University of Alberta

Availability of Constituents' Semantic Representations During the Processing of Opaque and Transparent Compound Words

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Psychology

Fall 2011
Edmonton, Alberta

Abstract

This project examined whether the availability of the semantic representations of the constituents of opaque compounds depends on the transparency of the first and second constituents. Four semantic priming experiments were conducted using a lexical decision task. Across the experiments, the transparency of the first or second constituents of compound primes was manipulated, while the transparency of the other constituent was held constant. Response times to targets preceded by related or unrelated compound primes were compared. Semantic priming was observed for all constituents, except the first constituents of fully opaque compounds. The lack of semantic priming for fully opaque compounds could be the result of a conflict between the constructed and retrieved meanings of these compounds (as discussed by Gagné & Spalding, 2009; Ji, 2008; Ji, Gagné, & Spalding, in press). This research suggests that constituent semantic representations are available and that semantic integration might occur even for opaque compounds.

Keywords: compound words; semantic transparency; semantic representations; morphological decomposition; position-in-the-string; semantic integration

Acknowledgement

Thank you to Christina Gagné and Tom Spalding for their supervision of this project. I would also like to express my appreciation to my committee members, Chris Westbury and Harald Baayen, for being willing to give of their time. As well, I am grateful to the members of the Complex Cognition lab, especially my lab mate and friend Allison Mullaly, for their support and assistance throughout this project. I also want to thank Connie Svob for her unwavering encouragement and treasured friendship.

Most importantly, I want to thank my family, I could not have done this without you. Thank you to my parents for supporting me in everything that I have ever undertaken; my thesis would not have been possible without you. Mom and Dad, you have selflessly provided guidance, wisdom, encouragement, enduring patience and unconditional love throughout this entire process. It has not gone unnoticed and I am more grateful than I can ever express. Thank you also to Caitlin for being such a loving and supportive sister, and most of all for always being willing to lift my spirits and make me laugh. I am truly blessed to have the family that I do and I cannot thank them enough. And last, but certainly not least, I want to thank Brendan. You have helped me in so many ways over the last two years, from small things to big things. I cannot even begin to thank you for being my rock, showing me patience and caring, even when it was not easy. When I say that I could not have done this without you, I really mean it.

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The relationship between complex words (i.e., suffixed, prefixed, and compound words) and their constituent parts has been examined in previous research in an effort to gain an understanding of the makeup of the mental lexicon (Libben & Jarema, 2004). Among complex words, compounds, in particular, provide a fruitful area of study. Compounds represent a middle ground between morphemes, which must be stored, and sentences, which are constructed. Compounds could either be stored in the same fashion as morphemes or their meaning could be constructed from their parts, as with sentences (Libben, 2006). Although there are differing claims in the literature, there is strong evidence to support the second alternative, suggesting that compounds are decomposed into their constituents during processing (Andrews, 1986; Andrews, Miller, & Rayner, 2004; Fiorentino & Poeppel, 2007; Hyönä & Pollatsek, 1998; Inhoff, Starr, Solomon, & Placke, 2008; Juhasz, 2007; Juhasz, Starr, Inhoff, & Placke, 2003; Libben, 1998; Taft & Forster, 1975, 1976; Zwitserlood, 1994; Zwitserlood, Bolte, & Dohmes, 2002). Debate remains, however, about the effect of semantic transparency on decomposition. Semantic transparency refers to the relationship between the meaning of the constituents of a compound and the meaning of the compound as a whole (e.g., *hogwash*, an opaque compound, means “nonsense” which is unrelated to the meaning of both *hog* and *wash*). In particular, it is unclear whether the semantic representations, or meaning, of the constituents of opaque compounds become available during processing. My project focuses on addressing this question.

Specifically, it examines the influence of semantic transparency of the first and second constituents on whether semantic representations are accessed during processing. Previous theories have focused on representational differences for opaque and transparent compounds (Libben, 1998; Marslen-Wilson, Tyler, Waksler, & Older, 1994; Schrueder & Baayen, 1995; Zwitserlood, 1994). I, instead, propose that there could be processing differences between these types of compounds. Specifically, the processing difference might consist of semantic integration and meaning construction (as proposed by other researchers, including Gagné & Spalding, 2009; Ji, 2008; Ji, Gagné, & Spalding, in press; Spalding, Gagné, Mullaly, & Ji, 2010). If semantic integration is applied to the processing of opaque compounds, then it is important to examine the role of the first constituent while holding the transparency of the second constituent constant (Experiments 1 and 2) and to examine the role of the second constituent while holding the transparency of the first constituent constant (Experiments 3 and 4).

In the Introduction, I briefly present three approaches to complex word processing and describe the predictions that these approaches make for the processing of opaque and transparent compounds. Then, I discuss my first claim–that semantic representations are available for compounds–and examine two presuppositions underlying this argument: decomposition occurs, and lexical access occurs regardless of transparency. Additionally, I consider whether there is evidence that semantic access occurs. I next discuss my second claim–that semantic integration could be applied to the processing of opaque compounds–and specify two presuppositions: that there is evidence of semantic integration for novel and transparent compounds, and that there is evidence of semantic integration for opaque compounds. I conclude by discussing two concerns in previous semantic priming experiments, and by providing an overview of my experiments.

Three Approaches to Complex Word Processing

The three broad approaches that describe the way complex words are stored and processed are: whole-word access (Butterworth, 1983), decomposition-only (Taft & Forster, 1975, 1976), and dual-route (Giraudo & Grainger, 2000, 2001; Pollatsek, Hyönä, & Bertram, 2000; Schreuder & Baayen, 1995; Taft, 1994). In the following section, I review the specific predictions that relevant theories make about the processing of opaque and transparent compounds. This will allow me to examine whether any of the approaches are compatible with the data about the availability of semantic representations of opaque and transparent compounds.

The first approach, Butterworth's (1983) whole-word access, suggests that complex words are accessed and stored as whole-forms (e.g., *farmer* rather than *farm -er*). Butterworth acknowledges, however, that there are a few cases, such as the processing of novel words or when access to the whole-form fails, in which people can use "rules", by which he means decomposition, as a backup to access the whole-form.

The second approach, decomposition-only, proposes that when morphologically complex forms are presented, the stimulus is decomposed into its constituent parts and is accessed through these constituents (Taft & Forster, 1975, 1976). There is no direct link between the whole-word orthographic representation and the lexical representation. The initial access point to the whole-word lexical representation is the lexical representations of the constituents. Additionally, in this view, the first constituent plays a special role in access (Taft & Forster, 1976). The researchers found that if the first constituent is a word, but the second constituent is a nonword, it is more difficult to make a lexical decision about that item, suggesting that the lexical status of the first constituent might play an important role in access.

The third approach, dual-route, proposes that complex forms are accessed both through decomposition of the complex word into its constituents and through whole-word access. If there is an interaction between the two routes, or if they compete, it can be dependent on a number of factors, including length (Bertram & Hyönä, 2003), frequency (Pollatsek et al., 2000), and semantic transparency (Pollatsek et al., 2000; Schreuder & Baayen, 1995). An additional distinction exists within dual-route approaches: the time course of activation of constituent and whole-word representations. Some researchers propose an early decomposition account, in which complex words are initially accessed via the lexical representations of their constituent morphemes, followed by access to the whole-word lexical representation (Taft, 1994). Other researchers propose a late decomposition account, whereby complex words are initially accessed via their full form lexical representation, which results in spreading activation to the constituents' lexical representations if the words are transparent (Giraudo & Grainger, 2000, 2001). Yet other researchers suggest parallel dual routes by which whole-word forms are simultaneously accessed alongside the representations of their constituents (Pollatsek et al., 2000; Schreuder & Baayen, 1995). Although the temporal order of decomposition and whole-word access during processing is an important question in its own right, it is not directly examined in my project. Instead, I examine the initial processing differences between opaque and transparent compounds.

Predictions About the Processing of Opaque Compounds

Opaque compounds allow researchers to test the relationship between storage and construction for compounds (Libben, 2006). Opaque compounds have idiosyncratic meanings (i.e., their meanings cannot be constructed from their constituents parts); therefore, there must be access to whole-word representations at the semantic level. However, it might also be possible that their constituents are still accessed. There are three proposals that exist to specify the complexities of the processing of opaque compounds: that they might not be decomposed (Marslen-Wilson et al., 1994), that they might be decomposed and have separate representations for each constituent at the lexical, but not the semantic level (Schreuder & Baayen, 1995), or that they might be decomposed and have separate representations for all constituents at the lexical level and some constituents at the semantic level (Libben, 1998, 2005; Zwitserlood, 1994).

In considering the processing of opaque compounds, it is important to note that transparency is not an all-or-none phenomenon. It is possible for one, both, or neither constituent to be related to the whole-word meaning. These differences in the transparency of each constituent result in a four-way classification of compound types: transparent-transparent compounds, TT (e.g., *bookshelf*); opaque-transparent compounds, OT (e.g., *ladybug*); transparent-opaque compounds, TO (e.g., *jailbird*); and opaque-opaque compounds, OO (e.g., *catwalk*). In some models, the transparency of each constituent matters and influences how particular constituents or compound types are represented (Libben, 1998; Zwitserlood, 1994).

A few models of complex word processing explicitly state the predicted differences between the representations of opaque and transparent forms. In particular, they state whether, and at what level, differential representations are expected for opaque compounds as compared to transparent compounds. Marslen-Wilson et al. (1994) propose that opaque complex forms are stored and accessed via their whole-word representation, as they did not observe priming between opaque complex words and their stems, or from stems to opaque complex words. They predict that neither lexical nor semantic priming will occur for opaque compounds.

In contrast, Schreuder and Baayen (1995) propose that opaque compounds are decomposed and that their constituents have separate representations at the lexical level. This model predicts that lexical priming will occur for opaque compounds. At the semantic level, they state that the constituents of partially (OT and TO) and fully opaque compounds (OO) do not have separate representations; therefore, semantic priming would not be expected for opaque compounds.

Libben (1998) and Zwitserlood (1994) also propose that opaque compounds are decomposed and that their constituents have separate representations at the lexical level. However, their predictions differ at the semantic level. Libben (1998) proposes that if a constituent is transparent, its semantic representation is connected to the semantic representation of the whole word and is accessed. However, he argues that if a constituent is opaque, there is an inhibitory link between its semantic representation and the semantic representation of the whole word. He proposes that the inhibitory link results in competition between a number of possible representations, causing the inhibition of nontarget units and preventing access to the constituent's semantic representation. This model predicts that semantic priming will occur only for the transparent constituents of compounds (i.e., the first constituents of TO compounds and the second constituents of OT compounds). In contrast, Zwitserlood (1994) proposes that the semantic representations of both constituents of OT and TO compounds are accessed and that they are connected to the semantic representations of the whole word. The semantic representations of the constituents of OO compounds, in contrast, are not connected to the semantic representations of the whole word. Thus, she predicts that semantic priming should occur for the constituents of OT and TO compounds, but not for the constituents of OO compounds.

Claim 1: Semantic Representations Are Available During Processing

I propose that the semantic representations of both opaque and transparent compounds are available. This claim, however, relies on two presuppositions: that compounds are decomposed into their constituents, and that the lexical representations of the constituents of both opaque and transparent compounds are available. In the following sections, I discuss the evidence to support these two presuppositions, before discussing whether there is evidence that semantic representations are available during processing.

Are Compounds Generally Decomposed into their Constituents?

Researchers have investigated whether morphological segmentation occurs automatically during processing and whether constituent access facilitates access to the compound as a whole. Strong empirical evidence in the literature, from a number of paradigms, demonstrates that complex words are decomposed into their morphological constituents (e.g., *walker* is decomposed into *walk* and -*er* and *blackboard* into *black* and *board*) during processing (see for example, Andrews, 1986; Fiorentino & Fund-Reznicek, 2009; Inhoff et al., 2008; Jarema, Busson, Nikolova, Tsapkini, & Libben, 1999; Juhasz et al., 2003; Libben, Gibson, Yoon, & Sandra, 2003; Marslen-Wilson et al., 1994; Rastle & Davis, 2008; Taft & Forster, 1975, 1976; Zwitserlood, 1994). Specifically for compounds, researchers have found that when compounds are matched on overall frequency, participants make lexical decisions more quickly about compounds with high-frequency constituents than about those with low-frequency constituents (Andrews, 1986; Inhoff et al., 2008; Juhasz et al., 2003; Taft & Forster, 1976). The processing advantage for compounds with high-frequency constituents is as predicted for a decomposition or dual-route approach because the lexical representations of the high-frequency constituents would be accessed more quickly and facilitate access to the representation of the compound word.

Other paradigms, such as eye-tracking, neuroimaging, naming, and picture naming, provide parallel results that demonstrate that constituents are automatically accessed during processing (Andrews et al., 2004; Fiorentino & Poeppel, 2007; Hyönä & Pollatsek, 1998; Inhoff et al., 2008; Juhasz, 2007; Juhasz et al., 2003; Zwitserlood, Bolte, & Dohmes, 2002). Specifically, researchers have been able to compare behavioural and neurological measures to examine the process of decomposition. An experiment by Fiorentino and Poeppel (2007) demonstrated that participants make lexical decisions more quickly and accurately about compounds than about frequency matched monomorphemic words. This suggests that compounds are parsed into their constituents and that access to these constituents facilitates lexical access to the whole word. In addition, the neuroimaging results from this experiment complement the behavioural results. The authors found that magnetoencephalograph (MEG) components, such as the M350, occurred earlier for compounds than for monomorphemic words. The M350 component reflects lexical access, which can be facilitated by properties of the stimulus such as frequency. The appearance of the M350 early in processing for compounds suggests that the constituents of the compounds, because they are of higher frequencies, are available before the whole-word representation. Together the behavioural and neurological results support a decomposition approach of compound processing. To summarize, the literature has strongly demonstrated through a number of paradigms that decomposition occurs for compounds and that access to the constituents facilitates processing of the whole-form.

Does Semantic Transparency Influence Whether Lexical Representations Are Available?

In the experiments previously discussed, researchers have found evidence of the decomposition of compounds into their constituent morphemes, but have not focused on whether semantic transparency might influence the availability of constituent representations (Andrews, 1986; Andrews et al., 2004; Fiorentino & Poeppel, 2007; Hyönä & Pollatsek, 1998; Inhoff et al., 2008; Taft & Forster, 1976; Zwitserlood et al., 2002). If decomposition were dependent on transparency, it might be the case that only transparent compounds are segmented into their constituents (Marslen-Wilson et al., 1994). It might also be the case that the constituents of both opaque and transparent compounds become available during processing, resulting in lexical priming (Libben, 1998; Schreuder & Baayen, 1995; Zwitserlood, 1994).

Before further discussion of the processing of opaque and transparent compounds, a brief review of the literature of opaque complex forms in general will provide evidence of lexical access to constituent parts regardless of transparency. For example, Schreuder, Burani, and Baayen (2003) examined whether the transparency of low-frequency suffixed words affected whether the base words were accessed. They observed lexical priming for the bases of opaque complex forms, regardless of transparency (Experiment 1). This suggests that the lexical representations of opaque complex forms are available during processing.

In the domain of complex word processing, there is currently debate about whether early morpho-orthographic and morpho-semantic decomposition occurs during the processing of complex word forms. In the experiments conducted with complex forms, participants were presented with a masked prime, which was the stem of the complex word, and then presented with the complex word as the target (e.g., a stem prime, *tough* and the complex target, *toughen*). Researchers found that responses to both opaque complex words (e.g., *corner*) and transparent complex words (e.g., *cleaner*) are facilitated, compared to when there is simply an overlap of form, for examp*le, brothel* (Diependaele, Sandra, & Grainger, 2009; Feldman, O'Connor, & Del Prado Martin, 2009; Marslen-Wilson, Bozic, & Randall, 2008; Rastle, Davis, & New, 2004; Schreuder et al., 2003). These results have been interpreted in two different ways.

Rastle and Davis (2008; Davis & Rastle, 2010) suggest that only morpho-orthographic representations become available, and that morpho-semantic representations do not. In their 2008 meta-analysis of 18 experiments, they found that transparent complex words on average were facilitated to a similar degree as opaque complex words. For both types of complex words, early morphological segmentation occurs when the word is complex, but does not rely on information about the underlying semantic relations. This finding is consistent with models (Libben, 1998; Schreuder & Baayen, 1995; Zwitserlood, 1994) that propose that initial lexical access to the constituents occurs for both opaque and transparent forms.

Feldman et al. (2009), on the other hand, propose that both morpho-orthographic and morpho-semantic representations become available early in processing. Their experiment found that participants responded more quickly to the stem of a transparent complex word after the presentation of the entire word as a complex prime than to the stem of an opaque complex word. The authors suggest that this is the result of processing that is sensitive to the transparency of complex words. Despite the fact that the empirical evidence from the study of complex words does not converge to tell a seamless story about how transparency affects processing, it still provides an indication that transparency might play a role during processing.

The processing of derived words is similar to the processing of compound words because both word types are a combination of two or more morphemes (Booij, 2005). However, the processing of opaque and transparent compound words might differ from that of the processing of suffixed or prefixed words. Suffixed and prefixed words are composed of a morpheme and a bound morpheme. In contrast, compounds are composed of two free morphemes, and this might result in differential processing. This leads to the question, are the lexical representations of both opaque and transparent compounds available? In lexical priming experiments, it does seem that the lexical representations of the constituents of opaque and transparent compounds are accessed (Fiorentino & Fund-Reznicek, 2009; Inhoff et al., 2008; Jarema et al., 1999; Libben et al., 2003;

Monsell, 1985; Zwitserlood, 1994). Across these experiments, there are two possible orders of presentations; participants are presented either with compound primes and constituent targets, or with constituent primes and compound targets. In both orders of presentation, participants are faster to make lexical decisions about repeated words, regardless of the transparency of the compound (Fiorentino & Fund-Reznicek, 2009; Inhoff et al., 2008; Jarema et al., 1999; Libben et al., 2003; Monsell, 1985; Zwitserlood, 1994).

One experiment in particular demonstrates the kinds of results that have been found in lexical priming experiments that investigated the availability of the lexical representations of the constituents of opaque compounds. In Experiment 1, Zwitserlood (1994) presented participants with opaque and transparent Dutch compounds as primes. Next, participants saw either the first or second constituent of the compound and were asked to make a lexical decision. There was facilitation to respond to the target after viewing the same constituent in the compound prime, regardless of whether the compound was transparent or opaque. I have also replicated these results for the first constituents of opaque and transparent compounds in my First-Year Research Project (FYRP).

The processing of transparent and opaque compounds can also be examined using other paradigms. Wong and Rotello (2010) conducted two memory experiments comparing the processing of opaque and transparent compounds in English. In their project, participants viewed compounds or single words during the study phase and were then asked to determine whether the item was old or new in the test phase. Overall, participants were equally likely to correctly recognize previously presented transparent and opaque compounds. However, the researchers found that participants were more likely to make mistakes in the test phase when asked to recognize a transparent compound or its constituents than when they were asked to recognize an opaque compound or its constituents. For example, for transparent compounds, participants incorrectly recognized *cheekbone* (TT) as old when *cheek* and *bone* were presented separately, and they also incorrectly recognized *tooth* and *pick* as old when *toothpick* had been presented. While there are processing differences between opaque and transparent compounds in this project, I propose that these differences might be due to the particular demands of this task. Other research, in contrast, strongly suggests that both transparent and opaque compounds are decomposed (for example, Fiorentino & Fund-Reznicek, 2009; Inhoff et al., 2008; Jarema et al., 1999; Libben et al., 2003; Monsell, 1985; Zwitserlood, 1994).

There are two additional paradigms that can provide insight into differences in access to the representations of opaque and transparent compounds: translation of words and picture naming (Dohmes, Zwitserlood, & Bolte, 2004; Gumnior, Bolte, & Zwitserlood, 2006; Zwitserlood et al., 2002). Gumnior et al. (2006) examined the translation into German of visually presented English monomorphemic targets (for example, *bag,* which was to be translated into *Tasche*). They presented three types of distractor compounds before the targets, related transparent compounds (*Handtasche,* “handbag” in English), related opaque compounds (*Plaudertasche*, “chatterbox” in English), or unrelated compounds (*Sundenbock*, “scapegoat” in English). They found that participants responded more quickly after the presentation of related distractors, but that there was no difference in the time to respond after the presentation of the opaque or transparent distractors. Dohmes et al. (2004) and Zwitserlood et al. (2002) found similar results in picture naming experiments in which participants were asked to name in German the picture of an object (e.g., a rose) after seeing one of three visually presented primes, a transparent compound (e.g., *Buschrose*, “rosebush” in English), an opaque compound (e.g., *Gurtelrose*, “shingles” in English), or an unrelated compound (e.g., *Honigwabe*, “honeycomb” in English). They found that participants responded more quickly to transparent and opaque compounds than to unrelated compounds regardless of the delay between prime and target. Additionally, there was no difference between the facilitation of naming a picture preceded by an opaque or transparent compound. This suggests that during processing the constituents of compounds are accessed automatically, regardless of transparency.

The authors of the previous experiments (Dohmes et al., 2004; Gumnior et al., 2006; Zwitserlood et al., 2002) suggest that the results demonstrate that lexical representations are accessed in the same way for opaque and transparent compounds and that they support a view of morphological processing in which both transparent and opaque compounds are represented as morphologically complex at the lexical level. I propose that these experiments might also provide evidence that the semantic representations are accessed. Specifically, when a picture needs to be named or a word translated, participants might be accessing the underlying semantic representation of the word. Participants might be faster to respond after related words not only because the lexical representations are accessed, but because the semantic representations are also accessed. In sum, the literature supports the presupposition that lexical representations of the constituents of transparent and opaque compounds are available during processing.

Is There Evidence that the Semantic Representations of Compounds Are Available?

In typical language processing, the meaning of a word, or its semantic representation, is automatically accessed when the word is heard or viewed (Davies, 1998; McNamara, 1992, 2005; Meyer & Schvaneveldt, 1971; Neely, 1976, 1991). Meyer and Schvaneveldt (1971) were the first to demonstrate that when participants viewed two words that were related (e.g., *bread* and *butter*) they were faster to make a lexical decision than when they were presented with two unrelated words. There are a number of proposed underlying reasons for this facilitation (see Collins & Loftus, 1975; Ratcliff & McKoon, 1988, for two examples). The spreading activation framework of Collins and Loftus (1975), for one, proposes that activation spreads from the first node (e.g., *bread*) to all related concepts (e.g., *butter*) and then to all related concept nodes further in the network (e.g., *loaf* and *dough*). This series of links allows for facilitation (as measured in decreased response time) of subsequent decisions about related concepts.

Semantic priming is a generally demonstrated phenomenon for single words, but it might not occur for the constituents of compounds. The investigation of ambiguous compounds has suggested that the language system operates on the principle of maximization of opportunity, in which all possible candidates are initially accessed (Libben, 2006). Specifically, early in processing, all semantic representations are accessed, even if they are not compatible with the final selected meaning (Coolen, van Jaarsveld, & Schreuder, 1991 1993; de Almeida & Libben, 2005; Libben, 1994; Libben, Derwing, & de Almeida, 1999). In the examination of ambiguous novel compounds, such as *cartrifle*, Libben et al. (1999) used a morpheme recall task in which participants were asked to recall either ambiguous novel compounds or semantic associates of all possible constituents. Participants recalled more semantic associates of all constituents of the ambiguous compounds (*car*, *trifle*, *cart*, and *rifle*) than unrelated words, despite the fact that one particular parse was selected based on semantic plausibility (Libben, 1994). For example, for the item *cartrifle*, the parse of *cart rifle* is selected because it is more conceivable as an object than a *car trifle*. It, therefore, seems that the language systems accesses all possible constituents early in processing, but later selects a meaning based on semantic plausibility.

More closely related to the current project, Schreuder et al. (2003) investigated whether semantic priming occurs for the bases of Dutch opaque complex forms. In Experiment 2 of their project, they investigated the time course of activation of constituent (i.e., base word) and whole-word meanings. At short stimulus onset asynchronies (SOAs) of 150 ms, priming was observed for associates of the whole-word meaning. In contrast, priming was observed for semantic associates of the bases at longer SOAs of 500 ms. The results of this project are interesting for two reasons. First, they suggest that the predictions of Schreuder and Baayen (1995) that opaque complex words are not represented as morphologically complex at the semantic level are incorrect. Second, they suggest that at different points in processing there can be access to the lexicalized meaning of compounds and to the semantic representations of opaque constituents.

Directly related to the current project are the experiments that examine whether the semantic representations of the constituents of opaque compounds are accessed during processing. Three projects used a semantic priming paradigm to directly investigate the availability of the constituents of opaque compounds. In the first project, Sandra (1990), employed a semantic priming paradigm in a lexical decision task using Dutch compounds. Participants were asked to make a lexical decision about compound word targets (e.g., *melkweg*, “milky way” in English) after semantic associates of either the first or second constituents were presented as primes (e.g., *koe*, “cow” in English). In Experiment 1, Sandra assessed whether semantic priming was occurring for the first and second constituents of opaque compounds. He generally used OT compounds for examining the availability of the first constituent and TO compounds for examining the availability of the second constituent. In this project, no significant differences between the times to respond to targets after related or unrelated primes were observed. However, in Experiment 2, Sandra (1990) did observe semantic priming for both the first and second constituents of transparent compounds. Sandra concluded from his results that only the semantic representations of the constituents of TT compounds are available during processing.

In the second project, Zwitserlood (1994) conducted a semantic priming experiment by presenting participants with transparent and opaque Dutch compounds as primes and then asking them to make a lexical decision about a target, which was a semantic associate of either the first or second constituent of the compound. As in the case of Sandra's (1990) experiments, there was facilitation to respond to the semantic associates of transparent compounds. In contrast, Zwitserlood (1994) also found facilitation to respond to semantic associates of partially opaque compounds. No facilitation was observed when participants responded to a semantic associate after the presentation of a fully opaque compound. Zwitserlood (1994) interpreted these results as suggesting that for transparent and opaque compounds, at the semantic level, the constituents of TT, OT and TO compounds are available, but those of OO compounds are not.

In the third project, Isel, Gunter, and Friederici (2003), conducted four intermodal semantic priming experiments in which participants were presented with acoustic German compound primes (either TT, OT, TO or OO) and were asked to make lexical decisions about visually presented semantic associates of the first constituents. The authors chose to focus on the first constituents of compounds, because Taft and Forster (1976) had demonstrated that this constituent plays the primary role in access to the compound. They also varied the prosodic information provided across the experiments. When there was prosodic information present about the second constituent (Experiments 1 and 4B), in contrast to the findings of Zwitserlood (1994), priming occurred only for the first constituents of compounds if the second constituent was transparent (TT and OT compounds). However, when prosodic information was present, but the presentation of the second constituent was suppressed (Experiments 2 and 4A), priming was not observed for any of the compound types. Finally, when the first constituents were presented with the prosody of single words, there was priming for the first constituents of all compound types (Experiment 3).

Isel et al. (2003) interpreted these results to suggest that the transparency of the second constituent determines whether or not the semantic representations of the constituents are accessed. If the second constituent is opaque, they propose that the semantic representation of the first constituent is not accessed. This occurs, according to the authors, because when prosodic information signals that the word presented is part of a compound, the processing system waits for access to the second constituent to determine whether the first constituent should be accessed. However, I propose that because the researchers do observe semantic priming when no prosodic information is available (Experiment 3), their results likely reflect processing differences due to the nature of presentation (i.e., prosody) of the stimuli. Therefore, in contrast to examining the structure of representations of opaque compounds in the mental lexicon, as Isel et al. (2003) claim, I propose that they are instead examining what occurs during processing when it is signaled that the presentation of the second constituent will be delayed. The transparency of the second constituent, in this case, becomes more important than it would be when the compound is presented visually.

It does not appear that all semantic representations of opaque compounds are available (Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994). Sandra (1990) did not observe priming for opaque compounds after semantic associates of their constituents were presented. Zwitserlood (1994), on the other hand, did observe priming for semantic associates of the constituents of partially opaque compounds. Isel et al. (2003) observed priming for semantic associates of the first constituents, but only when the second constituent was transparent (i.e., they only observed priming for semantic associates of the first constituents of TT and OT compounds when the duration of the first constituent suggests that it is a part of a compound). These results are puzzling because it has been shown that lexical representations are available for the constituents of opaque compounds (Fiorentino & Fund-Reznicek, 2009; Inhoff et al., 2008; Jarema et al., 1999; Libben et al., 2003; Monsell, 1985; Zwitserlood, 1994). If the lexical representations are available, then the results from the processing of single words and ambiguous compounds leads to the assumption that semantic representations should also be available.

The models that provide predictions about the processing of opaque compounds (Libben, 1998; Zwitserlood, 1994) focus on representational differences between transparent and opaque compounds. According to Libben (1998), there are inhibitory links between the semantic representations of opaque constituents and the semantic representation of the whole word. In contrast, Zwitserlood (1994) proposes that the constituents of OO compounds are not connected to the semantic representation of the whole word. However, both views predict that the lexical representations of the constituents of opaque and transparent compounds are available during processing. If this is the case, the work on the processing of single words (i.e., Davies, 1998; McNamara, 1992, 2005; Meyer & Schvaneveldt, 1971; Neely, 1976, 1991) has demonstrated that there should be a link between the lexical and semantic representations of the constituents. Ji et al. (in press) have noted that the language system would need to know whether a constituent is opaque to prevent activation from spreading from the lexical-level constituent representation to the constituent representation at the semantic level. Therefore, the lack of a link between the constituent and whole-word representation at the semantic level for OO compounds (Zwitserlood, 1994) should not influence whether the semantic representations of the constituents are accessed during processing. In Libben's (1998) view, the inhibitory links between the semantic representation of the whole word and the semantic representations of opaque constituents could provide a reason why the representations of opaque constituents are predicted not to be activated. However, Libben does not explicitly mention how his model would prevent activation from spreading from the lexical representations of the constituents (which he does state are accessed). Therefore, the automatic activation of semantic representations from their connected lexical representations might be sufficient to result in activation (and in turn, semantic priming). Is there another explanation for why it appears that semantic representations are not accessed during processing?

Claim 2: Semantic Integration Could Account for the Processing of all Compounds

The models previously discussed have ascribed the processing differences between opaque and transparent compounds to differences in their representations

(Libben, 1998, 2005; Marslen-Wilson et al., 1994; Schreuder & Baayen, 1995; Zwitserlood, 1994). Because there is strong evidence that all compounds (even opaque ones) are decomposed into their constituents, it might be important to consider how semantic integration of the constituents occurs. Semantic integration might be occurring for opaque compounds, as proposed by other researchers (Gagné & Spalding, 2009; Ji, 2008; Ji et al., in press; Libben, 2005; Spalding et al., 2010). If this is the case, semantic integration might provide an explanation for the discrepancies in the results of semantic priming projects with opaque compounds (Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994). In this section, I first discuss whether and how semantic integration occurs for compounds and then discuss whether there is evidence of the same process occurring for opaque compounds.

Does Semantic Integration of Compounds' Constituents Occur? If So, How?

Empirical investigations have demonstrated that semantic integration occurs for the constituents of transparent compounds. Gagné and Spalding (2009) have investigated the process through which the meaning of a transparent compound is specified. In their project, participants responded more quickly to a target compound when a compound that shared the same relational structure preceded it. For example, participants determined more quickly that *snowfort* had a sensible interpretation after having seen *snowman* than after they had seen *snowshovel*. This is because the first two items share the relational structure ____ *MADE OF snow*. This demonstrates that during processing, the semantic representations of transparent compounds are available and that they are integrated to create a meaning.

The process of semantic integration has also been supported using neurological methods, such as electroencephalography (EEG) and magnetoencephalography (MEG). In EEG experiments, transparent compounds in comparison to opaque compounds elicited a larger negative ERP shift, which the authors interpreted as representing the difficulty to integrate the meaning of the constituents (Koester, Gunter, & Wagner, 2007). Three constituent German compounds with semantically plausible second constituents elicited a larger N400 than compounds whose second constituents were less semantically plausible (Koester, Holle, & Gunter, 2009). In an MEG experiment, it was found that compounds elicited an M350 earlier than monomorphemic words (Fiorentino & Poeppel, 2007). Overall, the N400 and M350 reflect the degree of difficulty in processing, and when they have increases in magnitude (or appear sooner) it supports the proposition that additional processing must occur to integrate the semantic representations of the constituents of compounds (Kutas & Hillyard, 1980). In addition to the behavioural evidence, there seems to be neurological evidence that semantic integration is occurring.

The process by which constituents are integrated is specified by the Relational Interpretation Competitive Evaluation (RICE) theory of conceptual combination (Spalding et al., 2010). Broadly, the RICE theory follows a “suggest-evaluate” framework, in which possible relations for compounds are suggested (e.g., *adolescent doctor* could either be a *doctor FOR adolescents* or a *doctor*

WHO IS an adolescent) and they compete for selection. Then, in the evaluation stage, a judgement is made as to whether the correct relation for the compound has been selected. If it has, an expansion of the selected relation follows. In particular, the modifier (or first constituent) suggests relational interpretations (Gagné, 2001; Gagné & Shoben, 1997; Spalding et al., 2010). Then the head noun (or second constituent) is responsible for judging whether the interpretation is plausible. For instance, Spalding et al. (2010) discuss that when a meaning for a novel compound, such as *mountain planet* is suggested, the modifier would suggest the *LOCATED IN* relation. However, the head noun would evaluate this particular relation as implausible because a planet is too large to be located in the mountains. This theory has currently been tested with transparent and novel compounds.

There is evidence that multiple meanings can compete for selection for familiar and novel compounds (Gagné, Marchak, & Spalding, 2010; Gagné, Spalding, & Gorrie, 2005). Gagné et al. (2005) found that alternative interpretations for familiar compounds could compete with the lexicalized meaning of the compound during processing. When a compound (e.g., *bug spray*) was preceded by a sentence containing an alternative meaning of the compound (e.g., “As a defense mechanism against predators, the Alaskan beetle can release a deadly bug spray”), participants were slower to respond to the target (e.g., bug spray= spray FOR bugs) than when the compound was preceded by a sentence containing the lexicalized meaning of the compound (e.g., “Because it was a bad season for mosquitoes, Debbie made sure that every time she went outside, she wore plenty of bug spray”). Also, the researchers found that the participants’ judgement of the plausibility of the lexicalized meaning (e.g., bug spray=spray FOR bugs) decreased from 89% (when the compound was preceded by a sentence containing the lexicalized meaning of the compound) to 64% (when the compound was preceded by a sentence containing an alternative meaning of the compound). This suggests that competition can occur between lexicalized and alternative interpretations for familiar compounds and this competition might occur for opaque compounds, as well.

Is there Evidence of Semantic Integration for Opaque Compounds?

If the “suggest-evaluate” framework of RICE (Spalding et al., 2010) is the underlying mechanism responsible for the semantic integration of the constituents of compounds, the same process should generalize across compound types, including opaque ones (as previously discussed by Gagné & Spalding, 2009; Ji, 2008; Ji et al., in press). Consistent with Ji et al.’s (in press) claim, I propose that the semantic representations of opaque compounds are available during processing, and that an interpretation should be suggested via a relational link (e.g., *wash FOR a hog* for the compound *hogwash*). I also propose (in line with Ji’s (2008) and Ji et al.’s (in press) claim) that after a relational link has been suggested the composed meaning would conflict with the meaning retrieved from the lexicon (i.e., “nonsense” for the compound *hogwash*). This competition between meanings during the “evaluate” stage of RICE could potentially result in the suppression (or inhibition) of the constructed meaning to correctly determine that the compound is a word. This suppression might also lead to the suppression of the semantic representations of the constituents of opaque compounds. The spreading suppression due to the conflict between a composed meaning and a lexicalized meaning could be applied to the processing of opaque compounds and might provide an account for the lack of semantic priming in previous experiments (see Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994). As Libben (2006) has proposed, it could be that the mismatch resolution between the semantic representations of the constituents and that of the whole word occurs much later in processing, after lexical access has occurred. I, therefore, propose, in conjunction with Ji (2008) and Ji et al. (in press), that it is not that the semantic representations of constituents of opaque are unavailable, but rather that they are suppressed due to inhibition created by a conflict between a composed and a stored meaning.

It is possible to hypothesize that there could be systematic differences in the competition between constructed and stored meaning across compound types (as Ji et al., in press have discussed). TT compounds would show little competition between their constructed and stored meanings. In contrast, the constructed meanings of OT compounds and TO compounds would result in greater competition. However, meaning construction for OT and TO compounds might result in differing degrees of competition depending on the relative contribution of facilitation (or inhibition) of the modifier and the head in different stages of processing. It might be the case that for OT compounds the suggested relation will differ to a great extent from the stored interpretation and thus result in a greater degree of competition. As Jarema, Perlak and Semenza (2010) note, it could be that the modifier has primacy in determining an idiosyncratic meaning for a compound. In particular, they suggest that the first constituent carries the burden of specifying that a particular item is not a member of the category of the head noun (for example, a *hotdog* is not really a *dog* but that change in category is the result of the modifier *hot*) making it more difficult to process OT compounds. However, Isel et al. (2003) and Libben et al. (2003), suggest that compounds with an opaque head might be more difficult to process. This would be the case, according to RICE (Spalding et al., 2010), because the constructed meaning of TO compounds results in a greater degree of competition at the evaluation stage. TO compounds do not refer to items that are members of the head category and thus these compounds might more difficult to evaluate. Finally, for OO compounds, meaning construction would result in a constructed meaning that differs to the greatest extent (in comparison to TT, OT and TO compounds) from the lexicalized meaning. As Ji et al. (in press) mention, it could be the case that when the possible meanings are very different, it might be easier to reject the incorrect interpretation. It could also be the case that the very different constructed and stored meanings result in greater processing differences. This is an empirical question that I will not directly examine in this project.

A variety of aphasic patients (including Broca's, Wernicke's, mixed, amnesic and residual aphasia) have been shown to have disruptions in the processing of opaque compounds, which demonstrate that there might be a deficit in the suppression of the semantic representations of the constituents (Badecker, 2001; Blanken, 2000; Libben, 1993). For instance, Libben (1993) found that when he asked a mixed aphasic patient to provide the interpretation of *bellybutton*, the patient stated “the button in your stomach...for kids”. In this case, the semantic representation of the opaque constituent of the compound (i.e., *button*) was accessed, as well as the compound as a whole and its associates (i.e., for kids). If this deficit represents the loss of a suppression mechanism as Libben (1993) has proposed, it would suggest that in typical language processing, the semantic representations of opaque compounds are available early but later are suppressed to proceed with language comprehension.

For opaque compounds, people without aphasia also have processing difficulties when meaning composition is emphasized by adding spaces between the constituents, or when the constituents are presented in different colours (Frisson, Niswander-Klement, & Pollatsek, 2008; Ji, 2008; Ji et al., in press). Ji (2008; Ji et al., in press) found that when a composition route was emphasized, opaque compounds were not processed more quickly than matched monomorphemic words. However, in closed form (i.e., without a space between the constituents) they were processed more quickly. The meaning composition route, when compounds were presented in open form or with different coloured constituents, might have been more salient for opaque compounds and the composed meaning might have interfered to a greater degree with processing the lexicalized interpretation. Additionally, in two eye-tracking experiments, Frisson et al. (2008) found no effect of transparency on eye fixations such as gaze duration, first-fixation duration, and single fixation when the compounds were presented in closed form. When a space was added, however, there was an effect of transparency. Opaque compounds took longer to process and those with opaque second constituents took the longest to process. When it was made evident that a meaning could be computed from the constituents of opaque compounds, processing was more difficult. This finding suggests that the semantic representations of opaque compounds might be available for open compounds. This supports Libben's (2006) proposition that semantic information is sometimes available, even though it might not be possible to detect the access to semantic representations in a semantic priming task. Therefore, it would be reasonable to suggest that the semantic representations are automatically accessed for opaque compounds (even in closed form), and that presenting them in open form exaggerates the meaning composition process.

While I have previously discussed the difficulty in processing for opaque compounds in terms of online computational costs, it is also possible that this difficulty could be a result of learning. Schreuder and Baayen (1995) predict that opaque affixes are learned after transparent affixes. I additionally suggest that this prediction extends to opaque compounds. In specific, opaque compounds should be learned after transparent compounds because they have idiosyncratic meanings. If this is the case, the processing difficulty for opaque compounds might not in fact be due to processing of the compound each time it is accessed. Instead, the degree of difficulty associated with learning the peculiar association between the compound's constituent and whole word meanings might result in later and less fluent learning of the compound. This could result in more difficult processing (i.e., slower processing) of opaque compounds. While this is an interesting question in its own right, in the current project, it will not be possible to determine whether any observed difficulty is the result of processing or due to learning.

To summarize, it does appear that semantic integration occurs during processing. For opaque compounds, the constituents' semantic representations do appear to play a role and there is evidence that the constituents' meanings might be integrated (Frisson et al., 2008; Ji, 2008; Ji et al., in press). This is also in line with Taft's (2004) proposition that access to a complex word cannot be gained only via the whole-word representation; and that "a postdecompostion recombination stage cannot be circumvented" (p. 761). Specifically, in line with Ji's (2008; Ji et al., in press) proposal, meaning construction could be the mechanism that occurs for the processing of opaque compounds, and might provide an explanation of why researchers have found conflicting results in previous semantic priming experiments (Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994).

Two Concerns in Previous Semantic Priming Experiments

When a meaning construction view is considered, there are two possible concerns in methodology that might explain the discrepancies in the results of Isel et al. (2003), Sandra (1990) and Zwitserlood (1994). The first concern relates to whether compounds are the primes and semantic associates are the targets. The second concern relates to the kinds of compounds used as "opaque" in each experiment.

In the first place, previous experiments have not used a consistent order of presentation of the compound and the semantic associate. Isel et al. (2003) and Zwitserlood (1994) presented compounds as primes and semantic associates as targets. Sandra (1990), in contrast, presented semantic associates as primes and compounds as targets. In Sandra's paradigm, if meaning construction is occurring, increased access to the semantic representations of the constituents (via previous access to semantic associates) could result in increased competition between the stored and constructed meanings (as proposed by Ji et al., in press). Therefore, to make a lexical decision about an opaque compound, mismatch resolution would need to occur. Specifically, Ji et al. (in press) have proposed that in the case of Sandra's experiment, the resolution of the mismatch between the constructed and the stored meaning might explain why semantic priming was not observed. If this is the case, prior access to the constituents of transparent compounds would be beneficial, but prior access to opaque constituents would be problematic because it creates competition between the constructed and stored meanings. In contrast, in the order of presentation of Isel et al. (2003) and Zwitserlood (1994), if the semantic representations of constituents are automatically accessed during processing, there will be spreading activation to related words and response to the semantic associate targets should decrease. Specifically (as mentioned by Ji et al., in press), semantic priming should be observed in Zwitserlood's (1994) series of experiments because participants did not respond to the prime. Therefore, there was no need to resolve the mismatch between the constructed and the stored meaning, and thus the semantic representations that were initially accessed were not suppressed.

Both Isel et al. (2003) and Zwitserlood (1994) presented the compounds as primes and semantic associates of the constituents as the targets, but I have chosen to follow Zwitserlood's (1994) paradigm of visually presented primes and targets. As previously discussed, the presentation of primes in an auditory modality by Isel et al. (2003) created two possible issues. First, there was a delay in the onset of the second constituent. Second, prosodic information from the presentation of the first constituent modified whether semantic priming occured. The presentation of auditory primes resulted in a delay of the second constituent and could have allowed the language processing system greater time to suppress the semantic representation of the first constituent. Therefore, Zwitserlood's (1994) paradigm will allow me to test the availability of semantic representations early in processing and reduce the likelihood that the effects that I am observing are due to suppression of the semantic representations of the constituents due to a conflict between a constructed and stored meaning for opaque compounds.

The second concern relates to the kinds of compound words used. It seems to be the case that the independent roles of the first and second constituents might influence the availability of the semantic representations of opaque compounds. Studies have shown that there have been effects of position-in-the-string during the processing of compounds (Isel et al., 2003; Libben et al., 2003; Jarema, 2006; Jarema et al., 1999; Jarema et al., 2010). It has been possible to compare languages in which the head of the compound takes a different position. In

English, the head is the second constituent, whereas, in languages such as French, the first or second constituent can be the head. In these experiments, researchers have found that position-in-the-string and headedness interact when measuring lexical priming of the constituents of compounds (Jarema et al., 1999), suggesting that it is important to consider the influence of both constituents during processing.

It does seem that the independent roles of the first and second constituent matter in the processing of opaque compounds (Isel et al., 2003; Libben et al., 2003; Jarema et al., 2010). Specifically, Libben et al. (2003) found that the overall response time to make a lexical decision about TO and OO compounds was slower than about TT and OT compounds. Isel et al. (2003) also demonstrated that semantic priming occurred only for the first constituents of TT and OT compounds, but not for the first constituents of TO and OO compounds. Together these results suggest that the transparency of the constituents can influence processing and potentially that there can be an interaction between the transparency of one constituent and the availability of the other constituent.

As previously discussed, if a meaning construction framework is applied to the processing of opaque compounds (as proposed by Gagné & Spalding, 2009; Ji, 2008; Ji et al., in press), it is important to consider the role of both constituents. The transparency of each constituent could influence the competition between meanings resulting from semantic integration in different ways. It might be more difficult to process compounds with opaque first constituents (OT and OO compounds) because the modifier is responsible for suggesting relational interpretations. It might also be the case that it is more difficult to process compounds with opaque second constituents (TO and OO compounds) because the head evaluates the plausibility of suggested interpretations.

It is therefore problematic that the three semantic priming projects (Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994) used different kinds of compounds as their materials. Sandra (1990) generally used OT compounds when examining the first constituents (twelve out of sixteen items, based on my classification) and TO compounds when examining the second constituents (eight out of sixteen items, based on my classification). However, some OO compounds were included as well (two in Experiment 1, and seven in Experiment 2, based on my classification). Zwitserlood (1994), on the other hand, did differentiate between fully opaque compounds and partially opaque compounds. However, in the partially opaque condition, OT and TO compounds were classified together. Finally, Isel et al. (2003) considered all compound types, TT, OT, TO and OO, but only examined the availability of the first constituent.

My project will extend the work of Libben et al. (2003) and Isel et al. (2003) to examine whether the semantic representations of the constituents are available for both the first and second constituents of TT, TO, OT and OO compounds. While it is not possible to manipulate the position of the head in English, I will manipulate the transparency of one constituent, while holding the transparency of the other constituent constant.

Overview of Experiments

There is evidence that compounds are decomposed into their constituents, and that the lexical representations of these constituents are available (Fiorentino & Fund-Reznicek, 2009; Inhoff et al., 2008; Jarema et al., 1999; Juhasz, 2007; Juhasz et al., 2003; Libben et al., 2003; Taft & Forster, 1976; Zwitserlood, 1994). However, it appears, according to previous researchers, that not all the semantic representations of the constituents of opaque compounds are accessed (Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994). They suggest that this is the case because they do not observe semantic priming for all the constituents of all compound types. In contrast, I propose that a lack of semantic priming does not necessarily entail that the representations are not accessed but potentially that later processing interferes with the observation of semantic priming. The evidence in related domains suggests that all semantic representations are automatically accessed (de Almeida & Libben, 2005; Badecker, 2001; Blanken, 2000; Coolen et al., 1991, 1993; Libben, 1993, 1994; Libben et al., 1999), and that these representations are integrated to construct a meaning for the compound (Fiorentino & Poeppel, 2007; Gagné & Spalding, 2009). The RICE theory of conceptual combination might account for this paradox (Spalding et al., 2010). According to RICE, meaning composition should be attempted for all compounds, even opaque ones. If so, a composed meaning of an opaque compound (e.g., *rod THAT IS hot* for *hotrod*) would be suggested, and this would conflict with the stored meaning (e.g., “a fast car”). The composed meaning would be inhibited and would result in the suppression of the constituents’ semantic representations (in line with the proposition of Gagné et al., 2005; Ji, 2008; Ji et al., in press; Libben, 2005). This suppression would explain why previous researchers have found that not all semantic representations are available (e.g., Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994).

To examine whether the semantic representations are available during processing, I conducted four semantic priming experiments using a lexical decision task. I examined whether the semantic representations of the first (Experiments 1 and 2) and second constituents (Experiments 3 and 4) of all compound types (TT, OT, TO, and OO) become available, while holding the transparency of the second (Experiments 1 and 2) and first constituents (Experiments 3 and 4) constant. Specifically, if meaning construction occurs for compounds, it could be the case that the competition between meanings arising due to semantic integration might influence whether semantic priming of the constituents is observed. Depending on the relative contribution of the “suggest” and “evaluate” stages of RICE (Spalding et al., 2010), I might observe differential semantic priming effects for the constituents (either opaque or transparent) and these effects might be dependent on the constituents’ position in the string.

Construction of Materials

The experimental compounds in Experiments 1, 2, 3 and 4 were initially categorized as TT, OT, TO and OO using entries from the Oxford English Dictionary (Simpson & Weiner, 1993). If the constituent, or a close synonym, appeared in the dictionary entry it was classified as transparent. For example, a *catdoor* (TT), is defined as a “small door, usually swinging, which can be opened by a cat...”, while a *catfish* (OT) is a “name given to various fishes”. This measure of semantic transparency might be too crude to capture what is in reality a continuous measure. It could be the case that within a particular category (i.e., TT, OT, TO and OO), the degree of transparency of each constituent might vary. For example, *ladybug* (OT) maintains very little of the meaning of *lady*. On the other hand, *kidneybean* (OT) maintains some of the meaning of *kidney* because of the bean's shape. For this reason, a post-test was conducted to determine how much a particular constituent (e.g., *straw*) retains its meaning in the compound (e.g., *strawberry*). This allowed me to assess whether my classification of compounds was appropriate. Additionally, the results from this post-test will serve as a continuous measure of transparency that can be included as a predictor variable into the Linear Mixed Effects (LME) models. Constituents that receive higher ratings of transparency might produce a greater degree of semantic priming for their constituents. For transparent compounds this greater access to the semantic representation could be beneficial, but for opaque compounds, it might hinder processing. For additional information about the stimulus characteristics, see Table 1.

Table 1

Stimuli characteristics (means and standard deviations) as a function of word type for Experiments 1-4

Experiment and Condition	Letter	Lemma	C1 Lemma	C2 Lemma	C1 LSA	C2 LSA	C1 Trans	C2 Trans
Experiment 1								
Target	4.78 (1.12)	398.18 (736.78)	--	--	--	--	--	--
TT-Related Prime	8.78 (1.31)	3.37 (6.59)	337.00 (512.26)	314.22 (348.38)	0.40 (0.19)	0.19 (0.16)	5.79 (0.96)	5.66 (1.10)
OT-Related Prime	8.35 (1.10)	5.02 (8.49)	337.00 (512.26)	379.49 (682.96)	0.40 (0.19)	0.11 (0.08)	3.92 (1.36)	5.44 (1.20)
TT-Unrelated Prime	8.70 (1.26)	6.43 (16.93)	584.13 (1161.99)	870.58 (1496.20)	0.12 (0.08)	0.11 (0.11)	5.76 (0.98)	5.89 (0.97)
OT-Unrelated Prime	8.55 (1.24)	6.43 (16.93)	584.13 (1161.99)	400.09 (537.63)	0.12 (0.08)	0.11 (0.10)	4.01 (1.36)	5.67 (1.00)
Experiment 2								
Target	4.75 (1.16)	455.54 (546.18)	--	--	--	--	--	--
TO-Related Prime	8.53 (1.72)	5.14 (12.16)	547.86 (667.03)	486.14 (856.08)	0.46 (0.20)	0.14 (0.08)	5.88 (0.99)	4.63 (1.55)
OO-Related Prime	8.71 (1.44)	23.11 (92.44)	547.86 (667.03)	362.25 (566.07)	0.46 (0.20)	0.15 (0.11)	4.54 (1.32)	4.65 (1.45)
TO-Unrelated Prime	8.34 (1.38)	13.80 (31.00)	943.17 (1210.60)	1088.75 (1886.65)	0.12 (0.09)	0.16 (0.14)	5.84 (1.03)	4.64 (1.45)

OO-Unrelated Prime	8.69 (1.53)	3.48 (6.48)	943.17 (1210.60)	627.05 (1227.66)	0.12 (0.09)	0.12 (0.11)	4.75 (1.27)	4.37 (1.35)
Experiment 3								
Target	5.30 (1.79)	167.55 (266.49)	--	--	--	--	--	--
TT-Related Prime	9.48 (2.08)	0.53 (1.37)	388.40 (709.84)	447.43 (811.27)	0.19 (0.17)	0.40 (0.21)	5.87 (0.98)	5.23 (1.00)
TO-Related Prime	8.60 (1.68)	30.30 (149.86)	387.78 (466.09)	447.43 (811.27)	0.11 (0.10)	0.40 (0.21)	6.19 (0.88)	4.25 (1.40
TT-Unrelated Prime	8.88 (1.45)	4.02 (15.51)	268.09 (397.55)	493.81 (1150.21)	0.11 (0.11)	0.11 (0.09)	6.01 (0.95)	5.59 (1.02)
TO-Unrelated Prime	8.43 (1.30)	10.14 (25.45)	581.70 (633.81)	493.81 (1150.21)	0.09 (0.07)	0.11 (0.09)	5.64 (1.04)	4.67 (1.56)
Experiment 4								
Target	4.70 (1.30)	286.21 (407.00)	--	--	--	--	--	--
OT-Related Prime	8.23 (1.29)	7.61 (29.25)	543.57 (1339.92)	711.05 (1299.74)	0.11 (0.08)	0.42 (0.20)	4.20 (1.28)	5.57 (1.11)
OO-Related Prime	7.88 (1.24)	40.59 (165.85)	242.74 (474.76)	711.05 (1299.74)	0.11 (0.10)	0.42 (0.20)	4.40 (1.30)	4.68 (1.28)
OT-Unrelated Prime	8.28 (1.28)	11.92 (31.54)	436.96 (1093.34)	889.49 (1281.76)	0.10 (0.09)	0.11 (0.09)	4.55 (1.20)	5.70 (0.92)
OO-Unrelated Prime	7.93 (1.00)	12.67 (21.95)	495.57 (858.30)	889.49 (1281.76)	0.11 (0.09)	0.11 (0.09)	4.65 (1.47)	4.64 (1.51)

Note. Letter = number of letters; Lemma = whole-word lemma frequency (occurrences/million); C1 Lemma = lemma frequency for the first constituent (occurrences/million); C2 Lemma = lemma frequency for the second constituent (occurrences/million); C1 LSA = rating of semantic similarity of first constituent and the target; C2 LSA = rating of semantic similarity of second constituent and the target; C1 Trans = transparency rating for the first constituent; C2 Trans = transparency rating for the second constituent

Method.

Participants. Sixty-one psychology undergraduate students participated in this experiment for partial course credit. The participants in this experiment and the following experiments were native speakers of English. One participant was removed from this experiment because they were not a native English speaker.

Materials. The items in this experiment were the compound primes from Experiments 1, 2, and 3. The items were divided into four lists of 103 items and counterbalanced to reduce the number of repeated constituents. There were, however, some repeating constituents. When possible, the repeated constituents were in different positions within the compounds. For example, if the item appeared twice, it appeared as the first constituent once (e.g., *housefly*) and as the second constituent once (e.g., *courthouse*). The ratings for the experimental compounds from Experiment 4 were collected in Part 2 of Experiment 4.

Procedure. Participants were presented with the first constituent (e.g., *litter*) above the compound word (e.g., *litterbug*) on a computer screen. They were then asked to determine how much the top word retains its meaning in the bottom word on a scale from 1 (loses all of its meaning) to 10 (retains all of its meaning). This procedure was then repeated for the second constituent (e.g., *bug*). Participants were also asked to press the “n” key if they did not know the meaning of the bottom word (i.e., the compound).

Results. Participants indicated that they did not know the meaning of the compound word in 6.95% of the responses. The mean transparency rating for transparent first constituents was 5.90, and for opaque first constituents, the mean rating was 4.28. The mean rating for transparent second constituents was 5.60, and for opaque second constituents, the mean rating was 4.52. The continuous measures of transparency used in the following three experiments were the mean rating of transparency calculated for each constituent for each item. For example, the item *suitcase* (OT) in Experiment 1 received a mean rating of 4.60 for the first constituent and a mean rating of 7.53 for the second constituent, while the compound sharing the same first constituent, in this case, *suitjacket* (TT), received a mean rating of 7.67 for the first constituent and 7.47 for the second constituent.

Data Analysis

I fit three sets of models to examine my two claims. The first claim is that semantic representations should be available during processing. The second claim is that semantic integration should occur during the processing of all compounds. In this section, I first discuss the predictors included in each of the three models and then I discuss why I have chosen to fit three models. I fit Model 1 (the dichotomized model) with either inverse response time to the target or accuracy in responding to the target as dependent variables, and Transparency of the prime (Transparent and Opaque) and Relatedness (Related versus Unrelated) as fixed effect predictor variables, and participants and items were included as random effects.

I fit Model 2 (the continuous model) with measures of Continuous Transparency and Continuous Relatedness as fixed effects predictors and included the same random effects as Model 1. The continuous measures of transparency of the first (Experiments 1 and 2) and second (Experiments 3 and 4) constituents were derived from the ratings described in the Construction of Materials section. The continuous measure of relatedness was derived from Latent Semantic Analysis (LSA) ratings (Landauer, 2002; Landauer & Dumais, 1997) between the first (Experiments 1 and 2) and second (Experiments 3 and 4) constituents of the prime and the target.

I fit Model 3 (the model with covariates) with the addition of covariates, including the number of letters of the prime, the number of letters of the target, the log frequency of the target from Google (Brants & Franz, 2006), the log frequency of the prime from Google, the log frequency of the first constituent of the prime from Google (Experiment 1 and 2), the log frequency of the second constituent of the prime from Google (Experiment 3 and 4), the LSA ratings between the target and prime in closed form and the LSA ratings between the target and prime in open form. The results from Model 1 will be discussed in text, and the results of Models 2 and 3 can be found in the tables mentioned in the text.

I considered frequency measures from CELEX (Baayen et al., 1995) and Google (Brants & Franz, 2006) to include in the models. The frequencies from these two databases were highly correlated (for Experiment 1, target frequency, $r = 0.87$; prime frequency, $r = 0.75$; first constituent frequency, $r = 0.81$; and second constituent frequency, $r = 0.90$). However, for the prime frequency, the coverage was markedly better in Google, with 153 items, compared to 119 items in CELEX. This was also the case for the experimental items in all four experiments. For this reason, I selected the frequencies from Google as predictors in my models. Additionally, the model fit with covariates did not include all of the data points. When a data point was missing values for one of the covariates (e.g., *kingkiller* did not appear in the Google database), it was not included in the data set for that model. This occurs because the model cannot accurately estimate values of the coefficients for these variables when there are missing data, and thus the model fits a subset of the data.

Why have I selected to fit three separate models to my data? There are three questions that I can consider separately using one model to test each question. First, is the loss of power from separate analyses of variance by-subject (F_1) and by-item (F_2) problematic? Model 1 will serve as a direct point of comparison with previous studies that used separate analyses of variance calculated on the by-subject (F_1) and by-item (F_2) means (Isel et al., 2003; Zwitserlood, 1994) or only on by-item means (Sandra, 1990). As Baayen (2007a) notes this has been the "gold standard of psycholinguistics" (pp. 263), but it is potentially problematic due to a loss of power.

Second, should the variables of Transparency and Relatedness be considered as continuous rather than dichotomized? In Model 2, the fixed effect predictors of Continuous Relatedness and Continuous Transparency were included because it might be beneficial to consider Relatedness and Transparency as continuous variables, given that dichotomization results in a loss of power and information about the variables of interest (MacCallum, Zhang, Preacher, & Rucker, 2002). Model 2 will allow me to determine whether the effects remain the same when I consider these variables as continuous and thus increase my power.

Third, are there other factors (e.g., frequency and number of letters) that contribute to the variability observed in response time or accuracy? While it has been shown that factors such as number of letters, frequency and semantic similarity influence lexical access (see the discussion in Chapter 5 of Carroll, 2008), in my project, experimental primes and targets were not matched on these factors. Instead, experimental primes shared either the same first (Experiments 1 and 2) or second (Experiments 3 and 4) constituents. Overall, an increase in frequency, a decrease in the number of letters, or an increase in semantic similarity should result in decreased reaction time in responding to a target. If the underlying theoretical framework of meaning construction is assumed to be occurring for compounds these factors could influence lexical access. Easier lexical access would be beneficial in the case of transparent compounds, but not in the case of opaque compounds. If this information is not included as a covariate into the model, there will be a great deal of variability due to individual items and possibly unexplained error. If this variability is not accounted for, the model might not be able to detect whether there is indeed an effect of the main factors of interest, Relatedness and Transparency.

Experiment 1

The aim of the first experiment was to assess whether semantic priming occurs for the first constituents of compounds with transparent second constituents (TT and OT compounds). Libben (1998), Marslen-Wilson et al. (1994) and Schreuder and Baayen (1995) predict that semantic priming should occur for the first constituents of TT compounds, but not for OT compounds. This is the case, as Marslen-Wilson et al. (1994) and Schreuder and Baayen (1995) note, because the semantic representations of the constituents of opaque compounds are not available (e.g., *moon* in the compound *moonstone*) and there will not be facilitation to respond to a subsequently presented semantic associate. Libben (1998), in contrast, proposes that semantic priming should not occur because there are inhibitory links between the semantic representations of the opaque constituents and the semantic representations of the whole word. This would result in inhibition of the semantic representation of the first constituents of OT compounds, and thus a response to the target would not result in semantic priming and potentially even be slower than to an unrelated control condition. According to Zwitserlood (1994) and the RICE meaning composition account (Spalding et al., 2010), in contrast, semantic priming should occur for the first constituents of both TT and OT compounds. Zwitserlood (1994) suggests this will be the case, because the semantic representations of these constituents are connected to the semantic representation of the whole-word. Thus, during processing there should be access to the underlying semantic representations of the constituents, and subsequent response times to related words should be facilitated. According to RICE (Spalding et al., 2010), and as discussed in the Introduction, the constituents' semantic representations should be accessed early in processing. However, depending on facilitation (or inhibition) that might come from the modifier or the head in different stages of meaning construction there might be a lack of semantic priming for OT compounds, even though the semantic representations of the constituents are initially available.

Method

Participants. Fifty psychology undergraduate students participated in this experiment for partial course credit. In total, twenty-one participants were removed. Three participants were removed due to accuracy rates lower than 60% in the experimental conditions. Seventeen participants were removed due to accuracy rates lower than 60% in the filler conditions. One participant was removed due to accuracy rates lower than 60% in both the experimental and filler conditions. Thus, the data from twenty-nine participants were analyzed.

Materials. One hundred and sixty transparent-transparent (TT) compounds and opaque-transparent (OT) compounds were selected as prime items from the Oxford English Dictionary (Simpson & Weiner, 1993) and CELEX lexical database (Baayen, Pipenbrock, & Gulikers, 1995). The one hundred and sixty compounds were divided into eighty matched pairs of TT compounds and OT compounds. The pairs shared the same first constituent (e.g., *moonlight*, TT, was matched to *moonstone*, OT). Forty monomorphemic target words (e.g., *sky*) were selected from the University of South Florida Free Association Norms (Nelson, McEvoy, & Schreiber, 1998).

I created four conditions by combining the eighty matched pairs of compound primes and targets (see Appendix 1). The first condition consisted of TT primes with related targets (e.g., *moonlight* and *sky*). The second condition consisted of OT primes with related targets (e.g., *moonstone* and *sky*). The third condition consisted of TT primes with unrelated targets (e.g., *stepladder* and *sky*). The fourth condition consisted of OT primes with unrelated targets (e.g., *stepmother* and *sky*). The items were counterbalanced so that each participant saw each target only once along with one of the four primes. Across all trials, participants were presented with primes from all four conditions.

So that the response to the target could not be predicted based on the answer to the prime, one hundred and twenty filler items were also constructed. Three filler conditions were created. The first filler condition consisted of forty pairs in which the prime was a word and the target was a nonword (e.g., *necklace* and *hink*). The second filler condition consisted of forty pairs in which the prime and the target were both nonwords (e.g., *tinlotion* and *vov*) The third condition consisted of forty filler pairs in which the prime was a nonword and the target was a word (e.g., *foldercheese* and *wool*). In the third filler condition, twenty items out of the forty had a prime that was semantically related to the first constituent of the prime (e.g., *ricesong* and *food*). Across both experimental and filler items, 25% of the primes were followed by targets that were semantically related. I propose that this low ratio of related primes will not cause participants to develop a strategy to respond to the items based on primes and targets being related (McNamara, 2005). In this experiment and the following experiments, the order of presentation of experimental and filler prime and target pairs was randomized for each participant.

Procedure. The trials were self-paced. Participants were presented with a “Ready?” message on the computer screen. Next, they pressed the space bar, and a compound prime appeared in the centre of the computer screen. They then indicated whether the item was a word or a nonword by pressing one of two computer keys, “j” and “f”, respectively. The “Ready?” message appeared a second time and participants again pressed the space bar. The target appeared and they again indicated whether the item was a word using the “f” and “j” keys.

The primary reason that I selected self-paced presentation was that in semantic priming experiments it is easy to bias participants to make use of strategies. Specifically, I propose that self-paced presentation decreases the likelihood that participants are aware of the prime-target nature of the trials. As a result, participants should not develop either an expectancy that primes are followed by related targets or perform strategic matching as they search for a relation between the target and the prime (see Chapter 9, McNamara, 2005). It was necessary in the current project to examine effects driven by automatic rather than strategic processing and self-paced presentation is a potential solution.

Why is masked-priming not a potential solution to the problem of introducing strategic effects? Schreuder et al. (2003) observed that semantic priming of the base of opaque complex words does not occur early in processing. In their project, the semantic representations of the base of opaque complex words did not result in semantic priming until 500 ms. Therefore, the typical presentation of a masked-prime for 50 ms would have reduced strategic effects, but likely would have been insufficient to result in semantic priming.

Results

The data were analyzed using Linear Mixed Effects (LME) analysis (Baayen, 2007a, 2007b; Baayen, Davidson, & Bates, 2008; Bates, 2005). The analysis was conducted with the R software program (R Development Core Team,

2008) and the lme4 (Bates, 2005) and languageR libraries (Baayen, 2007b). Incorrect trials were removed prior to analyzing the data. Response times greater than 2.5 standard deviations away from each subject's condition mean were also removed, as were trials with response times greater than 2 seconds (in total, 3.07% of correct responses were removed). The mean target response time and standard error for each condition can be found in Table 2.

Table 2

Mean response times (in ms) to the targets with standard errors for Experiment 1

Condition	Mean RT (SE)
TT-Related	693 (13)
OT-Related	685 (11)
TT-Unrelated	732 (14)
OT-Unrelated	711 (12)

Note. Descriptive statistics were calculated by averaging over subjects.

In order to address my first claim, I fit a series of models to examine whether transparency of the first constituent influenced whether semantic priming occurred. In contrast to the predictions of certain models (Libben, 1998; Marslen-Wilson et al., 1994; Schreuder & Baayen, 1995), there was no interaction between the factors Relatedness and Transparency ($t = 0.74$, $p = 0.48$; see Table 3 for the results of Models 2 and 3). In line with the predictions of Spalding et al. (2010) and Zwitserlood (1994), the main effect of Relatedness was significant ($t = 3.25$, $p = 0.001$; see Table 4 for the results of Models 2 and 3)[1]. In other words, participants responded more quickly to related targets than unrelated targets. However, the main effect of Transparency was not significant ($t = 0.92$, $p = 0.32$; see Table 4 for the results of Models 2 and 3). There was no difference in response times to targets after transparent and opaque primes. The dichotomized model, the continuous model and the model with covariates converge and demonstrate that semantic priming occurs for the first constituents of TT and OT compounds and this in turn suggests that the semantic representations of these constituents are accessed during processing.

Table 3

Interaction of fixed effects for three models for RT analysis for Experiment 1

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.54	-1.54	-1.61	-1.48	-42.68	0.001
Relatedness	0.05	0.05	-0.002	0.10	1.78	0.07
Transparency	0.003	0.003	-0.05	0.05	0.13	0.89
Relatedness: Transparency	0.03	0.03	-0.05	0.10	0.74	0.48

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.48	-1.48	-1.54	-1.43	-42.50	0.001
Continuous Relatedness	-0.12	-0.12	-0.22	-0.02	-2.44	0.02
Continuous Transparency	0.0006	0.0002	-0.02	0.02	0.06	0.96
Continuous Relatedness: Continuous Transparency	0.02	0.02	-0.04	0.07	0.53	0.56

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.40	-1.40	-1.61	-1.17	-11.87	0.001
Relatedness	0.05	0.05	-0.02	0.12	1.39	0.15
Transparency	-0.007	-0.004	-0.07	0.06	-0.20	0.93
Number of Letters Target	-0.02	-0.02	-0.04	0.001	-1.78	0.06
Number of Letters Prime	0.02	0.02	0.0005	0.04	2.06	0.04
Log Lemma Target	-0.01	-0.02	-0.03	0.0003	-1.73	0.06
Log Lemma Prime	-0.01	-0.01	-0.03	0.003	-1.55	0.11
Log Lemma C1 Prime	0.01	0.01	-0.005	0.03	1.38	0.19
LSA Target Prime Closed	0.05	0.04	-0.17	0.27	0.45	0.77
LSA Target Prime Open	-0.02	-0.01	-0.19	0.16	-0.23	0.93
Relatedness: Transparency	0.04	0.03	-0.07	0.12	0.74	0.49

Note. MCMC *M* = the mean of a Monte Carlo Markov Chain using 1000 simulations; HPD95lower = lower boundary of the 95% confidence interval; HPD95upper = upper boundary of the 95% confidence interval; *p*MCMC = estimated by the Monte Carlo Markov Chain with 1000 simulations; Log Lemma Target = occurrences/million calculated from Google (Brants & Franz, 2006); Log Lemma Prime = occurrences/million calculated from Google; Log Lemma C1 Prime = occurrences/million calculated from Google; LSA Target Prime Closed = semantic similarity rating from LSA calculated between the prime in closed form and the target (Landauer, 2002; Landauer & Dumais, 1997); LSA Target Prime Open = semantic similarity rating from LSA calculated between the prime in open form and the target

Table 4

Fixed effects for main effects of three models for RT analysis for Experiment 1

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.55	-1.55	-1.61	-1.49	-44.29	0.001
Relatedness	0.06	0.06	0.03	0.09	3.25	0.001
Transparency	0.02	0.02	-0.01	0.06	0.92	0.32

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.48	-1.48	-1.54	-1.42	-42.43	0.001
Continuous Relatedness	-0.12	-0.12	-0.21	-0.02	-2.48	0.02
Continuous Transparency	0.005	0.005	-0.007	0.02	0.79	0.43

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.42	-1.41	-1.62	-1.18	-12.35	0.001
Relatedness	0.07	0.07	0.01	0.12	2.31	0.02
Transparency	0.01	0.01	-0.03	0.06	0.50	0.60
Number of Letters Target	-0.02	-0.02	-0.04	0.003	-1.79	0.08
Number of Letters Prime	0.02	0.02	0.001	0.04	2.03	0.05
Log Lemma Target	-0.01	-0.01	-0.03	0.002	-1.70	0.09
Log Lemma Prime	-0.01	-0.01	-0.03	0.004	-1.47	0.16
Log Lemma C1 Prime	0.01	0.01	-0.007	0.03	1.31	0.23
LSA Target Prime Closed	0.02	0.008	-0.21	0.21	0.16	0.92
LSA Target Prime Open	-0.01	-0.005	-0.17	0.17	-0.15	0.98

Note. The variables in this table refer to the same variables as described in Table 3.

In addition, it is possible to observe whether Transparency and Relatedness result in accuracy differences in responding to the targets. There was no interaction between the factors Transparency and Relatedness in accuracy measures ($z = 0.18$, $p = 0.86$; see Table 5 for the results of Models 2 and 3). There was also no difference for the main effects of Relatedness ($z = 0.36$, $p = 0.72$; see Table 6 for the results of Models 2 and 3) or of Transparency ($z = 1.22$, $p = 0.23$; see Table 6 for the results of Models 2 and 3). Therefore, it does not appear that the kind of prime affects accuracy in responding to the target. However, this is not surprising as the targets were monomorphemic words and the accuracy was high (98% mean accuracy in OT and TT related conditions, and 97% mean accuracy in OT and TT unrelated conditions). Together, the analysis of response times and of accuracy measures suggest that the semantic representations of the constituents of TT and OT compounds are both available during processing and that the transparency of the first constituent (when the second constituent is transparent) does not influence whether semantic priming occurs.

Table 5

Interaction of fixed effects for three models for accuracy analysis for Experiment 1

Model 1: Dichotomized Model			
Variable	Estimate	*z* value	*p* value
Intercept	4.19	9.07	<2e-16
Relatedness	0.11	0.18	0.85
Transparency	0.55	0.78	0.43
Relatedness: Transparency	0.19	0.18	0.86
Model 2: Continuous Model			
Variable	Estimate	*z* value	*p* value
Intercept	4.67	9.15	<2e-16
Continuous Relatedness	-0.51	-0.36	0.72
Continuous Transparency	0.45	1.65	0.10
Continuous Relatedness: Continuous Transparency	-0.52	-0.67	0.51
Model 3: Model with Covariates			
Variable	Estimate	*z* value	*p* value
Intercept	5.77	3.37	0.0008
Relatedness	-0.36	-0.24	0.81
Transparency	0.20	0.10	0.92
Number of Letters Target	0.35	0.48	0.63
Number of Letters Prime	-0.02	-0.05	0.96
Log Lemma Target	0.03	0.06	0.96
Log Lemma Prime	0.03	0.08	0.93
Log Lemma C1 Prime	-0.04	-0.08	0.94
LSA Target Prime Closed	0.70	0.13	0.90
LSA Target Prime Open	1.46	0.40	0.69
Relatedness: Transparency	0.84	0.38	0.71

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 3.

Table 6

Fixed effects for main effects of three models for accuracy analysis for Experiment 1

Model 1: Dichotomized Model

Variable	Estimate	*z* value	*p* value
Intercept	4.15	9.79	<2e-16
Relatedness	0.18	0.36	0.72
Transparency	0.64	1.22	0.23

Model 2: Continuous Model

Variable	Estimate	*z* value	*p* value
Intercept	4.56	9.92	<2e-16
Continuous Relatedness	-0.10	-0.08	0.94
Continuous Transparency	0.31	1.82	0.07

Model 3: Model with Covariates

Variable	Estimate	*z* value	*p* value
Intercept	5.63	3.34	0.0008
Relatedness	-0.17	-0.11	0.91
Transparency	0.76	0.76	0.45
Number of Letters Target	0.37	0.52	0.60
Number of Letters Prime	-0.02	-0.04	0.97
Log Lemma Target	0.04	0.09	0.93
Log Lemma Prime	0.02	0.05	0.96
Log Lemma C1 Prime	-0.06	-0.12	0.91
LSA Target Prime Closed	-0.36	-0.09	0.93
LSA Target Prime Open	1.44	0.40	0.69

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 3.

As concerns the second claim, with the current data it is not possible to directly observe meaning construction, but it is possible to test certain predictions that arise when the RICE approach (Spalding et al., 2010) is considered. If the semantic representations of the constituents are being integrated, the availability of the individual constituents should be predicted to play different roles for opaque and transparent constituents. For TT compounds, higher frequency constituents should aid in semantic integration and decrease response time. On the other hand, for OT compounds, high-frequency first constituents would result in easier access to a constructed meaning. The constructed meaning would be more readily available, and thus would result in stronger competition for the lexicalized meaning, and in processing difficulties. If this is the case, the availability of the constituent representations should also affect processing times for semantic associates. Specifically, if transparent constituents are more accessible (i.e., more frequent), this will be beneficial to the processing of semantic associates and should result in faster processing. If opaque constituents are more accessible, the constructed meaning should be more accessible and this will result in greater competition between the lexicalized and the stored meaning. This competition might then result in greater processing difficulty (as measured in increased response time) for semantic associates of the constituents. For this reason, a meaning construction framework would predict an interaction between constituent frequency, specifically the first constituent, and transparency.

I fit a series of models to examine the effect of first constituents frequency on inverse response time to the target. As predicted by a meaning construction framework, there was an interaction between first constituent frequency and Transparency (t = -2.23, p = 0.04; see Table 7 for the results of Models 2 and 3). Frequency operates in different directions for transparent (t = -1.87, p = 0.06) and opaque (t = 1.48, p = 0.16) constituents. In contrast, there is no predicted interaction between the second constituent frequency and compound type because the second constituent was transparent for both the TT and OT compounds. This is supported by the data (t = 0.00, p = 0.97; see Table 8 for the results of Models 2 and 3). Overall, the analysis of the interaction between frequency and compound types suggests that meaning composition might be occurring for both TT and OT compounds during processing; however, the effects of composition are different for these compounds. For OT compounds greater availability of the first constituent resulted in increased competition between the stored and constructed meanings, whereas the availability of the second constituent does not operate differentially for TT and OT compounds.

Table 7

Fixed effects for three models of RT analysis of interaction of frequency of the first constituent and transparency for Experiment 1

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.55	-1.55	-1.61	-1.48	-44.25	0.001
Relatedness	0.06	0.06	0.03	0.09	3.27	0.004
Transparency	0.02	0.02	-0.02	0.05	0.92	0.34
Log Lemma C1 Prime	0.01	0.01	-0.004	0.03	1.33	0.17
Transparency: Log Lemma C1 Prime	-0.03	-0.03	-0.05	-0.004	-2.23	0.04

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.48	-1.48	-1.54	-1.41	-42.28	0.0001
Continuous Relatedness	-0.12	-0.12	-0.21	-0.02	-2.47	0.02
Continuous Transparency	0.002	0.002	-0.01	0.01	0.36	0.72
Log Lemma C1 Prime	0.0006	0.0005	-0.01	0.01	0.09	0.94
Continuous Transparency: Log Lemma C1 Prime	-0.009	-0.009	-0.02	-0.001	-2.19	0.03

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.44	-1.44	-1.65	-1.22	-12.69	0.001
Relatedness	0.07	0.07	0.01	0.13	2.35	0.01
Transparency	0.02	0.02	-0.02	0.08	0.92	0.33
Number of Letters Target	0.02	0.02	0.003	0.04	2.34	0.01
Number of Letters Prime	-0.02	-0.02	-0.04	0.003	-1.90	0.06
Log Lemma Target	0.02	0.02	0.002	0.04	2.13	0.03
Log Lemma Prime	-0.01	-0.01	-0.03	0.002	-1.73	0.08
Log Lemma C1 Prime	-0.01	-0.01	-0.03	0.006	-1.29	0.21
LSA Target	-0.02	-0.03	-0.25	0.17	-0.21	0.80

Prime Closed						
LSA Target Prime Open	-0.006	-0.004	-0.17	0.18	-0.06	0.95
Transparency: Log Lemma C1 Prime	-0.04	-0.03	-0.07	-0.007	-2.25	0.03

Note. The variables in this table refer to the same variables as described in Table 3.

Table 8

Fixed effects for three models of RT analysis of interaction of frequency of the second constituent and transparency for Experiment 1

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.55	-1.55	-1.61	-1.48	-44.18	0.001
Relatedness	0.06	0.06	0.02	0.09	3.19	0.002
Transparency	0.02	0.02	-0.02	0.05	0.92	0.40
Log Lemma C2 Prime	-0.0001	-0.0004	-0.02	0.02	-0.02	0.97
Transparency: Log Lemma C2 Prime	0.00	-0.0001	-0.02	0.02	0.00	0.97

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.48	-1.48	-1.54	-1.42	-42.36	0.001
Continuous Relatedness	-0.12	-0.11	-0.21	-0.02	-2.38	0.01
Continuous Transparency	0.007	0.007	-0.005	0.02	1.06	0.31
Log Lemma C2 Prime	0.0001	-0.0003	-0.01	0.01	0.01	0.96
Continuous Transparency: Log Lemma C2 Prime	0.007	0.007	-0.001	0.02	1.64	0.11

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.40	-1.39	-1.64	-1.18	-11.64	0.001
Relatedness	0.07	0.07	0.02	0.13	2.62	0.01
Transparency	0.02	0.02	-0.03	0.06	0.76	0.40
Log Lemma C2 Prime	0.02	0.02	-0.003	0.04	1.50	0.12
Number of Letters Target	-0.02	-0.02	-0.04	0.004	-1.84	0.07
Number of Letters Prime	0.02	0.02	0.002	0.04	1.99	0.05
Log Lemma Target	-0.01	-0.01	-0.03	0.001	-1.75	0.08
Log Lemma Prime	-0.01	-0.01	-0.03	0.003	-1.59	0.09
LSA Target Prime Closed	-0.004	-0.01	-0.22	0.17	-0.04	0.92

LSA Target	0.02	0.02	-0.17	0.19	0.17	0.81
Prime Open Transparency: Log Lemma C2 Prime	-0.02	-0.02	-0.05	0.006	-1.26	0.20

Note. The variables in this table refer to the same variables as described in Table 3.

Experiment 2

The aim of the second experiment was to assess whether semantic priming occurs for the first constituents of compounds with opaque second constituents (TO and OO compounds). Marslen-Wilson et al. (1994) and Schreuder and Baayen (1995) predict that semantic priming will not occur for either TO or OO compounds. As in Experiment 1, this is the case because opaque compounds are not represented as morphologically complex, and thus the semantic representations of the constituents are not connected to the semantic representations of the whole word. According to Libben (1998) and Zwitserlood (1994), by contrast, semantic priming should occur only for the first constituents of TO compounds. The semantic representation of the first constituent of TO compounds should be connected to the whole-word representation and thus will be accessed during processing (Libben, 1998; Zwitserlood, 1994). Whereas, Zwitserlood (1994) proposes that OO compounds should not result in priming, because for fully opaque compounds the whole-word representations are not connected to the semantic representations of the constituents. Libben (1998) also proposes a lack of semantic priming for the first constituents of OO compounds. His rationale, in contrast to Zwitserlood (1994), is that there are inhibitory links between the semantic representations of the opaque constituents and the semantic representations of the whole word. This would result in inhibition of the semantic representations of both constituents of OO compounds and a lack of semantic priming or potentially slower processing of the target compared to an unrelated control condition. According to the RICE approach (Spalding et al., 2010), the semantic representations of the first constituents of TO and OO compounds should be available. However, depending on facilitation (or inhibition) that might come from either the modifier or the head during different stages of meaning construction the early availability of these representations could be cancelled out resulting in a lack of semantic priming for the constituents.

Method

Participants. Ninety-one psychology undergraduate students participated in this experiment for partial course credit. In total, thirty-one participants were removed. Seven participants were removed due to accuracy rates lower than 60% in the experimental conditions. Twenty-two participants were removed due to accuracy rates lower than 60% in the filler conditions. Two participants were removed due to accuracy rates lower than 60% in both the experimental and filler conditions. Thus, the data from sixty participants were analyzed.

Materials. One hundred and twenty-eight transparent-opaque (TO) compounds and opaque-opaque (OO) compounds were selected as prime items from the Oxford English Dictionary (Simpson & Weiner, 1993) and CELEX lexical database (Baayen et al., 1995). The one hundred and twenty-eight compounds were divided into thirty-two matched pairs of TO compounds and OO compounds. The pairs shared the same first constituent (e.g., *flowerbed*, TO was matched to *flowerchild*, OO). Thirty-two monomorphemic target words (e.g., *tulip*) were selected from the University of South Florida Free Association Norms (Nelson et al., 1998).

I created four conditions by combining the sixty-four matched pairs of compound primes and targets (see Appendix 1). The first condition consisted of TO primes with related targets (e.g., *flowerbed* and *tulip*). The second condition consisted of OO primes with related targets (e.g., *flowerchild* and *tulip*). The third condition consisted of TT primes with unrelated targets (e.g., *bigtop* and *tulip*). The fourth filler condition consisted of OT primes with unrelated targets (e.g., *bigwig* and *tulip*). The items were counterbalanced so that each participant saw each target only once with one of the four primes. Across all trials, participants were presented with items from all four conditions.

The filler items were similar to Experiment 1. However, because there were thirty-two experimental items, ninety-six filler items were constructed. The three filler conditions remained the same, but the numbers of filler items per condition was changed to thirty-two.

Procedure. The procedure was identical to that of Experiment 1.

Results

I fit LME models to the data using inverse response time or accuracy as the dependent variables, Transparency (TO and OO) and Relatedness (Related versus Unrelated) as fixed effect predictor variables, and participants and items as random effects. As in Experiment 1, I fit three sets of models, the first model will be discussed in text, and the results of the other two models will be in tables noted in the text. The covariates included in the third set of models were the same as those discussed in the Introduction. Incorrect trials were removed prior to analyzing the data. Response times greater than 2.5 standard deviations away from each subject's condition mean, and trials with response times greater than 3 seconds were also removed (in total, 0.54% of correct responses). The mean target response time and standard error for each condition can be found in Table 9.

Table 9

Mean response times (in ms) to the targets with standard errors for Experiment 2

Condition	Mean RT (SE)
TO-Related	729 (14)
OO-Related	773 (17)
TO-Unrelated	770 (14)
OO-Unrelated	760 (14)

Note. Descriptive statistics were calculated by averaging over subjects.

In order to address my first claim, I fit a series of models to examine whether transparency of the first constituent influenced whether semantic priming occurred. In this experiment, in contrast to Experiment 1, there was an interaction between Relatedness and Transparency ($t = 2.36$, $p = 0.02$; see Table 10 for the results of Models 2 and 3)[2]. As Libben (1998) and Zwitserlood (1994) would predict, the responses to targets in the related condition for TO compounds were faster than responses to targets in the unrelated condition ($t = 3.42$, $p = 0.001$). In comparison, there was no difference between the response times to related and unrelated primes after OO compounds ($t = 0.00$, $p = 0.97$). Models 1, 2 and 3 converge and demonstrate that the transparency of the modifier influences whether semantic priming occurs when the second constituent is opaque. Specifically, an opaque modifier appears to result in processing difficulties (such as the resolution of a conflict between a meaning constructed from the constituents and the stored meaning), but only when the second constituent is also opaque. I do not propose that the lack of semantic priming necessarily indicates that these representations are not accessed during processing; instead, I propose that there is later processing that interferes with the semantic priming process. I discuss the reasons for the lack of semantic priming for the first constituent of OO compounds in greater detail in the General Discussion.

Table 10

Interaction of fixed effects for three models for RT analysis for Experiment 2

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* Value	*p*MCMC
Intercept	-1.44	-1.44	-1.49	-1.38	-45.19	0.001
Relatedness	-0.0006	-0.001	-0.04	0.04	-0.03	0.94
Transparency	-0.06	-0.06	-0.11	-0.03	-2.97	0.002
Relatedness: Transparency	0.07	0.07	0.01	0.13	2.39	0.02

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* Value	*p*MCMC
Intercept	-1.44	-1.44	-1.49	-1.38	-45.96	0.001
Continuous Relatedness	-0.07	-0.07	-0.14	0.005	-1.85	0.07
Continuous Transparency	-0.02	-0.02	-0.04	0.005	-1.46	0.16
Continuous Relatedness: Continuous Transparency	-0.009	-0.008	-0.06	0.05	-0.30	0.80

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* Value	*p*MCMC
Intercept	-1.30	-1.30	-1.50	-1.08	-12.54	0.001
Relatedness	-0.05	-0.05	-0.12	0.02	-1.28	0.19
Transparency	-0.06	-0.06	-0.11	-0.005	-2.15	0.03
Number of Letters Target	0.003	0.003	-0.02	0.02	0.25	0.77
Number of Letters Prime	0.003	0.002	-0.02	0.02	0.33	0.75
Log Lemma Target	-0.03	-0.03	-0.05	-0.01	-2.99	0.001
Log Lemma Prime	-0.01	-0.01	-0.02	0.003	-1.47	0.14
Log Lemma C1 Prime	0.01	0.01	-0.007	0.03	1.14	0.31
LSA Target Prime Closed	-0.04	-0.03	-0.25	0.18	-0.37	0.78
LSA Target Prime Open	-0.06	-0.07	-0.23	0.09	-0.76	0.40
Relatedness: Transparency	0.09	0.09	0.02	0.17	2.15	0.03

Note. The variables in this table refer to the same variables as described in Table 6.

In contrast to the response time measures, for accuracy measures there was no interaction between Relatedness and Transparency (*z* = -1.07, *p* = 0.29; see Table 11 for the results of Models 2 and 3). There was also no difference in accuracy in responding to the target when the model was fit with main effects of Relatedness (*z* = 0.07; *p* = 0.95; see Table 12 for the results of Models 2 and 3) or Transparency (*z* = 0.42, *p* = 0.68; see Table 12 for the results of Models 2 and 3). Despite the fact that semantic priming effects differed for TO and OO compounds, the data suggest that participants' accuracy in responding to targets does not differ based on the transparency of the first constituent (when the second constituent is opaque).

Table 11

Interaction of fixed effects for three models for accuracy analysis for Experiment 2

Model 1: Dichotomized Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.55	12.47	<2e-16
Relatedness	0.31	0.79	0.43
Transparency	0.42	1.04	0.30
Relatedness: Transparency	-0.61	-1.07	0.29

Model 2: Continuous Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.75	14.02	<2e-16
Continuous Relatedness	0.04	0.07	0.95
Continuous Transparency	-0.01	-0.06	0.96
Continuous Relatedness: Continuous Transparency	0.13	0.27	0.79

Model 3: Model with Covariates			
Variable	Estimate	*z* value	*p* value
Intercept	3.98	5.53	3.30e-08
Relatedness	0.30	0.42	0.67
Transparency	0.27	0.50	0.62
Number of Letters Target	0.45	2.17	0.03
Number of Letters Prime	-0.23	-1.65	0.10
Log Lemma Target	0.60	3.36	0.0008
Log Lemma Prime	-0.14	-1.26	0.21
Log Lemma C1 Prime	0.10	0.69	0.49
LSA Target Prime Closed	1.01	0.45	0.65
LSA Target Prime Open	-0.17	-0.12	0.91
Relatedness: Transparency	-0.59	-0.71	0.48

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 3.

Table 12

Fixed effects for main effects three models for accuracy analysis for Experiment 2

Model 1: Dichotomized Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.69	13.68	<2e-16
Relatedness	0.02	0.07	0.95
Transparency	0.12	0.42	0.68
Model 2: Continuous Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.75	14.04	<2e-16
Continuous Relatedness	0.02	0.03	0.97
Continuous Transparency	0.03	0.25	0.80
Model 3: Model with Covariates			
Variable	Estimate	*z* value	*p* value
Intercept	4.12	5.93	3.05e-09
Relatedness	-0.03	-0.06	0.95
Transparency	0.008	0.02	0.98
Number of Letters Target	0.46	2.18	0.03
Number of Letters Prime	-0.25	-1.77	0.08
Log Lemma Target	0.62	3.45	0.0006
Log Lemma Prime	-0.16	-1.38	0.17
Log Lemma C1 Prime	0.12	0.81	0.42
LSA Target Prime Closed	1.40	0.63	0.53
LSA Target Prime Open	-0.25	-0.18	0.86

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 3.

As discussed in Experiment 1, the influence of semantic integration on processing can also be indirectly examined using this data. If meaning construction is occurring, it is predicted that first constituent frequency should interact with compound transparency. The targets presented after TO compounds with high-frequency first constituents should be processed more quickly, while the targets presented after OO compounds with high-frequency first constituents should be slower to process. In this experiment, first constituent frequency does not interact with Transparency ($t = 1.01$, $p = 0.32$; see Table 13 for the results of Models 2 and 3). There is no predicted interaction between second constituent frequency and Transparency because the second constituent was opaque in both the TO and OO conditions, and the data support this prediction ($t = 1.39$, $p = 0.19$; see Table 14 for Models 2 and 3). In contrast to Experiment 1, the effect of competition between constructed and stored meanings for OO compounds seems to be observed via lack of semantic priming for the first constituents of OO compounds rather than via an interaction between the frequency of the first constituent and Transparency. Therefore, it is possible to hypothesize that for OO compounds, in comparison to OT compounds, there might be greater competition between the constructed and stored meanings, and that this competition results in the suppression of the semantic representations of the first constituents.

Table 13

Fixed effects for three models of RT analysis of interaction of frequency of first constituent and transparency for Experiment 2

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.44	-1.44	-1.51	-1.40	-44.91	0.001
Relatedness	0.004	0.004	-0.04	0.05	0.18	0.84
Transparency	-0.06	-0.06	-0.10	-0.02	-2.83	0.006
Log Lemma C1 Prime	-0.004	-0.004	-0.03	0.02	-0.35	0.74
Relatedness: Transparency	0.07	0.07	0.01	0.13	2.20	0.03
Transparency: Log Lemma C1 Prime	0.01	0.01	-0.01	0.03	1.01	0.32
Relatedness: Log Lemma C1 Prime	-0.01	-0.01	-0.04	0.02	0.84	0.44

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.44	-1.44	-1.49	-1.38	-45.50	0.001
Continuous Relatedness	-0.07	-0.07	-0.15	0.01	-1.63	0.10
Continuous Transparency	-0.01	-0.01	-0.04	0.007	-1.32	0.17
Log Lemma C1 Prime	-0.009	-0.008	-0.03	0.02	-0.77	0.46
Continuous Relatedness: Continuous Transparency	-0.01	-0.01	-0.07	0.05	-0.44	0.67
Continuous Relatedness: Log Lemma C1 Prime	0.02	0.02	-0.05	0.10	0.61	0.59
Continuous Transparency: Log Lemma C1 Prime	-0.0001	-0.0001	-0.009	0.008	-0.02	0.99

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.29	-1.29	-1.48	-1.10	-12.61	0.001

Relatedness	-0.04	-0.04	-0.12	0.03	-1.08	0.25
Transparency	-0.06	-0.06	-0.12	-0.02	-2.31	0.01
Number of Letters Target	0.02	0.02	-0.002	0.05	1.66	0.10
Number of Letters Prime	0.002	0.004	-0.02	0.02	0.21	0.70
Log Lemma Target	0.001	0.0007	-0.02	0.02	0.12	0.96
Log Lemma Prime	-0.04	-0.04	-0.05	-0.02	-3.64	0.001
Log Lemma C1 Prime	-0.01	-0.01	-0.03	-0.0001	-1.70	0.06
LSA Target Prime Closed	-0.03	-0.02	-0.23	0.21	-0.25	0.86
LSA Target Prime Open	-0.04	-0.04	-0.19	0.11	-0.45	0.64
Relatedness: Transparency	0.09	0.10	0.01	0.18	2.26	0.02
Transparency: Log Lemma C1 Prime	0.01	0.01	-0.01	0.04	0.82	0.37
Relatedness: Log Lemma C1 Prime	-0.04	-0.04	-0.07	-0.004	-2.07	0.03

Note. The variables in this table refer to the same variables as described in Table 3.

Table 14

Fixed effects for three models of RT analysis of interaction of frequency of the second constituent and transparency for Experiment 2

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.45	-1.45	-1.51	-1.40	-46.05	0.001
Relatedness	0.007	0.006	-0.04	0.05	0.30	0.80
Transparency	-0.06	-0.06	-0.10	-0.01	-2.70	0.01
Log Lemma C2 Prime	-0.03	-0.03	-0.04	-0.01	-3.23	0.001
Relatedness: Transparency	0.06	0.06	-0.002	0.12	2.02	0.05
Transparency: Log Lemma C2 Prime	0.01	0.01	-0.005	0.03	1.39	0.19
Relatedness: Log Lemma C2 Prime	0.02	0.02	0.008	0.04	2.61	0.01

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.44	-1.44	-1.48	-1.38	-46.21	0.001
Continuous Relatedness	-0.08	-0.08	-0.15	-0.005	-2.10	0.03
Continuous Transparency	-0.02	-0.02	-0.04	0.004	-1.76	0.08
Log Lemma C2 Prime	0.004	0.005	-0.008	0.02	0.60	0.53
Continuous Relatedness: Continuous Transparency	-0.0004	-0.0001	-0.06	0.06	-0.01	0.98
Continuous Relatedness: Log Lemma C2 Prime	-0.04	-0.04	-0.08	-0.0002	-1.98	0.05
Continuous Transparency: Log Lemma C2 Prime	0.003	0.003	-0.006	0.01	0.63	0.55

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.32	-1.32	-1.52	-1.12	-12.48	0.001
Relatedness	-0.06	-0.06	-0.13	0.01	-1.47	0.12
Transparency	-0.06	-0.06	-0.11	-0.009	-2.10	0.04

Log Lemma C2 Prime	-0.02	-0.02	-0.04	-0.002	-2.15	0.04
Number of Letters Target	0.003	0.003	-0.02	0.03	0.24	0.77
Number of Letters Prime	0.0001	0.00	-0.02	0.02	0.01	0.99
Log Lemma Target	-0.03	-0.03	-0.05	-0.01	-2.97	0.01
Log Lemma Prime	-0.009	-0.009	-0.02	0.006	-1.22	0.20
Log Lemma C1 Prime	0.009	0.01	-0.008	0.03	1.08	0.26
LSA Target Prime Closed	-0.04	-0.03	-0.28	0.16	-0.41	0.75
LSA Target Prime Open	-0.07	-0.08	-0.23	0.07	-0.89	0.34
Relatedness: Transparency	0.08	0.08	0.01	0.17	1.95	0.03
Transparency: Log Lemma C2 Prime	0.01	0.01	-0.008	0.03	1.05	0.27
Relatedness: Log Lemma C2 Prime	0.03	0.03	0.006	0.05	2.60	0.02

Note. The variables in this table refer to the same variables as described in Table 3.

Experiment 3

The aim of the third experiment was to assess whether semantic priming occurs for the second constituents of compounds with transparent first constituents (TT and TO compounds). Libben (1998), Marslen-Wilson et al. (1994) and Schreuder and Baayen (1995) predict that semantic priming should occur for the second constituents of TT compounds, but not for TO compounds. This should occur because the semantic representations of the opaque constituents (e.g., *comb* in the compound *honeycomb*) are not connected to the semantic representation of the whole-word and thus will not be accessed (Marslen-Wilson et al., 1994; Schreuder & Baayen, 1995). Libben (1998), in contrast, proposes that semantic priming should not occur because there are inhibitory links between the semantic representations of the opaque constituents and the semantic representations of the whole word. This would result in inhibition of the semantic representation of the second constituents of TO compounds and thus a response to the target would not be facilitated and potentially even be slower than to an unrelated control condition. According to Zwitserlood (1994), semantic priming should occur for the first constituents of both TT and TO compounds because the semantic representations of these constituents are connected to the semantic representation of the whole word. Thus, during compound processing there should be access to the underlying semantic representations of the constituents and subsequent response times to related words should be facilitated. The RICE approach (Spalding et al., 2010) also predicts that the semantic representations of the second constituents of TT and TO compounds should be available. However, as discussed in the Introduction, depending on facilitation (or inhibition) that could come from the role of the modifier and the head in different stages of meaning construction there could also be a lack of semantic priming observed for TO compounds despite the fact that the constituents should be accessed early in processing.

Method

Participants. Seventy-nine psychology undergraduate students participated in this experiment for partial course credit. In total, twenty-seven participants were removed. Eleven participants were removed due to accuracy rates lower than 60% in the experimental conditions. Sixteen participants were removed due to accuracy rates lower than 60% in the filler conditions. Thus, the data from fifty-two participants were analyzed.

Materials. One hundred and sixty transparent-transparent (TT) compounds and transparent-opaque (TO) compounds were selected as prime items from the Oxford English Dictionary (Simpson & Weiner, 1993) and CELEX lexical database (Baayen et al., 1995). The one hundred and sixty compounds were divided into eighty matched pairs of TT compounds and TO compounds. The pairs shared the same second constituent (e.g., *haircomb*, TT, was matched to *honeycomb*, TO). Forty monomorphemic target words (e.g., *brush*) were selected from the University of South Florida Free Association Norms (Nelson et al., 1998).

I created four conditions by combining the eighty matched pairs of compound primes and the targets (see Appendix 1). The first condition consisted of TT primes with related targets (e.g., *haircomb* and *brush*). The second condition consisted of TO primes with related targets (e.g., *honeycomb* and *brush*). The third condition consisted of TT primes with unrelated targets (e.g., *snowsuit* and *brush*). The fourth condition consisted of TO primes with unrelated targets (e.g., *lawsuit* and *brush*). The items were counterbalanced so that each participant saw each target only once with one of the primes. Across all trials, participants were presented with items from all four conditions.

The filler items were similar to those in Experiment 1. However, the third filler condition, which contained a prime that was semantically related to the first constituent (e.g., *ricesong* and *food*), had to be modified. In Experiment 3, I modified the related items so that the target was semantically related to the second constituent (e.g., *ricesong* and *music*).

Procedure. The procedure was identical to that of Experiment 1.

Results

I fit LME models to the data using inverse response time or accuracy as dependent variables and Transparency (TT and TO) and Relatedness (Related versus Unrelated) as fixed effect predictor variables and with participants and items as random effects. Models 1 and 2 contain the same predictors as in Experiments 1 and 2. However, the covariates included in Model 3 differed. Incorrect trials were removed prior to analyzing the data. Response times greater than 2.5 standard deviations away from each subject's condition mean, and trials with response times greater than 2.4 seconds were also removed (in total 2.93% of correct responses). The mean target response time and standard error for each condition can be found in Table 15.

Table 15

Mean response times (in ms) to the targets with standard errors for Experiment 3

Condition	Mean RT (SE)
TT-Related	767 (11)
TO-Related	752 (12)
TT-Unrelated	777 (11)
TO-Unrelated	779 (12)

Note. Descriptive statistics were calculated by averaging over subjects.

In order to address my first claim, I fit a series of models to examine whether the transparency of the second constituent influenced whether semantic priming occurred. In contrast to the predictions of certain models (Libben, 1998; Marslen-Wilson et al., 1994; Schreuder & Baayen, 1995), there was no interaction between the factors Relatedness and Transparency (t = -1.16, p = 0.21; see Table 16 for the results of Models 2 and 3). For only the first set of models, there were main effects of Relatedness (t = 1.92, p = 0.04; see Table 17 for the results of Model 2) and of Transparency (t = 2.20, p = 0.02; see Table 17 for the results of Model 2).

I considered whether there was systematic variability in my items that was unaccounted for in Models 1 and 2. It appears that when the covariates are entered into the model, the effect of Transparency virtually disappears. If this is the case, one of the covariates might be accounting for the variability that in the first model is being attributed to Transparency. One possible candidate is the frequency of the primes; the primes were matched on second constituents, but their frequencies were not matched. In particular, the TT compounds tended to be less frequent.

This was confirmed when I examined the mean frequency of each condition. The opaque primes had a mean frequency of 208.5 occurrences per million, while the transparent primes had a mean frequency of 23.5 occurrences per million. To account for this variability, I fit Model 1 with the addition of log Google frequency of the prime. In this model, the effect of Transparency disappears ($t = 0.52$, $p = 0.62$; see Table 17 for the results of Model 3)[3], while there remains an effect of Relatedness ($t = 2.44$, $p = 0.01$; see Table 17 for the results of Model 3). Semantic priming is observed for the second constituents of TO and TT when the differences in frequency of the primes are accounted for. Therefore, there is evidence that suggests that semantic representations of these constituents are accessed during processing

Table 16

Interaction of fixed effects for three models for RT analysis for Experiment 3

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.44	-1.44	-1.49	-1.40	-51.65	0.001
Relatedness	0.04	0.04	0.004	0.08	2.17	0.04
Transparency	0.05	0.05	0.01	0.09	2.37	0.01
Relatedness: Transparency	-0.03	-0.03	-0.09	0.02	-1.16	0.21

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.39	-1.39	-1.44	-1.34	-51.92	0.001
Continuous Relatedness	-0.05	-0.05	-0.12	0.02	-1.36	0.17
Continuous Transparency	-0.0006	-0.0003	-0.02	0.01	-0.07	0.99
Continuous Relatedness: Continuous Transparency	-0.02	-0.03	-0.08	0.02	-0.93	0.31

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.34	-1.34	-1.44	-1.25	-27.30	0.001
Relatedness	0.04	0.05	0.006	0.08	2.27	0.02
Transparency	0.02	0.02	-0.02	0.07	0.85	0.37
Log Lemma Prime	-0.009	-0.008	-0.02	-0.0009	-2.41	0.02
Relatedness: Transparency	-0.02	-0.02	-0.08	0.04	-0.68	0.44

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 3, except for the addition of Log Lemma C2 prime which was calculated from Google (Brants & Franz, 2006)

Table 17

Fixed effects for main effects of three models for RT analysis for Experiment 3

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* Value	*p*MCMC
Intercept	-1.43	-1.43	-1.49	-1.39	-53.00	0.001
Relatedness	0.03	0.03	0.0006	0.05	1.92	0.04
Transparency	0.03	0.03	-0.0001	0.06	2.20	0.02

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* Value	*p*MCMC
Intercept	-1.39	-1.39	-1.44	-1.35	-51.96	0.001
Continuous Relatedness	-0.05	-0.04	-0.12	0.02	-1.29	0.20
Continuous Transparency	-0.006	-0.006	-0.02	0.005	-1.14	0.27

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.33	-1.33	-1.42	-1.24	-28.33	0.001
Relatedness	0.04	0.04	0.004	0.06	2.45	0.01
Transparency	0.008	0.009	-0.02	0.04	0.52	0.62
Log Lemma Prime	-0.009	-0.009	-0.02	-0.002	-2.59	0.01

Note. The variables in this table refer to the same variables as described in Table 16.

For accuracy measures, there was no interaction between the factors Transparency and Relatedness (z = -0.03, p = 0.98, see Table 18 for Models 2 and 3). For the main effects, there was also no difference in the accuracy. Participants were equally accurate to respond to the targets after related primes than unrelated primes (z = -0.87, p = 0.38; see Table 19 for the results of Models 2 and 3) and equally accurate to respond to targets after TT compounds than TO compounds (z = 1.58, p = 0.12; see Table 19 for the results of Models 2 and 3). The response times and accuracy measures suggest that the semantic representations of the constituents of TT and TO compounds are both available during processing and that the transparency of the second constituent (when the first constituent is transparent) does not influence whether semantic priming occurs.

Table 18

Interaction of fixed effects for three models for accuracy analysis for Experiment 3

Model 1: Dichotomized Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.83	12.61	<2e-16
Relatedness	-0.23	-0.66	0.51
Transparency	0.43	1.08	0.28
Relatedness: Transparency	-0.01	-0.03	0.98

Model 2: Continuous Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.86	14.12	<2e-16
Continuous Relatedness	0.26	0.37	0.71
Continuous Transparency	-0.13	-0.82	0.42
Continuous Relatedness: Continuous Transparency	0.33	0.68	0.50

Model 3: Model with Covariates			
Variable	Estimate	*z* value	*p* value
Intercept	3.96	11.90	<2e-16
Relatedness	-0.33	-0.92	0.36
Transparency	0.29	0.62	0.54
Log Lemma Prime	0.009	0.14	0.89
Relatedness: Transparency	0.10	0.17	0.87

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 16.

Table 19

Fixed effects for main effects of three models for accuracy analysis for Experiment 3

Model 1: Dichotomized Model			
Variable	Estimate	z Value	p Value
Intercept	3.84	13.73	<2e-16
Relatedness	-0.23	-0.87	0.38
Transparency	0.43	1.58	0.12
Model 2: Continuous Model			
Variable	Estimate	z Value	p Value
Intercept	3.85	14.20	<2e-16
Continuous Relatedness	0.23	0.33	0.74
Continuous Transparency	-0.05	-0.47	0.64
Model 3: Model with Covariates			
Variable	Estimate	z Value	p Value
Intercept	3.93	13.24	<2e-16
Relatedness	-0.29	-1.05	0.29
Transparency	0.36	1.17	0.24
Log Lemma Prime	0.01	0.18	0.86

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 16.

As discussed in Experiment 1, the influence of semantic integration can also be indirectly examined using this data. In the case of TT and TO compounds, an interaction between the frequency of the first constituent and the transparency of the compound would not be expected, because the transparency of the first constituent is held constant. This was confirmed by my data, which showed no interaction between Transparency and first constituent frequency ($t = 0.31$, $p = 0.78$; see Table 20 for Models 2 and 3). Also, it might be predicted that the frequency of the second constituent should not interact with compound type, because it is not as actively involved in suggesting a relational interpretation during meaning composition. Thus, the degree of availability of its semantic representation should not influence the amount of competition between the stored and composed meaning. When the model was fit with second constituent frequency, it did not interact with Transparency ($t = -0.37$, $p = 0.79$; see Table 21 for the results of Models 2 and 3). Thus the results of this experiment suggest that, in contrast to Libben et al. (2003) and Isel et al. (2003), the transparency of the second constituent does not influence whether semantic priming is observed when the first constituent is transparent.

Table 20

Fixed effects for three models of RT analysis of interaction of frequency of the first constituent and transparency for Experiment 3

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.43	-1.43	-1.49	-1.39	-53.03	0.001
Relatedness	0.03	0.03	-0.003	0.05	1.87	0.07
Transparency	0.03	0.03	0.003	0.06	2.26	0.03
Log Lemma C1 Prime	0.002	0.002	-0.009	0.01	0.33	0.71
Transparency: Log Lemma C1 Prime	0.003	0.003	-0.02	0.02	0.31	0.78

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.39	-1.39	-1.44	-1.34	-52.01	0.001
Continuous Relatedness	-0.05	-0.05	-0.11	0.02	-1.39	0.17
Continuous Transparency	-0.007	-0.007	-0.02	0.004	-1.22	0.24
Log Lemma C1 Prime	0.003	0.003	-0.006	0.01	0.68	0.47
Continuous Transparency: Log Lemma C1 Prime	0.004	0.004	-0.002	0.009	1.19	0.24

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.32	-1.32	-1.40	-1.23	-27.51	0.001
Relatedness	0.03	0.03	0.008	0.06	2.36	0.02
Transparency	0.009	0.009	-0.02	0.04	0.55	0.63
Log Lemma C1 Prime	0.005	0.006	-0.007	0.02	0.87	0.38
Log Lemma Prime	-0.01	-0.01	-0.02	-0.003	-2.87	0.001
Transparency: Log Lemma C1 Prime	0.006	0.006	-0.01	0.03	0.64	0.53

Note. The variables in this table refer to the same variables as described in Table

16.

Table 21

Fixed effects for three models of RT analysis of interaction of frequency of the second constituent and transparency for Experiment 3

Model 1: Dichotomized Model						
Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.43	-1.43	-1.48	-1.38	-52.97	0.001
Relatedness	0.03	0.03	-0.002	0.05	1.91	0.05
Transparency	0.03	0.03	0.001	0.06	2.20	0.04
Log Lemma C2 Prime	0.004	0.004	-0.01	0.02	0.51	0.61
Transparency: Log Lemma C2 Prime	-0.004	-0.003	-0.02	0.02	-0.37	0.79
Model 2: Continuous Model						
Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.39	-1.39	-1.44	-1.35	-52.09	0.001
Continuous Relatedness	-0.05	-0.05	-0.11	0.02	-1.30	0.20
Continuous Transparency	-0.007	-0.007	-0.02	0.005	-1.23	0.23
Log Lemma C2 Prime	0.003	0.003	-0.009	0.01	0.42	0.66
Continuous Transparency: Log Lemma C2 Prime	0.003	0.003	-0.004	0.01	0.84	0.37
Model 3: Model with Covariates						
Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.32	-1.32	-1.41	-1.23	-27.04	0.001
Relatedness	0.04	0.04	0.007	0.07	2.48	0.01
Transparency	0.006	0.006	-0.03	0.04	0.37	0.68
Log Lemma C2 Prime	0.009	0.009	-0.006	0.03	1.04	0.25
Log Lemma Prime	-0.01	-0.01	-0.02	-0.004	-2.78	0.006
Transparency: Log Lemma C2 Prime	-0.004	-0.005	-0.02	0.01	-0.45	0.64

Note. The variables in this table refer to the same variables as described in Table 16.

Experiment 4

The aim of the fourth experiment was to assess whether semantic priming occurs for the second constituents of compounds with opaque first constituents (OT and OO compounds). According to Marslen-Wilson et al. (1994) and Schreuder and Baayen (1995), semantic priming should not occur for either OT or OO compounds. This is the case, they note, because these compounds are opaque and thus the semantic representations of the constituents are not connected to the semantic representations of the whole-word. According to Libben (1998) and Zwitserlood (1994), semantic priming should occur only for the second constituents of OT compounds. The semantic representations of the second constituent of OT compounds will be connected to the whole-word representation and thus result in access to the constituent's semantic representations (Libben, 1998; Zwitserlood, 1994). The OO compound should not result in priming, because for fully opaque compounds, the full form representations are not connected to the semantic representations of the constituents (Zwitserlood, 1994). According to Libben (1998), the lack of semantic priming for the second constituents of OO compounds occurs because there are inhibitory links between the semantic representations of the opaque constituents and the semantic representations of the whole word. This would result in inhibition of the semantic representation of both constituents of OO compounds and a lack of facilitation to respond to the target and potentially even slower processing of the target compared to an unrelated control condition. In contrast, the RICE approach (Spalding et al., 2010) predicts that the semantic representations of the second constituents of OT and OO compounds should be available. However, depending on facilitation (or inhibition) that might come from the role of the modifier or the head during different stages of meaning construction, the early availability of these representations could be cancelled out resulting in a lack of semantic priming for the second constituents of OT and OO compounds. As mentioned in the section Construction of Materials, Part 2 of this experiment served as a continuous measure of transparency that can be included as a predictor variable in the LME models.

Method

Participants. Seventy-seven psychology undergraduate students participated in this experiment for partial course credit. In total, twenty-five participants were removed. Three participants were removed due to accuracy rates lower than 60% in the experimental conditions. Twenty-two participants were removed due to accuracy rates lower than 60% in the filler conditions. Thus, the data from fifty-two participants were analyzed.

Materials. One hundred and sixty opaque-transparent (OT) compounds and opaque-opaque (OO) compounds were selected as prime items from the Oxford English Dictionary (Simpson & Weiner, 1993) and CELEX lexical database (Baayen et al., 1995). The one hundred and sixty compounds were divided into eighty matched pairs of OT compounds and OO compounds. The pairs shared the same second constituent (e.g., *kettledrum*, OT, was matched to *humdrum*, OO). Forty monomorphemic target words (e.g., *guitar*) were selected from the University of South Florida Free Association Norms (Nelson et al., 1998).

I created four conditions by combining the eighty matched pairs of compound primes and targets (see Appendix 1). The first condition consisted of OT primes with related targets (e.g., *kettledrum* and *guitar*). The second condition consisted of OO primes with related targets (e.g., *humdrum* and *guitar*). The third condition consisted of OT primes with unrelated targets (e.g., *bullfrog* and *guitar*). The fourth condition consisted of OO primes with unrelated targets (e.g., *leapfrog* and *guitar*). The items were counterbalanced so that each participant saw each target only once with one of the primes. Across all trials, participants were presented with items from all four conditions. The filler items were the same as in Experiment 3.

Procedure. The procedure in Part 1 of the experiment was identical to that of Experiment 1. In Part 2, the procedure was similar to the procedure described in the Construction of Materials section. The only modification was that participants were not asked to press the “n” key if they did not know the meaning of the compound word.

Results

I fit LME models to the data using accuracy and inverse response time as dependent variables and Transparency (OT and OO) and Relatedness (Related versus Unrelated) as fixed effect predictor variables and participants and items as random effects. Incorrect trials were removed prior to analyzing the data. Response times greater than 2.5 standard deviations away from each subject’s condition mean and trials with response times greater than 2.5 seconds were also removed (in total 0.54% of correct responses). The mean target response time and standard error for each condition can be found in Table 22.

Table 22

Mean response times (in ms) to the targets with standard errors for Experiment 4

Condition	Mean RT (SE)
OT-Related	724 (13)
OO-Related	706 (9)
OT-Unrelated	737 (13)
OO-Unrelated	734 (13)

Note. Descriptive statistics were calculated by averaging over subjects.

In order to address my first claim, I fit a series of models to examine whether transparency of the second constituent influenced whether semantic priming occurred. In contrast to the predictions of certain models (Libben, 1998; Marslen-Wilson et al., 1994; Schreuder & Baayen, 1995; Zwitserlood, 1994), there was no interaction between the factors Relatedness and Transparency ($t = 0.65$, $p = 0.50$, see Table 23 for Models 2 and 3). While Models 1 and 2 contained the same predictors as in previous experiments, Model 3 differed. In this experiment, when Model 3 was fit with all covariates, it seemed to over fit, as none of the covariates or predictor variables reached significance. Thus, the model was fit using the covariates: length of the prime, log frequency from Google of the target, and LSA rating between the target and prime in open form. It is not surprising that semantic priming was not observed when only Relatedness and Transparency were added to the model. The primes were matched on their second constituent; however, other characteristics, such as length and frequencies of the primes were allowed to vary. The frequency of the targets ranged from 47.5 occurrences per million to

16,758.6 occurrences per million. The length of the prime ranged from six to eleven letters. The differences in the items in terms of these factors first needs to be parceled out before observing the effects of the factors of interest (i.e., Relatedness and Transparency). When the covariates that were previously mentioned were added, related targets were responded to more quickly than unrelated targets in Model 3 (*t* = 2.01, *p* = 0.04; see Table 24 for Models 1 and 2) [4], but the time to respond to targets after the OT and OO compound primes did not differ (*t* = -0.27, *p* = 0.79, see Table 24 for Models 1 and 2). When the model controlled for the effect of frequency, length, and semantic relation between the target and prime in open form, semantic priming was observed for the second constituents of OT and OO compounds.

Table 23

Interaction of fixed effects for three models for RT analysis for Experiment 4

Model 1: Dichotomized Model						
Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.51	-1.51	-1.56	-1.45	-52.10	0.001
Relatedness	0.004	0.004	-0.04	0.04	0.21	0.85
Transparency	-0.007	-0.007	-0.05	0.03	-0.34	0.75
Relatedness: Transparency	0.02	0.02	-0.04	0.07	0.65	0.50
Model 2: Continuous Model						
Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.50	-1.50	-1.55	-1.45	-54.26	0.001
Continuous Relatedness	-0.0003	-0.001	-0.07	0.07	-0.01	0.99
Continuous Transparency	0.009	0.009	-0.009	0.03	0.97	0.32
Continuous Relatedness: Continuous Transparency	-0.03	-0.03	-0.09	0.02	-1.00	0.30
Model 3: Model with Covariates						
Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.55	-1.55	-1.61	-1.48	-42.16	0.001
Relatedness	0.03	0.03	-0.02	0.08	1.29	0.19
Transparency	-0.01	-0.01	-0.05	0.03	-0.65	0.56
Number of Letters Prime	0.02	0.02	0.004	0.03	2.49	0.01
Log Lemma Target	-0.01	-0.01	-0.03	0.0005	-1.76	0.07
LSA Target Prime Open	0.12	0.12	-0.004	0.24	1.93	0.05
Relatedness: Transparency	0.02	0.02	-0.04	0.08	0.64	0.49

Note. The variables in this table refer to the same variables as described in Table 3.

Table 24

Fixed effects for main effects of three models for RT analysis for Experiment 4

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.52	-1.51	-1.56	-1.46	-54.01	0.001
Relatedness	0.01	0.01	-0.01	0.04	0.94	0.31
Transparency	0.003	0.002	-0.02	0.03	0.17	0.91

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.50	-1.50	-1.55	-1.55	-54.17	0.001
Continuous Relatedness	0.002	0.003	-0.07	-0.07	0.04	0.94
Continuous Transparency	0.002	0.002	-0.01	-0.01	0.34	0.71

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.55	-1.55	-1.62	-1.48	-43.09	0.001
Relatedness	0.04	0.04	0.0007	0.08	2.01	0.04
Transparency	-0.004	-0.004	-0.04	0.02	-0.27	0.79
Number of Letters Prime	0.02	0.02	0.004	0.03	2.49	0.02
Log Lemma Target	-0.01	-0.01	-0.03	0.003	-1.76	0.08
LSA Target Prime Open	0.12	0.12	0.0003	0.25	1.93	0.06

Note. The variables in this table refer to the same variables as described in Table 3.

In accuracy measures, there was no interaction between Transparency and Relatedness (z = -0.75, p = 0.46; see Table 25 for the results of Models 2 and 3). For the main effects, in Model 3, there was a marginally significant difference in the accuracy of participants in responding to related versus unrelated forms (z = -1.25, p = 0.21; see Table 26 for the results of Models 2 and 3) but no difference in the accuracy in responding to targets after the two types of compounds (z = 0.01, p = 0.99; see Table 26 for the results of Models 2 and 3). This supports the response time data and suggests that the second constituents of OT and OO compounds are available during processing.

Table 25

Interaction of fixed effects for three models for accuracy analysis for Experiment 4

Model 1: Dichotomized Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.94	12.35	<2e-16
Relatedness	-0.15	-0.37	0.71
Transparency	0.25	0.57	0.57
Relatedness: Transparency	-0.43	-0.75	0.46
Model 2: Continuous Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.96	14.75	<2e-16
Continuous Relatedness	-0.32	-0.48	0.63
Continuous Transparency	0.07	0.43	0.66
Continuous Relatedness: Continuous Transparency	0.08	0.15	0.89
Model 3: Model with Covariates			
Variable	Estimate	*z* value	*p* value
Intercept	4.55	8.39	<2e-16
Relatedness	-0.56	-1.13	0.26
Transparency	0.26	0.60	0.55
Number of Letters Prime	-0.07	-0.55	0.59
Log Lemma Target	0.08	0.85	0.40
LSA Target Prime Open	-1.60	-1.50	0.13
Relatedness: Transparency	-0.41	-0.73	0.47

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 3.

Table 26

Fixed effects for main effects of three models for accuracy analysis for Experiment 4

Model 1: Dichotomized Model			
Variable	Estimate	*z* value	*p* value
Intercept	4.05	13.96	<2e-16
Relatedness	-0.35	-1.25	0.21
Transparency	0.002	0.009	0.99

Model 2: Continuous Model			
Variable	Estimate	*z* value	*p* value
Intercept	3.97	14.79	<2e-16
Continuous Relatedness	-0.33	-0.50	0.62
Continuous Transparency	0.09	0.84	0.40

Model 3: Model with Covariates			
Variable	Estimate	*z* value	*p* value
Intercept	4.67	8.89	<2e-16
Relatedness	-0.77	-1.88	0.06
Transparency	0.02	0.08	0.94
Number of Letters Prime	-0.07	-0.57	0.57
Log Lemma Target	0.08	0.84	0.40
LSA Target Prime Open	-1.62	-1.51	0.13

Note. Analyses of accuracy used a binomial distribution. The variables in this table refer to the same variables as described in Table 3.

The influence of meaning construction (Spalding et al, 2010) on processing can also be considered with this data. As in Experiment 3, there is no predicted interaction between first constituent frequency and transparency of the prime because the first constituent is most active in suggesting a relational interpretation and its' transparency is held constant. This is demonstrated by the data, as no interaction is observed between Transparency and first constituent frequency ($t = -1.41$, $p = 0.15$; see Table 27 for the results of Models 2 and 3). In line with the results of Experiment 3, I predict that the second constituent frequency should also not interact with prime type. The influence of the frequency of the second constituent is not predicted to play as active a role, because it is not as actively involved as the first constituent in suggesting a relational interpretation during meaning composition. Specifically, the role of this constituent is to determine whether a suggested relation is plausible. In this way, the degree of the availability of the semantic representation of the second constituent should not influence the amount of competition between the stored and composed meaning. As predicted, second constituent frequency did not interact with compound type ($t = -0.78$, $p = 0.43$; see Table 28 for the results of Models 2 and 3). Thus the results of this experiment suggest that, in contrast to Libben et al. (2003) and Isel et al. (2003), the transparency of the second constituent does not influence whether semantic priming is observed when the first constituent is opaque.

Table 27

Fixed effects for three models of RT analysis of interaction of frequency of the first constituent and transparency for Experiment 4

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.51	-1.51	-1.56	-1.45	-53.87	0.001
Relatedness	0.01	0.01	-0.02	0.04	0.70	0.48
Transparency	0.004	0.004	-0.02	0.03	0.24	0.77
Log Lemma C1 Prime	0.01	0.01	-0.0005	0.02	1.80	0.07
Transparency: Log Lemma C1 Prime	-0.01	-0.01	-0.03	0.004	-1.41	0.15

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.50	-1.51	-1.56	-1.46	-54.14	0.001
Continuous Relatedness	0.005	0.004	-0.07	0.08	0.14	0.91
Continuous Transparency	0.002	0.002	-0.01	0.01	0.25	0.84
Log Lemma C1 Prime	0.005	0.005	-0.003	0.01	1.17	0.23
Continuous Transparency: Log Lemma C1 Prime	0.0006	0.0007	-0.005	0.006	0.22	0.82

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.55	-1.55	-1.62	-1.48	-43.03	0.001
Relatedness	0.04	0.04	0.002	0.09	1.96	0.06
Transparency	-0.003	-0.002	-0.03	0.03	-0.18	0.89
Log Lemma C1 Prime	0.01	0.01	-0.002	0.02	1.75	0.09
Number of Letters Prime	0.02	0.02	0.003	0.03	2.36	0.02
Log Lemma Target	-0.01	-0.01	-0.03	0.002	-1.84	0.06
LSA Target Prime Open	0.13	0.13	0.01	0.24	2.10	0.04

Transparency: Log Lemma C1 Prime	-0.007	-0.008	-0.02	0.01	-0.88	0.39

Note. The variables in this table refer to the same variables as described in Table 3.

Table 28

Fixed effects for three models of RT analysis of interaction of frequency of the second constituent and transparency for Experiment 4

Model 1: Dichotomized Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.51	-1.51	-1.56	-1.46	-54.01	0.001
Relatedness	0.02	0.02	-0.01	0.04	1.08	0.26
Transparency	0.002	0.003	-0.03	0.03	0.16	0.84
Log Lemma C2 Prime	-0.0002	-0.0001	-0.01	0.02	-0.03	0.99
Transparency: Log Lemma C2 Prime	-0.008	-0.008	-0.03	0.01	-0.78	0.43

Model 2: Continuous Model

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.50	-1.50	-1.55	-1.46	-54.09	0.001
Continuous Relatedness	-0.002	-0.001	-0.07	0.08	-0.06	0.99
Continuous Transparency	0.002	0.003	-0.01	0.01	0.37	0.76
Log Lemma C2 Prime	-0.003	-0.003	-0.02	0.009	-0.51	0.60
Continuous Transparency: Log Lemma C2 Prime	0.001	0.0008	-0.008	0.01	0.22	0.84

Model 3: Model with Covariates

Variable	Estimate	MCMC *M*	HPD95lower	HPD95upper	*t* value	*p*MCMC
Intercept	-1.55	-1.55	-1.62	-1.49	-42.98	0.001
Relatedness	0.04	0.04	0.003	0.09	2.01	0.05
Transparency	-0.004	-0.003	-0.03	0.03	-0.27	0.83
Log Lemma C2 Prime	0.001	0.001	-0.01	0.02	0.17	0.90
Number of Letters Prime	0.02	0.02	0.003	0.03	2.42	0.10
Log Lemma Target	-0.01	0.01	-0.03	0.002	-1.70	0.05
LSA Target Prime Open	0.12	0.11	-0.008	0.24	1.91	0.06
Transparency: Log Lemma C2 Prime	-0.006	-0.006	-0.03	0.01	-0.54	0.58

Note. The variables in this table refer to the same variables as described in Table 3.

General Discussion

Current theories about compound processing propose that the constituents of both opaque and transparent compounds are available at the lexical level (Libben, 1998; Schreuder & Baayen, 1995; Zwitserlood, 1994). However, there is still debate about the availability of the semantic representations of the constituents of opaque compounds (Isel et al., 2003; Libben, 1998; Marslen-Wilson et al., 1994; Sandra, 1990; Schreuder & Baayen, 1995; Zwitserlood, 1994). The aim of my project was to examine this question, specifically by manipulating the transparency of one constituent, while holding the transparency of the other constituent constant. Semantic priming was observed for the first and second constituents of TT compounds (Experiments 1 and 3), the first and second constituents of TO compounds (Experiments 2 and 3), the first and second constituents of OT compounds (Experiments 1 and 4) and the second constituents of OO compounds (Experiments 2 and 4). Thus, my data provide support for the proposition that semantic representations of the constituents are automatically accessed during processing, and that in the majority of cases, this access results in semantic priming.

In this section, I first examine the reasons why my strategy was effective in observing semantic priming for the constituents of opaque compounds. Second, I consider whether my data are compatible with any existing theories of compound processing. Finally, I discuss whether the data provide support to my two claims: that semantic representations are available during processing, and that semantic integration could occur for all compounds, even opaque ones.

Two Advantages in this Project's Strategy

There are two advantages in the strategy of my project that might explain why I have observed semantic priming when other researchers have not (Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994). First, the role of meaning construction was considered, making it necessary to consider the independent effect of the transparency of each constituent while holding the transparency of the other constituent constant. Libben et al. (2003) examined the availability of the first and second constituent independently, but only in a lexical priming task. Isel et al. (2003), by contrast, examined only the independent effects of the first constituent in a semantic priming task, but did not consider whether the second constituents' semantic representations became available. Therefore, my project makes the novel contribution of examining the influence of the transparency of the first and second constituents independently in a semantic priming task. The influence of the second constituent is important, according to RICE (Spalding et al., 2010), because both the first and second constituents are involved in meaning construction. Specifically, the head noun determines whether the relational information provided by the modifier is plausible. Semantic priming was observed for semantic associates of the second constituents of TT and TO compounds (Experiment 3) and OT and OO compounds (Experiment 4). Therefore, it is possible to infer that the semantic representations of the second constituents of all compounds are accessed during processing, regardless of their transparency. For meaning construction to occur, the semantic representations of the head must be available as the head is involved in evaluating possible relational interpretations.

While the current data cannot definitively point to meaning construction as a process that occurs for opaque compounds, it provides evidence that meaning construction cannot be rejected because seven out of eight constituents tested resulted in semantic priming.

The second advantage of my approach was the use of LME models. Specifically, these models allowed me to examine three questions by fitting separate models as discussed in the section Data Analysis. First, there does seem to be a loss of power from separate analyses of variance by-subject (F_1) and by-item (F_2). By using LME analysis, I was able to account for the random effects of subject and item at the same time. This is an advantage over previous projects that used by-subject and by-item analyses of variance (Isel et al., 2003; Zwitserlood, 1994) or simply by-item analyses of variance (Sandra, 1990) and thus could not account for the effects of both subjects and items at the same time, resulting in decreased power (Baayen et al., 2008). Specifically, the decrease in power is problematic because null results were expected for semantic priming of constituents (Isel et al., 2003; Sandra, 1990; Zwitserlood, 1994). However, the null results reported in these projects might not represent a lack of semantic access, but might be the result of insufficient power to detect semantic priming effects.

Second, it does not seem inappropriate to consider Transparency and Relatedness as dichotomized rather than continuous. Model 1 (Dichotomized) and Model 2 (Continuous) converge and provide very similar results across the experiments. Therefore, despite the loss of power and information about the variables of interest due to a median split (MacCallum, Zhang, Preacher, & Rucker, 2002), in the case of opaque and transparent compounds, the dichotomization of the variables does not appear to be problematic.

Third, there do seem to be other factors that contribute to the variability observed in response time. LME analysis allows for the inclusion of covariates that are linked to random effects. Specifically, in my project, it was necessary to account for systematic variability (such as differences in frequency) in the experimental items before the effects of relatedness and transparency could be assessed. In Experiments 3 and 4, semantic priming was not observed when base models with only Transparency and Relatedness were fit. When the information about the covariates was entered, semantic priming was observed. The semantic priming effect size for the second constituents could be smaller than that for the first constituents. If the effect size is smaller, power will be decreased for models fit for the second constituents. Therefore, it might be necessary to control for additional variability attributed to the individual items before observing semantic priming. There is some evidence in the literature that demonstrates that priming effects are larger for first constituents (Kehayia et al., 1999). My data support the proposition that greater priming effects occur for first constituents. The responses to targets preceded by TT primes with related first constituents were faster by a mean of 39 ms; whereas, those related to second constituents were faster by a mean of 11 ms (this pattern holds for all compound types, except for OO compounds).

Congruence of the Data with Existing Approaches to Complex Word Processing and Predictions About the Processing of Opaque Compounds

In light of this novel approval, my data can be evaluated in terms of existing theories. The data are incompatible with a whole-word access approach (Butterworth, 1983) because there is access to the semantic representations of the constituents, and thus, they demonstrate that constituents are accessed during processing. The data could be compatible with either a decomposition-only (Taft & Forster, 1975, 1976) or a dual-route approach (Giraudo & Grainger, 2000, 2001; Pollatsek et al., 2000; Schreuder & Baayen, 1995; Taft, 1994). Because the semantic representations of the constituents are accessed, there is evidence that decomposition of compounds into their constituent parts occurs. It is therefore necessary to examine the specific predictions that these accounts make for the processing differences between opaque and transparent compounds.

My data do not fit with any of the predictions that existing theories make about the processing of opaque compounds. The results are inconsistent with the predictions made by Marslen-Wilson et al. (1994) and Schreuder and Baayen (1995) because in my project, semantic priming was observed for both constituents of OT and TO compounds and the second constituents of OO compounds. Marslen-Wilson et al. (1994) and Schreuder and Baayen (1995) predict that opaque compounds can only be accessed through a full-form representation at the semantic level, and thus semantic representations of the constituents should not be accessed and as a result semantic priming should not occur for any of these compound types. Libben (1998) proposes that there should not be semantic priming for opaque constituents (instead there should be inhibition of semantic associates of opaque constituents), because at the semantic level opaque constituents are connected with an inhibitory link to the representation of the whole word. The findings from my experiments are inconsistent with his predictions, because semantic priming was observed for the first constituents of OT compounds and the second constituents of TO and OO compounds. The results of my experiments align most closely with Zwitserlood's (1994) proposition that semantic priming should occur for the constituents of all compounds except OO compounds. However, I observed semantic priming for the second constituents of OO compounds.

Availability of Semantic Representations

My first claim is supported by the data because the semantic representations of all constituents except those of the first constituents of OO compounds resulted in semantic priming. Therefore, I can infer that the underlying reason that participants were faster to respond to related words was because the semantic representations of the constituents were accessed during processing. However, it is puzzling that the first constituents of OO compounds did not result in semantic priming. In line with Libben's (2006) principle of maximization of opportunity, I propose that it is odd that during processing that only one (out of the eight) of the constituent types tested is not accessed. I propose, instead, that this lack of priming does not suggest that these representations are not accessed, but instead that there is later processing that interferes with the availability of these representations. Therefore, it might be beneficial to consider whether another account of compound processing could accommodate these findings.

Influence of Semantic Integration During the Processing of Opaque Compounds

My second claim is indirectly support by my data. If the process of meaning construction occurs for opaque compounds, there will be competition between the lexicalized and constructed meanings, and it might be possible to observe the indirect evidence of this competition using my data. For novel and transparent compounds, it has been demonstrated that there can be competition between multiple meanings, and this competition can slow processing (Gagné et al., 2005; Gagné et al., 2010). Specifically, if the competition between meanings is greater (either through how accessible or how plausible a certain meaning is) the slower participants will be to process the compound (Gagné et al., 2010). As Ji et al. (in press; Gagné & Spalding, 2009; Ji, 2008) have discussed, competition between possible meanings could also be occurring for opaque compounds. If this competition is occurring, there also might be differential effects of competition for the constructed and stored meanings of OT, TO and OO compounds (as previously discussed in the Introduction). The differential effects would depend on inhibition or facilitation coming from either the “suggest” or “evaluate” stages of the meaning construction process.

It is not clear from the current data how competition between possible meanings occurs and what the outcome of this competition might be. I have previously discussed the resolution of this competition in terms of inhibition of the constructed meaning, however it might be the case that inhibition is not necessary. Spalding et al. (2010) have discussed the way that different tasks can tap into individual stages of the RICE “suggest-evaluate” framework. They found that in sense-nonsense task, in which particpants were asked to determine if a novel compound has a sensible interpretation, that the role of the modifier of suggesting relational interpretations was strongest. This is in contrast to a verification task, in which participants are asked to determine if a particular interpretation is plausible, that found that the role of the second constituent is most important. I suggest (along with Spalding et al., 2010) that it might be possible that in a sense-nonsense task that there is competition between possible interpretations, but that this competition does not need to be resolved. It could be the case that as long as there is sufficient activation (either from the stored or constructed meanings) to reach a certain decision criteria, participants respond that this particular item makes sense. Therefore, inhibition of other possible meanings is not a necessary outcome of competition between possible meanings. In contrast, a verification task might tap directly into the role of inhibition of an inappropriate meaning (or meanings) because competitors must be ruled out. In the current project, the task of lexical decision was used and is similar to sense-nonsense because it is not necessary that a particular interpretation be selected. Researchers assume that the mental lexicon is being consulted in a lexical decision task, however it is not possible to ensure that one specific representation is being accessed. In this way, inhibition is not necessarily required during competition between possible meanings depending on the kind of task. I now discuss the outcome of meaning construction for TT, OT, TO and OO compounds.

In the current project, semantic priming was observed for the first and second constituents of TT compounds. The data do not suggest (in the measures of RT, accuracy or interaction of constituent frequency and transparency) that there is a much (if any) competition occurring between the constructed and the stored meanings of TT compounds. This is not unexpected because the constructed and stored meaning for these compounds should be very similar and thus result in little (if any) competition.

As mentioned in the Introduction, in contrast to TT compounds, TO and OT compounds are predicted to show greater degrees of competition between possible meanings. However, depending on the relative contribution of different stages in meaning construction, they could result in different degrees of competition. The proposition of conflict due to semantic integration is not unique to compounds. Researchers have suggested that morphologically complex forms can be facilitated early in processing (due to decomposition) but that these effects might later be obscured due to recombination (Kazanina, Dukova-Zheleva, Geber, Kharlamov, & Tonciulescu, 2008; Taft, 2004). Taft (2004) proposes that during comprehension, two paths are involved: recombination and access to the whole-word representation. In particular, he discusses how there might be effects observed early in processing that are due to decomposition, but that these effects could be cancelled out due to later processing that is a result of the combination of the constituents. Kazanina et al. (2008) specifically state that for opaque complex forms, in general, the recombination stage could be particularly problematic because it would result in a meaning that is inconsistent with the stored meaning. For opaque compounds, in specific, the same trade-off between facilitation due to decomposition, and processing difficulties due to recombination has been observed (Ji, 2008; Ji et al., in press).

For TO compounds, my data do not provide indirect evidence of competition between possible meanings. I observed semantic priming for both constituents of TO compounds. I also did not find that the transparency of either the first or second constituent influenced the effect of frequency of the constituents on response times to a semantic associate. Libben et al. (2003) and Isel et al. (2003) note that the processing of compounds with opaque heads is more difficult. My data, instead, suggest that there are cumulative effects of the transparency of the first constituent and second constituent. This is consistent with RICE (Spalding et al., 2010) because both constituents play a role in processing, the opacity of one of the constituents might be counterbalanced by the availability, due to the transparency, of the other constituent.

For OT compounds, in contrast to TO compounds, my data indicate that there is competition occurring between meanings. Despite this competition, the semantic representations of both constituents seem to be accessed and result in semantic priming for the targets. The competition between meanings is supported by the observation of an inhibitory effect to respond to the target, which was observed when the first constituents of OT compounds were higher frequency and thus the semantic representations of these constituents are more accessible. This finding is consistent with Ji et al. (in press) who also found that frequency of first constituents interacted with transparency in the same way. This might suggest that the increased availability of the semantic representation of the opaque constituent resulted in competition between the constructed and stored meanings, making it more difficult to access the semantic representation of a related word.

For OO compounds, in Experiment 2 of the current project, there is also indirect evidence that meaning construction is occurring. Previous researchers (Libben, 1998; Zwitserlood, 1994) have suggested that OO compounds will not result in semantic priming of semantic associates of their constituents. This is their prediction for two possible reasons; first, the lack of a link between the constituent semantic representations and the semantic representation of the whole word does not result in priming (Zwitserlood, 1994). Second, as Libben (1998) has proposed, the inhibitory links between the semantic representations of opaque constituents and the semantic representation of the whole word would result in inhibition of the constituents' semantic representations. The processing of semantic associates of the constituents of OO compounds should not result in priming and in fact might be slower compared to an unrelated control condition. As noted in the Introduction and by Ji et al. (in press), the lack of a link (Zwitserlood, 1994) or inhibitory links (Libben, 1998) at the semantic level would not be sufficient to explain the lack of semantic priming because the activation from the lexical representations should be sufficient to result in activation of the semantic representations.

As Ji et al. (in press) point out, the RICE theory of conceptual combination (Spalding et al., 2010) results in a different interpretation of these results. There are two possible reasons, according to RICE, that the processing of OO compounds could be more difficult. First, competition between a constructed and lexicalized meaning might be problematic, and second, the assignment of role for the constituents might be difficult.

The first reason that it might be difficult to process OO compounds is that in a meaning construction framework, the constructed interpretation should differ to the greatest extent for OO compounds (in comparison to TT, OT and TO compounds) and result in greater competition between the constructed and the lexicalized meanings. However, as noted in the Introduction, it is unclear whether this difference will make it easier to reject the incorrect interpretation (as Ji et al., in press have also discussed). The lack of semantic priming for the first constituents of OO compounds (Experiment 2) suggests that the constructed meaning of OO compounds is easier to reject than the constructed meanings of TT, OT or TO compounds. This might be the result because the constructed meaning (or meanings) of OO compounds is very different than the lexicalized meaning of these compounds (e.g., for the compound *hogwash*, the lexicalized meaning of “nonsense” is very different from the constructed meaning of *wash FOR hogs*). The greater difference between possible meanings for OO compounds could allow the constructed meaning to be inhibited with greater ease. My data suggest that this could be the case because the indirect effects of competition (as observed through a lack of semantic priming for the first constituents of OO compounds in Experiment 2) are greatest for OO compounds.

If the constructed meaning is suppressed, then why do the constituents' semantic representations remain available? If inhibition occurs (due to the constraints of the task, or because of the type of compound processed), I propose that the suppression occurs first for the constructed meaning and only later in processing spreads to the semantic representations of the constituents that have contributed to that constructed meaning. In this way, I predict a delay in suppression (or inhibition) of the semantic representations of the constituents relative to the suppression of the constructed whole-word meaning. Therefore, when semantic priming is not observed for the first constituents of OO compounds (Experiment 2), I can infer that the constructed meaning has been suppressed leading to suppression of the constituents. I will return to the discussion of why the first constituent is suppressed sooner than the second constituent later in the Discussion.

The second reason that it might be difficult to process OO compounds is that assigning each constituent a role could be problematic. Inherent to the "suggest-evaluate" process of RICE (Spalding et al., 2010) is the process of assigning the first constituents of English compounds to the role of modifier and the second constituents to the role of head noun. This is required because each constituent plays different roles during processing, as I discussed in the Introduction. For TT compounds, it should not be difficult to assign the roles of both constituents. In contrast, for partially opaque compounds (OT and TO compounds) one constituent is related to the whole-word meaning and therefore it might be possible to easily assign the role of the second constituent (in the case of OT compounds) or the first constituent (in the case of TO compounds). For OT and TO compounds, the information about the role of one constituent would allow the other constituent to be assigned to the other role by default. For OO compounds, role assignment might be more difficult because neither constituent contributes to the meaning of the word. Therefore, the only information that would be present for these constituents is the position-in-the-string and this might be a second reason why processing of these compounds is difficult (i.e., slower).

As I have previously discussed, according to RICE (Spalding et al., 2010), both constituents are involved in meaning construction and could result in different processing for the first and second constituents. My data indicate that opacity of one constituent can be counterbalanced by the transparency of the other constituent. The presence of semantic priming for the first constituents of OT compounds compared to the lack of semantic priming for the first constituents of OO compounds demonstrates that it is not sufficient to posit that the transparency of the modifier alone results in differential processing. This instead suggests that there are cumulative effects of transparency of the first and second constituents.

Why is semantic priming observed for the first constituents of OT compounds? In contrast to OO compounds, OT compounds are still members of the head noun category (e.g., a *ladybug* is still a *bug*). Therefore, for OT compounds the competition that occurs from a relational interpretation suggested by the opaque modifier might be cancelled out because the head is related to the whole-word meaning. It does appear that there are effects of competition for possible meanings for OT compounds, but they do not appear to be strong enough (or occur within the right timeframe) to cause the semantic representations of the first constituents to not result in semantic priming in Experiment 2. For OO compounds, in comparison to TO and OT compounds, the constructed meaning might not be preserved because it differs to the greatest extent from the lexicalized interpretation and thus this might result in suppression of the constructed meaning (this suppression should spread from the constructed whole-word representation to the semantic representations of the constituents). Previous research supports this proposition because it finds that OO compounds take the longest to process in comparison to OT and TO compounds (see Experiment 2 of Libben et al., 2003) and thus suggests that there might be additional processing (such as suppression of the constructed meaning) occurring for these compounds.

If there is greater competition between constructed and stored meanings for OO compounds compared to the other compound types, why is it only the case that semantic priming is not observed for first constituents of OO compounds? The answer might be that the modifier does not result in semantic priming for OO compounds because it plays a special (and early) role in processing. Juhasz et al. (2003) and Pollatsek et al. (2000) found in eye-tracking measures that the effects of the frequency of the first constituent occurred before those of the second constituent. Additionally, according to RICE (Spalding et al., 2010), the modifier should also play an early role, as it should suggest a relational interpretation, which will then be evaluated by the head. In my project, the intervening time between the prime and target (as presentation was self paced) might have been sufficient to allow for the competition to be resolved, perhaps by inhibition (or suppression) of the constructed meaning. Specifically, the semantic representation of the first constituent, in comparison to the semantic representation of the second constituent, might have had sufficient time to be inhibited (or suppressed) because it became available early in processing. For this reason, it might not be possible to observe semantic priming to words related to the first constituent of OO compounds.

Conclusion

In my project, clear semantic priming was observed for the constituents of all compound types, except for the first constituents of OO compounds. Specifically, the results of this project differ from previous experiments (Isel et al., 2003; Libben, 1998; Marslen-Wilson et al., 1994; Sandra, 1990; Schreuder & Baayen, 1995; Zwitserlood, 1994) because the availability of the semantic representations of the first constituent were examined while holding the transparency of the second constituent constant (Experiments 1 and 2) and the availability of the second constituent was examined while holding the transparency of the first constituent constant (Experiments 3 and 4). Finally, the current data suggest that semantic integration of the constituent meanings through a process such as RICE (Spalding et al., 2010), might account for the processing differences between opaque and transparent compounds (Gagné & Spalding, 2009; Ji, 2008; Libben, 2005). Specifically, the absence of semantic priming for the first constituents of OO compounds could be the result of a process of mismatch resolution after the construction of a meaning for these compounds.

Endnotes

[1] The analysis was initially conducted on all forty experimental targets. However, it was later discovered that three experimental primes were misclassified. Item 11, *witchdoctor* (OO) was coded as OT, Item 15 *crabcake* (TO) was coded as TT, Item 18 *wetsuit* (TO) was coded as OT, and Item 36 *gumshoe* (OO) was coded as OT. When these items were removed and Model 1 was run again the results remained the same. Relatedness was significant ($t = 2.48$, $p = 0.01$), while Transparency was not ($t = 1.07$, $p = 0.31$).

[2] The analysis was initially conducted on all thirty-two experimental targets. However, it was later discovered that four experimental primes were misclassified. Item 9, *cowpoke* (OO) was coded as TO, Item 21 *shipyard* (TT) was coded TO, Item 25 *eyesight* (TT) was coded as TO, and Item 32 *sweatsuit* (OO) was coded as TO. When these items were removed and Model 1 was run again the results remained the same. The interaction between Relatedness and Transparency was still significant ($t = 2.24$, $p = 0.04$).

[3] The analysis was initially conducted on all forty experimental targets. However, it was later discovered that three experimental primes were misclassified. Item 8, *eyesore* (OO) was coded as TO, Item 32 *sidekick* (OO) was coded as TO, and Item 34 *network* (OO) was coded as TO. When these items were removed and Model 3 was run again the results

remained the same. Relatedness was significant ($t = 2.46$, $p = 0.004$), while Transparency was not ($t = 0.52$, $p = 0.64$).

[4] The analysis was initially conducted on all forty experimental targets. However, it was later discovered that three experimental primes were misclassified. Item 1 and Item 17, *cockleshell* (TT) were coded as OT, and Item 26 *beanbag* (TT) was coded as OT. When these items were removed and Model 3 was run again the results remained very similar. Relatedness became marginally significant ($t = 1.94$, $p = 0.07$), while Transparency is still not significant ($t = 0.05$, $p = 0.97$).

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Appendix

Experiment 1 Materials

Item	Target	Prime			
		TT-Related	OT-Related	TT-Unrelated	OT-Unrelated
1	ear	eyesight	eyetooth	kingkiller	kingcrab
2	flame	firelight	firebird	wormfarm	wormwood
3	spine	backache	backtalk	courthouse	courtyard
4	blue	greenscreen	greenhouse	highchair	highway
5	country	flagpole	flagstone	keyhole	keystone
6	spice	pepperbox	peppermint	armrest	armchair
7	cattle	bullfight	bulldog	boardgame	boardroom
8	home	houseboat	housefly	turtlenet	turtledove
9	pen	paperweight	paperwork	gameboard	gameface
10	dark	nightgown	nightstick	corncob	cornlily
11	mouth	nosebleed	nosedive	witchhunt	witchdoctor
12	bean	peaplant	peanut	lifetime	lifeboat
13	point	arrowhead	arrowroot	floodwater	floodlight
14	woman	ladydoctor	ladybug	clubhouse	clubfoot
15	elf	fairyland	fairytale	crabcake	crabapple
16	needle	pincushion	pinstripe	jellymould	jellyfish
17	almond	nutshell	nuthouse	flashlight	flashcard
18	water	wetdock	wetsuit	bloodsucker	bloodorange
19	mouse	catdoor	catfish	dragonboat	dragonfly
20	flower	rosebush	rosewood	tapeplayer	tapeworm
21	finger	handbag	handbook	strawboard	strawberry
22	ground	landowner	landlady	coldroom	coldsore
23	ice	snowball	snowberry	springtime	springboard
24	donkey	horsepower	horseplay	hotair	hotcake
25	stove	potroast	pothole	restarea	restroom
26	puppy	dogbiscuit	dogwood	pipeline	pipedream
27	right	sidecar	sidesaddle	sunburn	sunfish
28	sky	moonlight	moonstone	stepladder	stepmother
29	cream	milkman	milkweed	heartbeat	heartland
30	pig	hogfarm	hogtie	bedbug	bedrock
31	raisin	grapevine	grapefruit	grassland	grasshopper
32	end	taillight	tailspin	lovesong	loveseat
33	duck	goosefeather	goosebumps	upstream	uproar
34	chicken	eggbeater	eggplant	ghoststory	ghosttown
35	lemon	limejuice	limestone	ragdoll	ragweed
36	candy	gumball	gumshoe	suitjacket	suitcase
37	face	headache	headstone	spearhead	spearmint
38	deer	buckskin	buckwheat	footstool	footnote
39	bread	buttermilk	butterfly	placename	placemat
40	color	blackcurrant	blacklist	sandbox	sandman

Experiment 2 Materials

Item	Target	Prime			
		TO-Related	OO-Related	TO-Unrelated	OO-Unrelated
1	tulip	flowerbed	flowerchild	bigtop	bigwig
2	dog	catnip	catwalk	pinecone	pineapple
3	fight	warhead	warlock	checkup	checkmate
4	tree	woodwind	woodchuck	powerbar	powerhouse
5	face	headlock	headcase	homesick	homerun
6	right	sideburn	sidekick	rainbow	raincheque
7	breeze	windsock	windbag	redhead	redneck
8	color	blackhead	blackjack	ladykiller	ladyfingers
9	calf	cowpoke	cowlick	hotdog	hotrod
10	dirt	sandbar	sandpiper	blueprint	blueblood
11	small	shortcut	shortstop	honeycomb	honeysuckle
12	silver	goldleaf	golddigger	hightop	highball
13	steel	ironwork	ironcurtain	aircraft	airhead
14	finger	knucklesandwich	knucklehead	hardship	harddrive
15	wet	watercress	waterworks	greenback	greenthumb
16	ground	landmark	landlord	funnybusiness	funnyfarm
17	room	hallway	hallmark	sweettooth	sweetheart
18	mind	brainchild	braindrain	whitewash	whitecollar
19	spine	backdrop	backlog	sugarcane	sugardaddy
20	bread	butterscotch	butterfingers	downpour	downside
21	sail	shipyard	shipshape	beatdown	beatbox
22	below	underpants	underdog	gateway	gatecrasher
23	poor	cheapskate	cheapshot	turntable	turnpike
24	important	mainstream	mainstay	walkabout	walkman
25	ear	eyesight	eyecandy	pothead	potluck
26	tired	lazybones	lazysusan	fullride	fullback
27	music	bandshell	bandwagon	coldcut	coldfeet
28	slice	cutback	cutthroat	workforce	workout
29	sleep	bedspread	bedhead	cardshark	cardstock
30	eat	feedlot	feedback	freelance	freestyle
31	candy	gumdrop	gumshoe	frontcrawl	frontrunner
32	child	babyboom	babygrand	sweatsuit	sweatshop

Experiment 3 Materials

Item	Target	Prime			
		TT-Related	TO-Related	TT-Unrelated	TO-Unrelated
1	bag	notecase	staircase	earthworm	bookworm
2	hole	tarpit	armpit	screwcap	kneecap
3	breeze	eastwind	woodwind	longbow	rainbow
4	insect	stinkbug	litterbug	handhold	household
5	jacket	wintercoat	housecoat	compostbin	loonybin

6	sneaker	kneesock	windsock	eyebrow	highbrow
7	chair	kitchentable	turntable	eyesight	hindsight
8	pain	footsore	eyesore	saucepan	dustpan
9	slice	haircut	shortcut	footprint	blueprint
10	ill	airsick	lovesick	soundwave	heatwave
11	silk	needlelace	necklace	grassfield	airfield
12	criminal	kingkiller	ladykiller	heatstroke	keystroke
13	meal	hamsandwich	knucklesandwich	sweatpants	underpants
14	cookie	chocolatecake	crabcake	drawstrings	heartstrings
15	almond	pinenut	doughnut	weddingdress	headdress
16	cat	sheepdog	hotdog	arrowhead	redhead
17	trail	gardenpath	warpath	shirtbutton	bellybutton
18	game	contactsport	spoilsport	sharktooth	sweettooth
19	dish	dinnerplate	nameplate	birdcage	ribcage
20	eagle	blackbird	jailbird	dewdrop	gumdrop
21	guitar	bassdrum	eardrum	clothesline	baseline
22	container	hatbox	chatterbox	fingersnap	gingersnap
23	weather	thunderstorm	brainstorm	coastguard	mouthguard
24	spine	hunchback	paperback	mouthwash	whitewash
25	pal	bestfriend	boyfriend	pullup	checkup
26	brush	haircomb	honeycomb	snowsuit	lawsuit
27	boat	pirateship	hardship	fishtank	drunktank
28	stick	walkingcane	sugarcane	basketball	oddball
29	donkey	racehorse	seahorse	iceskate	cheapskate
30	whale	reefshark	cardshark	dentalfloss	candyfloss
31	river	mountainstream	mainstream	sunburn	sideburn
32	corporation	homebusiness	funnybusiness	cornerkick	sidekick
33	noise	sonicboom	babyboom	handlebar	sidebar
34	job	yardwork	network	hilltop	bigtop
35	soap	bubblebath	bloodbath	postmark	landmark
36	mattress	waterbed	flowerbed	paleface	typeface
37	tree	beanplant	faceplant	fleabite	frostbite
38	door	combinationlock	wedlock	gunshot	jumpshot
39	cylinder	trafficcone	pinecone	roleplay	swordplay
40	dessert	applepie	cowpie	collarbones	lazybones

Experiment 4 Materials

Item	Target	Prime			
		OT-Related	OO-Related	OT-Unrelated	OO-Unrelated
1	finger	freehand	secondhand	cockleshell	bombshell
2	throat	crewneck	redneck	flashpoint	viewpoint
3	girl	busboy	tomboy	vampirebat	dingbat
4	pig	warthog	hedgehog	clubfeet	coldfeet
5	week	sunday	heyday	headlight	highlight
6	sheep	billygoat	scapegoat	headline	deadline

7	insect	ladybug	humbug	limestone	milestone
8	tree	rosewood	wormwood	beeline	deadline
9	lamp	headlight	limelight	cubbyhole	loophole
10	boulder	bedrock	shamrock	sandman	walkman
11	container	shadowbox	beatbox	downtime	ragtime
12	lawn	crabgrass	bluegrass	kettledrum	humdrum
13	kid	lovechild	flowerchild	briefcase	nutcase
14	end	bobtail	ponytail	trademark	hallmark
15	pear	crabapple	pineapple	wetbar	toolbar
16	career	oddjob	nutjob	drywall	firewall
17	beach	cockleshell	bombshell	dryrun	homerun
18	cookie	spongecake	beefcake	joystick	slapstick
19	tulip	sunflower	wallflower	suitcase	headcase
20	food	kidneybean	jellybean	rosewood	wormwood
21	space	stateroom	mushroom	flagstone	milestone
22	spot	trademark	hallmark	spongecake	beefcake
23	hour	downtime	ragtime	snapshot	hotshot
24	pain	coldsore	eyesore	chopstick	slapstick
25	game	horseplay	screenplay	setback	comeback
26	sack	beanbag	scumbag	crewneck	turtleneck
27	pole	crowbar	toolbar	dryrun	homerun
28	toes	clubfeet	coldfeet	chairman	walkman
29	spine	piggyback	feedback	boardroom	mushroom
30	letter	snailmail	blackmail	muskrat	rugrat
31	cat	bulldog	underdog	paperwork	clockwork
32	toad	bullfrog	leapfrog	chamberpot	jackpot
33	sky	newmoon	honeymoon	bobbypin	kingpin
34	almond	peanut	wingnut	bobtail	ponytail
35	office	paperwork	network	shadowbox	beatbox
36	pan	chamberpot	jackpot	greenhouse	powerhouse
37	needle	bobbypin	kingpin	newmoon	honeymoon
38	mouse	muskrat	rugrat	snailmail	blackmail
39	bird	vampirebat	dingbat	busboy	tomboy
40	guitar	kettledrum	humdrum	bullfrog	leapfrog