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Dissociating Morpheme Form and Meaning: Evidence for Morphological Decomposition
of Compound Words during Reading

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5289 words and numbers

Abstract

Compound words have two free morphemes whose individual meanings can have a transparent (e.g., roadside) or opaque (e.g., butterfly) relationship to the overall meaning. It is unclear when meaning is accessed during lexical processing of compounds (and other morphologically complex words), with conflicting results from priming in lexical-decision studies and from reading-time studies that examine how the characteristics of a compound affect its processing. The present studies examined eye-movement measures on target words in a sentence as a function of their relation in form and meaning to a prime word that occurred earlier in the sentence. In Experiment 1 the primes were transparent or opaque compounds and the targets were the first constituent of the compound (e.g., *doll* preceded by *dollhouse* vs. *container*; and *brief* preceded by *briefcase* vs. *portfolio*). First-pass measures showed that target-word recognition was facilitated by prior processing of the compound but that the amount of facilitation was not affected by semantic transparency, a pattern that suggests that there is a stage of processing where compounds are decomposed into their constituent morphemes regardless of their composite meaning. Experiment 2 used first constituents as primes and compounds as targets. First-pass measures showed priming on recognition of both transparent and opaque compounds. Priming facilitation persisted on later measures of lexical processing for transparent compounds but became inhibitory for opaque compounds. These results show that compounds are initially decomposed into their constituent words independently of meaning, but that later in processing activation of the meaning of a constituent word facilitates comprehension of semantically consistent compounds but competes with comprehension of semantically inconsistent compounds.

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Keywords: partial priming, compounds, complex words, morphological decomposition, semantic transparency, eye movements, sentence processing, semantic processing, morphological processing

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The ability to construct new word meanings from existing word representations is a critical component of the expressive power of language. In English, *compound* words are derived through the concatenation of existing stems or words into a unitary representation, with the resulting compounds varying along the dimension of *semantic transparency*. For highly transparent compounds, such as *mailbox* or *mouthwash*, the meanings of the constituent words are combined in a straightforward way to create the meaning of the compound. Other compounds, such as *butterfly*, are semantically *opaque* in the sense that the meanings of the constituent words do not depend in a clear way to the meaning of the compound. Comparing the processing of semantically transparent and opaque compounds provides a way to increase understanding the role of morphological structure during language comprehension particularly with respect to the part that is played by the meaning of morphological constituents.

One approach to understanding the role of morphological structure in lexical processing has been to examine how the characteristics of constituent morphemes contribute to processing in various tasks. Early studies demonstrated that after matching for the frequency of complex words, faster lexical decisions were observed for those with high-frequency stems as compared to those with low-frequency stems (Taft & Forster, 1975), a result that would be expected if the stem of the derived word is accessed during lexical processing. These morpheme-mediated frequency effects have also been demonstrated in fixation measures during reading where fixations were shorter when compounds had a higher frequency constituent word (Juhasz, 2003; Inhoff, Starr, Solomon & Placke, 2008; Pollatsek & Hyona, 2005), a finding that is consistent with the view that first-pass reading time is a sensitive measure of the ease of lexical processing

(Rayner, Sereno, Morris, Schmauder & Clifton, 1989). However, the initial landing position of the eyes on a compound does not differ as a function of the frequency of its constituent morphemes (Bertram & Hyona, 2003; Hyona & Bertram, 2011), a finding that is consistent with the notion that the targeting of saccadic eye movements during reading is based on the perceptually-accessible property of word length and is not influenced by higher-level linguistic properties of a word (Rayner, Balota, & Pollatsek, 1986). The role of morphological structure in lexical processing has also been examined by looking at the relationship between constituent-morpheme meanings and their compound word meaning. The findings on the role of semantic transparency in lexical processing are somewhat mixed, with some research showing that semantically transparent words (e.g. *roadside*), were read faster than their semantically opaque counterparts (e.g. *butterfly*, Juhasz, 2007), while other studies have not shown this pattern (Pollatsek & Hyona 2005; Frisson & Pollatsek, 2008).

A second approach to understanding the role of morphological structure in lexical processing has been to examine how the mapping of a morphologically related prime onto a target word affects ease of processing. Early studies provided mixed evidence about how the semantic relation between prime and target affects morphological priming, with a cross-modal study by Marslen-Wilson, Tyler, Waksler and Older (1994) showing priming for lexical decisions only when the prime and target had related meanings (e.g., *departure* primed *depart* but *department* did not) while a study by Zwitserlood (1994) found that priming by a compound of one of its constituent words did not depend on overlap of the meanings of the prime and target (e.g. both *kerkorgel* (church organ) and *drankorgel* (drunkard) primed their respective component words). These effects demonstrate that lexical processing includes a stage of *morphological decomposition* where a complex word is parsed into its constituent morphemes.

Subsequent research by Rastle, Davis & New (2004) further showed that morphological decomposition at early stages of lexical processing is only sensitive to morphological word forms and does not depend on there being a semantic relationship between constituent-morpheme and complex-word meanings. This dependence on form but not meaning was demonstrated by showing that pseudo-complex words, like *brother*, prime recognition of a constituent like *broth* that in principle could be composed in a semantically opaque way from morphemes like *broth* and *-er*. However, words like *brothel*, which embeds *broth*, but where *-el* would be an illegal suffix, did not prime recognition of pseudo constituents (Rastle et al., 2004; Brooks & Cid de Garcia, 2015). Results from studies using this type of manipulation showed that this early processing stage is guided by the regularity of morpheme structure and not simply by orthographic overlap. These results provide evidence for morphologically-based lexical processing. That morpheme information is accessed and utilized during lexical processing provides a basis for the *sublexical hypothesis*, which proposes that morpheme access leads to complex word recognition. However, this model of lexical access fails to explain why a derived word, such as *darkness*, does not require more processing time than its simple base word *dark* given that parsing *darkness* in to *dark* and *-ness* is computationally more intense. Sublexical accounts that endorse morpheme access prior to whole word access are in conflict with the *supralexical hypothesis* (Giraudo & Grainger, 2001) that proposes that complex words must be processed as a whole word before constituent morphemes are accessed.

Together, these studies have shown that there is constituent accessibility through morphological decomposition and lexical retrieval of constituent morphemes in complex word recognition, but it remains unclear when morpheme meaning is mapped onto morphological form during lexical processing, and how these meaning representations are combined when the

constituent morphemes are not semantically consistent with the meaning of the complex word. There are very few parsimonious accounts of how to account for the rapid morphological decomposition that occurs in early stages of lexical processing and meaning integration that occurs in later stages of processing. Using cross-modal priming, Meunier and Longtin (2007) observed that pseudo-words that do not exist in French (e.g. *cuisineur* “one who cooks”) but have an understandable interpretation produce facilitatory priming effects similar to that obtained with real complex words (*cuisinier* “a cook”). However, pseudo-words that do not have an understandable interpretation (e.g. *sportation* “sport” and a deverbalizing suffix *-ation*) did not lead to any priming effects. These results helped demonstrate that there may be two relevant levels of lexical processing: the first stage is morphological form-based and is influenced by the decomposition of complex words into morphological constituents but is not affected by the semantic value of the morphemes, while the second is responsible for the integration of these morphemes into one meaningful composite. At this stage, if the composition works, processing continues, but if it does not, those morphemes are deactivated and the word is then reanalyzed. This model promotes a rapid decomposition, which can be corrected for at a later stage, if needed. Currently, it is unclear if both these stages exist and how to transition between them if they do.

The current studies combine priming techniques that have successfully revealed characteristics of morphological processing in studies of isolated word recognition with eye-movement techniques that have provided a way of studying lexical processing for words in context. Experiment 1 uses *whole-part priming* where a compound word is used to prime processing of one of its constituent words. Experiment 2 uses *part-whole priming* where a constituent word is used to prime its related compound. These priming techniques are used to

investigate the role of semantic transparency during lexical access and sentence integration with the goal of identifying separable stages in the processing of compounds as proposed by Meunier and Longtin (2007).

Experiment 1

In masked priming, the processing of complex words is usually investigated using the complex word as the prime while an embedded morpheme serves as the target. These studies reveal that when accessing a derived complex word (e.g. *walker*), the root morphemes are also accessed and activated (Rastle et al., 2004; McCormick et al., 2008). These effects occur in the early stages of lexical access and appear to be insensitive to meaning. If similar stages of processing occur for compounds, then the process of reading a compound word should include accessing its constituent morphemes regardless of whether the compound is opaque or transparent.

Experiment 1 extends this *whole-part priming* logic to sentences by examining whether reading a compound word early in a sentence affects the processing of one of its constituent words when it appears later in the sentence. Within-sentence priming occurs robustly when words are repeated within a sentence (Gordon, Plummer & Choi, 2013; Ledoux, Gordon, Chamblin & Swaab, 2007; Lowder, Choi & Gordon, 2013), but the possibility of inter-word priming within a sentence has not previously been studied for words that are not direct repetitions. As shown in examples 1 and 2, priming is used to investigate the accessibility of morpheme forms within compounds by manipulating whether a target word (e.g., *doll* in 1) is preceded by a related compound (e.g., *dollhouse*) or by a control word (e.g., *container*). Eye tracking measures on reading of the target word are used to identify the time course of morpheme access and integration in the sentence.

1 Transparent: The purchased *container/dollhouse* was big enough for the large **doll** to fit in comfortably.

2 Opaque: I left the agenda in my leather *portfolio/briefcase*, so the meeting will be extremely **brief** this afternoon.

Method

Participants. Thirty-six undergraduates from the University of North Carolina at Chapel Hill participated to fulfill participant credit for an Introductory Psychology course. They were all native English speakers, had normal or corrected-to-normal vision, and gave informed consent.

Materials. Eighteen sentences containing transparent compounds and 18 containing opaque compounds were created. The semantic transparency of the compounds was determined using classifications from previous studies (Juhasz et al., 2003; Juhasz 2007). The sentences were constructed with the format presented in the Examples 1 and 2 where the primes in the partial-repetition condition (transparent or opaque compounds) occurred in the beginning of the sentence while the targets (first constituent of the prime compound) occurred toward the end of the sentence. The control sentences were identical to the experimental sentences except the prime was an unrelated, control word. Stimuli were controlled for sentence length, length of constituent words, the frequency of the first constituent word in the compound and the frequency of the compounds (see Table 1). The prime and target words did not appear within two words of the beginning or end of a line and both the prime and target always appeared on the same line. All experimental sentences are listed in the Appendix.

Design and procedure. Participants were asked to read a series of sentences, each of which was followed by a comprehension question. The experiment began with a warm-up block

of four filler sentences. Within the experimental block, each participant was presented with 108 sentences, of which 36 were experimental sentences and 72 were filler sentences. Presentation of stimuli was randomized for each participant. The experimental sentences were counterbalanced across participants.

The stimuli were presented using SR-Research Experiment Builder software. Participants were tested using an SR Research EyeLink 1000. The eye-tracker sampled at 1000 Hz in monocular mode using the participants' dominant eye, as determined using the Miles or "hole-in-the-hand" test (Miles, 1930; Roth, Lora, & Heilman, 2002). Participants were given a gamepad controller to progress from the sentence to the comprehension question and to indicate the truth-value of the comprehension question.

Analyses. Fixations were excluded that were beyond three standard deviations of the participants' mean for a given fixation measure. **Skipping** was defined as the proportion of trials where the participant did not fixate on the target word during first-pass reading. Differences in the rates at which same-length words are skipped reflect differences in the ease of recognizing the word while it is in parafoveal preview. This usually includes processing of word form information (Rayner 1978; Balota, & Rayner 1983; Schotter, Angele, & Rayner 2012; Gordon, Plummer, & Choi 2013). **Gaze duration** was defined as the summed first-pass fixations in a particular region from the first time it was left-bound entered until it was exited in either direction (Rayner, 1998). This first-pass measure is generally interpreted as an index of the time to access a lexical entry. **Regression path duration** or **go-past duration** was defined as the sum of the fixation durations from the first time a word is fixated until it precedes to the following word, which means it can consist of re-fixations on target and re-reading of earlier parts in the sentence (Rayner, 1998). This measure is generally interpreted as an index to the semantic

integration of the target word and it is typically regarded as a later measure. Longer fixation times on this measure reflect greater difficulty in integrating the meaning while shorter fixation times reflect a greater ease in integration.

For sentences where the participant skipped the target word on first-pass, a contingent-expansion procedure (Rayner & Duffy, 1986) was implemented to expand the target word region to include the preceding word when the target word was skipped with the assumption that the time allotted to processing the preceding word reflects the parafoveal processing on the target word.

Results

The results of the experiment are shown in Table 2. Skipping proportions were higher when the target word was primed than unprimed, a difference that was marginal in the subject-level analyses but robust in item-level analyses, $F_1(1,35) = 3.06$, $p < .09$; $F_2(1,30) = 7.57$, $p < .01$. The interaction of priming and transparency on skipping was not significant, $F_1(1,35) = .32$, $p > .5$; $F_2(1,30) = .73$, $p > .4$, showing that the compound priming effect did not differ significantly as a function of the semantic relation between the prime and target..

Gaze durations on the expanded region were shorter when the target word was primed than unprimed, $F_1(1,35) = 5.12$, $p < .03$; $F_2(1,30) = 5.30$, $p < .03$, a pattern that is consistent with the masked priming literature where the constituent head is recognized faster when it is preceding by its complex word. There was no reliable difference on reading times between the transparent and opaque compounds, $F_1(1,35) = 1.90$, $p > .17$, and the priming-by-transparency interaction was not significant, $F_1(1,35) = .74$, $p > .4$; $F_2(1,30) = .41$, $p > .5$. Regression-path durations were also shorter when the target word was primed than unprimed, $F_1(1,35) = 6.79$, $p < .01$; $F_2(1,30) = 4.96$, $p < .03$. There was no reliable difference on reading times between the

transparent and opaque compounds, $F_1(1,35) = .66$, $p > .4$, and the priming-by-transparency interaction was not significant, $F_1(1,35) = .41$, $p > .5$; $F_2(1,30) = .05$, $p > .8$.

Discussion

The first-pass measures of word recognition (skipping proportion and gaze duration) showed that processing of the target constituent was facilitated by earlier reading of the related compound, with the magnitude of this effect indistinguishable for transparent and opaque compounds as shown by the lack of interaction between the semantic relationship of the compound prime and its constituent target word. This pattern of effects on first-pass measures is consistent with those found in the isolated word recognition literature, where presenting a complex word as a masked prime facilitates lexical decisions on target constituent words regardless of the semantic relationship between the prime and target (Rastle, et al. 2004; McCormick, et al., 2008). These effects suggest that processing of a compound word (or other type of complex words) involves activation of constituent word forms that can facilitate subsequent recognition of those word forms. During reading, this facilitation can lead to higher skipping rates due to faster recognition of the constituent target word in the parafovea and to shorter first-pass reading times when the constituent is fixated.

Regression-path duration also showed facilitation in processing of the target constituent when it was preceded by a related compound. This measure includes regressions, gaze duration, and rereading and therefore is thought to reflect later stages of lexical processing that include how the meaning of a word is integrated with its context (Clifton, 2007). As with the first-pass measures, this facilitation effect on regression-path duration was observed for both opaque and transparent compounds. The meaning of the compound word prime is not co-activated with the processing of the constituent word target, which prevents interference in integrating the target

meaning into the sentence. These effects demonstrate that constituent word forms are accessed during compound processing and that this access facilitates later, meaning-dependent stages of lexical processing for the constituent word even when its meaning in isolation is not related to the meaning of the compound.

Experiment 2

Experiment 2 used a *part-whole* priming procedure to test whether the constituent meanings of transparent and opaque compounds are accessed during sentence reading. Previous studies have addressed this question by directly comparing reading times on transparent and opaque compounds on the supposition that accessing the meanings of constituent words might facilitate processing of transparent compounds but could not do so for opaque compounds. As noted above, the results of these studies are mixed (Pollatsek & Hyona 2005; Juhasz, 2007; Frisson & Pollatsek 2008). One possible reason for this is that the usual challenges of matching groups of different words on dimensions such as frequency and length are increased for compounds because of their small number. In contrast, priming methods sidestep the challenges of matching groups of words by using each word as its own control. As shown in examples 3 and 4, the effects of priming on compound word processing are assessed by manipulating whether a target compound word (e.g., *roadside* in 3) is preceded by its initial constituent (e.g., *road*) or by a control word (e.g., *town*) with the priming effect assessed both for transparent and opaque compounds. In this experiment, eye-tracking measures on target compound words were used to assess whether and how the mapping of a prime onto the morphological structure of a target word differs in relation to the word's semantic transparency.

3 Transparent: After my car stopped in the middle of the *town/road*, I walked to the

roadside gas station.

- 4 Opaque: I could not cut the *poor/dead* frog in the lab even though I have a **deadline** for the dissection.

Methods

Participants. Thirty-six undergraduates from the University of North Carolina at Chapel Hill, none of whom participated in Experiment 1, participated to fulfill participant credit for Introductory Psychology. They were all native English speakers, had normal or corrected-to-normal vision, and gave informed consent.

Materials, design and procedure. Twenty sentences containing transparent compounds and 20 containing opaque compounds were tested along with 80 filler sentences. The critical sentences contained a prime word, which appeared toward the beginning of the sentence, followed by the target compound word, which appeared toward the end of the sentence. The control sentences were identical to the experimental ones except that the prime was an unrelated, control word. Experimental and control sentences were matched for sentence length and constituent word length and frequency (see Table 3). All experimental sentences are listed in the Appendix. Other aspects of the design and procedure were the same as Experiment 1.

Analyses. Fixations were excluded that were beyond three standard deviations of the participants' mean for a given fixation measure. **Landing position** was defined as a proportion of the horizontal component of eye position in pixels, with respect to the beginning of the target, to the length of the compound in pixels. Analyzing the landing position on the compound provides information about what lexical properties can be processed parafoveally. This can be used to determine whether priming the morpheme form can affect the targeting of the compound

word since part of the compound word form has been previously processed. For the gaze duration and regression-path duration analyses, we defined the target region as the compound word region along with the preceding word, which tended to be a determiner or short adjective. The length of these words averaged slightly over 3 characters (3.325 ± 2.12). The preceding words were considered part of the target region because of the likelihood of parafoveal processing of the target as during those fixations.

Results

The results in Table 4 show that landing position on the target compound was not affected by priming, $F_1(1,35) = 0.00$, $p > .5$; $F_2(1,38) = .27$, $p > .5$, or transparency, $F_1(1,35) = 3.31$, $p > .05$; $F_2(1,38) = 3.33$, $p > .05$. However, it was lower when the preceding word was skipped as opposed to when it was fixated, $F_1(1,35) = 259.1$, $p < .001$; $F_2(1,38) = 184.8$, $p < .001$. Thus, the landing position reveals two effects: When the word preceding the target was skipped, the landing position of the saccade was at 30.6% of the length of the word measuring from the beginning to the end, as opposed to when the preceding word was fixated where the landing position on the target compound word was at 51.4% of the length, which is nearly the optimal viewing position of a word. Thus, the landing position was only affected by the launch position of the saccade and not by higher-level processing associated with priming or semantic transparency. Second, the targeting of the compound word suggests that the compound word is being regarded as a single linguistic unit at the launch site of the saccade. One assumption would be that orthographic activation of the prime, which is the first constituent, would affect the landing position of the target toward the beginning of the word, but this assumption is invalidated with the part-whole priming having no effect on landing position.

Table 5 shows reading time measures for the compound target region. Gaze durations were shorter by 24 ms in the primed than unprimed, $F_1(1,35) = 4.41, p < .04$; $F_2(1,38) = 5.68, p < .02$. Gaze duration did not differ reliably between transparent and opaque target compounds, $F_1(1,35) = 3.70, p > .05$; $F_2(1,38) = .49, p > .49$, and the priming-by-transparency interaction was not significant, $F_1(1,35) = 1.48, p > .23$; $F_2(1,38) = 1.90, p > .18$. In contrast, regression-path durations on the target compound did not differ due to priming, $F_1(1,35) = .02, p > .89$; $F_2(1,38) = .02, p > .90$ or transparency, $F_1(1,35) = .29, p > .59$; $F_2(1,38) = .00, p > .98$, but there was a reliable interaction between these factors such that priming caused 89 ms of facilitation in the processing of transparent compounds with but caused 68 ms of inhibition in the processing of opaque compounds, $F_1(1,35) = 6.80, p < .02$; $F_2(1,38) = 9.86, p < .003$.

Discussion

The eye-tracking results for the target words in Experiment 2 reveal three distinct phases in the processing of compounds. The first phase, in which the compound is treated as a single word, is indicated by the landing position of the first saccade to the compound; landing position was affected by whether the preceding word was fixated but not by repetition priming of its initial constituent word or by its transparency. This pattern of results is consistent with previous findings on saccadic targeting of compound words (Bertram & Hyona, 2003; Hyona & Bertram, 2011). The second phase, in which there is a form-based access to the constituent words of the compound is indicated by first-pass reading time on the compound; gaze duration was shorter with a related (first-constituent word) prime than with an unrelated control prime. This priming effect did not differ significantly as a function of transparency, which is in line with the idea that this phase of compound processing is not affected by the relation between the meaning of the constituent word and the meaning of the compound. This pattern is consistent with Experiment 1

where first-pass measures showed facilitation in the processing of a first-constituent target word after priming by a compound regardless of the semantic relation between the meanings of the compound and its initial constituent. Further, it is consistent with prior findings on isolated word recognition which has shown that there is a stage in lexical processing that is sensitive to morpheme form without regard to meaning (Zwitserlood 1994; Rastle et al. 2004). The third phase, in which the meanings of the compound and of its first constituent are simultaneously active, is indicated by regression-path duration; for transparent compounds, priming by a first constituent caused faster (facilitated) processing as compared to a control prime while for opaque compounds it caused slower (impaired) processing. This pattern supports the idea that there is a stage in lexical processing where the meanings of the constituent morphemes and of the compound can either support comprehension or interfere with it depending on how the meanings at these two levels are related.

General Discussion

The results of the two eye-tracking experiments presented in this article provide insight into when and how morpheme accessibility affects the recognition and comprehension of compound words. Experiment 1 demonstrated that with whole-part priming, a priming paradigm typically used in isolated word recognition paradigms, there were higher skipping proportions when the target constituent word was primed by its related compound. These target words also had reduced gaze durations when they were primed, with the magnitude of this effect indistinguishable for transparent and opaque compounds. The later measure, regression-path duration, showed facilitation effects on reading the target words for both transparent and opaque compounds. Experiment 2 complements this pattern, by showing that part-whole priming produces facilitation on eye movement measures of early processing for both transparent and

opaque compounds. A difference in the processing of transparent and opaque compounds emerged in the later measure of regression-path duration, with facilitation in processing when the meanings of the constituent prime and target compound were consistent but with inhibition in processing when the two meanings were inconsistent.

Figure 1 sketches a model that depicts the interactions between levels of processing during the reading of compounds. The initial steps are the same in processing both transparent compounds (Figure 1a) and opaque compounds (Figure 1b). The eye movement targeting system treats the compound as a single word with the initial fixation determined by the length of the word (and by whether or not the preceding word was skipped). The location of this initial fixation is not affected by the transparency or priming manipulations, a pattern that is consistent with previous results showing that initial fixation location is not influenced by the frequency of the constituent words of the compound (Bertram & Hyona, 2003; Hyona & Bertram, 2011). These findings on compounds are consistent with a substantial range of earlier evidence that shows that the landing position of the initial saccade on a word is not influenced by lexical factors other than word length (e.g., Bertram & Hyona, 2003). Fixation of the compound provides visual information that allows initial recognition of the compound word at the level of form. This proceeds to a stage of morphological decomposition where there is access to form-level representations of the constituent words of the compound (e.g., reading *roadside* causes activation in *road* and *side*). This activation of embedded words accounts for the facilitative effects of priming on first-pass measures for recognizing target words that consist of the first constituent of a compound (Experiment 1). This activation of constituent morphemes is also consistent with decomposition models proposed to account for patterns of masked priming in isolated word-recognition studies (Rastle et al., 2001, 2004; McCormick et al. 2008).

For transparent compounds, prior activation through priming of its initial constituent facilitates processing at the level of meaning through activation of shared features as shown by the connections within the meaning level. This facilitation effect on processing is consistent with results from isolated word-recognition studies that have observed processing benefits when primes and targets share both morpheme form and meaning (Marslen-Wilson et al., 2004; Meunier & Longtin, 2007). In contrast, for opaque compounds prior activation of the first constituent word leads to conflicting patterns of activation at the level of meaning because simultaneous activation at the word form level of the compound (e.g., *deadline*) and its constituent (e.g., *dead*), leads to competition at the meaning level between these two representations (e.g., semantic features such as ‘time’ and ‘limit’ are inconsistent with semantic features such as ‘deceased’ and ‘lifeless’). The model sketched in Figure 1b depicts this competition through inhibitory relations at the meaning level. This inhibition of inconsistent meanings is consistent with models in the isolated word recognition (Marslen-Wilson et al., 2004; Meunier & Longtin, 2007) where there are no benefits to processing when the primes and targets share morpheme forms but not morpheme meanings.

Studying the nature and extent of morphological decomposition during reading provides a way of determining whether lexical processing makes use of the kinds of relations proposed in linguistic analyses of how form and meaning combine in morphologically complex words. Morphological decomposition has been characterized in the isolated-word recognition literature as a process of automatic segmentation where complex words activate their constituent word parts; this characterization is supported by results from both of the current experiments. In addition, the results of the second experiment show that the decomposition products of compounds (or at least their first constituents) directly contribute to accessing meaning.

Extending this account from compounds to the more common types of morphologically complex words consisting of a free morpheme and a bound morpheme would suggest that lexical processing closely follows morphophonemic analysis. For example, *moths* would be decomposed into two morphemes (*moth* and the bound plural morpheme *s*) both of which would activate related meanings with the combination of those component meanings capturing the meaning of the word. For compound words, access to meaning from decomposed constituents could facilitate understanding because compound words have very low frequencies as compared to the frequencies of their constituent words.

While the results of Experiment 2 support the use of form-meaning relations in lexical processing of compounds, they also show that such relations cannot provide a complete account of the findings on compounds. In particular, the models sketched in Figure 1 characterize the semantic processing of compounds as a *dual-route* process in that meaning is activated from the constituent words of the compound but is also activated directly from the compound. The direct connection between the compound form and its meaning is conceptually required for opaque compounds because their meanings cannot be composed from those of their constituents; empirically, the operation of both direct- and constituent-based activations of meaning is supported by the semantic interference that was observed when an opaque compound was primed by its first constituent. The current results do not strictly require positing a direct connection between transparent compounds and their meanings. However, the model sketched in Figure 1 includes this direct connection because doing so allows the same processing mechanisms to be used for both opaque and transparent compounds.

Conclusion. These experiments provide support for morpheme access during compound word reading that unfolds over two separate levels of processing: lexical form and lexical

meaning. In sentence reading, these levels are accessed in three phases. In the first phase, the landing position on targeted compound words demonstrates that compound words are treated as a single word. In the second phase, first-pass reading demonstrates that morpheme forms are accessed in compounds independent of their meaning. In the last phase, morphemes reinforce compound word meaning when the morpheme meanings are consistent with the compound (i.e., transparent compounds), but they inhibit the compound word when their meanings are inconsistent (i.e., opaque compounds). Hence, morpheme form precedes morpheme meaning in compound word processing, which leads to a rapid parsing model where both the compound word and its related morphemes work together to activate features when their meanings are consistent with each other while inhibiting features when they are inconsistent.

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Tables and Figures

Table 1

Descriptive Statistics of Sentences from Experiment 1

Effect	Opaque	Transparent	T value	Sig
Compound Frequency	6.46 ± 2.10	5.49 ± 0.94	1.63	ns (0.12)
Number of Words	16.88 ± 1.31	16.75 ± 2.15	0.20	ns (0.84)
Number of Letters of First Constituent	4.31 ± 0.48	4.31 ± 0.48	0.00	ns (1.00)
First Constituent Frequency	10.63 ± 1.40	10.38 ± 1.14	1.63	ns (0.12)
Number of Letters of Second Constituent	4.25 ± 0.45	4.44 ± 0.51	-1.10	ns (0.28)
Second Constituent Frequency	11.79 ± 1.40	11.02 ± 1.14	2.26	0.03
Intervening Word Difference of Target and Prime	6.5 ± 0.26	7.81 ± 0.48	-2.39	.023

Note: Descriptives (Mean ± Standard Deviation). Frequencies are in log units.

Table 2 <i>Means of Eye-tracking measures from Experiment 1</i>			
Effect		Unprimed	Primed
Skipping	Opaque	$0.32 \pm .12$	$0.35 \pm .16$
	Transparent	$0.30 \pm .11$	$0.36 \pm .13$
Gaze Duration	Opaque	257 ± 29	240 ± 24
	Transparent	244 ± 27	235 ± 26
Regression Path Duration	Opaque	294 ± 63	273 ± 50
	Transparent	285 ± 55	257 ± 42

Table 3 <i>Descriptive Statistics of Sentences from Experiment 2</i>				
Effect	Opaque	Transparent	T value	Sig
Compound Frequency	6.58 ± 2.03	5.68 ± 2.57	1.24	ns (0.22)
Number of Words	16.95 ± 1.47	17.75 ± 2.47	-1.25	ns (0.22)
Number of Letters of First Constituent	4.60 ± 0.75	4.30 ± 0.80	1.22	ns (0.23)
First Constituent Frequency	10.07 ± .24	10.29 ± 1.36	-0.55	ns (0.59)
Number of Letters of Second Constituent	4.40 ± 1.00	4.70 ± 0.87	-1.02	ns (0.32)
Second Constituent Frequency	11.11 ± 1.24	11.16 ± 1.36	-0.16	ns (0.87)
Intervening Word Difference of Target and Prime	7.45 ± 1.76	6.60 ± 1.73	1.54	ns (0.13)
<i>Note:</i> Descriptives (Mean ± Standard Deviation). Frequencies are in log units.				

Table 4 <i>Landing Position Means by Priming from Experiment 2</i>			
Effect		Unprimed	Primed
Landing Position Proportions	Opaque	.39	.40
	Transparent	.42	.42
		Skipped	Fixated
	Opaque	.29	.50
	Transparent	.32	.52
<i>Note:</i> Position Proportion is defined as the ratio of pixel location to pixel length of word.			

Table 5 <i>Means of reading-time measures from Experiment 2</i>			
Effect		Unprimed	Primed
Gaze Duration	Opaque	372	361
	Transparent	366	329
Regression Path Duration	Opaque	575	643
	Transparent	706	617

Figure 1

Theoretical Model of Lexical Access for Transparent (A. left panel) and Opaque Compounds (B. right panel).

Appendix

Experiment 1 Materials

(Control/Experimental)

Opaque

I left the agenda in my leather portfolio/briefcase, so the meeting will be extremely brief this afternoon.

The professor's positive comments/feedback about the paper will merely feed Joe's massive ego even more.

During the storm, the young sailor/deckhand was called to the primary deck by the captain.

Harry earned his popular moniker/nickname from his tendency to accidentally nick himself while shaving.

She had lost her backup lantern/flashlight, but she saw the great flash of lighting out the window.

The blizzard excited the young animals/reindeer so much that Santa had to forcibly rein them in yelling.

The marriage would add a pricey mortgage/stepchild, so Glenn needed to seriously step up his job search.

Since Ned is a foolish imbecile/blockhead, the company wants to quickly block him from acquiring any more responsibility.

Tim knew that stealing would ostracize/blacklist him, but he didn't realize that those black marks would persist.

Susan finished her paper before the final cutoff/deadline, but now she is dreadfully dead tired from staying up.

I can't find the truck manuals/handbook so I'll probably need a skillful hand in changing the spark plugs.

Anna found the critical concepts/highlight of the reading helped her get a remarkably high score on the test.

Matt needs to use the nearest facility/restroom before we drive the entire rest of the way to Canada.

Hannah takes notes in cryptic phrasing/shorthand so nobody in her classes short of Hannah herself can read them.

Brett's talent as a powerful forward/fullback won him a prestigious full scholarship to the state university.

The bright glare from the truck's exterior/headlight made the young man's aching head hurt even more.

Transparent

While the luscious country/farmland was under property negotiation, all the animals on the quiet farm escaped into the street.

Dissociating Morpheme Form and Meaning

Since her vivid fantasies/dreamland seemed so real, she didn't know if it was a fantastic dream or reality.

Even though her large memorial/tombstone was elaborate, the glorious tomb still seemed to be missing something.

Though the painted gondola/sailboat was completed, the boy needed to replace the tattered sail for the first voyage.

My dentist recommends fluoride toothpaste/mouthwash since it helps a decaying tooth from completely rotting out.

Reading the dated travelogue/guidebook was so confusing that we hired a skilled guide to plan the trip.

The purchased container/dollhouse was big enough for the large doll to fit in comfortably.

Though the archaic activity/bullfight is exciting to watch, the frightened bull must feel a sense of panic.

For the sensitive procedure/darkroom to work properly, the camera film must stay dark to fully develop.

The car was left on the nearby shoulder/roadside since there was no one on the empty road who would help change the tire.

Because the dirty painting/wallpaper was extremely wet, the clean wall in the kitchen smelled of moldy wood.

The hectic junction/crossroad had a stoplight installed so bikers could cross without being injured.

We bought a bright appliance/nightlight so we could navigate at the darkened night in the house.

The optometrist bought a comfortable apparatus/headrest so her patients could rest their head during the examination.

The cleanup of the unmarked territory/minefield created a way to detect a hidden mine to prevent more deaths.

After his wife bought him a convincing toupee/hairpiece, Joseph admitted his graying hair was falling out.

Experiment 2 Materials

(Control/Experimental)

Opaque

When the bell rang for the ceremony/break the students had finished their breakfast and were ready to go.

After the critical/brief meeting ended, I put the documents in my briefcase to visit the company.

When I took out the pan/butter to make dinner, I saw a beautiful butterfly through the window.

The cook will shred/chop the pork into small pieces so we can use chopsticks for dinner.

Some animals such as the unicorn/dragon are imaginary whereas the dragonfly, it truly does exist.

After she gave the animals their soup/feed, she gave her son some feedback about the farm.

She organized a broad/grand plan for the homeless and asked her grandson to help out.

There were no more cans of apple/grape juice left so I chose the grapefruit one instead.

I saw roses/honey on the table when we arrived from our honeymoon last night.

He preferred a colorful/super glue for collages but the supermarket no longer had it.

After the man stole the local/black bean soup, the store added him to the blacklist of bad customers.

When she went shopping for a new picture/chair, she saw the chairperson from the school safety committee.

I could not cut the poor/dead frog in the lab even though I have a deadline for the dissection.

After he cleaned his face/hand he moved the psychology handbooks to the library.

I got a really bad/high grade on my English paper, which was the highlight of my week.

When the old secretary/lady watered the plant, she saw a spotless ladybug on the leaf.

When I asked the people/man for help, one of them/he fell into a manhole on the way over.

I took a class/rest first and then I went to the restroom to fix my makeup.

The cafeteria line was open/short so I was able to buy a strawberry shortcake for lunch.

When I messed up a turn/step at the dance competition, my stepmother was so angry.

Transparent

In a war, a soldier/battle can be cruel which can explain the battlefields left with bodies of the dead people.

It is not the size of the beast/bull but its strength during the bullfight that is the key in winning the battle.

A very pretty daisy/candle makes me feel romantic and the candlelight makes me look prettier.

She has a toy/doll but she never puts it away in the dollhouse after cleaning up.

Having a personal assistant/guide is very convenient but a guidebook is still fine for visiting museums.

Yesterday the studio/lamp was too dark because one of the lamplights stopped working.

He was truly of the upper/noble class but the other so-called noblemen were just as rich.

In order to gain access/pass through the security door, memorize the password every time.

No one checked the gadgets/sail so we decided not to take the sailboat out for safety reasons.

When people are buried in the earth/tomb they do not know what the tombstone will say about them.

There was a student/boy teasing me in class so my boyfriend beat him up.

The photos came out really ambiguous/dark because the darkroom had a light on while developing the photos.

If a child has a desire/dream of being a princess, Disney World can be a dreamland for her imagination.

Ever since the owner of the property/farm left town, the farmland turned into a children's playground.

Boxers cannot protect their skin/mouthguard but they can use a mouthguard to protect their teeth during the match.

There was information/news on salary increase so I read the newsletter word for word.

After my car stopped in the middle of the town/road, I walked to the roadside gas station.

The clear blue sky/sea makes people relaxed but dark seawater makes people become anxious.

After the quarterback was hit in the eye/side he had to sit on the sideline for the rest of the game.

After my three year old baby drew a tree/on the wall I cleaned the wallpaper with a bath towel.

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