Conceptual access of compound and pseudocompound “constituents”: Evidence from dichoptic presentation

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ABSTRACT

Conceptual Access of Compound and Pseudocompound "Constituents":

Evidence from Dichoptic Presentation

Kyan Salehi

How are (pseudo)complex words recognized? The present study investigates the nature of the visual word recognition system by employing a word-picture relatedness task with brief exposure to target stimuli. Participants were dichoptically presented word-picture pairs (133 ms and backward masked) and were instructed to judge whether the stimuli were related to each other. The main manipulation consisted of presenting a target compound (e.g., *bedroom*, *seatbelt*) or pseudocompound (e.g., *fanfare*, *shamrock*) word and a picture representing either the first or second "constituent" (e.g., *BED*, *BELT*, *FAN*, and *ROCK*, respectively). If the word recognition system decomposes letter sequences with knowledge of morpho-orthographic regularities but is blind to semantics, we predicted that the "constituents" of both compounds and pseudocompounds would be semantically accessed. On the other hand, if the word recognition system is morpho-semantically informed, only compound constituents would be accessed. Accuracy and response times to relatedness judgements were analyzed using linear mixed effects models. Results revealed that (a) pseudocompound "constituents" were semantically accessed, but to a lesser degree than compounds—with less accurate and longer response times—and (b) both compounds and pseudocompounds produced a first "constituent" advantage in accuracy, but not in RTs. We interpret these results as supporting a semantically blind morpho-orthographic parser that quickly accesses and composes "constituent" meanings, while suppressing morpho-orthographically legal but semantically anomalous compositions.

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Contribution of Authors

The present manuscript consists of one experiment that was conceived and designed by Kyan Salehi. Dr. Roberto G. de Almeida closely supervised the progression of the study, contributed to the experiment's design, and was greatly involved in revising this manuscript. Kyan created the materials, programmed the experiment, coordinated data collection, conducted the statistical analyses, and wrote the initial draft.

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How are complex words—and seemingly complex words—interpreted during visual word recognition? A complex word embeds morphemes that, together, compose the meaning of the full word (e.g., *bedroom*), whereas a pseudocomplex word orthographically embeds morpheme-like constituents that are semantically unrelated to the full word (e.g., *fanfare*). While it is uncontroversial to assume that the meaning of *bed* is accessed when recognizing *bedroom*, the more revealing case for the nature of our visual word recognition system is whether we semantically access *fan* in *fanfare*. In fact, since the seminal works by Murrell and Morton (1974), and Taft and Forster (1975), the word recognition system is taken to parse letter strings into morphemes and to subsequently access their meanings. However, what is controversial is (1) the kind of knowledge available to the morphological parser during recognition, (2) the locus of semantic effects in morphological processing, and (3) whether the meanings of both constituents and full words are simultaneously accessed.

Research on the role of morphology in word recognition has produced a wide range of proposals. At one extreme, some models do not attribute any role to morphology and, instead, propose either (a) that words are only recognized as a whole (Manelis & Tharp, 1977) or (b) for an amorphous process, whereby orthographic input directly maps onto semantic representations (Baayen et al., 2011). Conversely, morphological processing has been proposed to operate either (c) without the aid of semantic knowledge (i.e., morpho-orthographic parsing; Crepaldi et al., 2010; Rastle & Davis, 2003; Rastle et al., 2000, 2004; Taft, 1981, 1991, 1994, 2004; Taft & Forster, 1975), (d) with knowledge of semantics (i.e., morpho-semantic parsing; Feldman et al., 2009, 2012, 2015; Giraudo & Grainger, 2000, 2001, 2003), or (e) in parallel to other processes

(Burani & Caramazza, 1987; Kuperman et al., 2009; Libben & de Almeida, 2002; Schmidtke & Kuperman, 2019; Schmidtke et al., 2017). Crucially, morphological processing seems to have a special status in mediating the relation between orthographic input and semantic processing (see Amenta & Crepaldi, 2012, and Diependaele et al., 2012 for reviews). Empirical support for morphological processing has been extensively replicated cross-linguistically—such as in English (Beyersmann et al., 2016, 2018; Libben et al., 1999; Libben et al., 2003; Marslen-Wilson et al., 1994, 2008; Rastle et al., 2004; Taft & Forster, 1975), French (Colé et al., 1989; Longtin & Meunier, 2005; Longtin et al., 2003; Meunier & Longtin, 2007), Spanish (Dominguez et al., 2002; Duñabeitia et al., 2007), Dutch (Baayen et al., 1997; Zwitserlood, 1994) and Persian (Shabani-Jadidi, 2016). Morphological processing effects have also been found across a variety of techniques, such as those involving unprimed lexical decisions (Andrews, 1986; Chamberlain et al., 2020; Park et al., 2020; Taft, 1981), visual masked priming (Beyersmann et al., 2016; Crepaldi et al., 2013; Jarema et al., 1999; Kehayia et al., 1999; Marelli et al., 2009; Rastle & Davis, 2008), cross-modal priming (Allen & Badecker, 2002; Diependaele et al., 2005; Marslen-Wilson et al., 1994; Meunier & Segui, 1999; Zwitserlood et al., 2000, 2002) and eye-tracking (Amenta et al., 2015; Marelli & Luzzatti, 2012; Kuperman et al., 2009, 2010; Pollatsek et al., 2010). Additionally, models of visual word recognition that do not explicitly postulate knowledge of morphology do not seem to account for productivity and compositionality (see Fodor & Pylyshyn, 1988, 2015). This is so because our capacity to produce and understand indefinitely many complex words is dependent on the combination of morphemes following morphological rules. Thus, against models proposing (a) only whole word access and (b) amorphous processing—which reject the role of morphology in word recognition—evidence seems to overwhelmingly support the view that there is some form of morphological parsing.

The investigation of the nature of the visual word recognition system has relied on different types of morphologically complex words. The present study focuses on compound and pseudocompound words (e.g., *bedroom* and *fanfare*, respectively). Both word types are superficially similar, considering they embed letter sequences that can represent free-standing words (e.g., *bed* and *room*, as well as *fan* and *fare*). However, compounds are morphologically complex, thus embedding true constituent morphemes, whereas pseudocompounds only superficially embed "constituents". Comparing compound and pseudocompound processing allows us to understand whether the morphological parser is sensitive to constituents' morphological and semantic information. The goal of the present study is to examine whether "constituent meanings" are accessed when processing compound and pseudocompound words (e.g., *bedroom* and *fanfare*), thus extending the scope of research in lexical processing.

The Nature of the Visual Word Recognition System

While proposals on the nature of the visual word recognition system vary greatly in detail, they can be categorized according to one of four theories: (1) *form-then-meaning*, (2) *postlexical parsing*, (3) *form-and-meaning* and (4) *parallel processing* models (see Beyersmann et al., 2012).

The *form-then-meaning* account postulates that a morpho-orthographic parsing stage operates over letter strings prior to word recognition (Taft & Forster, 1975; Longtin et al., 2003; Rastle et al., 2000, 2004, 2008; Beyersmann et al., 2016). Under this view, the parser isolates potential morphemes based on knowledge of morpho-orthographic regularities but is blind to the meaning relation between the full word and constituents. This implies that complex and, crucially, pseudocomplex words are parsed without the aid of lexical or semantic representations. For instance, both *bedroom* and *fanfare* are expected to be decomposed into their "constituents".

The *form-then-meaning* model is supported by evidence from covert priming, whereby primes are presented to participants at a subconscious threshold (i.e., forward masked and with prime exposure durations shorter than 60 ms; see Forster & Davis, 1984). The priming paradigm supporting this theory involves presenting a prime that is related either morphologically (e.g., *whisking*), pseudo-morphologically (e.g., *whisker*) or orthographically (e.g., *whiskey*) to a target monomorphemic word (e.g., *WHISK*). Several studies have found that responses times to target words are facilitated when preceded by morphologically and pseudo-morphologically related prime words (e.g., Beyersmann et al., 2016; Feldman et al., 2002; Longtin et al., 2003; Rastle & Davis, 2003, 2008; Rastle et al., 2000; 2004; but see Feldman et al., 2009, 2012, 2015). The priming effect of pseudo-morphologically related prime-target pairs (e.g., *whisker*-*WHISK*) has not been found consistently when primes are presented for longer than 60 ms (Feldman et al., 2002; Rastle et al., 2000; but see Marslen-Wilson et al., 2008). Thus, the evidence from morphological priming suggests that parsing occurs in the early moments of visual word recognition.

An outstanding issue for *form-then-meaning* models is that, in some cases, the morphological parser incorrectly segments pseudocomplex words (e.g., *fan|fare*, *whisk|er*). There are two different views on how misparses are corrected. The interactive activation architecture proposes that orthographic input activates "nodes" across different levels of representation—i.e., morpho-orthographic parsing, lexical, and semantic levels (Crepaldi et al., 2010; Libben, 1998, 2003; Taft, 1991; 1994, 2004; inspired by McClelland & Rumelhart, 1981). Parsing is achieved by activating constituent "nodes" at the morpho-orthographic level. These activated "nodes" are, in turn, connected to the lexical and semantic representations of constituents and the full word. Relations between constituents and the full word are captured by excitatory or inhibitory links between their “nodes” at the lexical and semantic levels (Libben, 1998, 2003). That is, if the full word embeds morphologically and semantically related constituents, there are excitatory links between constituent “nodes” and the full word. If, on the other hand, constituents are not morphologically and semantically related to the full word, inhibitory links from the full word to the “constituents” suppress the latter’s lexical and semantic representations. For instance, *bedroom* activates the morpho-orthographic “nodes” *bed* and *room*, which activate the lexical and semantic representations of *bed*, *room*, and *bedroom*. The lexical and semantic representation of *bedroom* also activates its constituents, given that they are morphologically related. As for the pseudocompound *fanfare*, “constituents” are initially identified (e.g., *fan* and *fare*) and, in turn, activate the lexical and semantic representations of the full word and its “constituents”. Considering *fanfare* is not morphologically related to *fan* and *fare*, inhibitory links between the full word and “constituents” inhibit the latter’s representations. The strength of the interactionist approach is its potential to account for a wide range of phenomena in lexical processing, including morphological processing. However, according to this architecture, morphological structure is reduced to links between “nodes” (Libben, 2003). For instance, *boathouse* and *houseboat* are assumed to activate the same constituent “nodes” (e.g., *boat* and *house*). Crucially, there is no way of determining that the former example is a type of *house,* and the latter is a type of *boat*. Thus, links between “nodes” underspecify the morphological structure that combines morphemes together. As such, the interactive activation architecture seems ill-equipped to deal with the productive and compositional nature of the lexical system.

An alternative view dispenses with the interactive activation framework and imposes an obligatory combination stage following the semantic access of constituents (El Bialy et al., 2013;

Fruchter & Marantz, 2015; Lavric et al., 2011; Manouilidou et al, 2021; Meunier & Longtin, 2007; Neophytou et al., 2018; Stockall et al., 2019; Taft & Forster, 1975). That is, the morpho-orthographic parser initially identifies constituents and accesses their meanings. Then, the semantic composition stage integrates constituent meanings following a morphological structure. For instance, recognizing the word *bedroom* involves accessing and composing the meanings of *bed* and *room* to minimally yield the meaning "a room with a bed". In the case of *fanfare*, semantic composition yields the anomalous meaning "a fare for fans" (Fruchter & Marantz, 2015). Crucially, semantics quickly rules out the misparse in favor of the full word meaning (e.g., "a short musical tune") and suppresses "constituent" representations. Taken together, the *form-then-meaning* model involves the following stages: (1) a morpho-orthographic parsing, (2) lexical identification, (3) semantic access, (4) semantic composition and (5) a reanalysis if the parse is deemed incorrect.

The *postlexical parsing* framework (also referred to as "supralexical" parsing) proposes that first letter strings are recognized in the lexicon (Giraudo & Grainger, 2000, 2001, 2003). Following the recognition of the full word, only semantically related constituents are represented. Simply put, words are only parsed if they embed semantically related constituents. Under this view, *bedroom* and *fanfare* are first identified in the lexicon, but only the former is broken down into its constituents (e.g., *bed* and *room*). Following postlexical parsing, the constituent meanings of *bedroom* and the full word meaning of *fanfare* are accessed. The *postlexical parsing* model is supported by priming studies that find facilitation effects exclusively for truly affixed prime words but not for orthographically related primes. For instance, Giraudo and Grainger (2001, Experiment 2) found that recognizing the French target word *laitier* ("dairy" or "milkman" in English) is facilitated when primed by *laitage* ("dairy product") but not by *laitue* ("lettuce"). It is important to note that these results are in line with other morphological priming studies (e.g., Longtin et al., 2003; Rastle et al., 2004). Giraudo and Grainger's experiments (2000, 2001, 2003), however, did not include pseudo-morphologically related prime-target pairs (e.g., *whisker-WHISK*). While the *postlexical parsing* model posits that pseudocomplex words (e.g., *whisker*, *return*, *fanfare*) are not parsed during lexical processing, their experiments did not test these claims.

The *form-and-meaning* framework implements a parsing stage that is informed of constituents' morpho-semantic representations (Davis et al., 2019; Feldman et al., 2009, 2012, 2015; Marelli & Luzzatti, 2012). While the *form-and-meaning* and *postlexical parsing* models make similar claims about the nature of morphological processing, the former does not assume that whole word recognition precedes morphological analysis. Rather, the *form-and-meaning* model posits that morpho-semantic parsing and word recognition occur at the same time. When considering compound and pseudocompound processing, the *form-and-meaning* model posits that the former is parsed (e.g., *bedroom*), whereas the latter is recognized as a whole (e.g., *fanfare*). Thus, only the semantic information from compound constituents is accessed (e.g., *bed* and *room* in *bedroom*). The *form-and-meaning* model is supported by differential priming effects between morphologically and pseudo-morphologically related prime-target pairs (e.g., *whisking-WHISK* and *whisker-WHISK*, respectively) in covert priming experiments (less than 60 ms). Notably, in reviewing the findings from several priming studies, Feldman and her colleagues (2009) demonstrated that priming effects were greater in magnitude for morphologically related pairs as compared to pseudo-morphologically related pairs. Additionally, Feldman et al. (2009) replicated these results in a visual masked priming experiment with a brief prime exposure duration (50 msec; see also Feldman et al., 2012, 2015). This evidence goes against the notion that morphological parsing is blind to semantics (as proposed by the *form-then-meaning* model) and instead supports a morpho-semantic parser—i.e., morphological processing that operates with knowledge of semantic information.

The models reviewed up to this point describe a single route between orthographic and semantic processing. Conversely, models of *parallel processing* assume that lexical information is extracted from words across two or more paralleling routes (Beyersmann et al., 2012; Burani et al., 1984; Caramazza et al., 1985; Diependaele et al., 2005, 2009; Grainger & Ziegler, 2011; Kuperman et al., 2009; Libben & de Almeida, 2002; Schmidtke & Kuperman, 2019; Schmidtke et al., 2017). Early theories proposed dual routes that included morpho-orthographic parsing and whole word recognition streams. These early versions of the dual route model were in part motivated by whole word and root frequency effects in lexical decision tasks (Burani & Caramazza, 1987; Burani et al., 1984). Later iterations were further supported by evidence of differences in the magnitude of priming effects between complex and pseudo-complex words (Diependaele et al., 2005, 2009, 2013). That is, these studies found that priming effects were larger for *whisking*-*WHISK* (i.e., complex prime words) than for *whisker*-*WHISK* (i.e., pseudo-complex prime words). More recently, the notion that morphological processing proceeds according to one or two routes has been expanded to multiple parallel processes (Kuperman et al., 2009, 2010; Schmitdke & Kuperman, 2019; Schmitdke et al., 2017). In addition to whole word and morpho-orthographic routes, this latest version allows for the contribution of different sources of information, such as family size and orthographic neighborhood density. The multiple route model is based on findings from regression-based techniques demonstrating that lexical processing is predicted by interaction effects between constituent frequency, family size and semantic transparency—i.e., the meaning relation between constituent and whole word

(Kuperman et al., 2009, 2010). It is important to note that these distributional properties of complex words are taken as diagnostic measures of morphological processing. Altogether, the *parallel processing* models posit that compound and pseudocompound processing involves recognizing and accessing both the full word and their "constituents". Semantic information from the full word can rule out misparses, as would be the case for pseudocompounds (e.g., *fanfare*).[1]

To reiterate, all models predict that morphologically complex words, such as compounds (e.g., *bedroom*), are parsed during lexical processing, and the semantic information of their constituents is accessed (e.g., *bed* and *room*). The predictions of these models diverge with regard to pseudocompound processing (e.g., *fanfare*). *Form-then-meaning* and *parallel processing* models assume that the meaning of pseudo-constituents (e.g., *fan* and *fare*) are accessed but quickly inhibited following an anomalous semantic composition (e.g., "a fare for fans") or the influence of the whole word's meaning. On the other hand, *postlexical parsing* and *form-and-meaning* models posit that pseudocompounds are not decomposed, and the meaning of the whole word is accessed. There is a caveat, however, regarding the findings supporting these four models: they are rarely based on empirical evidence for semantic processing of morphological or lexical representations; rather, they are based on evidence from psychophysical tasks tapping word recognition and priming between letter sequence forms. It is thus of utmost importance to investigate the nature of the meaning that is accessed, which, by hypothesis, occurs beyond word recognition. This allows us to examine two intersecting stages of lexical processing—that is, an initial morphological processing stage and later stage involving access to semantic information.

[1] Based on this reasoning, Libben and de Almeida (2002) explicitly describe a postlexical "conflict resolution" stage that inhibits representations of semantically inconsistent constituents.

The Case for Compounds and Pseudocompounds

In order to examine the nature of the visual word recognition system, different classes of complex words have been employed. Complex words are generally produced through derivation (e.g., *undo*, *going*) and compounding (e.g., *bedroom*). In particular, compounding involves the combination of two or more free-standing words (Bauer, 2003; Libben, 2014) and is considered a universal process in language (Libben, 2006); Jackendoff (2002, p. 249) even claims that compounds are “protolinguistic fossils”. Compounding, in comparison to derivation, is the most productive word-formation process because it is not constrained by constituent morphemes’ selectional restrictions (Bauer, 2009; Libben, 2014). Novel English compounds can be created by novel two-word combinations—contemporary examples include *textspeak*, *greenwash* and *poutinefest*.

The interpretation of compounds remains a central issue for psycholinguists. Generally, compounds have a head constituent that conveys morphological, semantic, and syntactic properties of the full word (Dressler, 2006).[2] In English, the morphological head is the rightmost constituent—e.g., *houseboat* is a type of *boat*, and *boathouse* is a type of *house*. The leftmost constituent of compounds is the modifier. The compositional meaning of compounds is determined as a function of their constituents and modifier-head structure (see Lieber, 2004).

Although compounds incorporate free-standing constituents, some cases demonstrate an asymmetry between the conventional compound meaning and the compositional meaning. Semantic transparency has characterized this potential asymmetry in the semantic relation between each constituent meaning and the meaning of the whole compound. For instance, the

[2] One exception that defies the modifier-head relation is so-called copulative compounds, such as *singer-songwriter* (Bauer, 2003; Lieber, 2004). Their referents pick out subsets from both constituents, whereby a *singer-songwriter* is a type of *singer* as well as a type of *songwriter*.

meaning of *bed* is retained in *bedroom*, but the meaning of *butter* is not retained in *butterfly*. It is important to note, however, that semantic transparency has been defined and operationalized in different ways (see Schafer, 2018, for an overview). Constituents can be categorized according to the degree to which their meanings relate to the whole word's meaning (Libben et al., 2003; Sandra, 1990; Zwitserlood, 1994). Another view of semantic transparency is defined as the predictability of the full word's meaning given the combination of constituent meanings (Marelli & Luzzatti, 2012). The former definition of semantic transparency—i.e., semantic relation between constituents and compound—is more relevant to the present experiment, considering we investigated whether the meaning of compound and pseudocompound "constituents" are accessed. Another issue related to compound interpretation concerns the notions of endocentricity and exocentricity (Bauer, 2003, 2009; Dressler, 2006; ten Hacken, 2016). Endocentric compounds refer to a subcategory of the head (e.g., *bedroom* is a type of *room*). Exocentric compounds, on the other hand, do not pick out a subcategory of the head (e.g., *pickpocket* is not a type of *pocket*). Issues of semantic opacity and exocentricity are exceptions which highlight the scope of phenomena bearing on morphological and semantic representations. Crucially, semantically transparent and endocentric compounds are considered to be the default case (Lieber, 2004).

Pseudocompounds are morphologically simple and embed letter sequences that resemble free-standing words (e.g., *fanfare*). As such, their appearance of being morphologically complex is purely coincidental. In the present experiment, the object of study is limited to endocentric compounds, embedding two transparent constituents, and pseudocompounds. The comparison between pseudocompounds and compounds offers an opportunity to examine the nature of the morphological parser—specifically with regard to whether semantic information informs parsing.

Semantic Processing of Compounds and Pseudocompounds

There is no consensus regarding the role that compound and pseudocompound "constituents" play during lexical processing. In order to gain a better understanding of semantic processing, it is important to employ techniques that are sensitive to the timecourse of lexical processing. One such technique aiming to tap into the early moments of word recognition is the unprimed lexical decision task, which involves making word-nonword judgements to target letter strings. Research employing this technique has, in some studies, demonstrated a graded effect of semantic transparency for compound recognition (Davis et al., 2019; Libben et al., 2003; Libben & Weber, 2014), whereby compounds with transparent heads (e.g., *bedroom*) are recognized faster than those with opaque heads (e.g., *doughnut*). Kim et al. (2018) also reported that semantically transparent compound constituents (modifier and head) produced facilitatory effects. To a first approximation, the influence of semantic transparency in word recognition seems to suggest that morphological processing operates with knowledge of semantics. In contrast, de Almeida et al. (2020) employed anaglyph glasses to dichoptically—i.e., with distinct visual input to each hemi-retina—split compound and pseudocompound words presented for 60 msec and backward masked. They found that recognition is facilitated when compounds and pseudocompounds are segmented at the constituent boundary, which provides support for an early morpho-orthographic parsing mechanism. When comparing the results across these studies, the influence of semantics seems to be observed only when the target is presented either for a couple hundred milliseconds or until a response is made (e.g., Davis et al., 2019; Kim et al., 2018; Libben et al., 2003; Libben & Weber, 2014). As such, the effects of semantic transparency in these lexical decision studies may result from semantic processing occurring after word recognition.

The masked morphological priming paradigm has also been employed to investigate the nature of morphological parsing during word recognition. Investigations of compound processing consist of presenting prime-target pairs that include compounds (e.g., *bedroom*) and one of their constituents (e.g., *bed*). Priming studies have found that the prime compound facilitates the recognition of the target constituent word (e.g., *bedroom-BED*; Beyersmann et al., 2018; Gagné et al., 2018; Fiorentino & Fund-Reznicek, 2009; Zwitserlood, 1994). Pseudocompounds, on the other hand, seem to inhibit the recognition of pseudo-constituents (e.g., *fanfare-FAN*; Gagné et al., 2018). A delay in pseudocompound recognition suggests that an initial morpho-orthographic parse is followed by the suppression of pseudo-constituent representations.

The semantic priming paradigm measures the facilitation in lexical decisions to a target that is primed by a semantically related word. In investigations of compound and pseudocompound processing, the whole word (e.g., *carload*, *carrot*) is paired with a semantic associate of one of its "constituents" (e.g., *auto*, which is related to the "constituent" *car*). The assumption is that if compound and pseudocompound "constituents" are recognized and semantically accessed, then the presentation of a semantic associate would facilitate recognition. However, if "constituents" are not semantically accessed, then no facilitation effect would be expected. The findings from semantic priming studies have only found facilitation effects for compounds, but not for pseudocompounds (El Bialy et al., 2013; Melvie et al., 2022; Sandra, 1990; Zwitserlood, 1994). These results suggest that the meaning of pseudocompound "constituents" are not accessed, and, thus, that the morphological parser is sensitive to semantics.

However, another explanation for why semantic associates of pseudo-constituents did not yield facilitation effects considers the prime exposure durations. That is, the shortest prime-target stimulus onset asynchrony in these semantic priming studies was 110 ms (Melvie et al., 2022). In contrast, morpho-orthographic parsing effects have been found in morphological priming studies with covert prime presentations (i.e., durations shorter than 60 ms and immediately followed by the target; e.g., Rastle et al., 2000). It remains an open question whether pseudocompound "constituents" are accessed at these shorter prime presentation durations. Additionally, all three paradigms reviewed up to this point involve word recognition (e.g., [a] unprimed lexical decision tasks, as well as [b] morphological and [c] semantic priming paradigms).

Another important technique is the picture-word interference paradigm. This paradigm involves presenting target pictures with distractor words, and participants are instructed to name the picture. The version of the picture-word paradigm examining compound processing presents either distractor compounds or unrelated words and pictures depicting either the first or second compound constituent (e.g., the picture of a *bed* and the word *bedroom*). Studies have found a consistent facilitation effect in picture naming when paired with compound distractors, regardless of the semantic transparency and the position of the depicted compound constituent (Bölte et al., 2013; Dohmes et al., 2004; Zwitserlood et al., 2000, 2002). One experiment also included form-related distractor words that embed a pseudo-constituent and target pictures depicting the pseudo-constituent (e.g., *trombone-BONE*; Dohmes et al., 2004, Experiment 1). Picture naming was also facilitated for these form-related distractor words but to a lesser degree than transparent compound distractors. Crucially, the facilitation in picture naming seems to partially arise from the decomposition of distractor words and the semantic access of "constituents".

Taken together, the research on compound processing provides evidence in favor of a semantically blind morphological parser. However, the semantic access of pseudocompound "constituents" remains unclear, given that evidence from semantic priming suggests that the meaning of pseudo-constituents is not accessed. The picture-word paradigm, on the other hand, reveals pseudo-constituent access in word production. The inconsistent findings between semantic priming and the picture-word paradigm can be explained by their respective task demands, whereby the former requires word recognition, whereas the latter requires both word recognition, semantic access, lexical selection, and word production. Thus, it is possible that pseudo-constituent access in the picture-word paradigm is a result of mechanisms underlying word production, such as morpho-phonological planning.[3]

The Present Study

In the present study, we investigated whether the meaning of compound and pseudocompound "constituents" are accessed in a novel word-picture technique. This technique involves (a) the simultaneous presentation of word and picture targets in opposing lateral visual fields (i.e., dichoptically), while (b) participants judge the relatedness between both target pairs (see Antal & de Almeida, 2023). The main manipulation, here, consisted of presenting compound or pseudocompound words and pictures depicting one of their "constituents" (see Figure 1). The position of the "constituent" depicted by the picture was also manipulated, whereby either the first (modifier) or second (head) "constituent" of the target word was probed. The word-picture paradigm was motivated by the hypothesis that low-level systems of word and object recognition are modular and operate in parallel (Fodor, 1983, 2000). Visual word and

[3] Similar "constituent" effects have also been demonstrated in the typed production of compound and pseudocompound words, whereby motor movements seem to be chunked according to morpho-syllabic constituents (Bertram et al., 2015; Gagné & Spalding, 2016; Libben et al., 2021; Sahel et al., 2008).

object recognition systems are thus only in contact at the semantic (or conceptual) stage under a common amodal code (see de Almeida et al., 2019; Fodor, 1975). As such, relatedness judgements are based on comparing the outputs from word and object recognition systems, on the assumption that faster and more accurate judgements are made if a word "constituent" and a picture access the same representation. For instance, the presentation of the word and picture *bed*, by hypothesis, token the same semantic representation, thus allowing one to judge the stimuli as being related to each other at a post-recognition, semantic system.

Figure 1. Illustration of main manipulations with compounds (top row) and pseudocompounds (bottom row) alongside the picture depicting the first (left column) and the second (right column) “constituent”.

Considering that our technique aims at tapping into the early moments of object and word recognition, stimuli presentation was set at a brief exposure duration (133 ms). If the stimuli presentation duration was too long, trials with pseudocompound target words and pictures of their pseudo-constituents would be judged as unrelated (e.g., *fanfare-FAN*). In contrast, if the presentation of word-picture pairs is too brief, then relatedness judgements to compounds and pseudocompounds would be at or below chance. As such, prior to conducting the present study, we ran an online pilot experiment (*N* = 20) with stimuli presentation duration set to 100 ms and backward masked. The mean accuracy for target compound and pseudocompound words was around chance (see Appendix A). The stimuli presentation duration was ultimately extended to 133 ms in the present study (see details in Method, below).

Under our experimental manipulations, the *form-then-meaning* model predicts that compound and pseudocompound target words are expected to elicit equivalent relatedness judgements when presented with pictures depicting their "constituents". According to this model, the access of "constituent meanings" is driven by prelexical morpho-orthographic parsing, with semantics intervening at a later stage. To illustrate this point, Figure 2a presents the underlying mechanisms that allow participants to judge the word-picture *bedroom-BED* as being related to each other. The same process explains how the pseudocompound *fanfare* and the picture *FAN* yield relatedness judgements, given that the semantic representation [*FAN*] is accessed through word and object recognition. However, pseudo-constituents are quickly suppressed following the semantic integration of their meanings, which yield an anomalous interpretation (e.g., "a fare for fans"). Under the models of *postlexical parsing* and *form-and-meaning*, relatedness judgements between compound and pseudocompound target words are expected to be different. Specifically, both models predict that compound words and pictures of their constituent will yield "related" responses (see Figure 2b and 2c), whereas pseudocompounds will yield “unrelated” responses. This is so because the *postlexical* model assumes that the full word is initially recognized and only morpho-semantically related constituents are accessed (e.g., *BED* and *ROOM* in *bedroom*). Similarly, the *form-and-meaning* model postulates that morpho-semantic parsing and word recognition result in the access of semantically related constituents. Models of *parallel processes* predict that compound and pseudocompound “constituents” are accessed following the prelexical parsing route (see Figure 2d). However, parallel processes involve one additional stream that involves accessing the meaning of the whole word. While compounds and their constituents are semantically consistent with one another (especially in our set of target compound words), the representations of pseudo-constituents are assumed to be suppressed by the whole word’s meaning. Taken together, all models predict that a compound word and a picture of a constituent referent are expected to be judged as related. Conversely, the models’ predictions diverge for pseudocompound target words. Namely, models with a prelexical morpho-orthographic parser posit that pseudocompounds elicit “related” judgements (i.e., *form-then-meaning* and *parallel processing* models), whereas models accounting for the early influence of semantics on morphological parsing posit that pseudocompounds elicit “unrelated” judgements (i.e., *postlexical parsing* and *form-and-meaning* models).

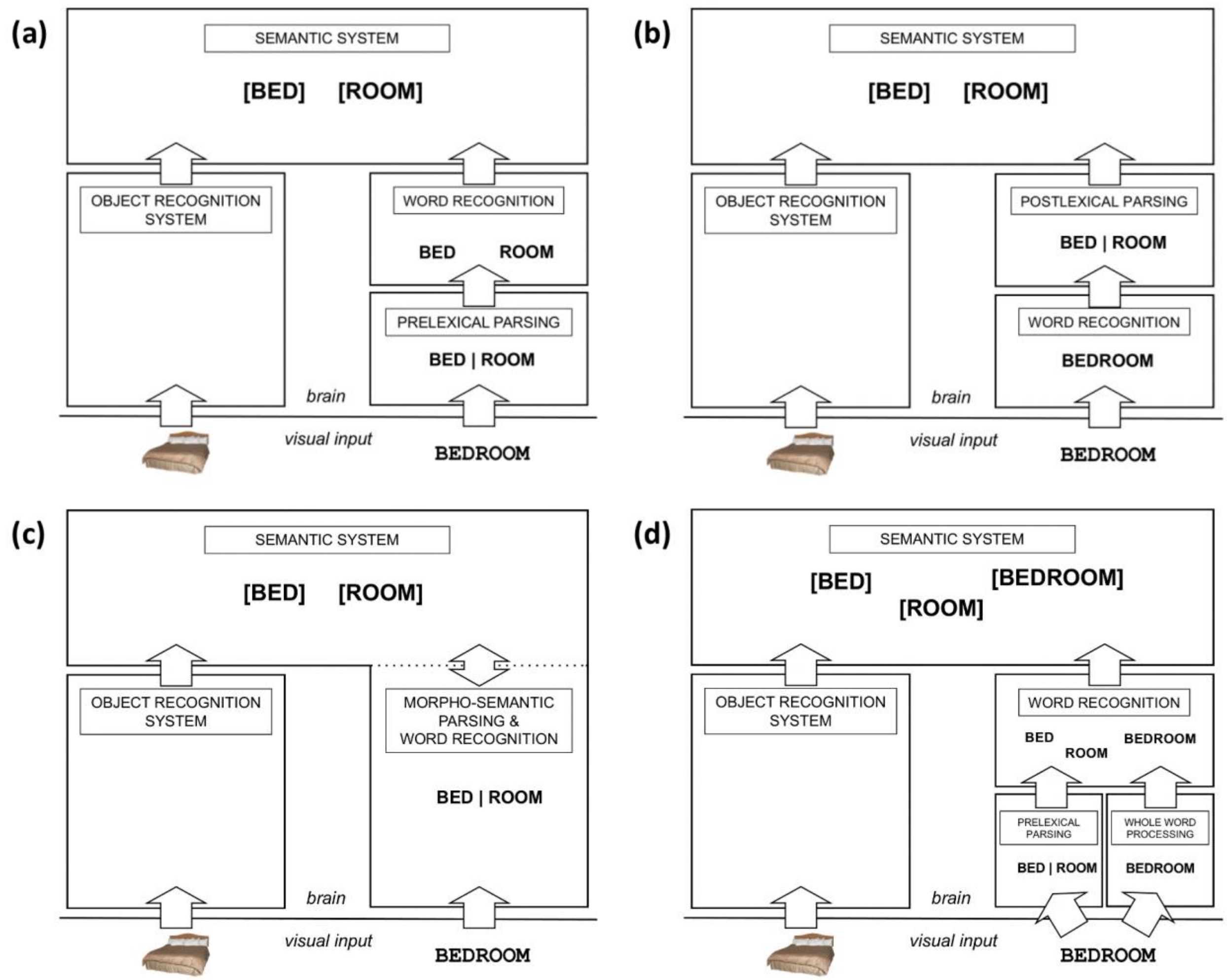

Figure 2. Relatedness judgements to the picture-word pair *BED-bedroom* under the models of (a) *form-then-meaning*, (b) *postlexical parsing*, (c) *form-and-meaning* and (d) *parallel processing*.

Another key factor in our investigation concerns the position of probed constituents. The default interpretation of compounds involves the modifier-head relation, whereby the head constituent (i.e., the rightmost constituent) determines the semantic category of the compound. Given the integral role of the head in forming compounds' compositional meaning, relatedness judgements are expected to be facilitated when probing the second constituent in comparison to the first constituent. This prediction is supported by evidence that compound recognition is promoted when the head is semantically transparent as opposed to opaque (Davis et al., 2019; Libben et al., 2003; Libben & Weber, 2014; Zwitserlood, 1994). However, another prevailing hypothesis proposes that constituents embedded at the edge of words are simultaneously identified, as it is the case of our set of compounds and pseudocompounds (Beyersmann et al., 2018; Grainger & Beyersmann, 2017). According to the hypothesis of edge-aligned parsing, relatedness judgements should not differ between first and second constituents. Evidence from morphological priming also suggests that constituent identification in compounds is not influenced by constituent position (Crepaldi et al., 2013; Fiorentino & Fund-Reznicek, 2009; Libben et al., 2018).

Method

Participants

Sixty-two participants (53 women, 8 men, and 1 non-binary) between the ages of 18 and 50 (*M* = 24.06, *SD* = 5.66). All participants were native English speakers (i.e., learned English before the age of 5 and used it as a dominant language) and had normal or corrected-to-normal vision. Participants were compensated with course credit through Concordia University's participant pool system. The study was conducted in accordance with the Human Research Ethics Committee of Concordia University (certification number 10000023).

Materials

Experimental materials were 24 compounds (*bedroom*) and 24 pseudocompounds (*fanfare*). Target words were paired with a picture probing one of their "constituents" (*bedroom-BED* and *fanfare-FAN*). The set of target pictures probing the first (C1) and second (C2) "constituents" of compounds and pseudocompounds were evenly distributed (see Appendix B). Item matching was achieved following the K-means clustering procedure reported by Guasch et al. (2017). Items in all fours sets of experimental target words were matched in (a) whole word frequency, (b) "probed" constituent frequency, (c) "unprobed" constituent frequency, (d) whole word length, (e) "probed" constituent length and (f) "unprobed" constituent length (see Table 1). Frequency was log-transformed and corresponded to the "per million" values from the *Corpus of Contemporary American English* (Davies, 2009). Length corresponds to the number of characters.

Table 1.

Sublexical, lexical and semantic characteristics of target compound and pseudocompound words.

	Compounds				Pseudocompounds			
	Picture probing C1		Picture probing C2		Picture probing C1		Picture probing C2	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Target frequency	0.42	0.44	0.42	0.33	0.42	0.29	0.42	0.47
Target length	7.08	0.67	7.42	0.51	7.00	0.95	7.17	0.72
Probed constituent frequency	1.38	0.55	1.37	0.43	1.30	0.50	1.36	0.48
Probed constituent length	3.42	0.67	3.75	0.62	3.25	0.45	3.75	0.62
Unprobed constituent frequency	1.77	0.66	1.83	0.44	1.68	0.75	1.78	0.87
Unprobed constituent length	3.67	0.49	3.67	0.49	3.75	0.97	3.42	0.51
Relatedness rating	5.57	1.43	4.73	1.92	2.20	1.47	2.43	1.90

In addition to word type and probed constituent position, we manipulated word complexity by presenting either the full target word (compound or pseudocompound) or the "constituent" together with the picture (*bed*, *fan*). This was done to obtain baseline accuracy and RTs for the relation between pictures and "constituents" embedded in compounds and pseudocompounds. To control for the size and position of the "constituents" in relation to their full word counterparts, hashmarks replaced the unprobed constituent of the full target word (e.g., the corresponding constituent target word for *bedroom* was *bed####*). The final manipulation controlled for the hemispheric projection of the target word, whereby words were presented either in the left or right visual fields (i.e., right and left V1 hemispheric projections, respectively).

In addition to the set of experimental word-picture pairs, filler trials were 48 related (e.g., *bus*-*BUS*) and 96 unrelated (e.g., *cup*-*COMPASS*) word-picture pairs. Among the unrelated fillers, 12 compound and 12 pseudocompound target words were paired with unrelated pictures. A proportional number of related and unrelated filler target words (relative to experimental target words) included hashmarks either to its left or right, ranging from 3 to 5 characters long. All target pictures were selected from the Bank of Standardized Stimuli (BOSS, Brodeur et al., 2010, 2014), which is a database of coloured object images with norms on name agreement, familiarity, visual complexity, object agreement, viewpoint agreement and manipulability.

An online rating study was conducted to assess the semantic relation between experimental word-picture pairs. The study was programmed on PsychoPy2 (Pierce et al., 2019) and hosted on the online platform Pavlovia (2020). Thirty-two native speakers of English were recruited to complete the word-picture rating task, as well as a second task unrelated to the present study. The rating task involved viewing word-picture pairs and judging the relatedness between the pair on a 7-point Likert scale (1 being completely unrelated and 7 being completely related). Mean relatedness ratings for experimental word-picture pairs are shown in Table 1.

Design

The experiment was a 2 x 2 x 2 x 2 factorial design, yielding 16 conditions. The manipulated variables were (1) whole word type (compounds and pseudocompounds), (2) word complexity (whole word and constituent), (3) probed constituent position (first and second "constituent" probed by the picture) and (4) word hemispheric projection (left and right hemisphere). The experimental word-picture pairs were counterbalanced across four lists such that each pair from a minimal pair appeared once per list. Participants completed two lists. We ensured that, across the two lists participants completed, both the full target word (e.g., *bedroom*) and probed "constituent" (e.g., *bed####*) were each presented once and in different visual hemifields. For instance, a participant could have been presented *bedroom-BED* in the first list and *BED-bed####* in the second—but never *bedroom-BED* and *bed####-BED*.

Procedure

The experiment was programmed using PsychoPy2 (Pierce et al., 2019) on a 21" iMac computer running OS 10.13 (resolution 1920 x 1080, refresh rate 60 Hz). Target words were coloured in black and displayed on a white background. Letters appeared in uppercase in monospaced Courier font. Participants were seated approximately 53 cm from the center of the computer screen, in a dimly lit room. A forehead and chin rest stabilized participants' heads to ensure their gaze was centered on the computer screen.

Participants were instructed to press the "L" key if the word and picture were related to each other or the "A" key if they were not related to each other, as fast and as accurately as possible. Trials had the following sequence: (1) a prompt instructing the participants to press the ‘spacebar’ to initiate the trial, (2) the fixation cross appearing for 1500 msec, (3) a word and a picture presented for 133 msec, (4) a backward mask presented for 200 msec to eliminate visual aftereffects, and (5) a blank screen until a response was given or after 3000 msec elapsed from stimuli onset (see Figure 3). If a response was not given within 3000 msec of stimuli onset, the trial was terminated. Words were presented either to the left or right of the fixation cross (i.e., right and left hemispheric projections, respectively), with the picture appearing in the opposite visual field. The edges of pictures and words subtended about 2 degrees of visual arc from the fixation cross. The entire experiment included 10 practice trials and two blocks of 192 trials each. The full session lasted approximately 25 minutes.

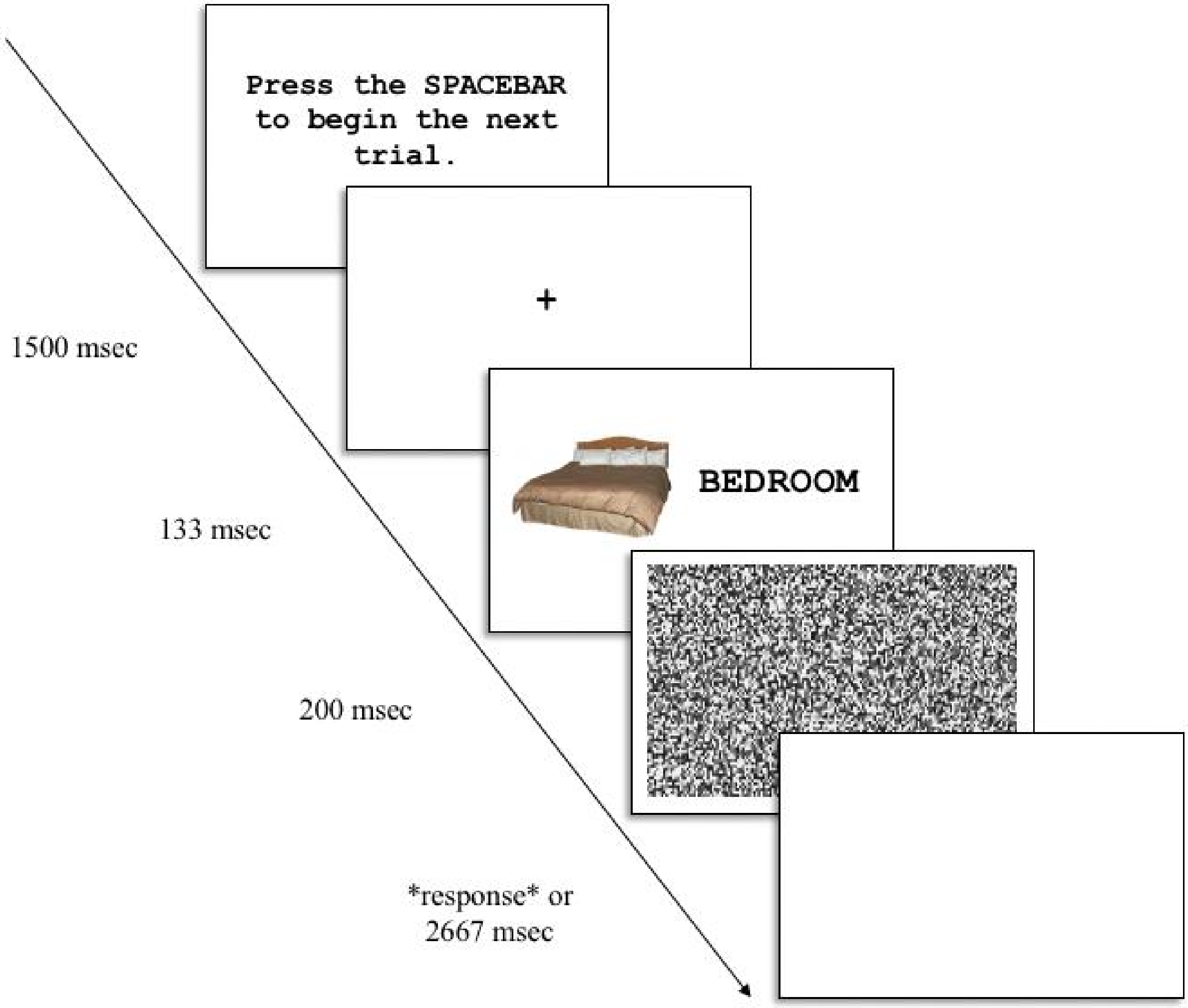

Figure 3. Timecourse for each trial in the word-picture relatedness task.

Results

Data Analysis

For experimental trials with pseudocompound target words, the "yes" responses (i.e., judgements of relatedness between pseudocompound and picture) were considered correct. While the correct response between a word-picture pair such as *fanfare-FAN* should be "no", responding "yes" reflects the degree to which the pseudo-constituent's meaning was accessed. In 151 out of 23808 trials, participants did not respond within 3000 ms of the target stimuli onset (0.63%). These trials were coded as missing data. Participants' overall accuracy was initially screened to ensure that mean performance was above chance (i.e., above 50% accuracy). All participants performed above chance, with mean accuracies ranging from 60% to 91% (M = 79.14, SD = 0.05). Subsequently, trials with RTs below 200 ms were removed, given that they were deemed to be anticipatory responses, following the criterion used in other studies (e.g., Beyersmann et al., 2020). One trial was removed following this criterion. Furthermore, RTs exceeding 2.5 standard deviations from the participants' respective means were considered outliers (Van Selst & Jolicoeur, 1994) and were replaced with the cutoff value (2.92 % of responses; Osborne & Overbay, 2004).

The accuracy and RT analyses were conducted with mixed effects models (Baayen et al., 2008) using the *lme4* package (Bates et al., 2015) in R (R Dev. Core Team, 2021). To analyze the effects of our manipulations on the outcome variables, all models included the three-way interaction between (1) whole word type (compounds and pseudocompounds), (2) word complexity (whole word or constituent), and (3) probed constituent position (first and second "constituent" probed by the picture), as well as (4) the main effect of word hemispheric projection (LH and RH). All models used the *BOBYQA* optimizer (Winter, 2019). Accuracy was analyzed in a logistic mixed-effects model, and RTs were analyzed in a linear mixed-effects model. The random effects structures were fit maximally unless there were convergence issues and singular fits. The fitted models for accuracy and RTs included random intercepts for participants and target words. Additionally, both models included by-participant slopes for word complexity and probed constituent position, as well as by-target slopes for word projection. Additional variance was factored out by including control variables, as justified by the likelihood ratio tests. Covariates in the accuracy model were block order and picture familiarity. The RT model included trial order, picture familiarity and visual complexity as covariates.[4] The *p*-values were derived for all analyses of model fit, main effects and interactions using the Likelihood Ratio Test, by comparing the full model against a reduced model excluding the relevant terms. Main and interaction effects were measured using the *mixed* function from the *afex* package (Winter, 2013, 2019; Singmann et al., 2018). The *emmeans* package with Bonferroni's correction was used to perform planned comparisons (Lenth, 2022). Following visual inspection of residual plots, RTs were log-transformed to meet the assumptions of homoscedasticity and normality of residuals (Osborne, 2002; but see Lo & Andrews, 2015). All reports of standardized effect sizes used the pooled standard deviation between two groups. The *ggplot2* package was used to create the figures below (Wickham et al., 2016). The error bars of all figures represent 95% CI of group means.

Accuracy

The full model was compared to a null model consisting of only random predictors and was found to provide a statistically better fit to the data, $\chi^2(10) = 111.00$, $p < .001$, $R^2 = 0.39$, 95% CI [0.07, 0.49]. There were significant main effects of whole word type, word complexity

[4] The picture norms were obtained from BOSS (Brodeur et al., 2010, 2014).

and picture constituent position, as well as a significant two-way interaction between whole word type and word complexity (see Table 2). We further breakdown these analyses as a function of the two-way interaction between whole word type and word complexity, as well as the three-way interaction between whole word type, word complexity and probed constituent position.

Table 2.

Logistic regression of accuracy to relatedness judgements as a function of whole word type, word complexity and probed constituent position.

Predictors	β	SE β	z-value	OR	95% CI of OR	Null Comparison
Intercept	-0.68	0.87	-0.78	0.51	[0.09, 2.77]	
Whole Word Type	-1.33	0.30	-4.48	0.26	[0.15, 0.47]	$\chi^2(1) = 34.29$, $p < 0.001$ *
Word Complexity	0.92	0.31	2.98	2.51	[1.37, 4.60]	$\chi^2(1) = 68.04$, $p < 0.001$ *
Probed Constituent Position	-0.69	0.30	-2.30	0.50	[0.28, 0.90]	$\chi^2(1) = 6.69$, $p = 0.01$ *
Word Projection	-0.23	0.12	-1.94	0.79	[0.63, 1.00]	$\chi^2(1) = 3.71$, $p = 0.054$
Block	-0.14	0.06	-2.14	0.87	[0.77, 0.99]	$\chi^2(1) = 4.49$, $p = 0.034$ *
Picture Familiarity	0.53	0.19	2.78	1.69	[1.17, 2.46]	$\chi^2(1) = 7.48$, $p = 0.006$ *
Whole Word Type x Word Complexity	0.69	0.43	1.63	2.00	[0.87, 4.60]	$\chi^2(1) = 7.59$, $p = 0.006$ *
Whole Word Type x Probed Constituent Position	-0.07	0.41	-0.17	0.93	[0.42, 2.09]	$\chi^2(1) = 0.08$, $p = 0.78$
Word Complexity x Probed Constituent Position	0.37	0.43	0.87	1.45	[0.63, 3.33]	$\chi^2(1) = 2.75$, $p = 0.097$

Whole Word Type x Word Complexity x Probed Constituent Position	0.30	0.59	0.52	1.36	[0.43, 4.30]	$\chi^2(1) = 0.27, p = 0.61$

Planned comparisons revealed that response accuracy to compounds was about 18% greater than pseudocompounds (*OR* = 3.93, 95% CI [2.62, 5.90], $p < .001$; see Figure 4). This pattern was also found when comparing the response accuracy of compounds and pseudocompounds to baseline “constituents”. That is, the decrement in accuracy between pseudo-constituents and pseudocompounds (*OR* = 7.04, 95% CI [4.55, 11.11], $p < .001$) was markedly larger in magnitude than between constituents and compounds (*OR* = 3.02, 95% CI [1.96, 4.76], $p < .001$). These results suggest that the meaning of pseudocompound “constituents” are accessed to a lesser degree than compound constituents. It seems that the morphological parser is partially sensitive to semantics. Although these effects can be attributed to a morpho-semantic parser, the theory of prelexical morpho-orthographic parsing cannot be ruled out.

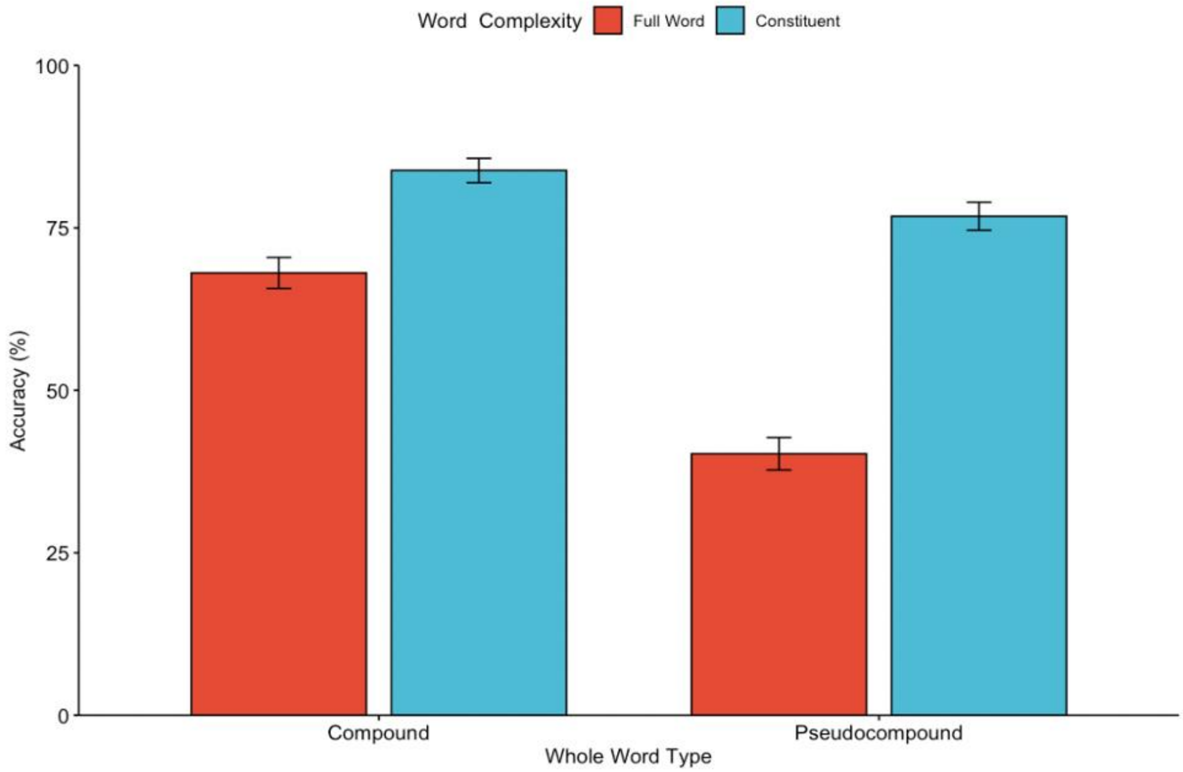

Figure 4. Mean accuracy for relatedness judgements as a function of word complexity for compounds (bedroom-BED and bed####-BED) and pseudocompounds (fanfare-FAN and fan####-FAN).

In addition, when probing the first "constituent", compounds elicited approximately 27% more accurate responses than pseudocompounds (*OR* = 3.80, 95% CI [2.12, 6.80], $p < .001$; see Figure 5). When the second "constituent" was probed, responses were around 28% more accurate for compounds in comparison to pseudocompounds (*OR* = 4.07, 95% CI [2.33, 7.12], $p < .001$). Thus, the compound advantage over pseudocompounds was also consistent for both probed constituent positions. Surprisingly, pictures probing the first "constituent" of compounds and pseudocompounds yielded more accurate responses than the second "constituent". Response accuracy was 15% greater when the target picture depicted the first constituent of compounds (e.g., *bedroom-BED*) as compared to the second compound constituent (e.g., *seatbelt-BELT*; *OR* = 1.99, 95% CI [1.11, 3.57], $p = .02$). Similarly, probing the first "constituent" of pseudocompounds (e.g., *fanfare-FAN*) yielded 16% more accurate relatedness responses than the second "constituent" of pseudocompounds (e.g., *shamrock-ROCK*; *OR* = 2.13, 95% CI [1.21, 3.74], $p = .01$). Crucially, the "modifier" position advantage seems to be at odds with hypotheses of edge-aligned identification and headedness advantage. Rather, the "modifier" advantage suggests that the morphological parser operates in a left-to-right fashion, thus initially identifying and semantically accessing the leftmost "constituent".

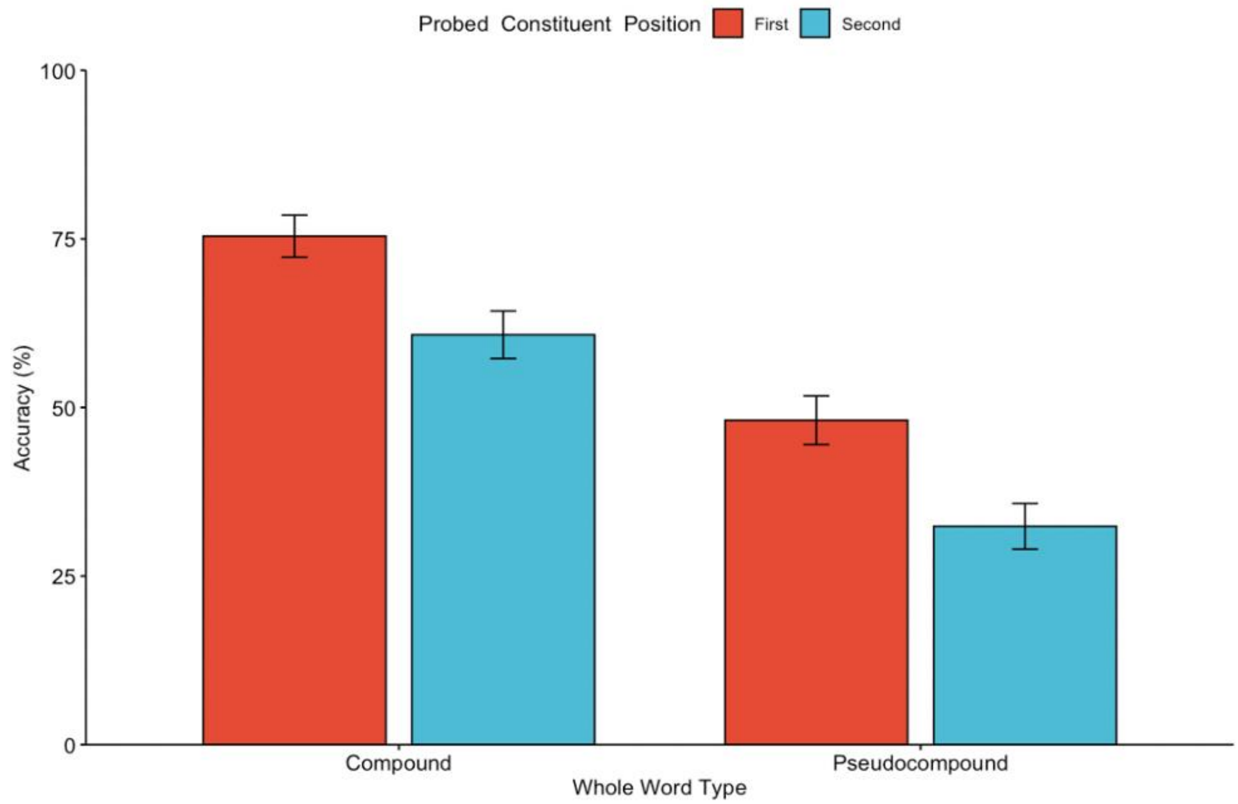

Figure 5. Mean accuracy for relatedness judgements as a function of probed constituent position for compounds (*bedroom*-*BED* and *seatbelt*-*BELT*) and pseudocompounds (*fanfare*-*FAN* and *shamrock*-*ROCK*).

Response Times

Only correct responses were included in the analyses of RT. The full model provided a statistically better fit to the data than the null model consisting of random effects, $\chi^2(11) = 246.00$, $p < .001$, $R^2 = 0.35$, 95% CI [0.01, 0.43]. The main effects of whole word type and word complexity were significant (see Table 3). There were no significant interaction effects. The analyses of RTs are further broken down, in the following sections, as a function of the whole word type by word complexity interaction, as well as the three-way interaction between whole word type, word complexity, and probed constituent position.

Table 3.

Linear regression of log10-transformed responses times to correct relatedness judgements as a function of whole word type, word complexity and probed constituent position.

Predictors	**β**	**SE β**	**t-value**	**95% CI of β**	**Null Comparison**
Intercept	3.11	0.04	77.52	[3.03, 3.19]	
Whole Word Type	0.02	0.01	1.58	[0.00, 0.04]	$\chi^2(1) = 10.94$, $p < 0.001$ *
Word Complexity	-0.05	0.01	-3.95	[-0.07, -0.02]	$\chi^2(1) = 40.99$, $p < 0.001$ *
Probed Constituent Position	0.00	0.01	0.33	[-0.02, 0.03]	$\chi^2(1) = 0.80$, $p = 0.37$
Word Projection	0.00	0.01	-0.19	[-0.01, 0.01]	$\chi^2(1) = 0.03$, $p = 0.85$
Trial Order	0.00	0.00	-13.70	[0.00, 0.00]	$\chi^2(1) = 183.07$, $p < 0.001$ *
Picture Familiarity	-0.02	0.01	-3.25	[-0.04, -0.01]	$\chi^2(1) = 9.98$, $p = 0.02$ *
Picture Visual Complexity	-0.02	0.01	-2.61	[-0.03, 0.00]	$\chi^2(1) = 6.46$, $p = 0.011$ *
Whole Word Type x Word Complexity	0.00	0.02	0.06	[-0.03, 0.03]	$\chi^2(1) = 0.39$, $p = 0.53$
Whole Word Type x Probed Constituent Position	0.01	0.02	0.64	[-0.02, 0.05]	$\chi^2(1) = 0.06$, $p = 0.80$
Word Complexity x Probed Constituent Position	0.00	0.02	0.11	[-0.03, 0.03]	$\chi^2(1) = 0.28$, $p = 0.60$

Whole Word Type x Word Complexity x Probed Constituent Position	-0.02	0.02	-0.71	[-0.06, 0.03]	$\chi^2(1) = 0.50$, $p = 0.48$

In line with the results for accuracy, responses to compound words were faster than to pseudocompounds (d = -0.28, p = .01; see Figure 6). These results further support the idea that accessing compound constituents is facilitated compared to pseudocompound "constituents". The discrepancy between compound and pseudocompound processing may suggest that the morphological parser is sensitive to morpho-semantic representations of the whole word. It is important to note that while relatedness judgements are initiated later for pseudocompounds, responses are nonetheless based on the semantic access of pseudo-constituents. Thus, the delay in pseudocompounds may be caused by retrieving representations that are semantically inconsistent with each other, such as pseudo-constituent and full word meanings. For instance, the word *fanfare* is judged as related to the picture *FAN* following access to the pseudo-constituent meanings of *fan* and *fare*. Crucially, the delay in RTs can be attributed to a semantic composition stage producing an anomalous interpretation of the target word. Another explanation for the delay in pseudocompounds assumes that the whole word meaning is concurrently accessed with "constituent meanings". The meaning of the whole word interferes with the "constituent meanings", which ultimately results in the suppression of the latter.

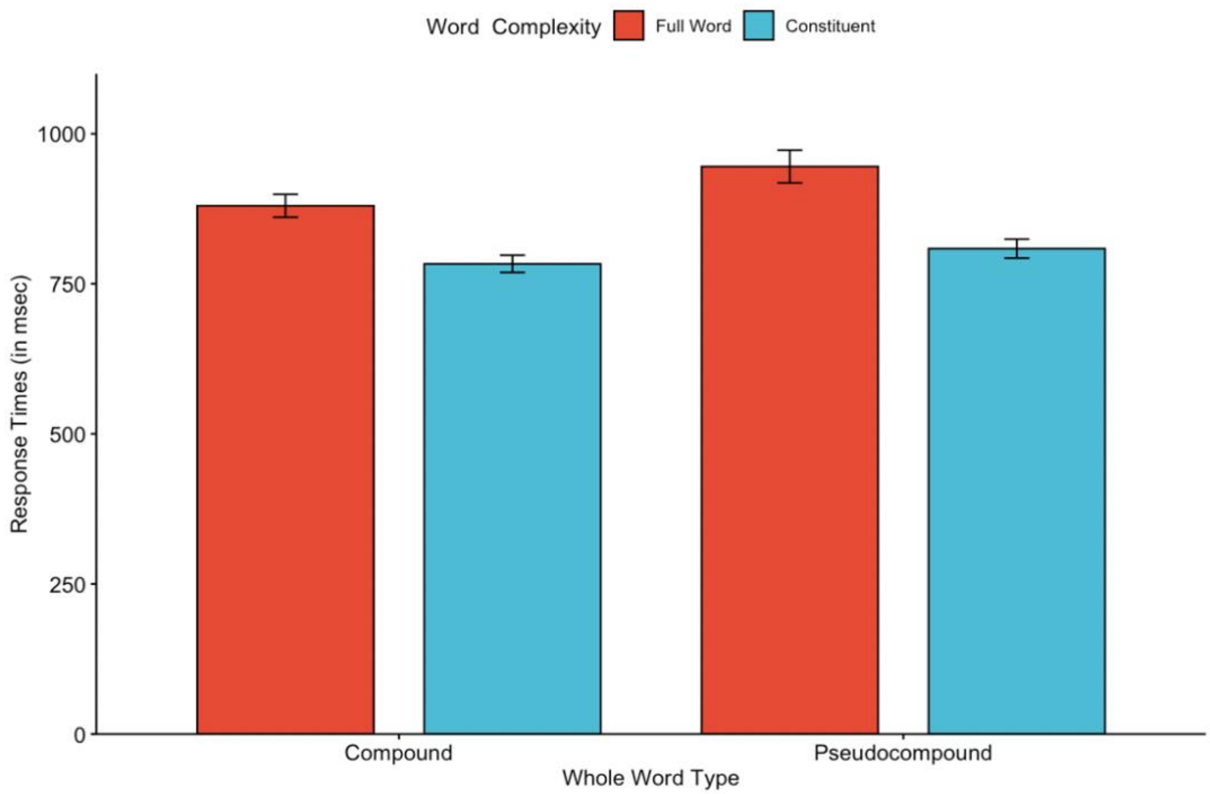

Figure 6. Mean RTs for correct relatedness judgements as a function of word complexity for compounds (*bedroom-BED* and *bed####-BED*) and pseudocompounds (*fanfare-FAN* and *fan####-FAN*).

Contrary to the results for accuracy, the delay in responding to pseudocompounds as compared to compounds was not consistent for both probed constituent positions (see Figure 7). When probing the first "constituent", there was no significant difference in RTs between compounds and pseudocompounds (e.g., *bedroom-BED* and *fanfare-FAN*; d = -0.19, p = .14). On the other hand, compounds elicited faster relatedness judgements relative to pseudocompounds when the target picture depicted the second "constituent" (e.g., *seatbelt-BELT* and *shamrock-ROCK*; d = -0.28, p = .03). However, the comparison between the first and second probed constituent positions did not yield significant differences for compounds (e.g., *bedroom-BED* and *seatbelt-BELT*; d = -0.04, p = .75), nor for pseudocompounds (e.g., *fanfare-FAN* and *shamrock-ROCK*; d = -0.15, p = .27). Our findings seem to suggest that morphological processing is not driven by the constituent's position in compounds and pseudocompounds. However, these RT results are inconsistent with the modifier position advantage observed in accuracy. That is, while there was no difference in the speed of relatedness judgements, responses were more accurate for both compounds and pseudocompounds when probing the first "constituent" in comparison to the second. We will return to this issue in the discussion section.

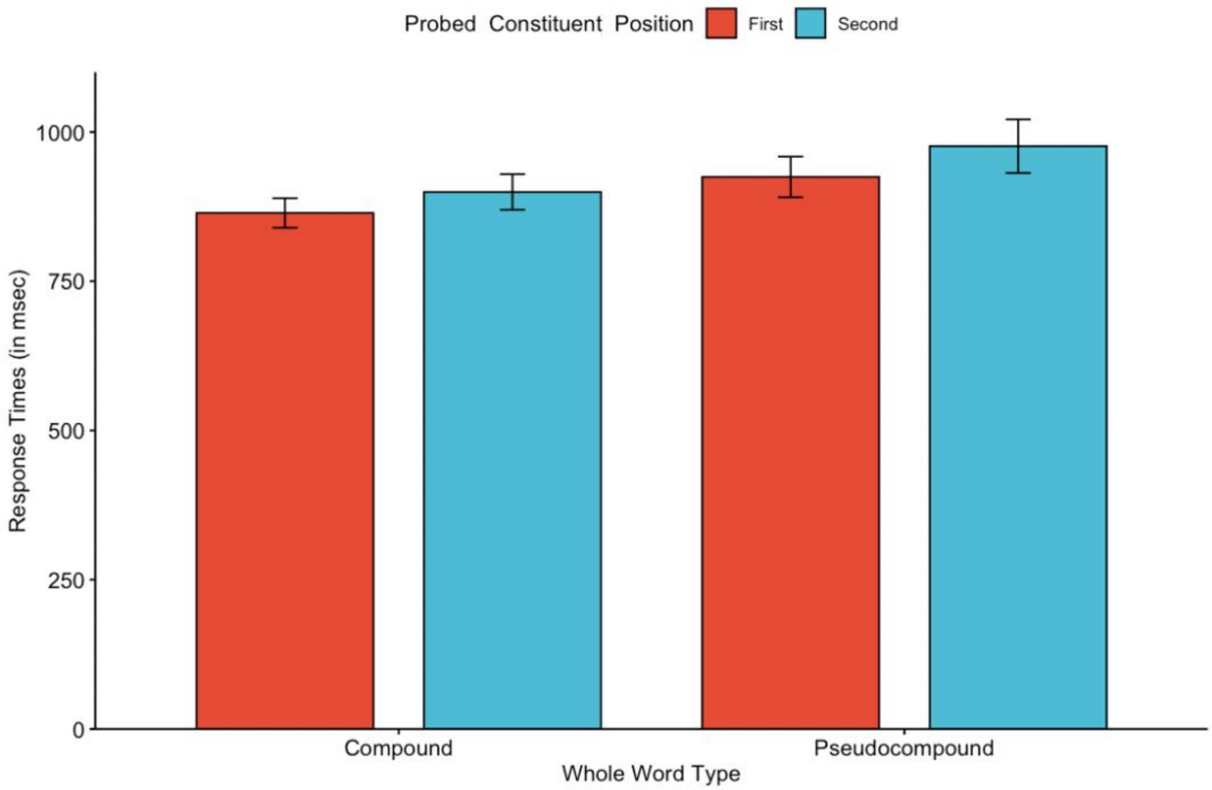

Figure 7. Mean RTs for correct relatedness judgements as a function of probed constituent position for compounds (*bedroom-BED* and *seatbelt-BELT*) and pseudocompounds (*fanfare-FAN* and *shamrock-ROCK*).

Discussion

The present study aimed to investigate whether the meanings of compound and pseudocompound "constituents" are accessed during lexical processing. We employed a word-picture relatedness task with targets presented dichoptically—thus without allowing for foveation—for a brief presentation duration (133 msec and backward masked). The technique aimed at tapping the early moments of word and object recognition and their access to semantic representations. The main manipulation involved presenting compound or pseudocompound words with pictures representing referents of their "constituents". The comparison between compound and pseudocompound processing allowed us to examine the nature of the morphological parser. Four models of visual word recognition and their respective predictions were reviewed. *Form-then-meaning* and *parallel processing* models posit that a prelexical morphological parser decomposes letter sequences while blind to semantics. Under both these views, compound and pseudocompound "constituents" are expected to be accessed, with the influence of semantics ruling out misparses. In contrast, *postlexical parsing* and *form-and-meaning* models propose that morphological processing operates with knowledge of the constituents' meanings. Thus, according to this view, only compound constituents are expected to be identified and semantically accessed.

Our key findings indicated that pseudocompound "constituents" are semantically accessed but to a lesser degree than constituents embedded in compounds. These results were supported by more accurate responses and shorter RTs to compounds compared to pseudocompounds. Additionally, relatedness judgements to pseudocompounds were around 48% when probing the first "constituent" and 32% when probing the second. Thus, pseudocompounds and the target pictures probing their pseudo-constituents (e.g., *fanfare*-*FAN*) elicited incorrect responses at a rate of approximately 40% (assuming that the correct response in these trials is "no"). Crucially, relatedness judgements are expected to be closer to zero, according to models positing a morpho-semantic parser (i.e., *postlexical parsing* and *form-and-meaning* cognitive architectures). In fact, a subset of unrelated filler word-picture pairs included pseudocompounds (e.g., *office-PITCHER*), and their mean error rate was around 18% (i.e., responding "yes" when the correct answer was "no"). Comparatively, experimental trials with pseudocompounds seemed to provide some evidence supporting the semantic access of pseudo-constituents. Overall, these results can be accounted for by models positing a morphological parser that identifies potential constituents without the initial aid of semantic knowledge.

If "constituents" are accessed following morphological parsing, why do relatedness judgements differ between compounds and pseudocompounds? The discrepancy between compounds and pseudocompounds suggests that semantics quickly rules out misparsed words. Both the *form-then-meaning* and the *parallel processing* models offer explanations for the role of semantic representations in rectifying misparses. The former model proposes that the semantic system composes the meaning of both "constituents" according to the modifier-head structure (Fruchter & Marantz, 2015; Neophytou et al., 2018; Stockall et al., 2019). For instance, semantic composition roughly yields the coherent meaning "a room with a bed" for the compound *bedroom*, and the incoherent meaning "a fare for fans" for the pseudocompound *fanfare*. In the case of pseudocompounds, semantically anomalous compositions trigger a reinterpretation, ultimately suppressing pseudo-constituent representations in favor of the whole word's meaning. Models of *parallel processes*, on the other hand, predict that the meaning of the whole word is accessed concurrently with "constituent" meanings (e.g., Caramazza et al., 1985; Diependaele et al., 2009; Libben & de Almeida, 2002). Under this view, the meaning of the full pseudocompound competes with pseudo-constituent meanings, and the latter is consequently suppressed.

Additionally, the decrement in accuracy for pseudocompounds relative to compounds was reliable when probing the first and second “constituents”, whereby compounds elicited more accurate responses than pseudocompounds regardless of probed “constituent” position. However, the compound advantage was only found when probing the second “constituent” in RTs. That is, when the target picture depicted the second “constituent”, relatedness responses were faster for compounds over pseudocompounds (e.g., *seatbelt-BELT* and *shamrock-ROCK*, respectively). Conversely, there was no significant difference in RTs between compounds and pseudocompounds probed through the first “constituent” (e.g., *bedroom-BED* and *fanfare-FAN*, respectively). These results broadly support the idea that whole word representations influence later stages of pseudocompound processing. Crucially, the inconsistent results in RTs may provide insight into two different levels of semantic processing: (a) an early stage driven by the semantic access of “constituents” and (b) a later stage involving the influence of semantics (as outlined above). Specifically, the lack of an effect in RTs between compounds and pseudocompounds when probing the first “constituent” can be attributed to the early access of “constituent” meanings following a left-to-right parse (see e.g., Libben, 1994; Taft & Forster, 1976). Thus, relatedness judgements may be initiated by comparing the initial outputs from word and object recognition systems.

Did the position of “constituents” influence semantic access? Regarding the effect of probed constituent position on compounds and pseudocompounds, results were inconsistent between accuracy and RTs. Participants’ responses were more accurate to referent pictures of the first “constituent” as compared to the second “constituent” for both word types. To a first approximation, the first "constituent" (or modifier) advantage suggests that morphological parsing proceeds in a left-to-right fashion—contra to hypotheses of a headedness effect and edge-aligned parsing (e.g., Grainger & Beyersmann, 2017; Libben et al., 2003). If morphological parsing first identifies the leftmost constituent, we would also expect to find a modifier advantage in RTs. Rather, RTs did not differ between probed constituent positions for compounds and pseudocompounds. Altogether, these results cast doubt on the proposal of left-to-right parsing. Another interpretation, reconciling the significant probed constituent position effects for accuracy but not for RTs, considers the semantic interference between the word's compositional meaning and the "constituent's" object referent. On the view of the *form-then-meaning* cognitive architecture, "constituent" meanings are initially accessed and quickly integrated following the modifier-head relation. For instance, the compositional meaning of *seatbelt* refers to a type of *belt* modified by *seat*. This compositional meaning is incongruent with the object referent *BELT*, which represents a generalized type of *belt*. The discrepancy in the degree of specificity between the compositional meaning and the object referent can justify the decrement in accuracy to "head constituents" (e.g., *seatbelt-BELT*, *shamrock-ROCK*). The similar RTs when comparing first and second "constituents" of compounds (e.g., *bedroom-BED* and *seatbelt-BELT*) and pseudocompounds (e.g., *fanfare-FAN* and *shamrock-ROCK*) can be explained by the idea that (correct) responses were initiated prior to forming the compositional meaning. Simply put, responses can be made as soon as word and object recognition systems access the same meaning.

As for the *parallel processing* framework, it seems unclear how this model can account for the semantic interference between the whole word and the probed "head constituent". Up to this point, we have assumed that the morphological parsing route only yields "constituent" access. Along these lines, *parallel processing* models lack the crucial semantic composition stage that integrates constituent meanings following the modifier-head structure. In fact, Schreuder and Baayen (1995) propose a dual-route model which initially decomposes letter sequences (along the morphological parsing route) and recombines the meanings of identified constituents. This version of the *parallel processes* model can be suited to explain the difference in accuracy between the first and second "constituent", given that it accommodates the composition of "constituent meanings".

Taken together, our findings partially support the view of a morphological parser that operates with knowledge of morpho-orthographic regularities in written language. This parser seems to initially treat compound and pseudocompound words the same, such that "constituents" are identified and semantically accessed. There was also some evidence pointing to a morphological parser that reads letter strings left-to-right. However, the first "constituent" advantage was only found in accuracy, whereas the RT analyses did not reveal significant probed "constituent" position effects for compounds and pseudocompounds. A rapid semantic composition process may account for these results, whereby constituent meanings are combined following a modifier-head structure. Thus, the compositional word meaning is inconsistent with the picture referent when probing the second "constituent", given that the former refers to a specific subset of a category, whereas the latter picks out a more general category. For instance, the compositional meaning of *seatbelt* picks out a subordinate type of *belt* that is incongruent with the picture depicting a more general *belt*. The lack of difference in RTs between probed constituent positions suggests that relatedness judgements can be initiated early in semantic processing. Specifically, assuming compounds and pseudocompounds are broken down, the initial outputs from word and object recognition access the meaning of the probed "constituent".

Simply put, the word-picture pair *seatbelt-BELT* initially accesses the meaning *belt* (prior to the semantic composition stage), thus triggering a relatedness judgement. While we did not find a headedness advantage, our results suggest that the "head constituent" seems to play a key role during the later stages of semantic processing—in line with evidence from unprimed and primed lexical decision studies (Libben et al., 2003; Libben & Weber, 2014).

Our results are in line with word-picture paradigms involving the picture naming task (Bölte et al., 2013; Dohmes et al., 2004; Zwitserlood et al., 2000, 2002). Namely, both word-picture paradigms (i.e., with relatedness judgements and picture naming) found evidence for compound and pseudocompound "constituent" access, which are assumed to be a consequence of prelexical morpho-orthographic parsing. This interpretation is in direct opposition to findings from semantic priming, which do not provide support for pseudocompound "constituent" access (El Bialy et al., 2013; Melvie et al., 2022; Sandra, 1990; Zwitserlood, 1994). A potential limitation of the morpho-semantic priming technique concerns the lexical decision task, which may be a less reliable indicator of semantic processing (Bueno & Frenck-Mestre, 2008; de Groot, 1990). On the other hand, our relatedness task with the dichoptic presentation of word-picture pairs captures the early moments of semantic access by relying on brief exposure durations of target stimuli (133 ms). Our findings can also be interpreted to support morpho-orthographic parsing with parafoveal viewing (see e.g., Angele & Rayner, 2013). Although the stimuli presentation was very brief, it is surprising that "constituent" meanings were not degraded to the point at which performance was at or below chance. Rather, this technique demonstrates that visual word recognition operates quickly even with degraded visual input from stimuli presentation.

In conclusion, considering the overarching goal of the present study, prelexical morpho-orthographic parsing seems to partially underlie the access of compound and pseudocompound "constituent meanings". Altogether, our results may be taken to support a visual word recognition system that decomposes letter strings with knowledge of morphology but is initially blind to semantics. In particular, *form-then-meaning* and *parallel processing* models propose such a morphological parser. Consequently, while the morphological parser does mistakenly segment morphologically simple words carrying pseudo-constituents (e.g., *fanfare*), the key to accessing their conventional meaning is the later influence of semantics. That is, the whole word representation can be accessed (a) following the semantically anomalous composition of pseudo-constituents—as proposed by the *form-then-meaning* model—or (b) concurrently with the pseudo-constituent meanings, via a whole word processing route—as proposed by *parallel processing* models.

More broadly, our study provides insights into the fundamental processes that allow us to derive meaning from lexicalized and novel words. Crucially, words play a special role in our cognitive architecture, considering they are one medium through which distal stimuli connect to semantic representations. Thus, understanding the interface between visual word recognition and semantics contributes to our understanding of how word knowledge is stored and processed in the mind.

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Appendix A

Summary Statistics of Accuracy in the Pilot Experiment

Table 4.

Mean accuracy (standard deviation in parentheses) in related judgements as a function of whole target words by probed constituent position.

	Compound	Pseudocompound
Picture probing C1	58.33% (2.53)	48.98% (2.54)
Picture probing C2	39.58% (2.51)	37.23% (2.51)

Appendix B

List of Experimental Materials Coded for Lexical, Sublexical and Semantic Properties

Target Word	Target Picture	Whole Word Type	Probed Constituent Position	Word Frequency	Word Length	Probed Constituent Frequency	Probed Constituent Length	Unprobed Constituent Frequency	Unprobed Constituent Length	Semantic Rating
SAWDUST	SAW	COMPOUND	First	0.36	7	2.43	3	1.53	4	4.94
PIGSKIN	PIG	COMPOUND	First	0.09	7	1.17	3	1.91	4	5.53
BOWTIE	BOW	COMPOUND	First	0.08	6	1.24	3	1.49	3	5.65
COWHIDE	COW	COMPOUND	First	0.06	7	1.16	3	1.57	4	4.29
BARNYARD	BARN	COMPOUND	First	0.21	8	1.10	4	1.49	4	6.35
DRUMBEAT	DRUM	COMPOUND	First	0.23	8	1.00	4	1.92	4	5.41
BEEHIVE	BEE	COMPOUND	First	0.25	7	0.99	3	0.50	4	5.53
ARMPIT	ARM	COMPOUND	First	0.29	6	1.87	3	1.19	3	4.12
EARRING	EAR	COMPOUND	First	0.35	7	1.50	3	1.69	4	5.24
STAIRWAY	STAIR	COMPOUND	First	0.49	8	0.40	5	3.05	3	6.94
DESKTOP	DESK	COMPOUND	First	1.03	7	1.64	4	2.42	3	5.71
BEDROOM	BED	COMPOUND	First	1.54	7	2.07	3	2.51	4	6.00
DUSTMOP	MOP	COMPOUND	Second	0.00	7	0.55	3	1.53	4	5.29
HEADLAMP	LAMP	COMPOUND	Second	0.18	8	1.01	4	2.54	4	5.47
SNOWSHOE	SHOE	COMPOUND	Second	0.18	8	1.21	4	1.74	4	3.35
NECKTIE	TIE	COMPOUND	Second	0.21	7	1.49	3	1.71	4	6.59
SEATBELT	BELT	COMPOUND	Second	0.30	8	1.41	4	1.84	4	3.65
SANDBOX	BOX	COMPOUND	Second	0.34	7	1.98	3	1.49	4	2.29
EYEBALL	BALL	COMPOUND	Second	0.40	7	1.96	4	2.00	3	3.24
ASHTRAY	TRAY	COMPOUND	Second	0.40	7	0.97	4	1.03	3	4.24
HANDBAG	BAG	COMPOUND	Second	0.44	7	1.81	3	2.48	4	5.18
DOORBELL	BELL	COMPOUND	Second	0.54	8	1.55	4	2.33	4	4.53
POPCORN	CORN	COMPOUND	Second	0.81	7	1.44	4	1.62	3	5.65
TEASPOON	SPOON	COMPOUND	Second	1.23	8	1.07	5	1.68	3	6.59
CARNATION	CAR	PSEUDOCOMPOUND	First	0.13	9	2.39	3	2.13	6	1.71

HAMPER	HAM	PSEUDOCOMPOUND	First	0.42	6	0.93	3	2.19	3	1.47
HATRED	HAT	PSEUDOCOMPOUND	First	1.13	6	1.55	3	2.24	3	1.53
POTION	POT	PSEUDOCOMPOUND	First	0.42	6	1.44	3	0.56	3	2.71
PILLAGE	PILL	PSEUDOCOMPOUND	First	0.18	7	1.04	4	2.31	3	2.88
PLUMMET	PLUM	PSEUDOCOMPOUND	First	0.35	7	0.67	4	2.11	3	2.53
RAMPAGE	RAM	PSEUDOCOMPOUND	First	0.46	7	0.92	3	2.03	4	3.11
VASELINE	VASE	PSEUDOCOMPOUND	First	0.18	8	0.63	4	2.40	4	1.94
PENCHANT	PEN	PSEUDOCOMPOUND	First	0.52	8	1.26	3	0.61	5	2.12
CAPSIZE	CAP	PSEUDOCOMPOUND	First	0.08	7	1.44	3	2.01	4	2.24
FANFARE	FAN	PSEUDOCOMPOUND	First	0.43	7	1.70	3	1.03	4	2.29
LEGION	LEG	PSEUDOCOMPOUND	First	0.72	6	1.62	3	0.56	3	1.94
SONNET	NET	PSEUDOCOMPOUND	Second	0.31	6	1.61	3	2.28	3	1.47
DONKEY	KEY	PSEUDOCOMPOUND	Second	0.67	6	2.13	3	1.65	3	1.41
HERRING	RING	PSEUDOCOMPOUND	Second	0.60	7	1.69	4	3.46	3	1.41
HEMLOCK	LOCK	PSEUDOCOMPOUND	Second	0.28	7	1.41	4	0.52	3	3.77
SEXTILE	TILE	PSEUDOCOMPOUND	Second	0.00	7	0.81	4	2.08	3	2.35
GANGLION	LION	PSEUDOCOMPOUND	Second	0.11	8	1.15	4	1.38	4	1.94
HEATHEN	HEN	PSEUDOCOMPOUND	Second	0.33	7	0.66	3	1.95	4	1.82
PAGEANT	ANT	PSEUDOCOMPOUND	Second	0.63	7	0.71	3	2.03	4	1.35
MANDRILL	DRILL	PSEUDOCOMPOUND	Second	0.02	8	1.13	5	2.88	3	5.22
THOUSAND	SAND	PSEUDOCOMPOUND	Second	1.73	8	1.49	4	1.13	4	3.65
CAPRICE	RICE	PSEUDOCOMPOUND	Second	0.23	7	1.61	4	1.44	3	1.65
SHAMROCK	ROCK	PSEUDOCOMPOUND	Second	0.16	8	1.95	4	0.56	4	3.06