4.22, 4.21, and 3.97 for the target, the S context word, and the D context word, respectively; 1 = completely unrelated, 6 = highly related; $F_2(2,70) < 1$).

An unrelated context (U), which is completely unrelated to the target at both the morphemic and the lexical levels (e.g., “皮帶 – leather ribbon”, belt), was also

prepared as a control baseline. To prevent repetition priming other than the one produced by the critical ambiguous morphemes, none of the other characters in context words and targets repeated themselves. Also, although it was impossible to completely control for radical overlapping across the entire set of materials (e.g., “園” and “圖” had the same radical and internal structure), no radical overlapping occurred in words containing the same ambiguous morpheme. Finally, given that no representative word frequency corpus was available for the university students in Hong Kong, 20 pilot participants were recruited to rate the familiarity of the words used (1= highly unfamiliar, 6 = highly familiar; pilot test 4). The ratings did not differ significantly across the three contexts ($F_2(2, 70) = 1.29$). Table 1 lists the sample materials and the results of the pilot tests. Appendix lists the materials containing the critical ambiguous morphemes.

To reduce participants' awareness of the manipulation in the context-target relationship, 36 filler trials were constructed such that the context word and the target were completely unrelated. Seventy-two nonword trials were also prepared for the lexical decision task. The nonwords were constructed by combining Chinese characters to produce non-existing and non-interpretable bimorphemic combinations (e.g., “歌塔– song tower”). All nonword targets were preceded by a legal Chinese word as the context. In one-third of the nonword trials, the context word shared a character with the nonword (e.g., “歌劇 – song drama”, opera). Therefore, lexical decision could not be performed based on whether a pair of context and target overlapped in their surface form.

To avoid target repetition, the experimental items were split into three lists. Participants in all experiments were presented with one list only. Within list, the same target appeared only once and there were 12 items for each context condition.

Condition was rotated across lists such that all context-target pairings were exhausted. The same set of fillers (and nonwords in the case of lexical decision) was added to each list. Eight practice trials were also prepared with a different set of stimuli not used in the main experiments.

Apparatus

All experiments were programmed with DMDX (Forster & Forster, 2003) and were run on a desktop personal computer. Stimuli were displayed on a 15-inch LCD monitor at a refresh rate of 75 Hz. The target pictures were presented at a size of approximately 7.5 cm X 7.5 cm on the screen. The context and the target words were displayed in PMingLiU font and DFKai-SB font, respectively. Both context and target words were approximately 4 cm X 2 cm on the monitor. Lexical decision responses were collected via a standard keyboard (the keys “M” and “Z” for positive and negative responses, respectively). Vocal responses were collected with a microphone connected to the computer. The threshold of response triggering was adjusted for each individual participant. Reaction times were recorded to the nearest millisecond.

Experiment 1: Lexical decision

In Experiments 1A, 1B, and 1C, we examined the role of ambiguous morpheme in word recognition using the masked priming, unmasked priming (SOA = 100 ms), and long lag priming procedures, respectively. Morphological priming should be observed due to the repeated exposure to the same morpheme in the context and the target words. The key question, however, is the relative importance of morphemic form and meaning. Although the issue was approached with ambiguous morphemes, we expected that our results would be similar to those obtained by manipulating

semantic transparency. Most previous experiments indicated that morphological decomposition is obligatory and insensitive to morphemic meaning at the early unconscious stage of word recognition. Effects of morpho-semantic constraint only emerge at the late conscious stage (e.g., Longtin et al., 2003; Marslen-Wilson et al., 1994; Rastle et al., 2004; Rastle & Davis, 2008; Rastle, Davis, Marslen-Wilson, & Tyler, 2000; but see Feldman, O'Connor, & Moscoso del Prado Martín, 2009).

Therefore, in the masked priming experiment, we predicted to obtain a facilitative priming of similar strength in the two conditions sharing morphemic form (i.e., S and D) relative to the unrelated control (U). In contrast, using the unmasked priming and the long lag priming procedures, we should observe a stronger facilitation in the S condition, as compared with both D and U conditions.

Participants

There were 72 participants in Experiments 1A, 1B, and 1C (i.e., 24 for each experiment). Participants were recruited at The Chinese University of Hong Kong for course credits or HK\$50 (about US\$6). All of them were native Cantonese (a dialect of Chinese spoken in Hong Kong) speakers and had normal or corrected-to-normal vision. None of them had participated in the pilot tests or more than one main experiment in the present study. In each experiment, participants were assigned to the three experimental lists randomly, with the same number of participants in each list. All participants were tested individually.

Procedure

Experiment 1A (Masked priming). Each trial began with a central fixation cross for 500 ms. A random stroke pattern, which was constructed by overlaying several

unrelated characters, replaced the fixation cross for another 500 ms as a forward mask. The context word was then presented briefly for 40 ms. A pre-test indicated that with these presentation parameters, participants were able to report the context words only in 0.23% of all trials. Therefore, we were confident that participants were unaware of the prime under this procedure. The target word appeared immediately after the offset of the context. The target stayed on the screen until participants responded or after 2000 ms. Participants were instructed to fixate at the center of the screen throughout the trial and to decide whether the stimulus presented was an existing Chinese word by pressing corresponding keys on a keyboard as quickly and accurately as possible. They were not informed about the presence of the context word but were told that they might see flashes of symbols before the target stimulus in each trial.

Experiment 1B (Unmasked priming). In each trial, a fixation cross was presented at the center of the screen for 500 ms, followed by a blank screen for another 500 ms. The context word was then presented at the center for 100 ms, which was sufficient for conscious awareness. Target word appeared immediately after the offset of the prime (i.e., SOA = 100 ms). Participants were not informed about the relationships between the context word and the target. Instead, they were instructed to “ignore” the context and respond only to the target. Other details of the experiment were identical to those in Experiment 1A.

Experiment 1C (Long lag priming). Following Rueckl and Aicher (2008), each trial began with a central fixation cross for 500 ms, followed by a blank screen for 500 ms. The stimulus for lexical decision was then presented at the center until participants responded or after 2000 ms. In all lists, the first ten trials were fillers or nonwords.

The context and the target words in a pair were separated by 8 to 12 intervening trials (mean = 10 trials) and participants were required to respond to all stimuli. Across lists, the context word and its corresponding target always appeared at the same position in the trial sequence. Only the type of the context word varied. Other aspects of the procedure were identical to those in Experiments 1A and 1B.

Results and Discussion

Incorrect responses and responses with extreme reaction times (± 2.5 S.D. of the individual mean) were treated as errors and were discarded from further analyses (3.36%, 3.94%, and 2.78% for Experiments 1A, 1B, and 1C, respectively). Mean reaction times and error rates for each condition are shown in Table 2. There were clear traces of facilitation in the morpheme sharing conditions, as compared with the unrelated baseline, in all experiments. However, morpho-semantic constraints appeared to be effective in Experiments 1B and 1C because facilitation was noticeable only in the same meaning condition. We examined these observations with Analysis of Variance (ANOVA), treating “experiment” (1A, 1B, and 1C) as a between-subjects and within-items factor and “type of context word” (S, D, and U) as a within-subjects and within-items factor.

For reaction times, there was a significant difference across different types of context word ($F_1(2, 138) = 14.27, MSE = 2038, p < .01, \text{partial } \eta^2 = .171; F_2(2, 70) = 11.99, MSE = 3919, p < .01, \text{partial } \eta^2 = .255$). The main effect of experiment was significant only in the item analysis ($F_1(2, 69) = 1.28, MSE = 26714, p = .28, \text{partial } \eta^2 = .036; F_2(2, 70) = 7.85, MSE = 6872, p < .01, \text{partial } \eta^2 = .183$). The interaction between experiment and context failed to reach significance in both subject and item analyses ($F_1(4, 138) = 1.31, MSE = 2038, p = .27, \text{partial } \eta^2 = .037; F_2(4, 140) = 1.20,$

$MSE = 3427, p = .31, \text{partial } \eta^2 = .033$). All effects involving error rates were not significant (interaction: $F_1(4, 138) = 1.07, MSE = 19.34, p = .37, \text{partial } \eta^2 = .025$; $F_2(4, 140) < 1$; main effect of experiment: $F_s < 1$; main effect of context: $F_s < 1$).

[Insert Table 2 about here]

Although the interaction between “experiment” and “type of context” was not statistically significant, given the apparent difference in priming patterns between Experiments 1A and 1B/1C, and the prior evidence supportive to such a difference (Marslen-Wilson et al., 1994 vs. Rastle et al., 2004), we decided to conduct further statistical tests separately for each priming procedure. In Experiment 1A, where the masked priming procedure was adopted, a clear priming effect on the reaction times emerged in both subject-based and item-based analyses ($F_1(2, 46) = 5.92, MSE = 1998, p < .01, \text{partial } \eta^2 = .205$; $F_2(2, 70) = 7.43, MSE = 2216, p < .01, \text{partial } \eta^2 = .175$). Pairwise comparisons suggested that relative to the unrelated (U) baseline, the mean reaction times were faster in both the same (S) meaning ($t_1(23) = 2.98, p < .01$; $t_2(35) = 3.53, p < .01$) and the different (D) meaning ($t_1(23) = 2.76, p < .01$; $t_2(35) = 2.88, p < .01$) conditions. The difference between the S and the D conditions did not approach significance ($t_1(23) = .30$ and $t_2(35) = .74, p_s > .1$). Effects on error rates were not significant ($F_1(2, 46) = 1.08$; $F_2(2, 70) < 1$).

The pattern was quite different in Experiment 1B, where participants could process the context word consciously. They again displayed a significant facilitation by morphological sharing in the mean reaction times ($F_1(2, 46) = 5.94, MSE = 2463, p < .01, \text{partial } \eta^2 = .205$; $F_2(2, 70) = 4.31, MSE = 7632, p < .05, \text{partial } \eta^2 = .110$). However, the facilitative priming was constrained by morpho-semantics, as responses were faster only in the S condition, as compared with both the D ($t_1(23) = 2.68, p < .05$; $t_2(35) = 3.06, p < .01$) and the U ($t_1(23) = 3.37, p < .01$; $t_2(35) = 2.44, p < .05$)

conditions. The difference between the D and the U conditions was not significant ($t_1(23) = .65, p = .52;$). The apparent difference in error rates across conditions was not statistically significant ($F_1(2, 46) = 1.38; F_2(2, 70) < 1$).

Similarly, a morpho-semantic effect could be observed with the long lag priming procedure (Experiment 1C). The main effect of condition was robust in the mean reaction times ($F_1(2, 46) = 4.76, MSE = 1653, p < .05, \text{partial } \eta^2 = .172; F_2(2, 70) = 3.32, MSE = 3877, p < .05, \text{partial } \eta^2 = .087$). The difference was attributable to the faster responses in the S condition compared with the D ($t_1(23) = 3.02, p < .01; t_2(35) = 2.13, p < .05$) and the U ($t_1(23) = 2.37, p < .05; t_2(35) = 2.35, p < .05$) conditions. All other effects were not statistically significant.

Using different versions of the priming paradigm, we obtained robust evidence for morphological priming during word recognition. Just as morphemes were [or morphology was] involved in reading opaque words (e.g., Davis & Raslte, 2010; Longtin et al., 2003; Rastle et al., 2004), morphemic ambiguity also did not lead to holistic word processing [the current construction is odd; should keep how phrases are formed constant within a sentence: affirmative+affirmative or negative+negative, but not affirmative+negative], even though one might have expected that the mutual competition among the productive meanings would make morphological processing highly inefficient (Bertram et al., 2000a; 2000b). Moreover, although the interaction between experiment and type of context was statistically non-significant, the patterns of morphological processing appeared to differ across experiments when the data were analyzed separately. In particular, adopting the masked priming lexical decision task (Experiment 1A), where participants were typically unaware of the prime, the facilitation in reaction times produced by the S and the D primes were statistically identical. These data are in line with the evidence of an early facilitative priming

based on morphemic form in the studies of semantic transparency (Rastle et al., 2004; Rastle & Davis, 2008).

On the other hand, when participants were given more time to process the prime consciously in Experiment 1B, they showed a facilitative priming on reaction time only when the intended morphemic interpretation in the context and the target words were identical (i.e., the S condition). Morphological priming did not occur in the D condition, where the context and the target only shared the morphemic form but not the meaning (the apparent effect on error rates was not statistically significant). Therefore, the correct interpretation of the ambiguous morpheme was available within 100 ms to constrain subsequent word recognition. Similarly, in Experiment 1C, a facilitation was observed only in the S condition. Taken together, the results in Experiment 1 are consistent with the predictions based on the two-stage model (Rastle & Davis, 2008). While the initial morphemic decomposition relies on the surface morphemic form, the representation that leaves a trace in the system and affects subsequent word recognition in the long run is morpho-semantic in nature. The meaning-inconsistent interpretation may be inhibited at the later conscious stage (Badecker & Allen, 2002). This “form-then-meaning” pattern agrees well with the purpose of word recognition, namely to retrieve meaning from the perceptual input.

Experiment 2: Picture naming

In Experiment 2, the picture-word interference paradigm (PWI) was adopted to explore the processing of ambiguous morpheme during word production. Previous studies demonstrated a robust morphological priming in picture naming, supporting the role of morphemes in word production. Therefore, we expected the same result when morphemic ambiguity was manipulated. On the other hand, in previous studies,

the strength of facilitation was identical for transparent and opaque words, which was taken as evidence for a purely form-based morphological processing in word production (Koester & Schiller, 2008; Roelofs & Baayen, 2002). However, the context words in these studies were usually fully visible to the participants and the results might thus be reflective to later stages of processing (e.g., lexeme retrieval; Levelt et al., 1999). Given that word production is a process that goes from meaning to word-form, the effect of morphemic meaning might be more pronounced at the earlier stages of the production process. To examine this hypothesis, as in Experiment 1, we compared the pattern of morphological priming observed with masked, unmasked, and long lag priming (Experiments 2A, 2B, and 2C, respectively).

Participants

There were 24, 24, and 21 participants in Experiments 2A, 2B, and 2C, respectively (one participant in Experiment 2C was discarded because of computer failure). They were recruited from the same population as in Experiment 1.

Procedure

The presentation parameters for masked, unmasked, and long lag priming were identical to those used in Experiment 1. The primary difference between Experiments 1 and 2 was that the target words in Experiment 1 were replaced with target pictures in Experiment 2. Participants were instructed to produce their verbal responses towards a microphone for responses recording. The sensitivity of the microphone was adjusted for each participant. Reaction times were measured from the onset of the target picture. An experimenter sat behind the participants to record the accuracy of their responses on an answer sheet. Each experiment began with a learning phase, in

which participants were shown all target pictures together with their names. They were instructed to memorize the name of each picture. The practice and the experimental trials were presented after participants could correctly recall the names of all pictures.

Results and Discussion

Incorrect responses and responses with extreme reaction times (± 2.5 S.D. of the individual mean) were treated as errors and were discarded from further analyses (1.50%, 5.67%, and 7.08% for Experiments 2A, 2B, and 2C, respectively). Mean reaction time and error rate for each condition are shown in Table 3. Morphological priming was apparent in all experiments. However, differences in the priming effects between the same (S) and the different (D) meaning conditions appeared to depend critically on the priming procedure. Following Experiment 1, we conducted an overall analysis with “experiment” as a between-subjects and within-items factor and “type of context word” as a within-subjects and within-items factor.

For reaction times, there was a significant difference across different types of context word ($F_1(2, 130) = 19.45, MSE = 3182, p < .01, \text{partial } \eta^2 = .230; F_2(2, 70) = 49.58, MSE = 10070, p < .01, \text{partial } \eta^2 = .586$). The main effect of experiment was significant ($F_1(2, 65) = 8.29, MSE = 37542, p < .01, \text{partial } \eta^2 = .203; F_2(2, 70) = 9.97, MSE = 10714, p < .01, \text{partial } \eta^2 = .222$). The interaction between the two factors was also significant ($F_1(4, 130) = 5.04, MSE = 3182, p < .01, \text{partial } \eta^2 = .134; F_2(4, 140) = 3.52, MSE = 8036, p < .01, \text{partial } \eta^2 = .091$). For error rates, all effects were not significant (all $F_s < 1$), except the main effect of experiment ($F_1(2, 65) = 8.36, MSE = 68.32, p < .01, \text{partial } \eta^2 = .205; F_2(2, 70) = 9.72, MSE = 80.39, p < .01, \text{partial } \eta^2 = .218$). There were fewer errors in the masked priming experiment, as compared with

the unmasked and the long lag procedures.

[Insert Table 3 about here]

To better illustrate the difference in priming patterns across priming procedures, we analyzed the data in each experiment separately. For masked priming (Experiment 2A), there was a clear type of context effect in reaction times ($F_1(2, 46) = 12.65$, $MSE = 2178$, $p < .01$, partial $\eta^2 = .355$; $F_2(2, 70) = 5.39$, $MSE = 7052$, $p < .01$, partial $\eta^2 = .133$). Further tests revealed that the effect originated primarily from the faster responses in the D condition compared with the U ($t_1(23) = 4.32$, $p < .01$; $t_2(35) = 3.08$, $p < .01$) and the S conditions ($t_1(26) = 4.14$, $p < .01$; $t_2(35) = 2.67$, $p < .05$). The difference between the S and the U conditions was not significant ($ts < 1$). No effects on error rates were found ($F_s < 1$).

On the other hand, adopting the unmasked priming procedure (Experiment 2B), both morphemic form and meaning of the context word appeared to play a role in facilitating subsequent picture naming. Specifically, although all effects about error rates were not significant ($F_s < 1$), a clear type of context effect in reaction times was obtained ($F_1(2, 46) = 10.45$, $MSE = 3874$, $p < .01$, partial $\eta^2 = .312$; $F_2(2, 70) = 7.38$, $MSE = 10573$, $p < .01$, partial $\eta^2 = .174$). The facilitation by the S primes relative to the baseline was robust ($t_1(23) = 4.19$, $p < .01$; $t_2(35) = 3.56$, $p < .01$). The difference between the S and the D conditions was also significant ($t_1(23) = 2.85$, $p < .01$; $t_2(35) = 2.12$, $p < .05$). And there was a marginal difference between the D and the U conditions ($t_1(23) = 2.16$, $p = .042$; $t_2(35) = 1.92$, $p = .063$).

Still another pattern of results was obtained with the long lag priming procedure in Experiment 2C. There was a significant type of context effect in reaction times ($F_1(2, 38) = 7.09$, $MSE = 3559$, $p < .01$, partial $\eta^2 = .272$; $F_2(2, 70) = 5.64$, $MSE = 10162$, $p < .01$, partial $\eta^2 = .139$). Picture naming was facilitated equally in the S

($t_1(19) = 2.49, p < .05$; $t_2(35) = 2.74, p = .01$) and the D conditions ($t_1(19) = 3.85, p < .01$; $t_2(35) = 2.95, p < .01$), as compared with the baseline. The apparent difference in error rates failed to reach statistical significance ($F_1(2, 38) = 1.48, MSE = 63.30, p = .24, \text{partial } \eta^2 = .072$; $F_2(2, 70) = 1.43, MSE = 100.9, p = .26, \text{partial } \eta^2 = .039$).

The strength of facilitation by the S and the D context words was statistically identical in Experiment 2C, indicating the absence of morpho-semantic effect. However, in Experiment 2A, morphological priming was restricted to the D condition and there were no differences between the S and the U conditions. In Experiment 2B, both S and D context words facilitated target picture naming, with a stronger effect in the S condition than in the D condition. The differences between the S and the D conditions in Experiments 2A and 2B suggest that morphemic meanings play a role in word production. On the one hand, these results support the involvement of ambiguous morphemes in word production. On the other hand, the presence of morpho-semantic constraints when participants were given limited time for context word processing challenges the assumption that morphological priming occurs only at the lexeme level and that morphemic meaning should have no influences on the production process (Koester & Schiller, 2008; Roelofs & Baayen, 2002).

Our demonstration of the importance of morphemic meaning in word production is consistent with a recent PWI experiment in Hebrew (Kolan, Leikin, Zwitterlood, 2011). Hebrew words consist of two morphemes, namely a root and a word pattern, intertwining with each other. The word pattern provides important semantic information about the whole word. For example, *mavreg* (“screwdriver”), *maxšev* (“computer”), and *mazrek* (“syringe”) share the word pattern *maCCeC* (the Cs denotes the root consonants), which indicates the semantic category of “instrument and tool”. In addition, the same word pattern can convey more than one meaning. For

instance, *maxšefa* (“witch”) contains the same word pattern *maCCeC* but it has nothing to do with the “instrument” meaning. Facilitation on picture naming was significant only when the ambiguous word pattern in a pair of context word and target shared the same interpretation. While Kolan et al. attributed their findings to the unique properties of the Hebrew morphological system (e.g., the non-linear concatenation of morphemes), the fact that similar results were obtained in Chinese suggests that the morpho-semantic effect in word production may be more stable than previously assumed.

Note that, *WEAVER++* (Levelt et al., 1999) can possibly be modified to accommodate the morpho-semantic effect observed in Experiment 2 by assuming that the lemma level representations are organized by morphemic meaning. While the idea of lemma was originally proposed to capture morpho-syntactic information (e.g., word class, grammatical gender), other researchers have extended the concept to include morpho-semantic properties as well. For instance, Taft and Nguyen-Hoan (2010) suggested that lemma is “a unit that represents a consistent association between form and function” (p. 280; also see Levelt, 1989). Therefore, the different interpretations of an ambiguous morpheme will have separate lemma representations (also see Kolan et al., 2011). As a result, morphological priming in word production will depend not just on the repeated access to the same lexeme, but also whether the lemma is shared between a context-target pair. Moreover, this modification can help explain the different patterns of morpho-semantic effects across priming procedures. *WEAVER++* assumes that word production goes from concept extraction to lemma retrieval and then to lexeme activation in a strictly serial order. When a pair of context and target were separated by a few intervening trials, participants would have enough time to process the context word at the lexeme level. Morphological priming in the

long lag procedure was thus governed by lexeme sharing of the ambiguous morpheme, which did not differentiate between the S and the D conditions. In contrast, if the context word was briefly presented, concept and lemma extraction might only be partially completed. The intended interpretation of the ambiguous morpheme might remain active when the target was shown. Accordingly, the strength of morphological priming would be influenced by both lemma and lexeme sharing, leading to the significant difference between the S and the D conditions.

Interestingly, while morphemic meaning further enhanced the strength of morphological priming in Experiment 2B (i.e., a stronger facilitation in the S than in the D condition), it appeared to cancel out the facilitation produced by lexeme sharing in Experiment 2A (i.e., no significant differences between the S and the U conditions). We can only speculate why the effect of sharing morphemic meaning is inhibitory in masked priming but facilitative in unmasked priming. One possibility is to assume the presence of semantic interference at the concept level. Semantic interference is a well-established finding in the PWI literature (e.g., Caramazza & Costa, 2000; Wong & Chen, 2008). Target picture naming is slower after categorically related context words (e.g., orange and banana) because the wrongly activated concept has to be suppressed before the correct one is available for subsequent processing. In the present experiment, although the S context word and the target picture are not categorically related, their meanings are connected via the shared morpheme (e.g., “公廁 – **public** toilet” and “公園 – **public** garden”). Semantic interference may be generalized to these cases with a morpho-semantic relationship.

Another explanation is specifically related to our materials. In the present study, both the S context word and the target picture were constructed with the dominant meaning of an ambiguous morpheme. By definition, the dominant meaning is used

more frequently than other alternative meanings, implying that many words are formed with it. To ensure an efficient processing of the context word, it may be important to inhibit other words containing the same dominant meaning (including the name of the target picture). Otherwise, the system may be overloaded by the partial activation of a large number of morphologically related words. The “side effect” of a more focused processing of the context word is the interference on the subsequent activation of the target name. This inhibition may be relatively transient. Once the activation of the target is sufficiently high, it will become the focus for further processing and enjoy the facilitation by sharing morphemic meaning (lemma) with the context.

Admittedly, our data do not provide a definite answer to the reversal of polarity of the morpho-semantic effect from masked to unmasked priming procedures. Our speculations are simply reasonable guesses that require explicit verification. For instance, whether words connected with morphemic meaning interfere with each other, just as words in the same semantic category do, is still an empirical question. Similarly, further studies are needed to test whether the subordinate meaning of an ambiguous morpheme produces less interference in masked priming because fewer words are formed with it. However, what is clear from Experiments 2A and 2B is that morphemic meaning must somehow be involved in the word production process. This conclusion is not simply based on an isolated finding or restricted to Chinese, because similar results have recently been obtained in Hebrew (Kolan et al., 2011), which has a very different morphological system than Chinese. Future research should explore in details the nature of this morpho-semantic effect, such as its time course (does it matter only at a relatively early stage of word production?) and locus (does it originate only at the lemma level?).

General Discussion

The present study examined the role of morphemes in word recognition and production. Instead of following previous studies in comparing the processing of transparent and opaque words, our materials were Chinese compound words that contain an ambiguous morpheme (similar to “*chairman*” and “*armchair*” in English). Specifically, the strength of facilitative priming when a prime-target pair contained the same ambiguous morpheme with the same interpretation (the S condition) or a different interpretation (the D condition) was evaluated against an unrelated baseline (the U condition). In addition, we investigated the time course of morphological processing with different priming procedures. In masked and unmasked priming, processing was explored within a scale of tens to hundreds milliseconds, while the long lag version allowed investigation on a relatively large temporal scale of about 10 seconds. Figure 1 presents a summary of the pattern of priming effects on reaction time across experiments.

[Insert Figure 1 about here]

As shown in Figure 1, evidence of facilitative priming can be found in all experiments. The effects cannot be easily explained by lexical factors. In particular, the sharing of lexical orthography (e.g., “*arm – arc*”) typically leads to an inhibitory priming instead of a facilitative one at short lags (Longtin et al., 2003), and the effect due to formal or semantic overlapping at the lexical level do not survive in long lag priming (Feldman, 2000). Therefore, we believe that the facilitation observed should be attributed to morphological sharing between the context word and the target. This suggests that the morphological representation is activated during lexical access, even when they do not provide a one-to-one mapping between form and meaning (i.e., they

are ambiguous). However, the dynamics of morpho-semantic processing differs sharply across word recognition and production. For word recognition, the influence of morphemic form precedes that of morphemic meaning. The facilitation was equally strong in both S and D conditions when participants were unaware of the context word (Experiment 1A), but was significant only after the S context word when participants were given more time for prime word processing (Experiments 1B and 1C). The reverse is true for word production. When the time for context word processing was limited, morphemic meaning affected picture naming speed such that the difference between the S and the D conditions was significant (Experiments 2A and 2B). In contrast, when time was sufficient (Experiment 2C), all meaning-related processes of the context word would have been completed, leaving only the morphemic form (lexeme) activated for priming target picture naming. The opposite temporal sequences of morphological processing in the two domains may reflect their different cognitive demands, namely meaning retrieval from the visual word form (recognition) versus articulating the phonetic form from the concept (production).

In the following, the implications of the present results will be discussed with reference to 1.) the processing of ambiguous morpheme; and 2.) similarities and differences of the morphological system in word recognition and production

Processing ambiguous morphemes

Although morphemic ambiguity is a phenomenon common to many languages, the issue has received little attention in the literature. For instance, whether words containing an ambiguous morpheme are processed holistically or through morphemic decomposition remains controversial. On the one hand, morphemic decomposition seems to be an obligatory and automatic process in lexical access (Rastle & Davis,

2008; Taft, 1994), On the other hand, if the constituent morphemes are ambiguous, it seems more efficient to bypass morpheme level analysis and process the words holistically (Packard, 1999). Empirical tests of the two predictions are insufficient and restricted to the domain of word recognition. The available data are also equivocal. Bertram et al. (2000a; 2000b) showed that the frequency of an ambiguous morpheme did not influence lexical decision times, but the effect of word frequency was significant. In addition, although Carreiras, Perdomo and Meseguer (2005) obtained an inhibitory effect when the target word shared an ambiguous morpheme with the prime word with a different interpretation, the effect was statistically identical to that produced by letter sharing. Carreiras et al. concluded that the effect was purely orthographic in nature and it did not involve any meaning competition at the morphemic level. These data are thus supportive to word processing models that do not assume obligatory decomposition, like the dual-route model (Baayen, Dijkstra, & Schreuder, 1997), which assumes a morpheme-mediated processing only when the holistic processing is ineffective (e.g., low frequency or novel words).

On the contrary, Allen and Badecker (1999) obtained a stronger inhibitory priming by sharing ambiguous morpheme than letter-sharing in an unmasked priming experiment. Furthermore, they (Badecker & Allen, 2002) demonstrated that the inhibition turned into facilitation when a masked priming procedure was adopted. Similarly, in Zhou et al. (1999), meaning-inconsistent primes [if you prefer to use “prime” then you need to add “a” in front, but in the present case I think using “primes” is more appropriate] facilitated target recognition at an SOA of 57 ms, but the effect disappeared when the SOA was lengthened to 200 ms. Therefore, Badecker and Allen proposed that the morpho-semantic constraint in word recognition emerges when participants were given enough time to select the intended meaning and inhibit

the inappropriate ones. In a spoken word recognition experiment, Tsang and Chen (2010) confirmed that the intended meaning of an ambiguous morpheme was selected before the meaning of the whole-word became available. The morphological priming observed in Experiment 1 of the present study is also in line with the involvement of ambiguous morphemes in word recognition. In addition, the results of Experiment 2 allow us to extend the conclusion to word production. Taken together, these data indicate that morphemic ambiguity does not necessarily result in holistic word processing.

Several factors might have improved the chance for the present study to detect morphological processing despite the ambiguity involved. First, whether the ambiguous morpheme contributes to the core meaning of whole-word may be critical. Bertram et al. (2000a; 2000b) examined the processing of words containing an ambiguous suffix. In contrast, Allen and Badecker (1999; Badecker & Allen, 2002) were interested in ambiguous stems (but see Carreiras et al., 2005, who also studied ambiguous stems). In Zhou et al. (1999) and the present study, the materials were compound words containing an ambiguous morpheme. While the suffix arguably serves more a morpho-syntactic rather than a morpho-semantic role, the stem and the constituent in compound words clearly contribute to word meaning. This may promote the development of an independent representation for each morphemic meaning, making the selection of the appropriate one more important and thus more readily detectable. Second, language difference may also be relevant. As morpheme boundaries are marked by spaces in the Chinese text in which each character is typically a morpheme, morphemic decomposition is a relatively easy and possibly automatic task. The benefit of activating morphemic meaning may thus outweigh the cost of committing possible interpretation errors due to ambiguity, making

morpheme-based processing the default route for Chinese compound word processing. Further studies are needed to examine how the properties of the material and the language difference may lead to the discrepant findings.

More importantly, results of the present study are highly comparable to the findings of lexical ambiguity. The different patterns of morphological priming across procedures and processing domains suggest that both morphemic form and meaning are important. We propose that an ambiguous morpheme is represented as a single morphemic form connected to two or more morphemic meanings (also see Badecker & Allen, 2002; Crepaldi et al., 2010; Kolan et al., 2011; Taft & Nguyen-Hoan, 2010). The selection of the appropriate meaning takes time and involves a competition [?] at the lemma level [if you want to say “a competition” then it’s necessary to specify “a competition between X and Y”, otherwise you should simply say “competition” without “a”—people then would assume it refers to “competition between lemmas”]. These properties of morphemic ambiguity processing are strikingly similar to the principles of lexical ambiguity resolution (e.g., Duffy et al., 1988; Swinney, 1979). Indeed, there is evidence showing that morphemic ambiguity resolution relies on similar mechanisms as lexical ambiguity does (Tsang & Chen, 2010). For instance, the frequency of the intended meaning and the availability of prior context are two important factors affecting the resolution process. These factors may also affect the balance between morphemic decomposition and holistic processing and deserve more attention in future research on morphemic processing.

Morphological processing from a time course perspective

In the present study, we compared the patterns of morphological priming in both word recognition and production. Special attention was paid to the relative importance

of morphemic form and meaning, and the time course of their contributions. We predicted that, although both form and meaning would be activated, the temporal order of the effects would be opposite in the two domains because of the unique processing demands (i.e., form-then-meaning in recognition vs. meaning-then-form in production). The results of Experiments 1 and 2 are in general supportive to these predictions. Therefore, while Roelofs and Baayen (2002) argued that there are important differences in the nature of morphological processing during recognition and production, this idea might apply only to specific stages of processing. When the time course of processing is taken into account, the activation of morphemic form and meaning in both domains indicates that there are also important similarities, a conclusion consistent with Baayen et al. (2008) and Lüttmann et al. (2011a). In other words, it is critical to examine the temporal dynamics in order to better understand morphological processing in word recognition and production.

The results of Experiments 1A to 1C are consistent with the two-stage model of word recognition (Rastle & Davis, 2008), which assumes that morphemic form is available prior to morphemic meaning. Therefore, given the restricted processing time of context word in masked priming, participants would only be able to extract its morphemic form. The subsequent recognition of a morpheme-sharing target would be benefited by the repeated access to the same morphemic form. As the different meanings of an ambiguous morpheme share the same representation at the form level, morphological priming at this early stage is insensitive to the intended interpretation. On the other hand, when participants were given more time for processing the context word (> 100 ms), the alternative meanings of an ambiguous morpheme would be activated and they would compete with each other in order to select the appropriate one at the later morpho-semantic stage (Badecker & Allen, 2002). This competition

would counteract the facilitation due to the sharing of morphemic form. In the present study, it completely cancelled out the effect, such that only the meaning-consistent context word facilitated target recognition. In contrast, the competition only reduced the strength of morphological priming in Zhou et al. (1999) but led to an inhibitory priming in Allen and Badecker (1999). A number of factors might contribute in determining the power of the competition and the result observed in the different meaning condition (i.e., null effect, facilitation, or inhibition). For instance, more frequently used meanings exert a stronger inhibition on less frequent meanings than the other way round (Duffy et al., 1988). Also, the facilitation due to morphemic form may be stronger in languages with clear morphemic boundary. These possibilities deserve more attention in future research.

According to the WEAVER++ model (Levelt et al., 1999), word production goes through the concept, lemma, and lexeme stages in a strictly sequential order. In Experiment 2C, we successfully replicated the finding that morphology is represented at the lexeme level, a word-form representation which is insensitive to morphemic meaning (Dohmes et al., 2004; Koester & Schiller, 2008; Roelofs & Baayen, 2002): Sharing an ambiguous morpheme between the context and the target produced a facilitation even when the intended morphemic interpretation differed. Yet, in previous works, it remains unclear whether morphology also matters at earlier stages. Our data suggest that it does. When participants were given limited time for context word processing, the representations for concept and lemma might remain active during subsequent target production. The strength of priming was thus determined also by concept and lemma sharing. At the earlier stages, sharing morphemic meaning either cancelled out or strengthened the morphological priming produced by the sharing of morphemic form (lexeme). It can be concluded that morpho-semantics is

activated during word production. And it is likely that morphemic meaning is represented at the lemma level, as Kolan et al. (2011) suggested. Admittedly, the morpho-semantic priming in word production is not a robust finding in the literature. The nature and detail of this effect need further research to clarify. For instance, it may be restricted to specific languages (e.g., Hebrew and Chinese) or observable only when morphemic ambiguity, instead of semantic transparency, was manipulated. It is also important to investigate exactly why the morpho-semantic effect reversed in polarity from Experiments 2A to 2B.

Conclusion

In the present study, the role of ambiguous morphemes in word recognition and production was tested with different priming procedures. Evidence of morphological processing can be observed in all experiments, suggesting that morphemic ambiguity does not trigger holistic word processing. Indeed, both morphemic form and meaning are activated, but the temporal order of activation differs across processing domains (Levelt et al., 1999; Rastle & Davis, 2008). While morphemic form is available prior to morphemic meaning in word recognition, the reversed is true in word production. Taken together, these data contribute to the comparison of morphological processing under different task demands and they help develop better models of morphological processing that can accommodate the similarities and differences in word recognition and production.

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Table 1. Stimuli examples and properties.

Target: 公廁 (washroom)		Same meaning prime	Different meaning prime	Unrelated prime
Examples		公園 (park)	公雞 (rooster)	皮帶 (belt)
Literal meaning		public - garden	male - chicken	leather - ribbon
Percentages of participants reporting the meaning (pilot test 1; N = 20)	Mean	84	9	--
	SD	16.09	10.11	--
	Range	50 – 100	0 – 35	--
Perceived meaning frequency (pilot test 2; N = 16)	Mean	5.82	3.89	--
	SD	0.41	0.66	--
	Range	4.94 – 6.63	2.85 – 5.13	--
Transparency rating (pilot test 3; N = 22)	Mean	4.21	3.97	--
	SD	0.80	1.06	--
	Range	2.64 – 5.73	2.27 – 5.64	--
Whole word familiarity (pilot test 4; N = 20)	Mean	4.21	4.11	4.46
	SD	0.96	0.79	0.81
	Range	2.30 – 5.85	2.30 – 5.70	2.30 – 5.80

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Table 2. Mean reaction times (ms) and error rates (%) for Experiments 1A, 1B, and 1C.

	Condition	Same meaning context	Different meaning context	Unrelated context
Reaction times	1A: Masked priming	663.90	667.44	704.02
	(N = 24)	(17.10)	(17.88)	(17.93)
	1B: Unmasked priming	669.40	706.35	716.26
	(N = 24)	(17.50)	(24.79)	(24.08)
	1C: Long lag priming	632.92	662.53	665.79
	(N = 24)	(19.06)	(21.49)	(24.26)
Error rates	1A: Masked priming	2.42	4.51	3.12
	(N = 24)	(0.78)	(1.23)	(0.98)
	1B: Unmasked priming	3.81	3.12	4.86
	(N = 24)	(0.87)	(0.84)	(0.99)
	1C: Long lag priming	2.43	3.47	2.43
	(N = 24)	(0.94)	(0.99)	(0.79)

Note: Standard errors of means in parentheses.

Table 3. Mean reaction times (ms) and error rates (%) for Experiments 2A, 2B, and 2C.

	Condition	Same meaning context	Different meaning context	Unrelated context
Reaction times	2A: Masked priming	848.64	793.38	854.98
	(N = 24)	(16.73)	(12.63)	(19.94)
	2B: Unmasked priming	815.08	854.35	897.21
	(N = 24)	(25.83)	(27.58)	(26.96)
	2C: Long lag priming	698.84	709.75	765.11
	(N = 20)	(28.62)	(33.08)	(35.39)
Error rates	2A: Masked priming	1.39	1.04	2.08
	(N = 24)	(0.65)	(0.57)	(0.75)
	2B: Unmasked priming	5.55	6.25	5.21
	(N = 24)	(1.19)	(1.52)	(1.40)
	2C: Long lag priming	5.83	5.83	9.58
	(N = 20)	(2.27)	(2.01)	(2.36)

Note: Standard errors of means in parentheses.

Figure captions

1. A summary of the priming effect on reaction times across experiments. The size of priming effect was calculated by subtracting the reaction time of the same meaning (S) and the different meaning (D) conditions from the unrelated baseline (U). A positive value indicates facilitation. Asterisks indicate significant priming effects ($p < .05$) as compared with the baseline.

Appendix

Target	Same meaning prime	Different meaning prime
公廁 (washroom)	公園 (park)	公雞 (rooster)
教師 (teacher)	教室 (classroom)	教宗 (pope)
花瓶 (vase)	花香 (fragrance of flower)	花費 (expense)
單車 (bicycle)	單獨 (solo)	單據 (receipt)
旗幟 (flag)	旗桿 (flagpole)	旗袍 (cheongsam)
日歷 (calendar)	日期 (date)	日本 (Japan)
風箏 (kite)	風暴 (storm)	風俗 (custom)
裁縫 (tailor)	裁剪 (cut)	裁判 (judge)
圖書 (book)	圖案 (pattern)	圖謀 (plot)
布匹 (cloth)	布袋 (bag)	布置 (decoration)
招牌 (signboard)	招待 (invitation)	招式 (moves in martial art)
樹葉 (leaf)	樹林 (forest)	樹立 (establishment)
鑽石 (diamond)	鑽戒 (diamond ring)	鑽探 (drilling)
殘障 (disability)	殘缺 (incompleteness)	殘酷 (cruelty)
閃電 (lightning)	閃光 (flash)	閃躲 (dodge)
乳牛 (cow)	乳癌 (breast cancer)	乳鴿 (squab)
盤菜 (big bowl feast)	盤子 (plate)	盤問 (interrogation)
果汁	果實	果然

(juice)	(fruit)	(really)
機師 (pilot)	機械 (machine)	機會 (opportunity)
角樓 (turret)	角落 (corner)	角色 (role)
草原 (grassland)	草藥 (herb)	草率 (carelessness)
管樂 (wind music)	管道 (pipeline)	管家 (housekeeper)
包裹 (parcel)	包袱 (wrapper)	包庇 (harbor)
報紙 (newspaper)	報告 (report)	報答 (reciprocal)
體操 (gymnastics)	體育 (sport)	體諒 (understanding)
雪糕 (ice-cream)	雪人 (snowman)	雪恥 (revenge)
神父 (Catholic father)	神聖 (holiness)	神經 (nerve)
月餅 (moon cake)	月圓 (full moon)	月薪 (monthly salary)
曲線 (curve)	曲尺 (carpenter square)	曲調 (melody)
青蛙 (frog)	青苔 (moss)	青年 (youth)
輪椅 (wheel chair)	輪胎 (tire)	輪迴 (transmigration)
頭盔 (helmet)	頭髮 (hair)	頭版 (front page)
背囊 (backpack)	背脊 (back of the body)	背叛 (betrayal)
指紋 (fingerprint)	指甲 (fingernail)	指導 (guidance)
方形 (square)	方塊 (cube)	方法 (method)
影片 (film)	影印 (photocopy)	影響 (influence)