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L1 and L2 processing of compound words: Evidence from masked priming experiments in English*

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This study reports results from a series of masked priming experiments investigating early automatic processes involved in the visual recognition of English bimorphemic compounds in native and non-native processing. Results show that NSs produced robust and statistically equivalent masked priming effects with semantically transparent (e.g., toothbrush-TOOTH) and opaque (e.g., honeymoon-HONEY) compound primes, but no priming with orthographic controls (e.g., restaurant-REST), irrespective of constituent position. Similarly, advanced Chinese learners of English also produced robust and statistically equivalent priming effects with transparent and opaque compound primes in both positions. However, a clear orthographic priming effect was observed in the WORD-INITIAL *overlap position but no such effect in the* WORD-FINAL *position. We argue that L2 compound priming originates from a different source from form priming. We conclude that these findings lend support to the sublexical morpho-orthographic decomposition mechanism underlying early English compound recognition not only in L1 but also in L2 processing.*

Keywords: masked priming, compounds, morphological processing, English as a second language, late bilinguals

Introduction

Representation and processing of morphologically complex words (i.e., inflected, derived, and compound, e.g., *created, creative, toothbrush*) has been a central topic in research on visual word recognition in psycholinguistics over the past four decades. Researchers have debated whether morphemic information plays a role in the storage and access of complex words. Different theoretical models, including the full-listing model (e.g., Butterworth, 1983; Manelis & Tharp, 1977), the obligatory decompositional models (e.g., Taft & Forster, 1975; Taft, 1979), and the dual-route models (e.g., Pinker, 1991; Schreuder & Baayen, 1995) have been proposed to account for the role of morphology in complex word recognition.

Over the years, these competing theoretical views have generated a considerable amount of empirical research into this issue. Evidence accumulated through frequency manipulations (e.g., Alegre & Gordon, 1999; Pollatsek, Hyönä & Bertram, 2000; Taft, 1979) and priming manipulations (e.g., Marslen-Wilson, Tyler, Waksler & Older, 1994; Rastle, Davis, Marslen-Wilson & Tyler, 2000; Sandra, 1990) has led to a consensus that, in native visual recognition of complex words, morphology does play a significant role and morphological decomposition does happen. However, there is no consensus regarding how and when this decomposition is achieved. The key theoretical debate now centers on the exact nature and locus of morphemic representation in the processing hierarchy from form to meaning (Diependaele, Sandra & Grainger, 2005; Rastle & Davis, 2008; Taft & Nguyen-Hoan, 2010). Another dimension that may complicate the picture, but at the same time enrich our understanding of the human word recognition system, is the processing of such complex words in non-native speakers (NNSs), which is much less understood.

Within the large body of literature on morphological processing, much experimental work has focused on how monolingual native speakers (NSs) process inflected forms (e.g., Alegre & Gordon, 1999; Bozic, Tyler, Ives, Randall & Marslen-Wilson, 2010; Clahsen, 1999; Crepaldi, Rastle, Coltheart & Nickels, 2010; Luke & Christianson, 2011; Smolka, Zwitserlood & Rösler, 2007) or derived words (e.g., Bozic, Tyler, Su, Wingfield & Marslen-Wilson, 2013; Clahsen, Sonnenstuhl & Blevins, 2003; Diependaele et al., 2005; Giraudo & Grainger, 2000; Rastle et al., 2000). Recent years have seen a growing number of studies exploring L2 processing of inflected and/or derived words (Basnight-Brown, Chen, Hua, Kostić & Feldman, 2007; Clahsen, Felser, Neubauer, Sato & Silva, 2010; Clahsen & Neubauer, 2010; Clahsen,

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Balkhair, Schutter & Cunnings, 2013; Diependaele, Duñabeitia, Morris & Keuleers, 2011; Feldman, Kostić, Basnight-Brown, Filipović-Đurđević & Pastizzo, 2010; Gor & Cook, 2010; Gor & Jackson, 2013; Heyer & Clahsen, 2014; Kirkici & Clahsen, 2013; Neubauer & Clahsen, 2009; Portin, Lehtonen & Laine, 2007; Portin, Lehtonen, Harrer, Wande, Niemi & Laine, 2008; Silva & Clahsen, 2008; Vainio, Pajunen & Hyönä, 2014).

Compounding, however, has generally received less attention in both L1 and L2 research. Research on compound words may in fact offer great value in contributing to our understanding of complex word processing. First, compounding is the most universal word formation type across all languages investigated to date (Dressler, 2006). Due to that universality, it can be argued that compound words may offer a better testing ground for investigating complex word processing cross-linguistically. Second, unlike affixed words, which contain a limited set of very frequent bound morphemes that occur in predictable positions (e.g*., -s, -ed, un-, anti-,* etc.), compound words involve combinations of two or more words (or free morphemes) in a variety of syntactic categories (e.g., *classroom*, noun + noun; *blackboard*, adj. + noun; *snowwhite*, noun + adj.; *takeout*, verb + adverb), with their position of occurrence unpredictable (e.g., the free morpheme *book* is the first constituent in *bookmark*, but is the second in *storybook*). The use of compound words therefore provides a stronger testing case for complex word processing that does not depend on affix-related factors (Fiorentino & Fund-Reznicek, 2009). Lastly, due to the morphological differences among inflectional, derivational, and compounding processes, processing of each type of complex words warrants empirical research as the underlying mechanisms for processing different types of complex words may be different (Kirkici & Clahsen, 2013).

The present study sets out to explore whether NNSs decompose compound words in early visual recognition as NSs do, and if so, to examine the locus of morphological representation in L1 and L2 processing. This present study focuses on early automatic processing of English compound words by using the masked priming paradigm in lexical decision tasks (Forster & Davis, 1984). In masked priming tasks, participants are presented with a prime word, which is displayed for a very short duration (e.g., 50ms) before a target word on which they are asked to perform a lexical decision, i.e., word or nonword. The prime is masked, i.e., preceded and/or followed by a pattern mask (e.g., a row of hash signs). This masked priming procedure prevents participants from being aware of the primes and allows researchers to investigate early processing of the prime words, as they influence lexical access of the targets. Through manipulation of the morphological, semantic and orthographic relations between the prime and the target words, this study tests whether masked morphological priming effects that are independent of pure orthographic overlap can be observed in compound processing, and, if so, whether the observed priming effects are mediated by the SEMANTIC TRANSPARENCY of the compounds (i.e., the degree to which the meaning of the compound word can be derived from the meanings of its constituents). In addition, the role of constituent position and the similarities and differences between L1 and L2 processing are of interest in the present study.

The locus of morphemic representation in L1 processing of complex words

Although it is now widely accepted that morphology plays a significant role in L1 visual recognition of complex words, there is no consensus among researchers regarding the locus of morphemic representation. Three competing models have been proposed. The SUBLEXICAL model (Rastle, Davis & New, 2004; Taft & Forster, 1976; Taft, 1994) posits that a complex word is automatically decomposed into its morphemic constituents purely based on orthography prior to the activation of its whole-word lexical access, also known as the 'morpho-orthographic' decomposition account. In this model, morphemic representations are contacted before whole-word representations, and morphological decomposition is used to facilitate lexical access of the whole word. The SUPRALEXICAL model (Giraudo & Grainger, 2000; Giraudo & Grainger, 2001), on the other hand, posits that morphemic representations are contacted subsequent to the recognition of the whole word, and morphological processing is constrained by the 'morpho-semantic' properties of the complex word. The HYBRID model (Diependaele et al., 2005; Diependaele, Sandra & Grainger, 2009) proposes a double locus of morphological representation as opposed to a single one, and includes both a sublexical morpho-orthographic processing system and a supralexical morpho-semantic processing system, operating in parallel, in early visual recognition.

Empirical evidence from masked priming has been used to argue for or against each of these models. Giraudo and Grainger (2000) found that the magnitude of morphological priming relative to orthographic controls was modulated by the surface frequency but not the cumulative root frequency (i.e., the summed frequency of all derived words sharing the same root) of the prime words. The absence of cumulative root frequency effects was used to argue against the sublexical hypothesis, and the presence of surface frequency effects was used to provide support for the supralexical model. Giraudo and Grainger (2001), in Experiment 1, found that derived suffixed words and their roots were equally effective primes for other suffixed derivations of the same roots in French, irrespective of prime exposure durations

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(43 ms and 57 ms). This finding runs counter to the sublexical hypothesis based on the assumption that the prelexical parsing of derived word primes should require extra computation and thus more time than the processing of free roots. In Experiment 2, they used derived suffixed words as targets preceded by derived suffixed word primes sharing the same roots (e.g., *laitage* [milk product] – *laitier* [milkman], which is like *creation* – *creator*) or monomorphemic word primes containing a pseudoroot (e.g., *laitue* [lettuce] – *laitier* [milkman], which is like *costume* – *costly*). They found that the former produced a priming effect, but the latter did not. Giraudo and Grainger used this finding as evidence against the blind morphological decomposition account.

Evidence in support of the sublexical account has been obtained from masked priming studies that manipulated prime-target relatedness across three conditions: (a) morphologically, semantically, and orthographically related (+M+S+O; e.g., *cleaner-CLEAN*); (b) morphologically and orthographically related, but semantically unrelated/opaque (+M-S+O; e.g., *department-DEPART*); and (c) orthographically related only (-M-S+O; e.g., *brothel-BROTH*). It has been consistently found in a number of studies that significant masked priming occurs in conditions (a) and (b), but not in condition (c). That is, facilitative masked priming occurs with both semantically transparent and opaque primes, while mere orthographic overlap is not sufficient to produce priming effects (Fiorentino & Fund-Reznicek, 2009, on compound words; Rastle & Davis, 2008, for a qualitative meta-analysis of 19 empirical studies on derived words). More importantly, the priming effects for the transparent and opaque primes are statistically equivalent in the majority of the studies (Rastle & Davis, 2008). This pattern of masked priming effects has been taken as evidence for an early stage of automatic and blind decomposition that is independent of semantic transparency but largely guided by what orthographically appears to be morphological structure, which is known as the morpho-orthographic segmentation hypothesis (Rastle et al., 2004).

A few recent studies, however, have observed a semantic transparency effect in early visual masked priming (Diependaele et al., 2005; Diependaele et al., 2009; Diependaele et al., 2011; Feldman, O'Connor & Moscoso del Prado Martín, 2009; Feldman, Kostić, Gvozdenović, O'Connor & Moscoso del Prado Martín, 2012; Morris, Frank, Grainger & Holcomb, 2007). Diependaele and colleagues (2005, 2009, 2011), for example, in their investigation of masked priming with derived words (including both prefixed and suffixed), found the same pattern of priming effects, i.e., significant facilitative priming with both transparent and opaque primes, but stronger priming for the transparent than for the opaque primes. In a statistical meta-analysis of the same studies included in Rastle and Davis (2008), Feldman and colleagues (2009) showed a significant advantage of transparent primes over opaque primes, although this advantage is not always significant in individual studies. The pattern of graded priming, across semantically transparent and opaque primes, seems to be difficult to reconcile with the pure sublexical morpho-orthographic processing account. Diependaele and colleagues (2009) then proposed a hybrid account that includes both sublexical morpho-orthographic processing and supralexical morpho-semantic processing, operating in parallel in early visual recognition. The advantage of transparent primes over opaque ones can be explained by this account in that the constituent priming from transparent words benefits not only from sublexical morpho-orthographic activation, but also from top-down supralexical morpho-semantic facilitation, while the constituent priming from opaque words can only benefit from one source (i.e., sublexical morpho-orthographic activation that decays quickly).

Major issues in L2 processing of morphologically complex words

Research on L2 processing of complex words has been an extension of L1 morphological processing, and the major research question has been whether morphology also plays a role in L2 complex word processing. It is hotly debated whether L2 morphological processing differs from L1 processing, and, if so, how and why. Some researchers have argued that L2 and L1 morphological processing are fundamentally different and the differences cannot be sufficiently explained by L1 transfer or cognitive resource limitations (e.g., Clahsen et al., 2010). Across a number of studies on the processing of inflected words, Clahsen and colleagues found significant masked stem priming effects in NSs but no such effect for L2 learners (English regular past-tense -ed with Arabic L1 speakers in Clahsen et al., 2013; Turkish regular verb inflection with various L1 speakers in Kirkici & Clahsen, 2013; German inflected forms with Polish L1 speakers in Neubauer & Clahsen, 2009; English regular past-tense -ed with Chinese, Japanese, and German L1 speakers in Silva & Clahsen, 2008). They argue that "adult L2 learners are less sensitive to morphological structure than native speakers and rely more on lexical storage than on morphological parsing during processing" (Clahsen et al., 2010, p. 21).

Some other researchers have argued, however, that L2 and L1 morphological processing share the same mechanisms, and the differences between the L1 and L2 processing performance can be attributed to L1 transfer (Basnight-Brown et al., 2007; Portin et al., 2008) or domain-general cognitive resource limitations (McDonald, 2006). There has been evidence from research involving both inflection and derivation that partially supports this position (Diependaele et al., 2011; Feldman et al., 2010; Gor & Cook, 2010; Portin et al., 2007). With regard to inflection, Basnight-Brown et al. (2007) found that both Serbian–English and Chinese–English bilinguals process English regular verbs similarly and like NSs in a cross-modal priming study. In addition, Feldman and colleagues (2010) found reliable masked priming effects for English regular past tense *-ed* in both NSs and NNSs (Serbian L1s). L2 evidence on derivations comes from Diependaele et al. (2011), who compared masked priming effects of English derived words among NSs and two groups of NNSs (Spanish and Dutch L1s). They found that both native and bilingual participants (regardless of L1s) showed similar patterns of priming effects, and therefore suggested that late bilinguals largely use the same processing strategies as NSs do.

The issue of whether the mechanism underlying L2 processing of complex words is similar to or distinct from L1 processing is far from settled. It is important to note that these competing views have been informed exclusively by research on inflections and derivations. In a recent study, Kirkici and Clahsen (2013) tried to draw attention to "the morphological differences between inflectional and derivational processes" (p. 776), and found psycholinguistic evidence for different priming patterns for inflection and derivation within the L2 group (i.e., significant priming for derived forms, but no priming for inflected forms, in L2 learners of Turkish). These different patterns of priming effects for inflection and derivation suggest that there may be different mechanisms underlying L2 processing of complex words depending on the type of morphology. The question whether the underlying mechanism for L2 processing of COMPOUNDS is the same as or different from L2 processing of inflected and/or derived words warrants empirical investigation.

Empirical research on L1 and L2 processing of compound words

A comprehensive review of previous empirical research on L1 compound processing using different experimental paradigms is beyond the scope of this present study. Instead, our focus is on masked priming studies that have investigated the role of semantic transparency since it is pertinent to the discussion of the locus of morphemic representation. The two published studies on English compound processing that used the masked priming paradigm (Fiorentino & Fund-Reznicek, 2009; Shoolman & Andrews, 2003), did not find an effect of semantic transparency. Using compounds as targets, and their monomorphemic constituents as primes, Shoolman and Andrews (2003) found that both the first and second constituents primed the compounds regardless of semantic transparency. Arguing that Shoolman and Andrews' (2003) overt presentation of compounds as targets leaves it unclear whether the observed priming effects reflect automatic processing, Fiorentino and Fund-Reznicek (2009) used compounds as primes and their constituents as targets. They found significant and statistically equivalent facilitative priming effects in the transparent and opaque conditions but no priming in the orthographic overlap condition, in both the word-initial and the word-final overlap positions. They concluded that the morpho-orthographic segmentation independent of semantic transparency that has been consistently found in the processing of affixed words can be generalized to compound processing. In Chinese compound processing, however, semantic transparency has been found to play a role in visual masked priming. Peng, Liu, and Wang (1999), in a masked priming experiment with compounds varying in semantic transparency presented as primes for 56 ms, found significant priming effect only for semantically transparent compounds, not for opaque compounds. Liu and Peng (1997) found similar results in a visual priming task with an SOA of 86ms. These findings point to early decomposition for transparent compounds, but whole-word access for opaque compounds with possible supralexical decomposition in Chinese compound processing.

When it comes to L2 compound processing, there have been much fewer studies. The line of the studies that investigated cross-language activation in L2 compound processing (Cheng, Wang & Perfetti, 2011 with Chinese–English bilingual children; Ko, Wang & Kim, 2011 with adult Korean–English bilinguals; Wang, Lin & Gao, 2010 with adult Chinese–English bilinguals) used lexical decision tasks without priming and concluded that they found evidence for compound decomposition in L2 processing. Lemhöfer, Koester, and Schreuder (2011) found that both NSs and adult German–Dutch bilinguals responded faster to Dutch compounds that contained an orthotactic cue in a lexical decision task, which provides evidence for compound decomposition in L2 processing. De Cat, Klepousniotou, and Baayen (2015) examined L2 processing of English transparent, low-frequency noun-noun compounds in native Spanish and German speakers and found evidence for compound decomposition by advanced NNSs with L1 interference effects. Most relevant to the present study in terms of design, Ko (2011) used masked priming to explore English compound processing by adult Korean–English bilinguals. It should be noted that Ko used constituents as primes and compounds as targets, and therefore, her data may not reflect early automatic processing of compounds. Ko used a masked priming lexical decision task with both a forward mask (500ms) and a backward mask (150ms) with a prime duration of 50ms. Ko did not find a masked priming effect in any of the four conditions (+M+S+O, +M-S+O, -M-S+O, and -M+S-O). She concluded that either unbalanced adult Korean–English bilinguals do not

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rely on morphological decomposition in L2 processing, or her participants may not have accessed the L2 primes at all in her task condition.

The present study

The present study investigated early automatic processes involved in visual recognition of English bimorphemic compound words in native and non-native processing, using masked priming in lexical decision tasks. Chinese-speaking learners of English were chosen for the L2 group because their L1 Chinese makes extremely wide use of compounding (i.e., over 70% of words used in Modern Chinese are compounds, according to the Institute of Language Teaching and Research, 1986) and uses a different script (i.e., logographic) than English (i.e., alphabetic). The morphological, semantic and orthographic relations between prime and target words were manipulated to examine (a) whether a masked morphological priming effect can be observed in L1 and L2 compound processing, and (b) if so, whether the observed masked priming effect is mediated by semantic transparency at the early stage of processing in L1 and L2. In addition, this study examined whether constituent position plays a role in compound processing, i.e., whether a compound word primes its constituents to an equivalent extent. If it does not prime its constituents equivalently, then we want to determine which of its constituents the compound primes to a greater extent, the word-initial constituent or the word-final constituent? Finally, this study aimed to compare similarities and differences between L1 and L2 processing of English compounds.

Four experiments were conducted: Experiments 1a–b examined native processing of compound words, with Exp. 1a focusing on the priming of the word-initial compound constituents, using the compound as a masked prime and its first constituent as a target (e.g., *toothbrush-TOOTH*), and Exp. 1b focusing on the priming of the word-final compound constituents (e.g., *toothbrush-BRUSH*). Experiments 2a–b examined non-native processing of compounds, with Exp. 2a again focusing on the priming of the word-initial constituents and Exp. 2b on the priming of word-final constituents.

Participants

Fifty NSs of English (L1 group) participated in this study, 24 in Exp. 1a and 26 in Exp. 1b. They were all undergraduate students from the University of Maryland (UMD), and participated for course credit. Forty-six Chinese learners of English (L2 group) participated, 23 in Exp. 2a and 23 in Exp. 2b, and were each paid $10 for their participation. One NNS participant's data were excluded due to high error rate (>20%); accordingly, 45 L2 learners' data remained for analysis. The 45 L2 participants (35 females) were all graduate students from China studying at UMD at the time of testing, aged 22–33 (median 23, mean 24.25). They were born in China, had been first exposed to English in formal classroom settings between 5 to 15 years old (median 10, mean 9.69), had extensive classroom learning experience in their home county (mean 12.07 years), and did not come to the U.S. or an English-speaking country until at least 18 years old (AoA, i.e., Age of Arrival, mean 22.20, range 18–30). By the time of testing, they all had been studying in the U.S. or an English speaking country for at least one year (mean 2.37 years, range 1–9 years). TOEFL iBT (Test of English as a Foreign Language Internet-Based Test) score (N = 33, mean = 101.73, range = 94–111) was taken as a measure of learners' English proficiency for those whose length of residence (LOR) in an English-speaking country was no longer than two years. For those who had been in an English-speaking country for more than two years (N = 12), their LOR was used as an indication of L2 proficiency. All the L2 participants can be considered advanced learners of English.

Table 1 summarizes the background information of the L2 participants in Exp. 2a and Exp. 2b. The two groups were comparable in terms of age of testing, gender distribution, age of start, length of instruction, AoA, LOR, TOEFL score, and self-rated scores in listening, speaking, reading and writing.

Design and Stimuli

Table 2 shows the design of the study, which was a 3 (Condition/Prime Type: +M+S+O, +M-S+O, -M-S+O) × 2 (Relatedness: related, unrelated) × 2 (Target position: 1st constituent, 2nd constituent) design. In terms of the classification of compounds based on semantic transparency, Libben, Gibson, Yoon & Sandra (2003)'s classification was applied for the purpose of this study: TT (Transparent-Transparent) (e.g., *bedroom*), OT (Opaque-Transparent) (e.g., *strawberry*), TO (Transparent-Opaque) (e.g., *jailbird*), and OO (Opaque-Opaque) (e.g., *hogwash*). The TT compounds were used in the +M+S+O condition, and the OO compounds were used in the +M-S+O condition.

The English Lexical Project (Balota, Yap, Cortese, Hutchison, Kessler, Loftis, Neely, Nelson, Simpson & Treiman, 2007) was used to select the experimental stimuli based on word length, log-frequency and orthographic neighborhood size. Only compounds with noun-noun combinations (e.g., *toothbrush*) were used in the study. A set of 16 fully transparent compounds (TT) and 16 completely opaque compounds (OO) that had been piloted with NSs to collect subjective ratings of semantic transparency, and with Chinese learners of English in the target L2 population to check word familiarity (see details below), served as morphological primes

Table 1. *Background information of the Chinese learners of English in Experiments 2a and 2b*

	Experiment 2a Priming of word-initial position in NNSs ($N = 23$)		Experiment 2b Priming of word-final position in NNSs ($N = 22$)			
	Mean	*SD*	*Mean*	*SD*	*Statistics*	*p*
Age[1]	23.91	2.39	24.62	2.89	$U = 205.5$	0.38
Female/male	20/3		15/7		$X^2 = 2.340$	0.13
Age of start	9.30	2.60	10.09	2.41	$U = 216$	0.40
Length of instruction	12.30	2.48	11.82	3.19	$U = 245$	0.85
Age of arrival[1]	21.97	1.57	22.45	2.74	$U = 198.5$	0.31
Length of residencex (in *month*)	23.87	17.84	33.09	30.44	$U = 232$	0.63
TOEFL[2]	102.32	4.63	100.93	3.99	$U = 113$	0.46
Speaking[3]	7.00	1.21	6.86	1.17	$U = 230.5$	0.59
Listening[3]	7.48	1.34	7.59	1.10	$U = 251.5$	0.97
Reading[3]	7.57	1.44	7.59	1.10	$U = 248$	0.91
Writing[3]	6.52	1.56	6.64	1.18	$U = 248$	0.91

[1] There is one missing value for *Age* and *Age of Arrival,* respectively in Experiment 2b; the n size therefore is 21 for them in Experiment 2b.
[2] TOEFL scores were collected for those whose LOR is no longer than two years. The n size for TOEFL scores in Experiment 2a is 19; the other four participants in this experiment have a mean LOR of 5 years. The n size for TOEFL scores in Experiment 2b is14; the other eight participants in this experiment have a mean LOR of 5.5 years.
[3] The scores for speaking, listening, reading, and writing skills are self-rated on a scale from 1 (minimal) to 10 (near-native).

Table 2. *Design and Example Stimuli*

	Position 1 (Experiments 1a & 2a)			Position 2 (Experiments 1b & 2b)		
Prime Type	Related Prime	Unrelated Prime	Target	Related Prime	Unrelated Prime	Target
TT (+M+S+O)	toothbrush	waterfall	tooth	toothbrush	waterfall	brush
OO (+M-S+O)	honeymoon	videotape	honey	honeymoon	videotape	moon
Ortho overlap (-M-S+O)	restaurant	fantastic	rest	tomorrow	desperate	row

with their constituents as targets to test word-initial (e.g., *toothbrush-TOOTH*) and word-final constituent priming (e.g., *toothbrush-BRUSH*). In the orthographic overlap condition, two sets of monomorphemic words were used as primes. One set contained words with an embedded pseudo-morpheme in word-initial position and a non-morphological ending (e.g., *restaurant-REST*), whereas the other set contained words with an embedded pseudo-morpheme in word-final position and a non-morphological onset (e.g., *tomorrow-ROW*). The former were used as controls for the testing of word-initial constituent priming and the latter for the testing of word-final constituent priming. When selecting these items, care was taken to make sure that the related orthographic prime and its target overlapped not only in orthography but also in phonology, since that was the case for the related prime-target pairs in the morphological conditions. Unrelated control compounds were selected to match the compound primes, and unrelated control primes that also contain an embedded pseudo-morpheme in word-initial or word-final position were selected to match with the orthographic-overlap primes. The Appendix contains complete lists of the experimental items for both positions.

The lexical properties of the experimental stimuli across the TT, OO, and Ortho conditions were matched with one another in terms of prime length and frequency as well as target length, frequency, and orthographic neighborhood size, both in word-initial and word-final positions (see Tables 3 and 4; all $F < 1.55$, all $p > .22$, one-way ANOVA). The unrelated control primes were paired with the related primes on length and frequency across each of the three conditions (all $F < 0.20$, all $p > .60$, one-way ANOVA). The two lists of targets (the 1st constituents vs. the 2nd constituents) were matched on word length, log

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Table 3. *Stimuli properties across conditions (Word-initial position / 1st constituents as targets)*

Property	Condition (before item deletion) TT	OO	Orth1	Condition (after item deletion) TT	OO	Orth1	ANOVA (after item deletion)
Prime length	8.50	8.56	8.56	8.64	8.58	8.75	$F(2,31) = .055, p = .946$
Prime freq.	7.81	7.82	7.87	7.91	8.16	8.12	$F(2,31) = .168, p = .846$
Target (1st) length	4.25	4.19	4.25	4.36	4.25	4.25	$F(2,31) = .086, p = .917$
Target (1st) log freq.	10.37	9.91	9.55	10.58	10.21	10.40	$F(2,31) = .265, p = .769$
Target (1st) Orth N	8.06	10.06	9.00	7.93	10.17	9.25	$F(2,31) = .572, p = .570$

Note: the number of items in the original set for each condition (i.e., TT, OO, Orth1) is 16. After the item exclusion procedures, the number of items for each condition (i.e., TT, OO, Orth1) is 14, 12, 8, respectively, for RT analysis.

Table 4. *Stimuli properties across conditions (Word-final position / 2nd constituents as targets)*

Property	Condition (before item deletion) TT	OO	Orth2	Condition (after item deletion) TT	OO	Orth2	ANOVA (after item deletion)
Prime length	8.50	8.56	8.38	8.64	8.58	8.63	$F(2,31) = .010, p = .990$
Prime freq.	7.81	7.82	7.93	7.91	8.16	8.22	$F(2,31) = .241, p = .788$
Target (2nd) length	4.25	4.38	4.38	4.29	4.33	3.88	$F(2,31) = .881, p = .875$
Target (2nd) log freq.	10.12	10.80	9.99	10.45	10.89	10.03	$F(2,31) = .920, p = .579$
Target (2nd) Orth N	7.19	8.19	8.13	7.21	8.83	12.50	$F(2,31) = 2.159, p = .132$

Note: the number of items in the original set for each condition (i.e., TT, OO, Orth2) is 16. After the item exclusion procedures, the number of items for each condition (i.e., TT, OO, Orth2) is 14, 12, 8, respectively, for RT analysis.

frequency, and orthographic neighborhood size (all $p >$ .20, *t*-test).

The semantic transparency of the 32 critical compounds (which served as related morphological primes) was rated by a group of 60 NSs of English. The participants were asked to rate on a 4-point scale, the extent to which the constituent morpheme (either the 1st or the 2nd) contributes to the overall meaning of the compound word, ranging from *Not at all* (1), *Very little* (2), to *Somewhat* (3), and *To a great extent* (4). The words were presented in pairs, with the first member of the pair always the compound and the second either its 1st or 2nd morpheme. Two lists were created such that the 32 compound words occur on each list only once, with half of the compounds paired with its 1st constituent, and the other half with its 2nd constituent. Items were randomly ordered within each list. Thirty NSs completed List A and another thirty completed List B. The results show that the opaque compounds were rated much lower than the transparent compounds with both their first constituents ($M_{TT} = 3.54$; $M_{OO} = 2.23$), $t(30) = 5.408$, $p < .001$, and their second constituents ($M_{TT} = 3.58$; $M_{OO} = 2.19$), $t(30) = 8.048$, $p < .001$.

An additional 48 words, including 32 compound words, and 16 monomorphemic words were used as primes for 48 nonword targets. The nonword targets were matched with the real word targets in length. The primes were matched with experimental primes on length and log frequency.

The targets for each position (word-initial and word-final) were divided into two counterbalanced lists such that half of the experimental targets were preceded by related primes and the other half by unrelated primes. Each participant in each experiment completed a single list. The total number of trials in each list was 96.

Procedure

A masked priming lexical decision task was used in the experiments. Stimuli were visually presented in the center of the screen, with black text on a white background, using DMDX software (Forster & Davis, 1984). The stimuli were presented in a different random order for each participant. Participants were instructed that they would see a string of letters on the screen and were asked to decide as quickly and accurately as possible whether each string of letters that they saw was a word or a nonword. Participants were instructed to press the 'Yes' key with the right index finger if they identified the letter string as a real word, and the 'No' key with the left index finger if they identified the letter string as a nonword.

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In the task, a fixation '∗' was first presented for 500ms, followed by a forward mask ('##########') for 500ms. The length of the forward mask was equal to the length in letters of the longest prime word. The mask was then followed by the visual presentation of the prime in lower-case for 50ms in Times New Roman font, Size 12. For English NS participants, i.e., in Experiments 1a-b, the prime was then immediately substituted by the target stimulus in upper-case in the same font size as the prime. The target remained on the screen until the participant responded via button press or a 3000ms timeout. A typical trial looked like: ∗ - ########### - marketplace - MARKET. Eight practice trials were presented at the beginning of the experiment to familiarize participants with the task.

The masked priming procedure was the same for Chinese-speaking learners, in Experiments 2a-b, except that a 50ms blank interval was inserted between the prime and the target. The procedure of adding a 50ms blank interval for NNSs was not new and was used in Jiang (1999) in order to allow for more processing time for adult Chinese learners who are slower in processing English letters. After the experiment, Chinese-speaking learners completed a written word translation task. They were asked to translate all real word experimental stimuli into Chinese, that is, they translated both the stimuli they saw consciously (i.e., targets) and unconsciously (i.e., primes, related and unrelated). This word translation task was used to screen out items with words unknown to the NNSs. This screening procedure was important with NNSs because knowing all the words, including their meanings, was critical to test the role of semantic transparency in morphologically related pairs. Chinese-speaking learners also filled out a short language background questionnaire.

Results and discussion

Two NS participants' data in Exp. 1b were excluded from analysis because they reported awareness of the existence of the primes. One NNS participant's data were excluded due to high performance error rate (>20%). Items with either the prime word or the target word for which a NNS failed to provide the correct translation were excluded from RT analysis for that participant. This procedure resulted in an exclusion of ten items (including ten related prime-target pairs and their corresponding ten unrelated control pairs; marked by an asterisk ∗ before the item number in the Appendix) for each position, due to the high error rates for those items in the post-hoc word translation task from the NNSs. In addition, an anonymous reviewer pointed out that a few monomorphemic prime words in the orthographic overlap conditions can be exhaustively decomposed into potential morphemes, which are similar to the "*corn-er*" type of stimuli that have been argued to yield masked morphological priming in Rastle et al. (2004). A close scrutiny of all items in the orthographic conditions revealed that there were four such items for each position (i.e., *scar-let*, *log-ist-ic, earn-est, pump-kin* for the word-initial position, and *pro-found*, *inter-view, com-plain, ob-serve* for the word-final position, marked by a double asterisk ** in the Appendix). An analysis on these eight "corner" type of items revealed a significant priming effect ($p = .005$) when the RT data from both NSs and NNSs for both positions were included. A decision was then made to exclude these items from the final analysis.

After the above exclusion procedures, the remaining 34 items, 14 for the TT condition, 12 for the OO condition, and eight for the orthographic control condition (for each position, respectively), were included in the final analysis. The lexical properties of these items across the three conditions were still matched well with each other (see Tables 3–4). The two lists of targets were also matched on word length, log frequency, and orthographic neighborhood size (all $p > .63$). The mean semantic transparency ratings of the remaining compounds in the TT and OO conditions for both positions were even more distant (Position 1: $M_{TT} = 3.66$; $M_{OO} = 2.10$; Position 2: $M_{TT} = 3.58$; $M_{OO} = 1.98$; both $p < .001$).

Only correct responses to real words were included in RT analysis. This exclusion procedure resulted in the removal of 5.3% of the RT data in Exp. 1a (NSs, Position 1), 6.7% in Exp. 1b (NSs, Position 2), 12.7% in Exp. 2a (NNSs, Position 1), and 13.1% in Exp. 2b (NNSs, Position 2). We dealt with RT outliers by establishing cut-offs at 2.5 standard deviations above and below each participant's mean RT. This resulted in a loss of 2.0% of the data in Exp. 1a and Exp. 2b, 2.1% in Exp. 1b, and 1.4% in Exp. 2a. In total, 7.2% of the RT data were removed in Exp. 1a, 8.8% in Exp. 1b, 14.1% in Exp. 2a, and 15.1% in Exp. 2b, respectively. None of the RTs included for final analysis were below 300ms or above 1500ms.

The RTs in each experiment were analyzed using linear mixed-effects models and the accuracies using generalized linear mixed-effects models in SPSS 21.0. There was no averaging of the data prior to the analyses. All RTs were inverse-transformed[1] (i.e., -1000/RT) to reduce the positive skew in the distributions. When fitting mixed-effects models for each experiment, prime type, relatedness and their interaction were included as fixed effects, and participants and items were modeled as random variables (Baayen, Davidson & Bates, 2008). We started with a basic model in which all parameters are fixed and then added random intercepts for participants and items, and then random slopes for participants and

[1] Inverse transformation was used because for the current sets of data, log transformation was not strong enough to correct the positive skew of the RT distributions of some groups whereas inverse transformation was able to put all groups into the acceptable range of normal distribution.

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items, following Field's (2013) recommendation (p. 831). After a series of model fitting, random intercepts for both participants and items were included in all models because their inclusion significantly improved the fit of the models using χ^2 likelihood ratio tests (Baayen et al., 2008). Random slopes for participants and items, however, were not included because the inclusion of either or both of them did not improve the models significantly. For the purpose of the present study, we report results of F tests for each of the fixed variables (including their interaction) from the model of the best fit for each experiment and pairwise comparisons depicting the effect of relatedness (priming) at different levels of prime type (TT, OO and Orth).

In the following, we report the RT and accuracy results for each experiment in order. A joint analysis of the RT data from the four experiments will then follow, taking into consideration two more fixed variables, i.e., Position (word-initial vs. word-final), and Nativeness (native vs. non-native).

Experiment 1a. Priming of word-initial position in NSs of English

Experiment 1a focused on the priming of word-initial position in native processing of English compounds. The means and number of observations for raw RTs (after data exclusion procedures) and accuracy rates for each condition are presented in Table 5. The inverse-transformed RT data revealed a significant main effect of Relatedness, F (1, 703) = 11.096, p = .001, and of Prime Type, F (2, 33) = 4.558, p = .018; however, the Prime Type × Relatedness interaction did not reach significance, F (2, 703) = 1.680, p = .187. This pattern of results suggests that the effect of relatedness can be generalized to all levels of prime type and that the magnitude of relatedness/priming effect does not differ across prime types. It was hypothesized, however, that there should be no significant priming (or relatedness) effect in the purely orthographic overlap condition in L1 processing under such design based on previous findings (e.g., Fiorentino & Fund-Reznicek, 2009). In order to see whether significant priming effect existed for each of the three prime type conditions, planned comparisons regarding the effect of Relatedness at each Prime Type level were conducted. The results from such comparisons yielded a significant facilitative priming effect for the transparent condition (26 ms), F (1, 701) = 9.401, p = .002, and for the opaque condition (29 ms), F (1, 702) = 8.929, p = .003, but no significant priming for the orthographic overlap condition, F (1, 705) = 0.066, p = .798. While the interaction between Relatedness and Prime type did not reach significance, which could partially be due to the reduced number of items included in the final analysis[2] and the relatively small number of participants, we have evidence from multiple comparisons that there was no priming in the purely orthographic overlap condition but there were significant priming effects in the compound conditions. The priming effects observed in the compound conditions could not simply be due to form overlap because such effect was not observed in the purely orthographic overlap condition.

The role of semantic transparency was tested by examining the interaction between Relatedness (priming) and Prime Type (at TT and OO levels only) and the interaction turned out to be non-significant, F (1, 535) = .046, p = .830. This non-significant interaction suggests that the magnitude of priming did not differ across the TT and OO conditions.

The accuracy analysis showed no significant main effect of either Prime Type, F (2, 810) = 2.347, p = .100, or Relatedness, F (1, 810) = 0.192, p = .662. The interaction between Prime Type and Relatedness was not significant either, F (2, 810) = 0.340, p = .832.

In Exp. 1a, significant and statistically equivalent facilitative masked priming effects were obtained for the word-initial constituents of semantically transparent and opaque compounds while no priming was observed in the orthographic overlap condition. These results replicate the findings of Experiment I in Fiorentino and Fund-Reznicek (2009), the earlier study that examined native processing of English compounds using the same task and design. This pattern of priming effects also converges with the majority of those observed for the root of derivationally suffixed words under similar masked priming conditions (e.g., Longtin, Segui & Hallé, 2003; Rastle et al., 2000; Rastle et al., 2004). This pattern contrasts with the findings from Diependaele et al. (2005) and Diependaele et al. (2011) that examined French and English suffixed derivations, in that significantly larger facilitative priming was found for semantically transparent items relative to opaque items in their studies, but no such semantic transparency effect was observed in this current experiment. The findings of this experiment thus contribute evidence in favor of a fast automatic sublexical morpho-orthographic decomposition mechanism independent of semantic transparency in native compound processing.

Experiment 1b. Priming of word-final position in NSs of English

Experiment 1b examined the priming of word-final position in native processing of English compounds. The raw mean RTs and accuracy rates for each condition are

[2] In the final analysis, we removed items that learners do not know and those that are potentially decomposable in the orthographic control condition.

Table 5. *Mean reaction times and accuracy rates per condition in Exp. 1a (NSs, Position 1)*

	RT					Accuracy	
	Mean RT (SD) in ms			# of observations			
Prime Type	Related	Unrelated	*Effect*	Related	Unrelated	Related	Unrelated
TT	536 (104)	561 (104)	26**	157	157	.95	.95
OO	555 (122)	584 (131)	29**	134	134	.94	.95
Orth	581 (102)	581 (86)	0	88	87	.95	.93

** <.01.

Table 6. *Mean reaction times and accuracy rates per condition in Exp. 1b (NSs, Position 2)*

	RT					Accuracy	
	Mean RT (SD) in ms			# of observations			
Prime Type	Related	Unrelated	*Effect*	Related	Unrelated	Related	Unrelated
TT	556 (102)	578 (103)	22*	158	148	.95	.90
OO	556 (103)	577 (96)	21**	138	128	.97	.94
Orth	597 (107)	591 (105)	-6	87	85	.92	.90

* <.05;
** <.01.

presented in Table 6. The inverse-transformed RT data revealed a significant main effect of Relatedness, F (1, 688) = 5.812, p = .016. The main effect of Prime Type did not reach significance, F (2, 32) = 2.463, p = .101. The interaction between Prime Type and Relatedness was marginally significant, F (2, 689) = 2.702, p = .068. Planned comparisons regarding the effect of Relatedness at each Prime Type level revealed a significant facilitative priming effect for the TT condition (22 ms), F (1, 690) = 5.162, p = .023, and for the OO condition (21 ms), F (1, 688) = 8.918, p = .003, but no significant priming for the Orth condition, F (1, 688) = 0.281, p = .596.

As for the role of semantic transparency, the interaction between Relatedness (priming) and Prime Type (at TT and OO levels only) was not significant, F (1, 526) = .343, p = .558, suggesting that the magnitude of priming did not differ across the TT and OO conditions.

The accuracy analysis showed no significant main effect of either Prime Type, F (2, 810) = 2.207, p = .111, or Relatedness, F (1, 810) = 2.818, p = .094. The interaction between Prime Type and Relatedness was not significant either, F (2, 810) = 0.275, p = .759.

In this experiment, significant and statistically equivalent priming effects were obtained for the word-final constituents of semantically transparent and opaque compounds, while no priming was observed in the orthographic control condition. These findings replicate those in Experiment 1a as well as those in Fiorentino and Fund-Reznicek (2009), Experiment II, that examined word-final constituent masked priming in native processing. This pattern of priming effects for the word-final constituents of compounds also converges with the pattern of priming observed for the root of derivationally prefixed words in Dutch reported by Diependaele et al. (2009), Experiment 1, under similar masked priming conditions in L1 processing. The same patterns of priming effects in Experiments 1a and 1b in the current study provide converging evidence for a fast automatic sublexical morpho-orthographic decomposition mechanism independent of semantic transparency in native processing of compounds.

Experiment 2a. Priming of word-initial position in Chinese learners of English

Experiment 2a explored the priming of word-initial constituents in non-native processing of English compounds by a group of advanced Chinese learners of English. The raw mean RTs and accuracy rates for each condition are presented in Table 7. The analysis of the inverse-transformed RT data revealed a significant main effect of Relatedness, F (1, 622) = 36.356, p < .001. The main effect of Prime Type was not significant, F (2, 33) = 1.049, p = .362, nor was the interaction between Prime Type and Relatedness, F (2, 622) = 1.011, p = .365. Planned comparisons evaluating the effect of Relatedness at each Prime Type level yielded significant facilitative

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Table 7. *Mean reaction times and accuracy rates per condition in Exp. 2a (NNSs, Position 1)*

	RT					Accuracy	
	Mean RT (SD) in ms			# of observations			
Prime Type	Related	Unrelated	*Effect*	Related	Unrelated	Related	Unrelated
TT	659 (142)	677 (139)	18**	154	144	.96	.91
OO	646 (164)	711 (155)	65**	126	113	.93	.84
Orth	668 (144)	742 (184)	74**	71	64	.79	.70

** <.01.

Table 8. *Mean reaction times and accuracy rates per condition in Exp. 2b (NNSs, Position 2)*

	RT					Accuracy	
	Mean RT (SD) in ms			# of observations			
Prime Type	Related	Unrelated	*Effect*	Related	Unrelated	Related	Unrelated
TT	670 (161)	702 (157)	32**	135	127	.91	.84
OO	667 (146)	686 (122)	19**	119	109	.91	.86
Orth	696 (131)	692 (120)	-4	72	73	.86	.81

** <.01.

priming effects for the TT condition (18 ms), $F(1, 618) = 10.341$, $p = .001$, the OO condition (65 ms), $F(1, 620) = 22.695$, $p < .001$, as well as for the Orth condition (74 ms), $F(1, 625) = 7.891$, $p = .005$.

The role of semantic transparency was again tested by examining the interaction between Relatedness and Prime Type (at TT and OO levels only). The interaction failed to reach significance, $F(1, 493) = 1.776$, $p = .183$, indicating that the magnitude of priming effects did not differ significantly across the TT and OO conditions.

As for accuracy analysis, unlike NSs who demonstrated no effect for either Relatedness or Prime Type, advanced Chinese learners of English showed a significant main effect of Prime Type, $F(2, 776) = 18.124$, $p < .001$, and of Relatedness, $F(1, 776) = 9.764$, $p = .002$. The interaction between Prime Type and Relatedness was not significant, $F(2, 776) = 0.373$, $p = .689$. Accuracy rates were significantly higher in the TT and OO conditions (with no significant difference between them) than that in the Orth condition, and accuracy following related primes was higher than following unrelated control primes.

Experiment 2a, which tested the priming of word-initial constituents in non-native processing of compounds, elicited a significant masked priming effect not only in the transparent and opaque compound conditions, but also in the orthographic overlap condition. Similar to L1 processing, significant facilitative masked priming effects were observed in L2 processing for both transparent and opaque compound primes, and the magnitudes of the priming effects did not differ significantly between the TT and OO conditions. Unlike NSs, however, Chinese-speaking learners showed a clear facilitative form priming effect when the target word overlaps with the initial part of the prime. This finding will be discussed in more detail in the subsequent general discussion section.

Experiment 2b. Priming of word-final position in Chinese learners of English

Experiment 2b investigated the priming of word-final constituents in non-native processing of English compounds by another group of advanced Chinese learners of English. The raw mean RTs and accuracy rates for each condition are presented in Table 8. The analysis of the inverse-transformed RT data showed a significant main effect of Relatedness, $F(1, 582) = 6.136$, $p = .014$, but no significant main effect of Prime Type, $F(2, 33) = .244$, $p = .785$. More importantly, a significant interaction between Prime Type and Relatedness was found, $F(2, 583) = 3.909$, $p = .021$, suggesting that the effect of relatedness changes depending on the level of prime type. Planned comparisons gauging the effect of Relatedness at each Prime Type level yielded significant facilitative priming effects for the TT condition (32 ms), $F(1, 584) = 9.325$, $p = .002$, and for the OO condition (19 ms), $F(1, 581) = 8.223$, $p = .004$, while no significant facilitation was found in the Orth condition, $F(1, 582) = .813$, $p = .368$.

In terms of the role of semantic transparency, the interaction between Relatedness and Prime Type (at TT and OO levels only) was not significant, $F(1, 446) = .011$, $p = .917$, indicating that the magnitude of priming effect did not differ significantly for transparent and opaque primes.

The accuracy results showed a significant main effect of Relatedness, $F(1, 742) = 4.881$, $p = .027$, with higher accuracy following related primes. The main effect of Prime Type was not significant, F (2, 742) = 1.276, $p = .280$, nor was the interaction between Prime Type and Relatedness, $F(2, 742) = 0.125$, $p = .883$.

Experiment 2b, which tested the priming of word-final constituents in L2 processing of compounds, elicited significant and statistically equivalent masked priming in the transparent and opaque compound conditions and no priming in the orthographic overlap condition. This pattern of priming effects converges with those observed in Experiments 1a and 1b as well as those reported in Fiorentino and Fund-Reznicek (2009) on L1 processing of English compounds. These results seem to suggest that advanced Chinese learners of English use the same morphological processing strategy as native speakers. That is, an automatic sublexical morpho-orthographic decomposition mechanism that is independent of semantic transparency also seems to operate in advanced Chinese learners of English.

Joint Analysis

We merged the RT data from the four experiments to explore the effects of two more variables, i.e., Position (word-initial vs. word-final) and Nativeness (native vs. non-native), in addition to Prime Type and Relatedness. A significant main effect was found for Nativeness, $F(1, 94) = 63.568$, $p < .001$, with NSs responding significantly faster than NNSs, and for Relatedness, F (1, 2657) = 50.951, $p < .001$, with RTs significantly shorter following related primes. The main effect of Prime Type was marginally significant, F (2, 66) = 3.004, $p = .056$. The main effect of Position was not significant, F (1, 142) = 0.392, $p = .532$. The four-way interaction between Nativeness, Position, Prime Type, and Relatedness was not significant, F (2, 2657) = 1.031, $p = .357$, nor were any of the three-way interactions (all $p > .113$).

The two-way interaction of Prime Type and Relatedness was significant in this big model, F (2, 2658) = 5.926, $p = .003$, with the Relatedness effect significant at the transparent and opaque prime type levels (23 ms for the transparent prime type, F (1, 1066) = 33.096, $p < .001$; 32 ms for the opaque prime type, $F(1, 894) = 42.049$, $p < .001$), but nonsignificant at the orthographic control level ($F(1, 537) = 0.759$, $p = .384$). It is important to note that although the Prime Type × Relatedness interaction did not reach statistical significance in each of the four separate models in the four experiments (i.e., it was significant in L2 processing at Position 2 ($p = .021$), marginally significant in L1 processing at Position 2 ($p = .068$), and not significant at Position 1 for both the L1 group ($p = .187$) and the L2 group ($p = .365$)), the interaction did turn out to be significant in the joint analysis model, providing support to our interpretation that the compound priming effect observed in the study could not be simply due to orthographic overlap.

The two-way interaction between Position and Relatedness was also significant, $F(2, 2657) = 5.427$, $p = .020$. The effect of Relatedness was significantly larger at the word-initial overlap position (30 ms, F (1, 1351) = 48.844, $p < .001$) than at the word-final overlap position (17 ms, F (1, 1301) = 19.663, $p < .001$). Although the three-way interaction between Nativeness, Position and Relatedness did not reach statistical significance, F (1, 2654) = 2.520, $p = .113$, separate analyses for the two language groups showed that the interaction of Position and Relatedness was not significant for the English NS group, F (1, 1390) = .337, $p = .562$, and was only significant for the NNS Chinese group, F (1, 1201) = 5.579, $p = .018$. These results suggest that there was no position effect in L1 processing, but there was a position effect in L2 processing with larger priming effect for the word-initial overlap position. Relating this to the results of the four separate models presented earlier (see Tables 5–8), we suspect that the larger priming effect for the word-initial position in L2 processing is likely to be driven by the presence of the large priming effect in the orthographic control condition at that position. We then decided to run another joint analysis of the RT data from the four experiments, excluding those in the orthographic control conditions, to clarify any effects of Position and Nativeness in COMPOUND processing.

When the orthographic control conditions were excluded from the joint analysis, there was again a significant main effect for Relatedness, F (1, 2040) = 79.208, $p < .001$, and for Nativeness, F (1, 93) = 62.426, $p < .001$. The RTs following related primes were significantly shorter than those following unrelated primes in the compound conditions. In addition, native English speakers were 114 ms faster than Chinese learners of English across the board in compound processing (NS Grand Mean RT = 562 ms; NNS Grand Mean RT = 676 ms). Other than these two main effects, none of the other main effects (including Position, $F(1, 130) = .451$, $p = .503$ and Prime Type, F (1, 50) = .274, $p = .603$) were significant, nor were any of the two-way, three-way or four-way interactions. The interaction of Prime Type (TT & OO) and Relatedness was not significant, F (1, 2049) = 1.229, $p = .268$. The interaction of Position and Relatedness was not significant either, $F(1, 2030) = 1.130$, $p = .288$. The interaction of Nativeness × Position × Relatedness was not significant, $F(1, 2040) = .445$, $p = .505$. The four-way interaction of Nativeness × Position

× Prime Type × Relatedness was not significant, F (1, 2049) = .616, p = .433. These results suggest that the magnitudes of the priming effects for the transparent and opaque compounds did not differ across positions in either NS or NNS processing of compounds (i.e., no Position effect) and that except for being slower, this group of advanced Chinese learners of English process English compound words in similar ways as NSs of English (i.e., no Nativeness effect).

General Discussion

In native English compound processing, this study found robust and equivalent masked priming with semantically transparent and opaque compound primes but no priming with monomorphemic words with embedded pseudo-morphemes, irrespective of constituent position (i.e., either word-initial or word-final). This pattern of masked priming effects suggests that automatic morphological decomposition that is not due to mere orthographic overlap occurs at a very early stage of visual recognition and that this decomposition is independent of semantic transparency and largely guided by the analysis of orthography. These results replicate Fiorentino and Fund-Reznicek's (2009) findings, and are in conformity with the majority of those observed for the root of derived words under similar masked priming conditions (e.g., Longtin et al., 2003; Rastle et al., 2000; Rastle et al., 2004), providing support for the sublexical morpho-orthographic segmentation hypothesis, originally proposed by Rastle and colleagues (2004) for derivation processing. The findings of this study reinforce Fiorentino and Fund-Reznicek's conclusion that morphological segmentation does not depend on the presence of an affix or other formal regularity and that early morpho-orthographic segmentation generalizes across word-formation types.

When it comes to L2 compound processing, the results show that the priming effects in advanced Chinese learners of English are similar to those of NSs, with one exception. The pattern of the priming effects for the word-final constituents across the three prime type conditions is the same as that of L1 processing, i.e., robust and equivalent masked priming with semantically transparent and opaque compound primes, but no priming in the orthographic control condition. However, the pattern of the priming effects for the word-initial constituents turns out to be different, with significant masked priming not only for the transparent and opaque compound primes, but also for the orthographic control primes. This finding of a clear masked orthographic priming effect at the word-initial overlap position in L2 processing is not surprisingly new. While previous masked priming studies did not show any facilitation with NSs for purely orthographically related pairs, two recent studies clearly showed evidence of orthographic priming with NNSs (Diependaele et al., 2011; Heyer & Clahsen, 2014). Diependaele and colleagues (2011) reported a clear masked orthographic priming effect in two NNS groups, but no such effect in the NS group, in the context of investigating the processing of English suffixed derivations. Heyer and Clahsen (2014) directly compared purely orthographically related and derived prime-target pairs (*scanner-SCAN*; *scandal-SCAN*), and found that while NSs showed morphological but not orthographic priming, NNSs produced significant and statistically equivalent magnitudes of masked priming for both prime types. The finding of L2 masked orthographic priming in the present study and the above two studies suggests that early visual word recognition in an L2 may rely more on surface-form properties than it does in the L1. The finding of form priming in NNSs also resonates with the findings from the word association literature which has shown that NNSs produced more form-related response words than NSs, suggesting their heavier reliance on form relationships. For example, the NNS participants in Wolter (2001), produced a high 35% of form-related or clang responses; so did the participants in Namei (2004), i.e., 26% and 16% for the Persian bilingual 3rd and 6th graders, respectively.

Admittedly, the clear masked orthographic priming effect observed at the word-initial overlap position in L2 processing may be partially due to the presentation formats of the targets and primes. Following the typical protocol of the masked priming procedure, the targets (in UPPERCASE) did not fully mask the primes (in lowercase) because the targets were about four letters shorter than the primes. The unmasked initial letters (one or two) of the prime might have helped NNSs recognize the target, therefore contributing to faster responses following the related primes in the orthographic condition. It is worthwhile investigating whether masked form priming still persists in a future study with the same materials and procedure but using a larger font size for the targets that fully mask the primes.

It should be noted that L2 masked orthographic facilitation has only been observed in the word-initial overlap position thus far (Diependaele et al., 2011; Heyer & Clahsen, 2014; the present study). Based on the finding of statistically equivalent masked priming effects for derived items and purely orthographically related items in NNS processing, Heyer and Clahsen (2014) questioned whether the effects for derived words in NNS processing are morphological in nature, as those effects could simply be due to orthographic overlap. A novel contribution of the present study is that we found a clear masked form priming effect in the word-initial overlap position but a LACK of such an effect in the word-final overlap position in the context of compound processing. Compound priming effects are indeed difficult to disentangle from form priming at word-initial position in a visual masked priming task. However, the presence of form priming in the orthographic control condition does not automatically rule out morphological priming in the compound conditions. The existence of compound priming effects dissociable from pure orthographic overlap observed in word-final position provides strong evidence that the compound priming is not simply due to form overlap, but is morphological in nature. The fact that compound priming occurred regardless of position while form priming is constrained by position is a clear indication that compound priming originates from a different source or locus from that of form priming.

Semantic transparency was not found to play a role in the early stage of visual English compound processing, either in NSs or in NNSs in the current study. These results add evidence for the lack of a semantic transparency effect in early L1 English compound processing and provide new evidence for L2 English compound processing at an early stage. These results suggest that both L1 and L2 processing of English compounds is entirely driven by the analysis of orthography at the initial stage, with semantic information not yet being activated. These results seem to run counter to the findings from Chinese compound processing. Previous masked priming results demonstrate a compelling semantic transparency effect in early Chinese compound processing in NSs (e.g., Liu & Peng, 1997; Peng et al., 1999). These differences can be explained by the distinct writing systems the two languages use. Chinese is logographic such that, in most cases, a single printed character maps to a single morpheme in a bimorphemic compound (e.g., 书架, bookshelf). The clear boundary and visual saliency of the two morphemes embodied in two separate characters gives rise to the early activation of semantic information in Chinese reading. English, on the other hand, is alphabetic. A long string of letters in an English compound may require a longer time for the analysis of orthography before the semantics of either the whole word or each morpheme can come into play.

With regard to the locus of morphological decomposition in general, the findings of the current study have theoretical import in that they lend support to the sublexical morpho-orthographic decomposition model (Rastle et al., 2004) and run counter to the supra-lexical morpho-semantic processing model (Giraudo & Grainger, 2001). Regarding the hybrid model in which parallel sublexical morpho-orthographic processing and supralexical morpho-semantic processing are both assumed (Diependaele et al., 2005; Diependaele et al., 2009; Diependaele et al., 2011), the current results from compound processing do not provide evidence to support this model. It should be cautioned, however, that the hybrid model was formulated based on derivation, and compounding is likely to involve semantic processing of a different kind than derivation. Compared with the semantic transparency of derivations (e.g., *viewer* vs. *department*), transparent and opaque compounds (e.g., *homeland* vs. *honeymoon*) as defined in the current study are not so categorically divided, because (1) each constituent is more or less related to the overall meaning, (2) the relation between the constituents may be more or less difficult to infer, and (3) the overall meaning may be based on the relationship, but it is also metaphorical, i.e., far removed from the literal relation. It is probable that the processing of a semantic relation between constituents for compounds in English does not take place during masked priming and is supralexical, whereas the relation to the morphological family for derivations may be established faster. Considering the different properties of semantic transparency in derivation and compounding, we are not surprised that no semantic transparency effect was found in this study and Fiorentino and Fund-Reznicek (2009). That being said, we conclude that we found no evidence for semantic transparency in early English COMPOUND processing.

In terms of the role of constituent position in compound processing, masked priming was found in both word-initial and word-final overlap positions, and the magnitudes of the priming effects did not differ across positions in either L1 or L2 processing. The statistically equivalent magnitudes of masked priming for both positions suggest that both morphemic constituents of a compound prime, regardless of position, are activated to a similar extent in early visual recognition of compounds in both native and advanced non-native readers. Given the right-headedness of English noun-noun compounds used in the study, these results seem to be inconsistent with earlier findings of a greater role of word-final constituents in L1 visual recognition of right-headed compounds (Juhasz, Starr, Inhoff & Placke, 2003; Libben et al., 2003; Marelli, Crepaldi & Luzzatti, 2009). Using a lexical decision task, Juhasz et al. (2003) found a robust frequency effect of the second constituent, but a much more limited role of the first constituent in English compound processing. Using a constituent priming paradigm (SOA = 150 ms), Libben et al. (2003) found that the semantic transparency of the second constituent played a more important role than that of the first constituent. Marelli and colleagues (2009) found a larger priming effect for the word-final than for the word-initial constituent in right-headed compounds in Italian (SOA = 300 ms). It should be noted that in the above two constituent priming studies, monomorphemic constituents were used as primes and compounds as targets; therefore, the results of these studies may reflect later stages of compound processing while the results of the present study from masked priming reflect the initial stage of automatic processing. Taken together, it seems that the position effect combined with headedness may come into play at later stages of processing, but it may

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not play a role at the very initial stage in L1 processing. When it comes to L2 processing, more recently, De Cat et al. (2015), using a masked priming lexical decision task in which English compounds were presented with their constituents nouns in licit versus reversed order (prime duration = 100 ms; SOA = 150 ms), found that Spanish speakers whose L1 has the opposite word order in compound directionality produced greater over-acceptance of reserved English compounds and longer response times than the native group while the German group who were matched with the Spanish group in L2 English proficiency did not perform significantly differently with the native group. This finding suggests that L2 compound processing may be affected by head directionality of L1. It remains to be tested in a future study whether a position effect would be found in English compound processing when NNSs of a language with left-headed compounds are tested under such masked priming conditions.

Finally, with regards to the similarities and differences between L1 and L2 compound processing, it was found that Chinese learners of English were 114 ms slower than English NSs in response to simple monomorphemic target words. Apart from this difference, this group of L2 speakers was found to process English compounds in a similar fashion to NSs, at least at the initial stage. The advanced Chinese L2 learners of English were found to be sensitive to the morphological structure of compounding and to decompose compounds rapidly and automatically at the initial stage of visual processing. These results converge with previous findings obtained using masked priming to examine the L2 processing of derived words. Diependale et al (2011) found that Spanish–English and Dutch–English bilinguals decompose English suffixed derivations in ways similar to NSs. On the other hand, these results diverge from the body of masked priming evidence gathered by Clahsen and colleagues who found no masked stem priming effects with inflected forms in NNSs (Clahsen et al., 2013; Kirkici & Clahsen, 2013; Neubauer & Clahsen, 2009; Silva & Clahsen, 2008). It should also be noted, however, that Feldman and colleagues (2010) found a significant masked priming effect with English regular past tense *–ed* in advanced Serbian-speaking learners. Further research is needed to unravel what factors may have contributed to the inconsistent findings across studies and what the underlying mechanism is for L2 processing of inflections. One can argue that different mechanisms might underlie the L2 processing of complex words depending on the type of morphology involved, due to the morphological differences between inflectional, derivational, and compounding processes (such that inflectional morphology serves primarily grammatical functions, whereas derivation and compounding are used to create new words in the language). However, it remains to be tested whether the initial processing steps tapped by masked priming are common to all types of complex words in L2. Another possibility for the similarities observed between L1 and L2 compound processing may be due to the close typological distance between the learners' L1 and L2 with reference to compounding (Vainio et al., 2014). The L2 participants in this study were Chinese L1 speakers and Chinese relies on compounding as the primary means of word formation. It is likely that the decomposition strategy that they use in processing compounds in their L1 may be easily transferred to the processing of a similar structure in L2. When it comes to the processing of inflected or derived words, which Chinese lacks, processing strategies in this group of learners may be distinct from English native speakers' processing.

Conclusions

The present results provide new evidence from compound processing that fast and automatic segmentation of compound words that is entirely driven by the analysis of orthography operates not only in L1 processing, but also in L2 processing in advanced learners. The findings lend support to the sublexical morpho-orthographic decomposition model of complex word processing, run counter to the supra-lexical morpho-semantic model, and do not provide support for the hybrid model in which both sublexical and supralexical representation and processing are assumed.

Appendix. Critical stimuli

Prime Type	Item No.	Related Prime	Unrelated Prime	Target (Pos1)	Target (Pos2)
TT	1	marketplace	basketball	MARKET	PLACE
TT	2	classroom	motorcycle	CLASS	ROOM
TT	3	bodyguard	trademark	BODY	GUARD
TT	4	railroad	graveyard	RAIL	ROAD
TT	5	headache	storyline	HEAD	ACHE
TT	6	homeland	seafood	HOME	LAND
TT	∗7	teaspoon	pathway	TEA	SPOON
TT	∗8	bathtub	pancake	BATH	TUB
TT	9	earthquake	girlfriend	EARTH	QUAKE
TT	10	toothbrush	waterfall	TOOTH	BRUSH
TT	11	sandstorm	wheelchair	SAND	STORM
TT	12	birthday	warehouse	BIRTH	DAY
TT	13	sunlight	landscape	SUN	LIGHT
TT	14	cookbook	roommate	COOK	BOOK
TT	15	footwear	lipstick	FOOT	WEAR
TT	16	handgun	cowboy	HAND	GUN
OO	∗17	bottleneck	screenplay	BOTTLE	NECK
OO	18	copyright	nightmare	COPY	RIGHT
OO	19	honeymoon	videotape	HONEY	MOON
OO	20	milestone	spaceship	MILE	STONE
OO	21	deadline	workshop	DEAD	LINE
OO	22	passport	notebook	PASS	PORT
OO	23	eggplant	payroll	EGG	PLANT
OO	24	rainbow	weekday	RAIN	BOW
OO	25	background	masterpiece	BACK	GROUND
OO	26	framework	paperback	FRAME	WORK
OO	27	butterfly	viewpoint	BUTTER	FLY
OO	28	pineapple	housewife	PINE	APPLE
OO	∗29	dashboard	coastline	DASH	BOARD
OO	∗30	nutshell	bookmark	NUT	SHELL
OO	31	cocktail	airline	COCK	TAIL
OO	∗32	pitfall	rosebud	PIT	FALL
Orth1	33	investigate	tournament	INVEST	
Orth1	34	formidable	furniture	FORM	
Orth1	∗35	determine	passenger	DETER	
Orth1	∗36	tentative	carnation	TENT	
Orth1	37	bulletin	sentence	BULL	
Orth1	38	costume	assassin	COST	
Orth1	**39	scarlet	generous	SCAR	
Orth1	40	twinkle	flutter	TWIN	
Orth1	∗41	parenthesis	enterprise	PARENT	
Orth1	42	restaurant	fantastic	REST	
Orth1	∗43	cartridge	rationale	CART	
Orth1	44	messenger	barbecue	MESS	
Orth1	45	cardinal	courtesy	CARD	
Orth1	**46	logistic	exponent	LOG	

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Appendix. Continued

Prime Type	Item No.	Related Prime	Unrelated Prime	Target (Pos1)	Target (Pos2)
Orth1	**47	earnest	proverb	EARN	
Orth1	**48	pumpkin	rapport	PUMP	
Orth2	33	investigate	enterprise		GATE
Orth2	*34	cartridge	chocolate		RIDGE
Orth2	*35	carnation	badminton		NATION
Orth2	36	assassin	thorough		SIN
Orth2	**37	profound	massacre		FOUND
Orth2	38	asterisk	moustache		RISK
Orth2	*39	scaffold	porridge		FOLD
Orth2	*40	flutter	stipend		UTTER
Orth2	41	accommodate	apprentice		DATE
Orth2	**42	interview	represent		VIEW
Orth2	43	tomorrow	desperate		ROW
Orth2	**44	complain	discipline		PLAIN
Orth2	45	surround	stubborn		ROUND
Orth2	46	handicap	beverage		CAP
Orth2	**47	observe	attract		SERVE
Orth2	48	offence	hostage		FENCE

* These items were excluded because they induced high error rates from the NNSs in the post-hoc word translation task;
** These items were excluded because they can be exhaustively decomposed into potential morphemes (i.e., "corn-er" type);
Note. Orth1 refers to Orthographic control condition for Position 1. Orth2 refers to Orthographic control condition for Position 2.

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