ABSTRACT

Title of Document:	LEXICAL STRUCTURE AND THE NATURE OF LINGUISTIC REPRESENTATIONS
	Robert D. Fiorentino, Doctor of Philosophy, 2006
Directed By:	Professor David Poeppel, Department of Linguistics

This dissertation addresses a foundational debate regarding the role of structure and abstraction in linguistic representation, focusing on representations at the lexical level. Under one set of views, positing abstract morphologically-structured representations, words are decomposable into morpheme-level basic units; however, alternative views now challenge the need for abstract structured representation in lexical representation, claiming non-morphological whole-word storage and processing either across-the-board or depending on factors like transparency/productivity/surface form. Our cross-method/cross-linguistic results regarding morphological-level decomposition argue for initial, automatic decomposition, regardless of factors like semantic transparency, surface formal overlap, word frequency, and productivity, contrary to alternative views of the lexicon positing non-decomposition for some or all complex words.

Using simultaneous lexical decision and time-sensitive brain activity measurements from magnetoencephalography (MEG), we demonstrate effects of initial, automatic access to morphemic constituents of compounds, regardless of whole-word frequency, lexicalization and length, both in the psychophysical measure (response time) and in the MEG component indexing initial lexical activation (M350), which we also utilize to test distinctions in lexical representation among ambiguous words in a further experiment. Two masked priming studies further demonstrate automatic decomposition of compounds into morphemic constituents, showing equivalent facilitation regardless of semantic transparency. A fragment-priming study with spoken Japanese compounds argues that compounds indeed activate morphemic candidates, even when the surface form of a spoken compound fragment segmentally-mismatches its potential underlying morpheme completion due to a morpho-phonological alternation (*rendaku*), whereas simplex words do not facilitate segment-mismatching continuations, supporting morphological structure-based prediction regardless of surface-form overlap. A masked priming study on productive and non-productive Japanese de-adjectival nominal derivations shows priming of constituents regardless of productivity, and provides evidence that affixes have independent morphological-level representations.

The results together argue that the morpheme, not the word, is the basic unit of lexical processing, supporting a view of lexical representations in which there *are* abstract morphemes, and revealing immediate, automatic decomposition regardless of semantic transparency, morphological productivity, and surface formal overlap, counter to views in which some/all complex words are treated as unanalyzed wholes. Instead, we conclude that morphologically-complex words are decomposed into abstract morphemic units immediately and automatically by rule, not by exception.

LEXICAL STRUCTURE AND THE NATURE OF LINGUISTIC REPRESENTATIONS

By

Robert D. Fiorentino

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Advisory Committee:
Professor David Poeppel, Chair
Professor Colin Phillips
Professor William Idsardi
Professor Norbert Hornstein
Professor Nan Bernstein Ratner

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Chapter 1: Introduction

Section 1: Basic Issues and Research Approach: Lexical Representation

The main thrust of the last 30-40 years of research on language has presupposed some version of the computational theory of mind. However, it is now sometimes argued that alternative systems for representing lexical and sentential processes, i.e. without recourse to abstract representations and algebraic rules for their combination, are now sufficiently well developed to challenge the basic tenets of the computational theory of mind (Elman, 2004, Hay and Baayen, 2005, Seidenberg and Gonnerman, 2000, among others). How can one adjudicate among these fundamentally opposing viewpoints on mental representation? One way forward is to explore the tenability of the competing viewpoints on mental computation in a narrow domain, in which specific divergent hypotheses arise under the opposing viewpoints. We argue here that word structure is one such domain, research from which may move us further in deciding among the alternatives. This kind of research on the basic units in language, with the aim of better understanding the inventory of mental representations and computations involved, offers opportunities in its course for pressing forward in the development of linking hypotheses among knowledge of grammar, language use, and its neural instantiation (i.e. linguistics, psycholinguistics, and neurolinguistics).

In this dissertation, we will address the foundational question of whether abstract representations are the basic units which enter into hierarchical structure-dependent relationships in language processing, or whether the representational inventory is quite different, consistent with alternative views on what kinds of things linguistic representations are, by focusing in on the nature of lexical representations. Our main focus will be on whether there is evidence that lexical representations are indeed treated as internally-structured representations, consistent with approaches to lexical representation positing abstract morphological level structures, and our methods will include both psychophysical and neural measurements of aspects of language processing.

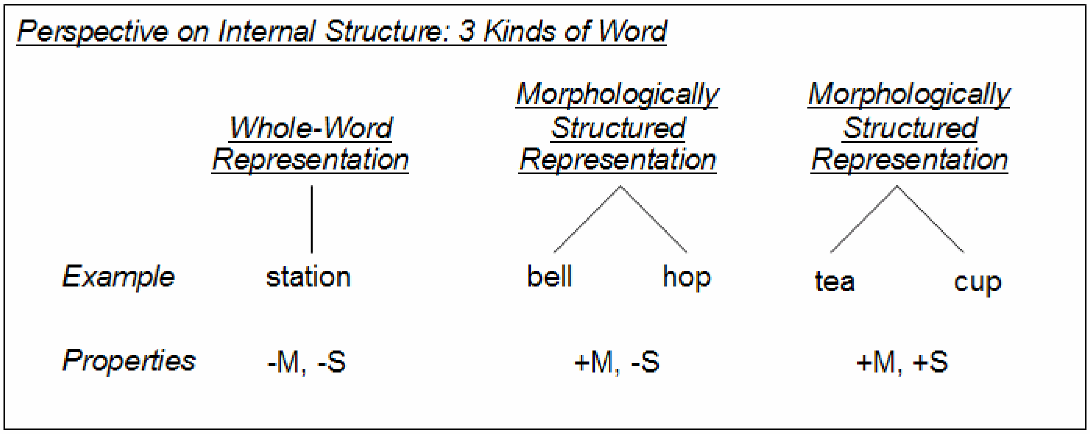
The issue of the nature of linguistic structure has been highly controversial in the domain of word structure. Specifically, alternative views question whether there is any role for morphological-level decomposition in the processing of putatively complex words (such as *cars*, *darkness*, or *teacup*). The question is whether the basic-level units in lexical processing are morphemes, that is, abstract units which enter into structured representations, or whether the so-called complex words can be treated as unanalyzed wholes (see e.g., Hay and Baayen, 2005). These concerns motivate several basic questions about language from a cognitive neuroscience point of view, regarding the basic nature of linguistic representations from a representational and processing perspective, including their neural basis, the building and interpretation of structure in real time, and the organization of linguistic knowledge (for example, the role of idiosyncrasy in considering the architecture of language).

We will approach these questions from an experimental point of view in the current dissertation, taking the word formation process of compounding as a major test case, which can bring important new findings to bear on this debate, testing specific divergent predictions regarding the presence and precise time course of decomposition under competing models. Through a variety of experimental methods, we hope to test whether retrieval of items from lexical memory indeed is mediated by decomposition into morpheme-level constituents, what kinds of information involving the morphological level (such as morphologically-conditioned phonological variation) play a role in morphological decomposition, and what role potential constraints play in determining whether words are represented and processed decompositionally (such as semantic transparency, word frequency, and productivity), focusing specifically on whether these constraints indeed preclude morphological-level decomposition in some cases. Here, we will both examine compounding in this light, and also extend our survey beyond compounding to investigate the representation of roots and affixes in derivational morphology. We will conclude the dissertation with supporting research from a distinct domain, lexical semantics, which we show to further support our experimental approach and conclusions about the nature of lexical representation.

Section 2: Words: A Bird's Eye View

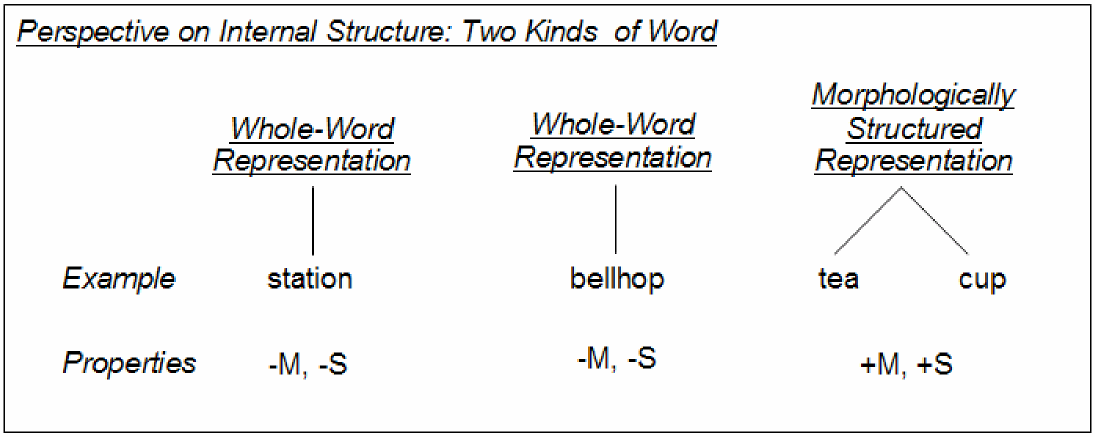
Three types of word. A standard linguistic view on the lexicon is that there are three types of word: those which are morphologically and semantically decomposable (+M, +S) (e.g., *teacup*), those which are morphologically but not semantically decomposable (+M,-S) (e.g. *bellhop*), and those which are neither morphologically nor semantically decomposable (-M, -S) (e.g. *station*); see Figure 1. However, this view is arguably *not* the standard assumption in psycholinguistic or neurolinguistic thinking.

Figure 1 Representational System with Three Kinds of Word



Two types of word. A standard approach in these research areas, recently promulgated by Pinker, Ullman, and colleagues, is that there are essentially two types of word, namely those which are 'regular' complex words, which will be processed in terms of their parts (i.e., they are +M, +S), and those which are atoms (represented and processed as monomorphemic), including 'irregular' complex words; they will be (-M, -S), as shown in Figure 2. Under this 'Words and Rules' approach, the former type are associated with 'computation', and the latter with 'storage' (e.g., Pinker, 1999, Ullman, 2001).

Figure 2 Representational System with Two Kinds of Word



One type of word. An alternative view of the lexicon posits that in fact there is only one kind of word. Under this family of approaches, there is no direct motivation to posit internal structure to any word from a morphological perspective, including those which *seem* complex, although arguably the cases like *teacup* have different patterns of semantic activation with relation to other atoms, *tea* and *cup*, in comparison to the other two instances, *bellhop* and *station*; see Figure 3. There are several intuitions which may perhaps point in the direction of this viewpoint. The first of them (shared with the *Words and Rules* approach) is that idiosyncrasy of meaning or form may suggest that storage (of something, somewhere) is necessary.[1] As recently expressed, morphemes in such a case are a "highly problematic theoretical

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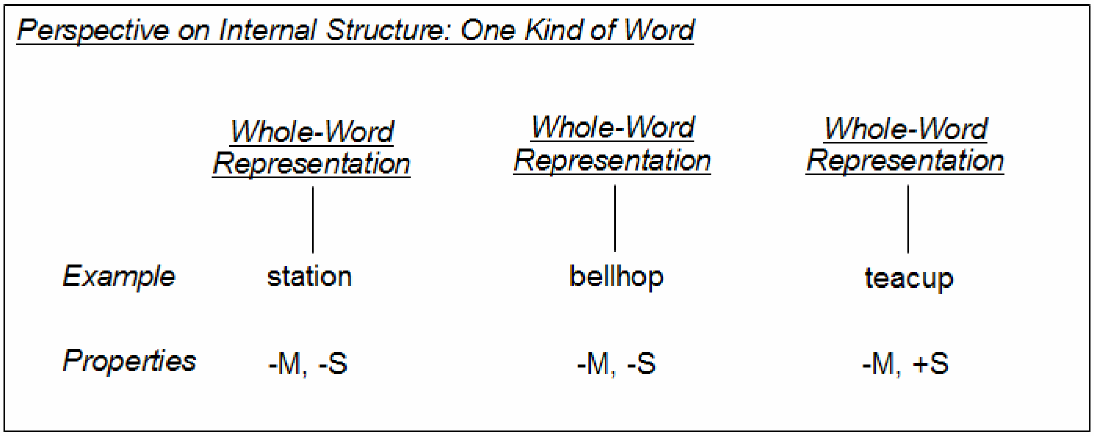
[1] This intuition is undoubtedly on the right track, and any account will have to recognize the consequences of idiosyncrasy even in processing measures; however, idiosyncrasy in complex words does *not* straightforwardly imply consequences such as the lack of morphological decomposition, lack of internal morphological structure, and storage of full forms, although such consequences are often standardly assumed. In what follows, we will explore empirically whether these attributes indeed follow in the occasion of various types of idiosyncrasy (of meaning, form, and productivity), and do the same for other putative limiting factors, such as surface frequency and lexicalization.

construct" (Hay and Baayen, 2005). The second is that given the view of the brain as capable of massive storage, the arguments for something like storage economy fail to carry weight; here, reference is made to the "profligate capacity" of the brain which computation-based views of morphology are thought to underestimate; again, see Hay and Baayen (2005) for a recent articulation of this view. The third (and at least in partial opposition to the *Words and Rules* view), is that if simpler 'neurally plausible' similarity-based processing can account for putative abstract morphological-level computations, the commitment to abstraction as a representational system at the word level has less motivation (Elman, 2004, Seidenberg and Gonnerman, 2000, among others).

Figure 3 Representational System with One Kind of Word



What is at stake among these alternative views of lexical representation from a bird's eye view? It is worth taking stock from the beginning of what is at issue behind these specific proposals and the assumptions about lexical storage and computation that they explicitly or implicitly assume – before we turn to experimental tests, in context of which we must engage very specific theories on retrieval from lexical memory for various kinds of word, and various kinds of putative constraints, in order to adjudicate among these theories empirically. Behind the views on the kinds of words, there lie distinct notions on the presence of internal structure and abstraction in the system. Under the first linguistically-motivated view, the lexicon contains both basic units and more complex internally-structured representations made up of these units, and this internal structure is not fully reliant on a formal or semantic relationship; under this view, there is no epistemological bias to treat words as atomic. Under the third view, there is no need to posit internal structure or computation over these structures. “Words” can be represented and processed as atoms (and seeming effects of structure can be explained in other ways). The second view both makes reference to abstract internal structure and computation (but in this case, these features are circumscribed to cases in which there is some sense of regularity) and to storage as atoms for irregular ‘complex’ words as well as simplex words (i.e., monomorphemic words); this view, which has indeed pushed heavily for computation and against storage in cases showing regularity, makes massive commitments to unstructured storage and analogical processing when faced with idiosyncrasy.

Distinguishing the alternatives. Is there a way into the question of which representational system is on the right track, from a cognitive science perspective? Indeed, there is a rich literature on lexical processing, some of which directly attempts to answer these questions. Remaining intentionally vague for the time being, in keeping with the bird’s eye view: some findings argue for internal structure; some for internal structure only under some circumstances, and others against the notion of internal structure and abstraction in the representation and processing of lexical items in the mind and brain. The aim of the current dissertation will be as follows. We will investigate the nature of lexical representation, with specific focus on the issue of morphological-level representation, with the goal of better understanding three issues: (i) Do true morphological-level effects hold? (ii) Can we find environments in which we can tease apart whether these effects can be epiphenomena of formal or semantic properties which do not imply internal morphological representation? (iii) Can we get a better sense of whether the putative constraints which have been cited in arguing either for a view in which internal structure holds only in cases exhibiting regularity (as the second view holds) or in which processing at the level of morphological structure is not necessary at all (compatible with the third view), indeed do initially constrain the processing of lexical representations such that some or all so-called complex words are indeed treated as atomic? Ultimately, the cross-method research presented here, in context of the previous psycholinguistic literature, will argue that the initial processing of so-called complex words in terms of internal structure is widely evident, and will argue that the role of idiosyncrasy as a countervailing factor at the initial stages of lexical processing might, contrary to standard views, be on the wrong track.

Section 3: Organization of the Dissertation

In this dissertation, we report a series of experiments designed to clarify the nature of lexical representations using (i) morphological-level decomposition, and (ii) effects of ambiguity on lexical representation, as major test cases. First, we report an experiment using a combined lexical decision and MEG recording methodology designed to test directly for effects of word structure, comparing morphologically simplex words and compound words matched on overall properties, but with internal morphological level constituents of shorter length and higher frequency (e.g. *flagship* vs. *crescent*). These results show response times which are shorter to the compounds than matched single words, as predicted by constituent rather than whole-word properties: further, effects of reduced latency in the electrophysiological signal support the notion that this difference holds during initial lexical activation, since the differences across conditions showing constituent rather than whole-word properties also predicted the latency of the first MEG component sensitive to lexical properties of words (the M350 component). This argues for initial rather than late decomposition (late decomposition is morphological activation subsequent to full-form processing), whereas both early and late decomposition were in principle compatible with the lexical decision responses alone. This study also addresses the first of the putative constraints on decomposition which we will examine in this dissertation— surface frequency, which has been claimed to affect whether words are processed as unanalyzed wholes or decompositionally, and our results suggest *across-the-board decomposition* regardless of surface frequency.

Following these results, we move to a set of masked priming studies with the following goals. The masked priming studies aim to provide converging evidence that morphological constituents are indeed activated automatically during compound processing, as suggested by the findings from our first experiment, and further, to test whether (i) this occurs both for head and non-head positions, and crucially (ii) both for semantically transparent and semantically opaque compounds. This directly tests not only morphological decomposition, but also the issue of putative constraints (here, we focus on semantic transparency), and the tenability of late rather than initial decomposition (e.g., Giraudo and Grainger, 2000), and alternative non-morphological accounts of activation relying solely on semantic or formal overlap (see Hay and Baayen, 2005, Seidenberg and Gonnerman, 2000). These studies also have a third goal: to determine whether previous masked priming results using affixed primes can be accounted for as due to affixal salience rather than to decomposition in the general case (for discussion of this issue, see, e.g., Andrews et al., 2004, Longtin et al., 2003, Longtin and Meunier, 2005). In our study, the compounds facilitate responses to their constituents *regardless of semantic transparency*, supporting automatic full decomposition, presenting challenges for approaches lacking a central role for morphemes, and establishing that masked morphological priming effects cannot be solely attributed to affixal salience.

Following these studies, we next consider whether the evidence for internal morphological-level structure also holds for spoken word processing, and crucially, whether these effects hold even when the surface formal input mismatches with the underlying morpheme representation (as can be caused by morphologically-conditioned phonological changes in complex words). To do so, we investigate cross-modal fragment priming in Japanese, extending the use of this paradigm to the investigation of lexical activation in complex word processing. We focus on a morphologically-conditioned phonological alternation in which, when two morphemes are sisters in a compound (e.g. *shiro*+*kani*; Gloss: 'white'+ 'crab'), the initial segment of the second morpheme undergoes a voicing alternation (called sequential voicing, or *rendaku*) in some environments, from unvoiced to voiced (thus 'white crab' is *shiro**ga**ni*, not *shiro**ka**ni*). If the parser follows only the phonological surface form in processing spoken words, the target '*kani*' should not be activated when the word '*shirogani*' unfolds, say, at the moment when the input stream contains the fragment '*shiroga_*'. However, if the parser considers a possible compound structure continuation and "undoes" *rendaku*, then hearing only *shiro* (white) plus *ga* (the initial fragment of the voiced counterpart of *kani*) should also activate 'kani' in addition to phonological cohort candidates like *gake* (Gloss: 'cliff') or *gara* (Gloss: 'pattern'). We found the predicted priming for '***ka**ni*' after 'shiro***ga_***', when contrasted with the control point (right after *shiro*, but before -*ga*). Thus, activation is not limited to phonological cohort members, but includes possible morphemic constituents compatible with a morphologically-conditioned phonological variation. These findings suggest that compound structure is predicted incrementally in spoken word processing, and support the conclusion that abstract morphemes are activated online in a manner not bound by surface formal identity, but involving underlying structural hypotheses.

In the next chapter, we explore an additional question raised by complex words beyond compounds which has not received previous attention: if the lexicon is organized in terms of abstract morphemes, then do affixes also have independent representations? This allows us to directly engage the final putative constraint on decomposition which we will discuss: *productivity*. Are only productive affixes represented separately? To resolve these issues, we conduct a masked affix-priming study using two Japanese nominalizing suffixes (*–mi*, *–sa*) which serve the same function (de-adjectival nominalization) but differ extremely in their productivity. The results show significant facilitation regardless of productivity, suggesting the conclusion that that affix priming holds, like root priming, and importantly, that even unproductive root-affix combinations are decomposed, calling into question the locus of the difference among productive/unproductive forms (cf. Ullman, 1999, Bertram et al., 2000).

We conclude the dissertation by testing the combined psychophysical and MEG method which we presented in the first experiment, in a new domain of lexical representation, namely that of lexical semantics. Within linguistic theory, homonymous words (e.g. *bank*) are routinely taken to have separate lexical entries, while serious controversy remains whether polysemous words (e.g. *paper*) also have separate entries or a single lexical entry. We investigate this using simultaneous MEG and visual lexical decision, parametrically varying number of senses and number of lexical entries, following Rodd et al. (2002). The results show distinct effects of senses and entries; more entries, but not more senses, caused response time delays and later peak latency in the MEG component around350 ms post-onset. This supports a conception of the lexicon in which homonymous words have separate entries, and polysemous words a single entry, counter to the view in which multiple senses, like multiple homonymous meanings, engender separate lexical entries. The MEG results lend converging evidence for a lexical locus of the response time effects and confirm the utility of this MEG component for investigating the nature of lexical representations (Beretta et al., 2005), and once again reinforce the general conclusion that the *nature of lexical representation is not defined solely by atomic token representations, but by linguistically-motivated distinctions on the internal structure of basic units* (morphemes) across domains, as shown across word types, languages, tasks, and measures in the current dissertation.

Chapter 2: Why Compounds?

Section 1: Nature of Compounding

The core of the dissertation, especially the first three studies (Chapters 3-5), will focus on compounding, first examining English compounding (Chapters 3-4), and then moving on to Japanese compounding (Chapter 5). Before looking at these experiments in detail, it is necessary to reflect on why compounds may make a good choice for answering the questions we set out with in the Introduction, namely, what is the nature of lexical representation? What do complex words such as compounds tell us about the basic units and combinatorics of language?

Recall that much of the argumentation for the major “bird’s eye” views on lexical representation research presented above has utilized evidence adduced from complex words involving the word-formation processes of derivation and inflection (most famously, recall the ‘past tense debate’ which has been focused mainly on the *Words and Rules* vs. the word-form/atomist viewpoints). It is then useful, for the sake of introducing the current studies and placing them in context of this primary literature, to highlight some respects in which compounds are particularly well-suited for addressing the questions raised in this debate on the foundations of lexical representation and processing and engaging these questions in interesting ways. Note that we will not limit ourselves to compounding in the current dissertation, with Chapters 6 and 7 presenting studies on affix representations and productivity (Chapter 6) and lexical-semantic effects on the representation of lexical items (Chapter 7).

However, since we place a large focus on compounding, it is worth setting the stage here.

Section 2: Compounding as Research Domain

Subsection 1: Goals

Compounding is a word formation process which involves the joining of two (or more) open-class morphemes (content words) to form larger complex words (e.g., *tea* + *cup* → *teacup*). As a word formation process, compounding is an environment which allows one to raise an interesting set of issues directly related to the nature of lexical representations. Among these are to what extent complex words are represented and processed in terms of internal morphological structure (and conversely, to what extent seeming effects of internal structure can be explained due solely to formal and/or semantic effects while holding to a whole-word-form representational system which makes no commitment to internal structure or an abstract morpheme-based lexicon). As always, the investigation of these issues in complex words raises interesting issues regarding the effects of formal or semantic idiosyncrasy on structure. As we will see below, studying compounding experimentally carries some important benefits that engage these issues and offer ways to extend the existing literature on the representation and processing of complex words in important ways. While we will address these issues in detail in the experiments to follow, we briefly mention some relevant points at which compounding allows a unique window into better understanding the impact of these various factors in the processing of complex words.

Subsection 2: Meaning

Perhaps the most well-known and most often studied aspect of compounding concerns semantic transparency, or the relation of the compound's parts to the whole compound word. Quite unlike inflection, and to a greater extent than derivation, the compound word can carry a meaning that is seemingly closely related to one or both parts (e.g. *teacup* seems related to both *tea* and *cup*, while *strawberry* seems related to *berry*, though not to *straw*), or related to neither part (at least synchronically), such as *bellhop*, (one who carries luggage at a hotel).

The processing of compounds, which show wide variation in the level of semantic transparency, is thus relevant to the debate on internal structure for the following two related reasons involving semantic transparency. The first is that, given cases like *bellhop*, in which the meaning of the compound is not straightforwardly related to its parts, building up the meaning from the parts on the fly (as is often attributed to a default morphological decompositional architecture) seems to be difficult, thus leading to the claim that perhaps at least opaque compounds (and other surface forms) are represented and processed as unanalyzable wholes (see Sandra, 1990, for example); for a similar claim for derivations, see Marslen-Wilson et al., (1994). Unsurprisingly, if this is on the right track, it begs the question whether morphological-level representation is then needed at all, or whether any putative effects for semantically-transparent compounds may be wholly accountable based on semantic relationship among whole-words, without any need for positing morphological structure. Further, just as semantically opaque compounds challenge a view in which all compounds are represented and processed using morphological-level representations, it is often mentioned that even among so-called transparent cases, the relation among the morphemic constituents is underdetermined (see Downing, 1977, among many others, for problems outlining the possible relations among compound constituents, and Gagné and Shoben, 1997, among others, for some studies on how constituent combinations may be interpreted online). Under these circumstances, it has often been assumed that semantic opacity on the one hand makes a strong argument for atomism, and semantic transparency offers a chance to account for evidence of morphological constituency as relations among atoms at a semantic level instead.

We will directly address the issue of semantic transparency in the experiments in Chapter 4, in which we report a set of masked priming studies probing for the activation of compound constituents from compound primes which are either semantically transparent or semantically opaque, showing priming effects regardless of transparency. The issue of semantic activation will also come into play in the experiment reported in Chapter 5, regarding constituent activation in spoken compound words (here looking at priming from novel spoken word fragment primes to their rightmost (head) morpheme). In this experiment, as we discuss in more detail in Chapter 5, semantic relationships are held constant across experimental and control conditions, suggesting that the reported experimental vs. control condition difference, which is attributed to morphological-level structure, cannot be accounted for using semantic means. We will thus argue from the findings in these priming studies that semantic transparency does not strongly constrain morphological-level processing, contrary to a view in which idiosyncrasy at the semantic level precludes the possibility of internal structure-based processing (which reminds us of similar arguments made with respect to phrasal idioms, and brings up important questions regarding how, then, the idiosyncratic knowledge is represented).

Subsection 3: Form

We now turn to a brief discussion of what may be studied regarding the potential role for surface formal features in the processing of putatively complex words. As suggested above, much attention has been paid to whether effects attributed to morphological-level constituency can instead be accounted for as overlaps in surface formal features (i.e., orthographic/phonological overlaps), which, if such effects were to reduce to surface features, the reasoning goes, there would no longer be a need to posit morphological-level abstract representations for these words in the mental lexicon (again, see Hay and Baayen, 2005, Seidenberg and Gonnerman, 2000, for accounts along these lines). In the following, we consider some surface factors with import for yielding effects (or pseudo-effects) of morphological-level constituency, which may benefit from study specifically with compounds, as outlined below (we have selected cases which we pursue experimentally in this dissertation, and thus do not intend the areas discussed below to constitute an exhaustive list).

Affixal salience. This factor is addressed in all the experiments on compounds (Chapters 3, 4, and 5), and a detailed discussion of issues of affixal salience is included in Chapter 4, in which studies on the masked priming of compound constituents are presented. As discussed there, studies of morphological decomposition using compounds constitute a novel test of whether previously observed decompositional effects using derived and inflected complex words rely specifically on the ability to quickly recognize a salient, closed class form (the affix). With affixed forms, it is not clear whether seeming effects of rapid automatic decomposition (see the masked priming results of Longtin et al., (2003) or Rastle et al., (2004), for two examples) arise solely because of the perceptually salient affix form, or whether morphological-level segmentation occurs automatically in the general case (see Andrews et al. (2004) and Longtin et al. (2003) among others, for more discussion of this issue in compounding and derivation, respectively). The reasoning for testing compounds (which are made, in languages such as English, exclusively from open-class 'content' morphemes)[2] is then straightforward, but crucially important: if morphemic constituent activation is seen for compounds in the

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[2] We are leaving aside, for the moment, compounding in languages (such as German) which involve the insertion of linking elements, but return to this issue in Chapter 5, where we discuss an interesting test case regarding linking elements in German compounding. (The English cases which are most useful for the kinds of test we are discussing here are those in which the compound is presented orthographically without a space or hyphen, in order to test for the presence of morpheme-based processing in compounds orthographically represented as single words).

same environments where it has been observed for affixed forms (e.g. masked priming), it can be argued that these decompositional effects do not depend on the presence of a salient, closed class affix, but indeed extend to morphological processing in the general case.

Orthographic/phonological overlap, and morpho-phonological alternation.

Like other complex word forms, compounding allows for tests of whether seeming effects of morphological structure are independent of factors such as orthographic or phonological overlap. That is, is there a difference in having shared form and sharing identical morphemes? For example, from a linguistic point of view, *cartwheel* and *cart* overlap in sharing a morpheme, while *cartwheel* and *car* share orthographic formal overlap but not morphological overlap. However, understanding whether there are indeed morphological-level effects in the processing of complex words which can be teased apart from effects of formal similarity has played a crucial role in evaluating the evidence for internally-structure based processing (which assumes a morphological-level analysis), as opposed to alternative accounts which do not recognize morpheme-based processing or representation in the mental lexicon (see, e.g. Seidenberg & Gonnerman (2000) for one such approach). Interestingly, the masked priming paradigm offers a testing ground for this issue, since it has been observed that while morphological overlap yields facilitation, orthographic overlap does not (but yields inhibition); we will return to these issues in Chapters 4 and 6 of this dissertation, which involve masked priming for compounds and derivationally-affixed words, respectively.

In this dissertation, however, we also test one interesting morpho-phonological alternation (called sequential voicing or *rendaku*) which plays a role in how the second morpheme of some compounds in Japanese will be phonologically realized, which may speak directly to issues of surface form constraints on lexical activation in complex words in a new way. Interestingly, in Japanese compounding (in certain phonological environments), a phonological change (a voicing alternation) will take place on the initial segment of the second morpheme, which crucially is triggered by the presence of the morpheme boundary between the first and second constituents in order for the alternation to take place. While we will present the mechanisms of this alternation in detail in Chapter 5, we briefly mention it here to show that, under these circumstances, a mismatch among the morpheme's surface form within a compound and the morpheme's form in isolation is engendered. Using a cross-modal fragment-priming technique (in which a fragment is heard by the participant, immediately followed by a visually-presented target word), we show a way to test whether the underlying morpheme form is indeed activated during the processing of spoken compound fragments despite the phonological segment-level *mismatch* in surface form; we predict that if abstract internal structure is predicted online, the underlying morpheme should be activated despite the morpho-phonological mismatch. Thus, responses to the underlying morpheme should be consistent with the pattern of activation effects which hold for matching standard single-word fragment completions (e.g., bro_ → broth), and in contrast to the pattern of effects which holds for single-word mismatching fragments in the same paradigm (e.g. b**l**o_ → b**r**oth). We present results suggesting that the *rendaku*-compatible continuation is indeed activated online, despite the segment mismatch, and explore the implications for the online computation of compound structure and abstract morpheme-level representations, in Chapter 5 below.

Position effects. Unlike derivationally complex words or inflectionally complex words, compounds contain open-class roots in both head and non-head position, allowing for the study of constituency effects in all positions of a compound word, whereas typically for inflected and derived words, experimental investigation of constituency effects relied on root effects from one position in the complex word. Ultimately, tests of position are quite useful for (i) identifying whether what looked like morphological activation effects may simply be word-onset activation (which would predict no priming for the non-onset morpheme, for example), and (ii) for teasing apart the relative role of linear position and headedness, or position within the internal structure (see, e.g., Jarema et al., 1999, for a study with this particular focus).

We test this factor in the experiments in Chapter 4, to verify whether masked priming effects hold across position, by testing for priming from whole compounds both to their first (left/non-head) constituent, and to their second (right/head) constituent. The findings indeed show significant priming for both the non-head and the head position of English compounds in the masked priming paradigm. Chapter 5 also offers evidence from spoken compound processing for activation of lexical candidates for the right (head) position in Japanese compounds.

Subsection 4: Structure

Issues involving morphological constituency and the processing of complex words as internally-structured objects lie at the core of this dissertation, and form the foundation of all of the experiments presented here. We will focus on bimorphemic word structure here; for the most part, we will not consider issues of internal hierarchical structure for multimorphemic compounds (save for a bit of discussion of the properties of *rendaku* in multimorphemic Japanese compounds), although it is worth pointing out that the possibility of investigating the internal hierarchical structure within multimorphemic complex words has been a subject of research in morphological theory, and has begun to attract attention experimentally; see Krott et al. (2004) for one example, and Libben and de Almeida (2005) for some discussion of issues in multimorphemic word processing.

Section 3:Summary

As a word formation process, compounding (especially in languages like English) is perhaps striking first in its simplicity, involving the simple merger of two open class words to form a complex word. At first glance it may be counterintuitive to think that this process yields particularly useful testing cases for the direct role of internal morphological structure, as suggested by a morpheme-based view of the lexicon as comprised of abstract morphemes and involving morphological decomposition and composition. However, we have briefly mentioned some properties of compounds that will come into play in the experiments in this dissertation. Experimental research using compounding indeed makes possible very specific tests of aspects of lexical processing upon which hinge the commitment to alternative views of the mental lexicon – namely, whether there is empirical evidence that complex words are indeed treated as internally morphologically structured, and whether any such evidence may arise from non-morphological factors such as formal or semantic overlap which carry no particular commitment to structure, or abstraction, for the so-called complex words, and finally, whether the treatment of words as internally complex is fundamentally, initially affected by idiosyncrasy.

Subsection 1: New Empirical Evidence on Morphological Representation in Compounding

In the next chapter, we will report the first experiment involving compounding, which is designed to test directly for effects of internal structure in complex words using English bimorphemic compounds. In the initial sections of the chapter, we present a brief survey of the previous experimental results and models which have been proposed to account for the nature of morphological complexity effects observed in tasks such as lexical decision, eye-tracking, and priming. Then, we present our first study, which is designed to directly compare effects of internal structure by contrasting compounds with monomorphemic controls, matched on overall properties but mismatched such that the compounds carry morphemic constituents which are higher in word frequency and shorter than the whole compound or matched monomorphemic words. Further, the experiment is designed such that not only response times (a measurement at the very endpoint of lexical decision) but brain activity millisecond-by-millisecond from the onset of the word stimuli is also measured using MEG, allowing a detailed set of dependent measures during the time course of processing preceding the overt response. We now turn to the first experiment, in Chapter 3.

Chapter 3: Morphological Decomposition in Compounds: Evidence from Simultaneous Visual Lexical Decision and Magnetoencephalography[3]

Section 1: Introduction

Subsection 1: Background and Some Classic Findings from Lexical Decision

The role of morphological complexity in the representation and processing of compound words and inflectionally- or derivationally-affixed words is hotly contested in the psycholinguistic literature (e.g., Dominguez et al., 2000, Forster, 1988, McQueen and Cutler, 1998, Seidenberg and Gonnerman, 2000, Taft, 1991). The literature on this topic over the last 30 years includes research on inflections, on derivationally complex words, and, to some extent, on compound words. Compounds, which are comprised of two or more root morphemes, are widely attested in many languages, and, as discussed above, may show either transparent (e.g. *teacup*) or opaque (e.g. *bellhop*) semantic relations among the parts and the whole (see, e.g., Bauer, 1983, Downing, 1977, Levi, 1978, Spencer, 1991). The research on morphological complexity in the psycholinguistic literature has variously supported both decompositional and non-decompositional accounts, as we will review in more detail below. Further, the locus of putative effects of decomposition has not yet been fully understood, including when they hold during the time course of lexical

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[3] Portions of this chapter are adapted from Fiorentino and Poeppel (in press).

processing. Ultimately, however, a better understanding of these issues is crucial, both from the psycholinguistic and the broader cognitive science perspectives, as the differing viewpoints on compound representation and processing make very different claims on the nature of the representation of linguistic material in the cognitive architecture of language. The aim of the current study is to present a new cognitive neuroscience experimental approach for testing the non-decompositional hypothesis of compounds against the class of decomposition models, adding a neural index of access to constituents to the behavioral measure. We present behavioral and neural evidence for structured representation in the lexicon, which is reflected in the early decompositional processing profile of known compound words. We discuss these findings in the context of the emerging literature on early morphological parsing and other results suggesting abstract structured representations in the lexicon.

Experiments by Taft and Forster (1975) were among the first to use the lexical decision task to investigate the processing of affixed words. Taft and Forster (1976) extended this research to compounding, showing effects of morphological constituency in compounds, which were taken to suggest the *online decomposition of complex forms*. For example, Taft and Forster (1976), Experiment V compared response times to compounds with high vs. low-frequency first constituents, when whole-word frequency is held constant, showing that compounds with higher-frequency first constituents (e.g. *headstand*) were responded to more quickly than those with lower-frequency first constituents (e.g. *loincloth*). However, this conception of lexical processing did not go unchallenged. Butterworth (1983) offered a competing analysis of the role of morphological structure in processing, positing a *non-decompositional* account; this followed from the intuition that full parsing could not work since the idiosyncrasies observed in complex words (such as lack of full productivity for morphological rules) suggested that morphological rules could not drive lexical processing online. In this type of account, words that seem to be morphologically complex are not treated as such; instead they stored and processed as whole words. Non-decompositional processing has been claimed for many types of complex word, even including words which seem to have been formed by morphological processes such as regular past-tense formation (for some experimental studies supporting this view, at least in part, see Baayen et al., 1997, Manelis and Tharp, 1977, Sereno and Jongman, 1997, Stemberger and MacWhinney, 1986, among others).

Subsequent lexical decision research continued to utilize the basic paradigm of the early experiments such as Taft and Forster (1976), manipulating frequency of compound constituents and looking for differential frequency effects. Briefly, the logic behind the differential frequency effect is that, given the assumption that lexical items with higher frequency of occurrence may be retrieved from lexical memory more quickly than those with lower frequency of occurrence, then if compounds are indeed decomposed into morphemic constituents during lexical access, a compound with a high frequency morpheme in a given position should be responded to more quickly than an otherwise matched compound with a lower frequency morpheme in the same position. Two studies on compounds subsequent to Taft and Forster (1975, 1976) which examined the effects of manipulating constituent frequency within compound words are Andrews (1986) (Experiments 2 & 3) and (Juhasz et al., 2003) (Experiment 1).

In Andrews (1986) and Juhasz et al. (2003), internal constituent frequency was manipulated and constituent frequency in fact affected reaction time, with higher frequency first or second constituent frequency correlating with faster response time. Andrews (1986) found consistent effects of constituent frequency; Juhasz et al. (2003) also report constituency effects, but note that first constituent effects were more clear when second constituents were low frequency, suggesting that access to the constituents depended centrally on the properties of the second (head) constituent. For example, compounds like *starlight*, with a low-frequency first constituent and high frequency second constituent, were responded to more quickly than words like *starboard*, with a low-frequency first constituent and low-frequency second constituent (Juhasz et al., 2003). Further, although Andrews (1986) found the predicted constituency effects for compounds, the effects for derivationally complex words depended on the stimulus set: the effects were significant only when compound words were part of the stimulus set, leading to the conclusion that decompositional effects, including compound constituent effects, were not prelexical, and were probably controlled rather than automatic. While both results suggest some role for morphological constituency, the computation of constituency and its locus in the time course of lexical processing remain unclear. While we have quickly mentioned two differential-frequency studies on compounds (Andrews, 1986 and Juhasz et al., 2003), it is worth noting that there are many additional studies which follow this basic approach, especially for other types of morphologically complex word, such as inflected and derived words. In those studies, the logic of the experiments is quite similar to the differential frequency effect for compounds mentioned above; in the studies on inflection and derivation, the basic reasoning is that, under the assumption that these types of word are decomposed during lexical processing, then effects of the frequency of the root morpheme (*base-frequency effects*) should be evident, when whole-word frequency is kept equal, for example (e.g., Baayen et al., 1997, Colé et al., 1989, New et al., 2004, among many others).

Subsection 2: A Major Hurdle for Lexical Decision Research

A major hurdle. While lexical decision results have been used from the very beginnings of this debate on internal structure in words, it is worthwhile to preface some of the potential dangers of interpretation that come along with it. By its very nature, lexical decision is a measurement at the very end stage of processing, and thus is potentially sensitive not only to the initial stages of lexical access, but also stages following this, all the way through the planning of the response. This is a value in that the lexical decision task is directly relevant for the testing of hypotheses at all these stages, and further, any effect in the lexical decision task must be accommodated at some stage of one's computational model, so one does not want to say that lexical decision is not useful, only that the locus of effects detected in lexical decision is underspecified – it is not straightforward to attribute them to effects of lexical access or post-access processing (e.g. Balota & Chumbley, 1984; Monsell, Doyle, & Haggard, 1989; Seidenberg, Waters, Sanders, & Langer, 1984). This leads to the a difficulty of interpretation, which has perhaps made it much more challenging to tease apart when morphological decomposition does or does not occur, arising when predicted decompositional effects are not visible in lexical decision (Bertram et al., 2000b, cf. Taft, 2004). Just as the kind of *differential-frequency* effects in compounds and *base-frequency* effects in inflected and derived words cited above have been used to argue for decomposition during lexical processing, the lack of such effects in other cases has been used for non-decomposition (see, e.g. Bertram et al., 2000, for a taxonomic view by which many word types do not yield these results, and are thus considered to be stored).

Given the nature of the lexical decision task, both kinds of conclusion face challenges, perhaps not fairly recognized in the literature, for clarifying the nature of lexical processing, due to the fact that (i) on the one hand, the positive evidence for decomposition needs to be reckoned with, but is in principle possible to account for as a late effect following atom-based processing (and perhaps not directly related to morphemic processing at all); arguments in that spirit have been made, and we address them in this dissertation; (ii) on the other hand, evidence regarding, say, the *lack* of differential-frequency or base-frequency effects in lexical decision is susceptible to the same type of argument– the lack of these effects cannot be straightforwardly localized to lack of initial decomposition, given that by its nature, lexical decision is in principle sensitive to post-decompositional processing. This point, with a few exceptions, has not been reckoned with.

Much work has been done which speaks to the nature of lexical representation and processing – specifically concerning complex words and their impact on this debate, and we build on these in pursuing the current experiments, with an eye toward making progress in *what happens when*. Arguably, we will have a better sense of whether and how broadly decomposition occurs only insofar as we are able to view the evidence in terms of the time course of processing.

Subsection 3: Evidence Regarding Morphological Complexity from Other Methods

Eye-tracking. Research on constituent effects has extended beyond lexical decision, for example to studies on eye-tracking.[4] The eye-tracking method has the advantages of high temporal sensitivity, and thus eye-tracking, like the electrophysiological method we will present below, can potentially play a large role in cross-method research aimed at understanding the role of morphological structure in the time course of lexical processing. Further, unlike lexical decision, eye-tracking has the ability to make measurements during natural reading. Given the potential for mapping computations onto separate time-sensitive components in the eye movement record, eye-tracking is especially relevant for morphological complexity research.

Eye movements have been used to study effects of decomposition of complex words such as compounds (Andrews et al., 2004, Bertram and Hyönä, 2003, Inhoff et al., 1996, Juhasz et al., 2003, Pollatsek et al., 2000, Pollatsek and Hyönä, 2005,

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[4] See, e.g. Rayner, (1998) for a comprehensive view of eye-tracking methodological issues and results. Some challenges for the linking linguistic computations to component measures in the eye-movement record include that accounting for recognition effects that are often distributed over several fixations (e.g., Inhoff et al., 1996) and may be subject to parafoveal preview effects (e.g., Rayner and Pollatsek, 1989); but see Deutsch et al. (2000) for an interesting use of the parafoveal preview benefit to detect morphological decomposition in Hebrew.

among others). Andrews et al. (2004) for example, recorded eye movements during the reading of English compounds in sentence context, along the lines of work done in Finnish by Pollatsek et al. (2000), and by Hyönä and Pollatsek (1998), which showed frequency effects in the reading of Finnish compounds. The results of Andrews et al. (2004) from English suggest some influence of first-constituent frequency on first fixation, and effects of both first and second constituent frequency on gaze duration. Like the earlier studies, whole-word frequency showed an effect on gaze duration and total looking time (in regression analyses on whole-word frequency). In Andrews et al. (2004), these data are taken to reflect a process of *segmentation-through-recognition*, where access to compound words involves processing of both constituent and whole-word representations. Together, these studies point to a role for constituents early in time course, suggesting access to compounds as internally-structured representations, inconsistent with a whole-word only approach.

As regards compounds, these constituency effects seem to hold not only in lexical decision tasks but also in eye-tracking studies of compound processing in sentence context (see e.g. Pollatsek & Hyönä, 2005 (Finnish), Andrews et al., 2004 (English), among others). It is worth noting that this links to a common concern: whether effects found in isolated word tasks like lexical decision would extend to studies of reading. For example, Bertram, Hyönä & Laine (2000a) found that sentence context seems to play a role in whether decompositional processing is evident for inflected Finnish words carrying the ambiguous suffix –jA. In sentence reading, fixation and gaze duration measures, as well as reading time measures in self-paced reading, indeed show base frequency effects (although base frequency effects were typically weak on first fixation durations and reading times on the inflected word, and more robust in gaze duration and in measures on the following word in both methodologies), whereas in a simple lexical decision task, base frequency effects were not evident. Hyönä, Vainio and Laine (2002) have found a distinction in the opposite direction— complexity effects in lexical decision but not reading— using Finnish case-marked complex words vs. single words). For compounds, we are able to adduce some evidence from the literature for internal-structure based processing during sentence reading, but the relation among effects in single-word and sentence studies is complicated, as these examples show. Further cross-method research of the kind mentioned here is bound to be informative on the nature of complex word representations, and the eye-tracking method certainly addresses one of our desiderata for understanding where putative decompositional effects and their constraints hold in time course – *what happens when*. In what follows, we consider whether such evidence can be adduced and enriched even within the isolated-word methods.

Priming. Priming studies have been used to assess the morphological representation of complex words. These experiments have generally been focused on dissociating the contributions of formal overlap, morphological overlap, and semantic relatedness in the priming of morphologically structured (or pseudo-morphemically structured) complex words and their constituents (i.e. investigating effects of decomposition, and possible contravening factors leading to atomic processing, along with factors which could possibly explain ‘morphemic effects’ in a non-abstractionist, morphological framework).

These experiments have often relied on delayed repetition priming tasks and cross-modal priming (e.g., Marslen-Wilson et al., 1994, Monsell, 1985, among others). Marslen-Wilson et al. (1994) showed, using a cross-modal repetition priming task, that semantically transparent derived forms yield priming effects (e.g. *government – govern*), regardless of phonological transparency, although semantically opaque forms do not show priming effects (e.g. *apartment – apart*), behaving instead like monomorphemic words; this led to the conclusion that transparent words such as *government* are parsed into their constituent morphemes, whereas opaque words such as *apartment* are treated as monomorphemic. These cross modal effects have also observed in other studies (see, e.g., Longtin et al., 2003, Experiment II, among others).

However, cross-modal priming may be sensitive to factors, semantic or otherwise, that come into play *subsequent* to morphological decomposition; it is worth noting that typically in this paradigm, targets are presented subsequent to the full presentation of the complex word, resulting in long stimulus-onset-asynchronies among prime and target morphemes (and considering uniqueness points, arguably, among the whole prime word and target), overt processing of the full prime word, and opportunities for participants to overtly perceive the prime-target relation, allowing for episodic or strategic effects to develop. An influential set of findings from this paradigm are those of Marslen-Wilson et al. (1994), the results of which suggested that opaque derived words are monomorphemic in lexical entry since they do not prime in the cross-modal paradigm. This led to the speculation that, unlike the linguistically-motivated analysis of these words as morphologically complex although semantically opaque, the cognitively-real morphological analysis does not hold for opaque words, which are treated as monomorphemic online. However, this conclusion raises questions regarding what pattern of results would be obtained in other tasks, given that fair questions can be raised about whether this task reflects the initial stages of morphological processing. The question of whether opaque complex words are indeed treated as monomorphemic, even at the initial stages of morphological processing, is a question that may be addressed by considering these results in context of other tasks, in order to get a better picture of when, and thus at which level, transparent and opaque words differ. One way that researchers have tried, within the priming tradition, is to look at overt immediate repetition priming and masked priming.

Recently, masked priming (see Forster, 1999 for a recent discussion) has yielded particularly interesting results regarding the processing of morphologically complex words, mainly focusing on derivational morphology (e.g., Frost et al., 1997, Longtin et al., 2003, Rastle et al., 2004, among others). These studies show that masked prime words with apparent morphological complexity significantly facilitate responses to the apparent constituent targets (e.g. priming of ‘apart’ by ‘apartment’), whereas words with orthographic overlap without apparent morphological constituency do not prime the overlapped word part (e.g. no priming for ‘elect’ by ‘electrode’). Such findings suggest that apparently complex words may be parsed rapidly and automatically into morphological-level constituents.[5] We examine these studies in more detail in the Discussion section below, and in the next chapter.

As regards compounds, Shoolman and Andrews (2003) used masked priming to test the effect of constituent priming on compound recognition. This study focused on the masked priming of compounds (*bookshelf*), pseudo-structured words (*hammock*) and various types of nonword. The results showed both first and second constituent priming of compounds by their constituents (e.g. *tea – teacup*) regardless of semantic relatedness. These results converge with those obtained by Zwitserlood (1994) in a slightly different paradigm, with a longer prime duration (100 ms). Zwitserlood (1994) used the immediate constituent-repetition priming and semantic priming paradigms (in which the brief, but most likely consciously detected, visual prime is followed by either a constituent target, or a target semantically related to the constituent, respectively) to explore the processing of semantically transparent, partially transparent, and opaque compounds in Dutch. The results of the two experiments reported there show constituent priming by compound words regardless of semantic transparency. Significant priming was found both for transparent prime-target pairs, such as *kerkorgel – orgel* (gloss: *church organ – organ*) and for opaque pairs, such as *klokhuis – huis* (lit. gloss of prime: clockhouse, meaning: *apple* –

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[5] These priming results are not without controversy. As regards methodological concerns, the view that masked priming is relatively insensitive to overt strategic effects compared with overt priming has been challenged, for example by Masson and Bodner (2003) and Masson and Isaak (1999). The latter presents the argument that nonword priming effects suggest a pre-lexical locus of masked priming effects. However, Forster (1998, 1999) and others argue that the findings on nonword priming can be explained in context of masked priming operating at the lexical level. The claim that results from the masked priming of complex words implicates the existence of morphological-level constituency has been challenged from the distributed-connectionist viewpoint (see the Models section below for more discussion).

house). On the other hand, there was no priming for targets with only orthographic overlap, but not morphological constituency, such as *kerstfeest – kers* (gloss: *Christmas – cherry*). When testing the priming of semantic relatives of the target constituents, only the totally and partially transparent items showed significant priming. The results on the partially transparent items contrast with Sandra (1990) who did not find semantic priming from the opaque constituent of the partially transparent compounds.[6] Nevertheless, the results are suggestive of morphological-level complexity for both transparent and opaque compounds at some level, and suggest a difference among morphological and semantic relatedness, in that priming was observed in brief and unconscious priming conditions regardless of semantic transparency for both derivationally complex words, and , in at least one previous study, compounds (although in that case, Shoolman and Andrews (2003), compounds were used as targets not as primes, in contrast to most of the derivational literature, and the Zwitserlood study on compounds mentioned above; in Chapter 4, we provide direct evidence from masked priming showing that compound primes also significantly prime their constituents, on a par with the derivational morphology studies).

The patterns emerging from the priming literature suggest a role for morphological constituency which is (a) separable from formal overlap, as the former tends to be facilitative and the latter inhibitory in masked priming tasks, and (b) modulated by semantic relatedness but maybe only at some delay, as constituent priming holds for all kinds of constituent structures in masked priming, while

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[6] Sandra (1990) used what amounts to a longer SOA, as Zwitserlood (1994) notes.

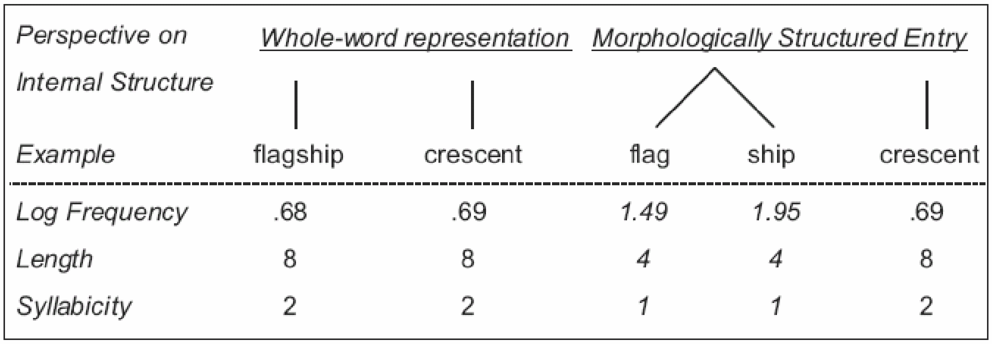
constraints such as semantic transparency are detectable in overt, longer lag (e.g. cross-modal) priming tasks, if at all. These findings suggest a broad decompositional conception of the lexicon.

Subsection 4: Detecting Morphological Constituency in Compounding

Morphological processing: direct comparison method

What is virtually absent in the literature is a method for the direct comparison of compound words varying in internal structure in lexical decision. One previous dataset in English that did allow for such a comparison was Andrews (1986). While Andrews (1986) reported significant constituency effects in the first constituent position, the potentially interesting direct comparisons with monomorphemic controls available in that study were not significant (high frequency first constituent compounds were numerically, but not significantly faster than monomorphemic controls in both compound experiments (Experiments 2 and 3)). Although Andrews (1986) controlled for length and number of syllables, and for frequency as well as possible given the sampling error of corpora at very low frequencies (using the Kučera & Francis, 1967 counts) the mean whole-word frequencies reported are higher for the monomorphemic words (2.8) than for the high- (1.8) or low-frequency first-constituent compound stimuli.

Figure 4 Pairwise Matching Method: Experiment I



Perspective on Internal Structure	Whole-word representation		Morphologically Structured Entry		
Example	flagship	crescent	flag	ship	crescent
Log Frequency	.68	.69	1.49	1.95	.69
Length	8	8	4	4	8
Syllabicity	2	2	1	1	2

We re-calculated the frequencies of these items using a newer, but also larger corpus (Collins Cobuild, 320 million words; for Cobuild resources, see http://www.cobuild.collins.co.uk), and tested the differences statistically (note that all monomorphemic words, but not all compounds, were in this corpus; the raw frequency values of the four missing compounds were replaced with the mean raw frequency for that condition). Log frequencies were also higher in this corpus, as in Kučera and Francis (1967) for the monomorphemic words than the compound words ($F(3,56)=5.223$, $MSE=.214$, $p<0.004$).[7] This suggests that it might be more difficult to directly compare the compounds and control monomorphemic words directly in that case, although it says nothing about the constituency effects found among the high- versus low-frequency compound words.

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[7] Planned contrasts of CW and SW averaged log frequency were significant ($p<0.001$) as were comparisons of the CW with high frequency first constituent versus controls and CW with low frequency first constituents ($p<0.02$ and $p<0.009$, respectively). ANOVA on letter length was also significant ($F(3,56)=5.157$, $p<0.004$). Contrast of the averages of the CW and SW length was significant ($p<0.004$) as was contrast of high first constituent CW vs. controls ($p<0.002$). Letter length among low first constituent frequency CW vs. controls did not differ significantly ($p<0.293$). Word length is also significantly shorter among the controls (paired t-test, $t(29)=2.8$, $p<0.009$, two-tailed).

In the current study, we take advantage of the direct comparison of compounds and single words, using carefully matched compounds and single words differing only in *constituent* properties; see the example in Figure 4 above. This allows us to test directly for differences among words with hypothesized internal morphological structure and those which are monomorphemic in structure, under controlled conditions. The two types of word (compound and single word) make very different predictions under decompositional vs. non-decompositional viewpoints, and under different articulations of decompositional/dual-route models; see Figure 5 below.

Subsection 5: A Look at Models of Lexical Retrieval and Their Commitments Regarding Internal Structure

Models

Non-decompositional models. The non-decompositional model (Figure 5, model III) predicts no online role for morphological-level constituents. Fundamental aspects of the non-decompositional account persist today (i) in those accounts that propose that full-storage of complex structures is pervasive (e.g., Bybee, 1995), and (ii) in accounts which claim no abstract representation of words at all. For example, Bybee's (1995) model handles 'constituency' as associative relations among related, separate words, where lexical relatedness is defined as strength of connections in phonological and semantic features. Under this model, so-called constituency effects emerge by the associative activation of related forms, mediated by frequency: so-called complex words with high token frequency have weaker lexical relations, and thus are predicted to show reduced 'constituency' effects (Bybee, 1995).

Distributed-connectionist models (e.g., Seidenberg and Gonnerman, 2000) seek to capture relations among whole-words and constituents without recourse to abstract morphemes or a morphological level of analysis. These approaches instead attribute effects among complex words and their constituents to direct form-meaning overlaps (i.e. overlap in phonology, orthography or semantics), which can be modeled using weighted connections in a connectionist network. Data from tasks such as masked priming has been put forth as a challenge to the distributed-connectionist account, since morphological priming has been shown to persist regardless of formal or semantic overlap; i.e. priming holds for semantically transparent and opaque complex words, although words with only orthographic overlap do not show significant priming; for challenges to the conclusion that these results implicate morphological-level processing, see e.g. Seidenberg & Gonnerman (2000) and Gonnerman, Seidenberg, & Andersen (ms.); for discussion of another network model without abstract lexical representations, see Elman (2004), and for a recent description of an approach to morphological complexity which challenges the necessity of morphemes, see Hay & Baayen (2005).

Whole-word processing survives also in how *known* words are treated in many models, including the *supralexical model* (in which initial access is always via whole-word representation), e.g. Giraudo & Grainger (2000), and *parallel dual route models* (parallel access to whole-word representations), e.g. Schreuder & Baayen

(1995), both models also incorporating some form of morpheme-level processing. We consider these models in turn below.

Late decomposition models. The late decomposition model (Figure 5, model II) predicts that constituents are activated subsequent to whole-word access; initial access is always done via whole-word representations. One example is the *supralexical model*, which claims that initial processing proceeds via whole-word representations, with access to morphological constituents following afterward, and only under some circumstances, such as when the relation among whole word and constituents is semantically transparent (e.g. Giraudo & Grainger (2000); see Diependaele et al. (2005) for more discussion).

Early decomposition models. Early decomposition models posit that constituent morphemes are activated early and automatically during processing of a complex word. *Dual-route* models suggest that both decompositional and whole-word processing routes are available, although various factors influence which route will be successful for a given word form. A variety of dual-route models have been proposed, which posit differences in when whole-word and decompositional pathways will be taken due to factors such as transparency, lexicality, productivity, and frequency.

For example, the Morphological Race Model (MRM) (Baayen et al., 1997, Schreuder and Baayen, 1995, among others) is a parallel dual-route model in which decompositional and whole-word access are deployed in parallel and race, allowing for facilitation from parts to whole and fully decompositional parsing in the case of novel or non-listed words (see Figure 5, Model I). While both the MRM and the Augmented Addressed Morphology model (AAM) (e.g., Caramazza et al., 1988) posit that whole-word and morphological-level representations can be accessed, both tend to assume that whole-word processing will typically be more rapid for known compound words (decomposition requires extra steps in processing under these approaches, which can account for effects of whole-word access prior to access to morphological parts). As for the MRM, Schreuder & Baayen (1997) conclude that lexicalized compounds are accessed as full-forms, based on a reanalysis of Taft and Forster's high vs. low first-constituent frequency manipulation (Taft and Forster, 1976, Experiment 5).

However, under some variants of a dual-route model, morphemic constituent effects for lexicalized compounds would be predicted. For example, in a parallel dual-route model allowing for activation of constituents to add activation to whole-word representations and vice-versa, and assuming that short, high-frequency constituents are activated early in parsing the compound, this may facilitate access to the whole compound's entry (see, e.g. the Andrews et al. (2004) *segmentation-through-recognition* model, and the parallel dual-route of Pollatsek, Hyönä, and Bertram (2000)). Further, both the MRM and AAM may also be able to capture morpheme-level processing in cases such as high base/low surface frequency mismatches in which morphological stems are of high frequency relative to the whole-word form (for this claim regarding the AAM , see e.g., Laudanna et al., 1997).

In contrast, the full-parsing approach is explicit in predicting that words are automatically decomposed into constituents, and that all processing is done by the decompositional route (see e.g., Stockall and Marantz, in press, Taft, 2004). Access to constituents at an initial stage is only one part of the computation of morphologically complex words along a decompositional route. Some subsequent stage of morpheme combination, which we may term composition, should be a part of the set of computations (Schreuder and Baayen, 1995, Taft, 2004, among others). There are several possibilities regarding what the composition stage might include, under full-parsing, which would affect predictions on the speed of judgments to complex words. Composition may comprise simply 'glueing together' the parts (what this might entail is not clear, nor is whether it is affected by properties like frequency of combination, as speculated by Taft (2004)); alternatively, composition might always involve more costly interpretive combinatorial processes (as in claimed under some versions of the MRM dual-route model, for example).[8] Under a full-parsing model in which combination is costly, we might expect early facilitation of constituent morphemes, but a contrasting delay in response time for both known and novel compounds; however, under a full-parsing model in which morpheme-combination can (sometimes) be rapid, such a model would be able to account for early activation of morphemes and facilitation in response time. Neither variety requires any full-storage of lexicalized compounds.

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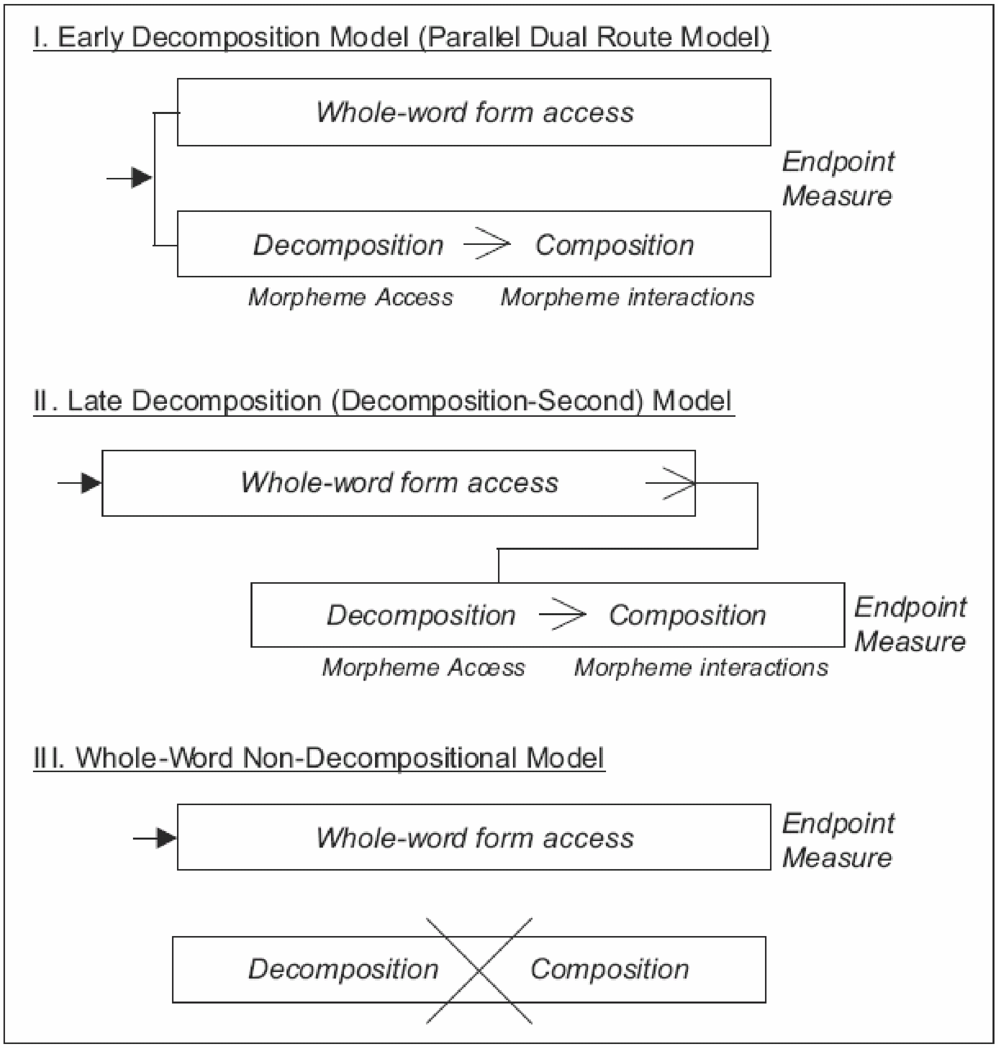
[8] One speculation is that whether and how these composition effects are manifested may be affected by task, item-set, and other factors which are already known to influence post-lexical processing.

Figure 5 Three Perspectives on Whole-Word Processing and Morpheme-based Decomposition in the Time Course of Lexical Processing



Subsection 6: Adding Brain-level Dependent Variables

Electrophysiological component measurement in word recognition.

The primary method of research on lexical access has been the lexical decision task. As discussed above, it is clear that lexical decision results are able to speak to important questions regarding the nature of lexical representations, and that the task can also generate results relevant to specifying the locus in time course of various processing stages. Further, lexical decision offers the methodological benefits of a strictly time-locked measurement from word-onset, without look-ahead or other sentential context effects. However, criticism citing the drawbacks of the lexical decision paradigm is not new. A central claim is that lexical decision is not only sensitive to lexical processes but also post-lexical processing (see, e.g., Balota and Chumbley, 1984, Monsell et al., 1989). Since effects of constituency are expected to occur in distinct points during time course of processing, and to represent a complex set of computations, and since lexical decision is a single response measure taken at the very end stage of processing, it makes sense to add additional dependent variables along the way to decision to test for the presence of decomposition and the nature of its computation in time course. Given such additional dependent variables, we may begin to make progress in understanding whether morphological-level decomposition occurs, and whether the putative constraints thought to engender atomic representation and processing for 'complex' words (e.g. limited transparency or productivity, high frequency, among other factors) indeed do preclude morphological-level decomposition, rather than affect stages post-decomposition. In the first experiment, we utilize the addition of an electrophysiological measure during a lexical decision task, with the intention that the interaction of the brain-level effects and behavioral measures may help narrow in on specific sub-components of the processing of complex words.

Electrophysiological brain recording measures such as EEG and MEG provide direct measures of neural activity during tasks such as language processing with millisecond temporal resolution. A body of recent MEG research (e.g., Beretta et al., 2005, Cornelissen et al., 2003, Embick et al., 2001, Helenius et al., 1998, Helenius et al., 2002, Koyama et al., 1998, Koyama et al., 1999, Pylkkänen et al., 2002, Pylkkänen et al., 2004, Pylkkänen et al., 2006, Sekiguchi et al., 2001, Simos et al., 2002, Stockall et al., 2004, Tarkiainen et al., 1999) identifies a series of components in the MEG waveform following visual word onset which map onto different subprocesses during the time course of visual word recognition. The first component, a bilateral occipitotemporal component around 150-200ms post word onset, reflects pre-lexical properties of the visual word stimulus, such as letter-string length and letter position effects (Cornelissen et al., 2003, Tarkiainen et al., 1999, among others). A second component, peaking between 200-300ms with a complex of underlying neural sources in the posterior portion of the left hemisphere, is less well understood but has shown sensitivity to prelexical phonological properties of word stimuli (Pylkkänen et al., 2002). The third component, called the M350, is a response peaking approximately 350 ms post-onset of a stimulus, with a left superior temporal cortex generator. Studies have shown its sensitivity to factors such as word frequency, repetition priming, semantic relatedness, morphological relatedness, morphological family frequency and size, and properties of root semantics such as homonymy and polysemy (Beretta et al., 2005, Embick et al., 2001, Pylkkänen et al., 2002, Pylkkänen et al., 2004). As argued by Pylkkänen and Marantz (2003), this response may be conceived as a sub-component of the N400 response seen in ERP, a broad distribution appearing from around 200-600ms post-onset of a visual word stimulus, which is thought to be sensitive to both semantic integration and automatic lexical access properties.

There are also studies which argue for very early responses sensitive to length and frequency (around 125-175 ms post-stimulus onset), whereas the literature cited above concludes that responses in this time window reflect aspects of visual word form processing. For example, Assadollahi and Pulvermüller (2003) conducted an MEG study contrasting responses to short and long words of high and low frequencies. Each condition contained 4 words, repeated multiple times. The authors report length effects after 100 ms post-stimulus onset, but also report frequency effects for the short words in this time window; effects for long words were detected later.[9] What subroutine of lexical access happens when in time, and is indexed by

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[9] As regards the issue of when the first contact with the lexicon occurs, it is of the utmost concern to disentangle effects of visual word form properties with lexical properties such as word frequency. Given that the MEG responses from 100-200 ms are sensitive to properties of the visual word form (letter-length, discriminability in low-contrast presentations, etc.) it is important to consider the possible role of these properties when testing for early frequency effects. For example, while the length and frequency controls were reported in Assadollahi and Pulvermüller (2003), there is no mention of orthographic/phonological regularity or probability controls. On the view that these properties are likely to correlate with frequency, this is of concern given the many studies showing the components around 100-200ms post-onset are sensitive to letter-string encoding (e.g. Tarkiainen et al., 1999; Cornelissen et al., 2003, among others), making the interpretation of the effects as lexical-level more difficult. Further differences which are potentially relevant, as noted by Assadollahi and Pulvermüller

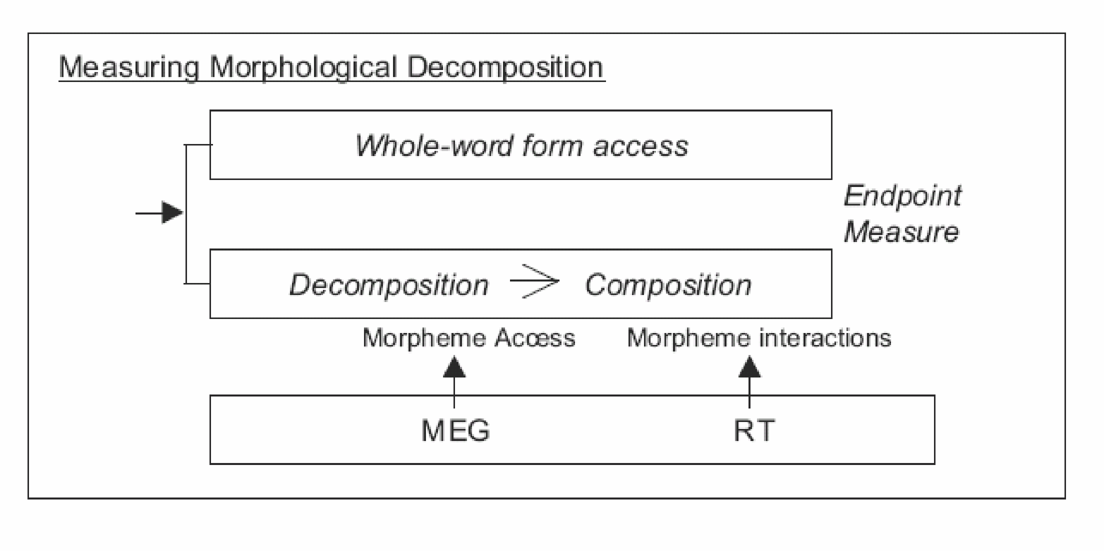
what dependent measure, covers a range of interesting research questions that remain under current investigation. As it is beyond the scope of this paper to engage in all such questions, we note that the present study aims to test one particular hypothesis about one aspect of morphologically-complex word processing, namely whether contrasts of whole-word vs. morphemic constituent properties results in a divergence in response times and/or components which have been identified in the MEG signal preceding the behavioral response; we do not aim to test for, nor argue for, what the absolute earliest point at which it is possible to elicit any putatively lexical effect in any electrophysiological study (see also Hinojosa et al., 2004, Martin-Loeches et al., 1999, Sereno et al., 1998, for further discussion of early effects in lexical access in electrophysiology). Rather, in the current study, we focus on a narrow set of hypotheses on the processing of complex words, contrasting models which predict that morphemic properties should affect the components along time course of lexical processing (accounts positing rapid and automatic decomposition) with those which do not ascribe a role for constituents in online lexical processing (accounts claiming non-decompositional processing during initial access to the lexicon).

In sum, including electrophysiological recordings in our experimental paradigm allows for the testing each of the electrophysiological components along the way to a participant's lexical decision for subtle differences (if any) reflecting the stimulus manipulation (our whole-word vs. constituent contrast), with *directional*

(2003), are the differences in design among the studies showing earlier vs. later effects of frequency, and differences in how the frequency effects that were reported were reflected in the signal (amplitude modulation vs. latency modulation).

predictions on how such effects should look and pattern with the response time measure, under competing conceptions on the role of morphological decomposition (see Figure 3). The MEG component peaking around 350 ms (M350) is important in this regard, given its sensitivity to lexical properties, as reported in the literature summarized above, and its location in time course (prior to the overt response time measure) for the investigation of effects of morphological structure in word recognition.

Figure 6 Potential for MEG Measure of Early Morpheme-Based Decomposition



Subsection 7: Present Study: Experiment I

The present study utilizes simultaneous lexical decision and brain-level (MEG) measures to track the time course of decomposition in compound words. In this way, it is possible to measure access to constituents with the properties of specific components in the electrophysiological signal and their patterning with and divergence from the RT data, as predicted under competing conceptions of morphological decomposition.

We test for the effects of compound word structure by pairwise matching *single words* and *lexicalized compound words orthographically written as one word* on overall properties thought to affect access. Crucially, the morphemic constituents of the compounds are mismatched to the single words such that their morpheme-level properties would give them an advantage in access, under a decompositional approach, as shown in Figure 4. We show that morphological structure is reflected in the combined brain and behavioral measures in a manner that rules out non-decompositional theories and is most consistent with models incorporating early effects of abstract morphological structure.

Section 2: Methods

Subsection 1: Stimuli and Design

The materials consisted of 120 word items, drawn from the Collins Cobuild English corpus (320 million words), and 120 non-word items, approximately one-half of which were formed from orthographic transcription of non-word items from Vitevich and Luce (1999). The 120 word items were comprised of 60 disyllabic, single (monomorphemic) words and 60 bi-morphemic noun-noun compounds orthographically represented without spacing as drawn from the Collins Cobuild corpus. Table 1 shows a summary of the item controls and example items for each condition; see Appendix I for the complete list of items.

Table 1 Item Controls and Examples, Experiment I

Condition	*Mean Log. Freq.**	*Mean # Letters*	*Example*
Compound (CW)	0.451	7.82	flagship
CW 1st/2nd constituents	*1.96/1.98*	*3.82/4.0*	*flag/ship*
Single Word (SW)	0.459	7.78	crescent
Nonword (NW)	-	7.81	nishpern
Word-Nonword Foil (WNW)	-	7.94	crowskep

* Parts per million (ppm): CW 2.82 ppm; CW 1st/2nd constituents 91.2/95.5 ppm; SW 2.88 ppm.

For the overall comparison of compounds versus single words, the compounds and single words were matched for whole-word properties (i.e., length, frequency, and syllabicity of the whole compound as compared with the whole single word). The compounds and single words were pairwise matched on frequency[10] (compound mean frequency = 0.451, single word mean frequency = 0.459, $t<1$), overall letter-length (compound mean length = 7.82, single word mean length = 7.78, $t<1$), and syllabicity (exactly matched in every case, all disyllabic).[11]

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[10] The frequency counts used here are lemma frequency (the frequency of a word form and its inflectional variants). The lemma frequency counts for whole compounds and single words are counts for the whole word form uninterrupted e.g. by hyphenation, that is, in the same form that they are presented in the experiment.

[11] Note that Cobuild is advantageous due to its extremely large sample size, allowing a good estimate of word frequency among words not at the top of the frequency range, like the current items. However, we consulted the Francis and Kučera (1982) analysis of the Brown Corpus (first published 1961; approximately 1 million tokens) for the sake of comparison. Only 60% of the compound words, and 70% of the single words were represented in that corpus. Nevertheless, measures of frequency (log frequency, raw frequency) and distribution (number of sources in which lemma appears, number of text samples in which lemma appears) showed that the subsets of these items were

However, the compound words were selected for inclusion such that their first- and second-position constituents would contrast with the single words in these three parameters. The compound constituents had higher log frequency (first constituent mean log frequency = 1.96, second constituent mean log frequency = 1.98) compared with the overall compound word and matched single word frequency. This frequency manipulation resulted in the intended frequency mismatch, in which both first constituent (C1) and second constituent (C2) have significantly higher frequency, as shown by Analysis of Variance (see Appendix II for statistical tests on all the item controls reported in this section).

The same holds true for length in letters for compound constituents (first constituent mean letter length = 3.82, second constituent mean log letter length = 4.00) as compared with the overall compounds and matched single words (compound letter length = 7.82, single word letter length = 7.78), again resulting in a statistically significant difference in letter length among constituents and whole words (see Appendix II). As regards syllabicity, all constituents were monosyllabic and all whole compounds and single words were disyllabic.

To enable comparisons among compounds and single words across word frequency levels (i.e., compounds vs. single words when their whole-word frequencies are either high, medium or low frequency), three frequency, length, and syllabicity-matched subsets of 12 pairs of compound and single words were selected

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matched; log frequency differed by only 0.09 across conditions among the extant CW and SW on this count. In the Carroll et al. (1971) American Heritage Intermediate Dictionary corpus (approximately 5 million tokens), approximately 85% of the stimuli were represented in the corpus. The mean log frequency of the extant CW and SW was again matched; log frequency differed by only 0.05 across conditions.

from among the top, middle and bottom 20% log-frequency of the whole set of compounds and single words in this experiment. (We note here that the terms high, middle, and low are meant with respect to the stimuli being categorized here, as a way to identify subsets at three relatively different frequency strata within the stimulus set.)

As in the overall comparison of compounds vs. single words, word frequency, length and syllabicity were matched within the high, medium, and low-frequency subsets of compounds and single words. Frequencies were not significantly different, and both syllabicity and mean letter-length for the compound vs. single word comparisons was matched identically in each of the three the high-frequency subsets of the single and compound words, as shown in Appendix II. The letter-lengths in the bins were 8.08 letters for high frequency, 7.75 letters for medium-frequency, and 7.17 letters for low-frequency; as for differences in length across frequency bins, only the contrast among high- and low-frequency items was significant in a planned comparison, also reported in Appendix II.

As before, compound constituent properties vs. whole-word properties were mismatched, yielding the intended contrast in which the compound constituents have significantly higher frequency, shorter length and fewer syllables than the whole-words (see Appendix II for details).

The 120 non-words included 104 disyllabic pronounceable nonwords, approximately one-half of which were generated using orthographic transcriptions of monosyllabic nonwords from Vitevich and Luce (1999). Mean letter-length of these 104 nonwords was 7.81 (word vs. nonword length matched, t<1). Sixteen additional non-words formed the category of Word-Nonword foils. These non-words contained a monosyllabic English noun in the first-syllable position and a monosyllabic nonword second syllable. Mean log frequency of the morphemic first syllable of the Word-Nonword foils was 1.48 (*SD*=0.84), and mean letter-length was 3.81 (*SD*=0.66). Overall mean length for the word-nonword foils was 7.93 (*SD*=0.68).

Predictions for Response time. Since RT is sensitive to early and to late lexical processes, either an early decomposition (decomposition-first or parallel dual-route model) or a late decomposition (decomposition-second) account allows for the prediction that compounds will differ from single words, due to the properties of the constituents rather than the whole word. A non-decompositional account would predict no differences due to word structure, as the overall word properties are matched.

Electrophysiological predictions. The latency of the MEG component at 300-400ms after word onset, indexes processing related to lexical access rather than post-lexical processing (e.g., Embick et al., 2001, Pylkkänen et al., 2002). Given this measure, early decomposition predicts an effect not only in response time but also in the M350 component, reflecting constituent over whole-word properties. Late decomposition predicts response time differences but, like the non-decompositional account, no M350 divergence. Further, since the CW are lexicalized and have short constituents, lexicalization and length constraints predict no RT or M350 differences.

Given the properties of our stimuli (mismatches among whole-word and morphemic constituent properties) and the two types of measurement used (response time and electrophysiology), we thus test the following directional predictions:

a) Compounds should overall be faster than single words in both RT and M350 latency, if decomposition is deployed online and early in time course.

b) Compounds should overall be faster than single words only in RT, if at all, if decomposition is deployed online but late in time course.

c) The response time advantage should not persist for those items for which early access to constituents may not facilitate response to an internally-structured representation, such as the word-nonword foils.

Subsection 2: Procedure

Psychophysical procedure. Stimuli were visually presented using Psyscope (Cohen et al., 1993) in a randomized order, in three blocks of 80 stimuli with a pause after each block to provide resting time for the participant. The experimental paradigm was continuous lexical decision, for which the participants were instructed to decide as quickly and accurately as possible whether each item was a word or a nonword. Each trial was initiated with a 1000 ms fixation point in the center of the screen, followed by visual presentation of the stimulus, lasting until participant's response via button press. The intertrial interval was varied pseudorandomly among values at 50 ms intervals between 500 and 1000 ms. 'Word' responses were made by button-press using the dominant (right) hand, 'Nonword' responses by button-press with the non-dominant (left) hand.

During the experiment, the participants lay in a dimly-lit magnetically-shielded room (Yokogawa Electric Corporation, Tokyo, Japan), viewing items presented on a screen fixed 37cm above the participant's eye-level. The text was presented in Geneva font, size 48, in Magenta letters on a black background. Words subtended approximately 1.4˚ vertically and 6.4˚ degrees horizontally (range 4.6 to 8.6 degrees). Button-press responses were made using a two-pad non-magnetic fiber-optic response-button system (Current Designs, Inc., Philadelphia, PA).

Neuromagnetic recording procedure. Neuromagnetic signals were recorded continuously with a 160-channel whole-head axial gradiometer MEG System (Kanazawa Institute of Technology, Kanazawa, Japan). Prior to the recording, five electromagnetic coils were positioned on the participant with respect to anatomical landmarks: the nasion, preauricular flaps, and two forehead positions. The nasion and pre-auricular points were then digitized, as was the location of each of the five coils. The location of these coils with respect to the sensors was recorded immediately before and after the experimental recording for subsequent coregistration with digitized headshape or MRI images, to make possible analyses of this data which may involve source localization.

Data were recorded at a sampling rate of 1000Hz, filtered online with a band-pass filter of 1-200Hz and a band-elimination filter at 60Hz. The continuous data file was then noise-reduced relative to three reference magnetometer coils using the

Continuously Adjusted Least Squares Method (CALM) (Adachi et al., 2001). Trials were then averaged by condition with epochs beginning 100ms before stimulus onset and extending to 600ms post-onset. The trials were then level-rejected at +/-2.5 pT to remove trials with eye-blinks or other artifacts, if any. The averaged data were baseline-corrected relative to a 100ms prestimulus interval, and low-pass filtered at 30Hz.

Subsection 3: Participants

Twelve right-handed, monolingual American English-speaking adults with normal or corrected-to-normal vision (8 females; ages 18 to 26, mean age 21) provided their written informed consent to participate in this experiment. Participants were paid for their participation.

Section 3: Psychophysical Results

Subsection 1: Psychophysical Data Analysis

Response times and accuracy were analyzed for each participant as follows. Data from incorrect trials (approximately 5.5% of data) and responses differing by more than 2 standard deviations from the condition mean (overall word category CW, SW, Word-Nonword Foil, Nonword) were removed from participants' response time results (approximately 3.7% of the data points). Response time was compared among the single words and compound words, and among the compound words and single words vs. word-nonword foils. These analyses were conducted both on the overall set of items, and on the three subsets of compounds and single words (high, mid, and low frequency levels). The mean response times and accuracy rates are discussed Below.

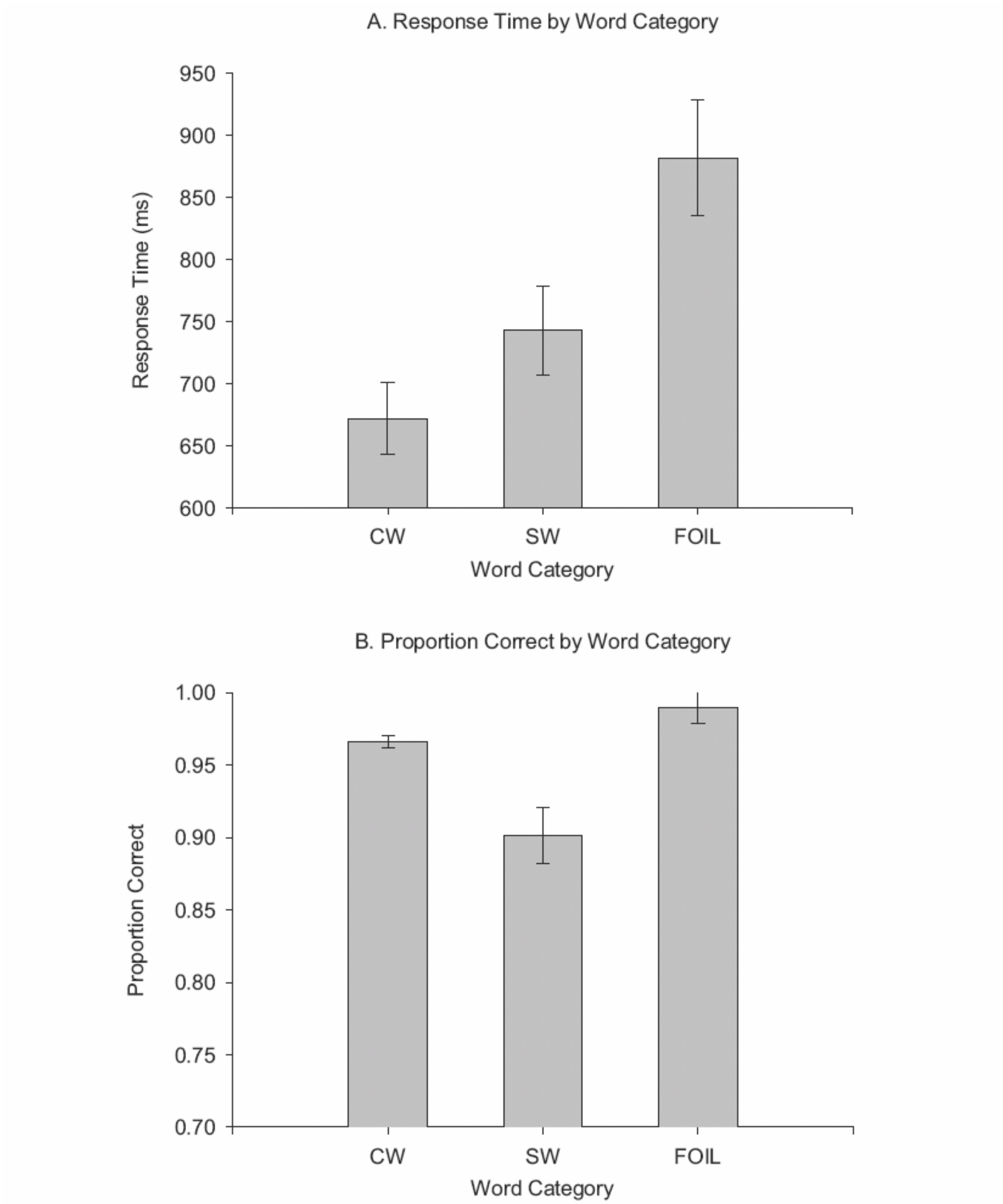
Subsection 2: Response Time: Main Comparisons by Word Type

Response times differed significantly by word category (*F*(2,22) = 24.057, *MSE* = 5708.597, *p*<0.001). Planned comparisons showed that compounds (*M* = 672 ms) were responded to faster than single words (*M* = 743 ms) (*F*(1,11) = 42.103, *MSE* = 722.39, *p*<0.001), that Compounds were responded to more quickly than Word-nonword foils (*M* = 882 ms) (*F*(1,11) = 31.402, *MSE* = 8452.686, *p*<0.001), and that Single Words were responded to more quickly than Word-nonword foils (*F*(1,11) = 14.608, MSE = 7950.643, *p*<0.004). Non-foil nonword fillers were responded to with a mean RT of 793 ms (S.E. = 35.6). The overall response times and accuracy rates are summarized in Table 2 below; Figure 7 shows response time and accuracy for compounds, single words, and word-nonword foils.

Table 2 Overall Response Times and Accuracy, Experiment I

Condition	*Mean RT (ms)*	*SE*	*Accuracy (%)*
Compound	672	29	97%
Single Word	743	36	90%
Word-Nonword Foil	882	47	99%
Other Nonwords	793	36	99%

Figure 7 Response Time and Accuracy for Compounds, Single Words, and Word-Nonword Foils



Subsection 3: Accuracy: Main Comparisons by Word Type

While our main goal is to test for *timing* differences across word types, a direct comparison of accuracy among Compounds, Single words, and Word-nonword foils may also be potentially telling about differences due to the representation of word structure, and also as to whether foil accuracy shows a speed-accuracy tradeoff or strategic response strategy. The omnibus ANOVA for accuracy shows a significant difference by word category ($F(2,22) = 13.010$, $MSE = 0.002$, $p<0.001$). Planned comparisons show that the Compound words ($M = 97\%$) were responded to with higher accuracy than Single words ($M = 90\%$) ($F(1,11) = 13.933$, $MSE = 0.002$, $p<0.004$). Compounds and Word-nonword Foils ($M = 99\%$), on the other hand, did not differ significantly in accuracy ($F(1,11) = 3.887$, $MSE = 0.001$, $p<0.075$), although Single words were responded to with lower accuracy than Word-nonword foils ($F(1,11) = 14.668$, $MSE = 0.003$, $p<0.004$). Non-foil nonword fillers were responded to with a mean accuracy of 99% (S.E. = 0.5%). Note that the compounds and word-nonword foils were both responded to with high accuracy, suggesting that a strategy based on word-like first syllable is not at play.[12]

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[12] While the fact that non-word responses were made with the left (non-dominant) hand makes the interpretation of the response time slowdown more complicated since it requires comparing responses across hands (however see, e.g. Taft & Forster (1976) among many others for the same result), the high accuracy on this condition provides support to the notion that compound responses were not entirely driven by spotting a morpheme. As for the crucial Compounds vs. Single Words comparison, both responses were made on the dominant (right) hand. One way address concerns about response hand would be to vary response hand by participant or block; this solution was not utilized in the current study in order to avoid across-participants or across-block analyses of the electrophysiological data (MEG), as across-participants comparisons are non-standard, and number of carefully matched samples should be

Subanalyses at Three Frequency Levels. Groups of 12 words each from among the highest, middle and lowest 20% of pair-wise log-frequency matched single words were selected for separate response time and accuracy analysis. These results are discussed in the following two sections; the mean response times and accuracy rates are also summarized in Table 3 below; Figure 8 also shows these data for compounds, single words and word-nonword foils.

Subsection 4: Response Time at Three Frequency Levels

The overall ANOVA (2 word structures X 3 frequency levels) revealed significant effects of word structure ($F(1,11) = 27.979$, $MSE = 2218.071$, $p<0.001$), and of frequency level ($F(2,22) = 16.863$, $MSE = 3721.713$, $p<0.001$), although the Structure X Frequency interaction was not significant ($F(2,22) = 1.355$, $MSE = 1598.517$, $p<0.280$). The effect of frequency was significant in planned comparisons among high vs. mid frequency ($F(1,11) = 13.208$, $MSE = 3133.386$, $p<0.001$), with a non-significant interaction with word structure ($F(1,11) = 1.163$, $MSE = 7239.796$, $p<0.305$), and significant in a planned comparison of mid vs. low frequency ($F(1,11) = 8.786$, $MSE = 2543.013$, $p<0.014$), again with a non-significant interaction with word structure ($F(1,11) = 3.050$, $MSE = 5338.474$, $p<0.11$). Planned comparisons among compounds and single words at each frequency level show significant RT

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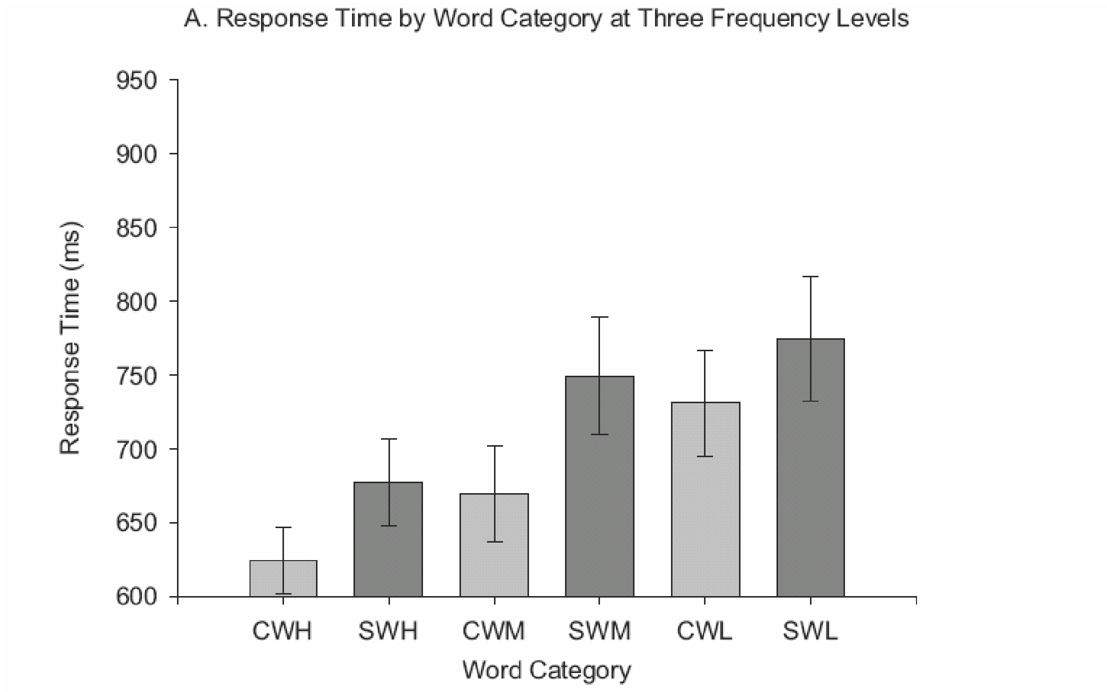
maximized to achieve the highest signal-to-noise ratio in the MEG responses. We note also that in a replication study (reported below), we elicited ‘yes’ responses and ‘no’ responses both on the dominant hand (‘yes’ responses with index finger, ‘no’ responses with middle finger); the pattern of results was the same as that reported in the main experiment.

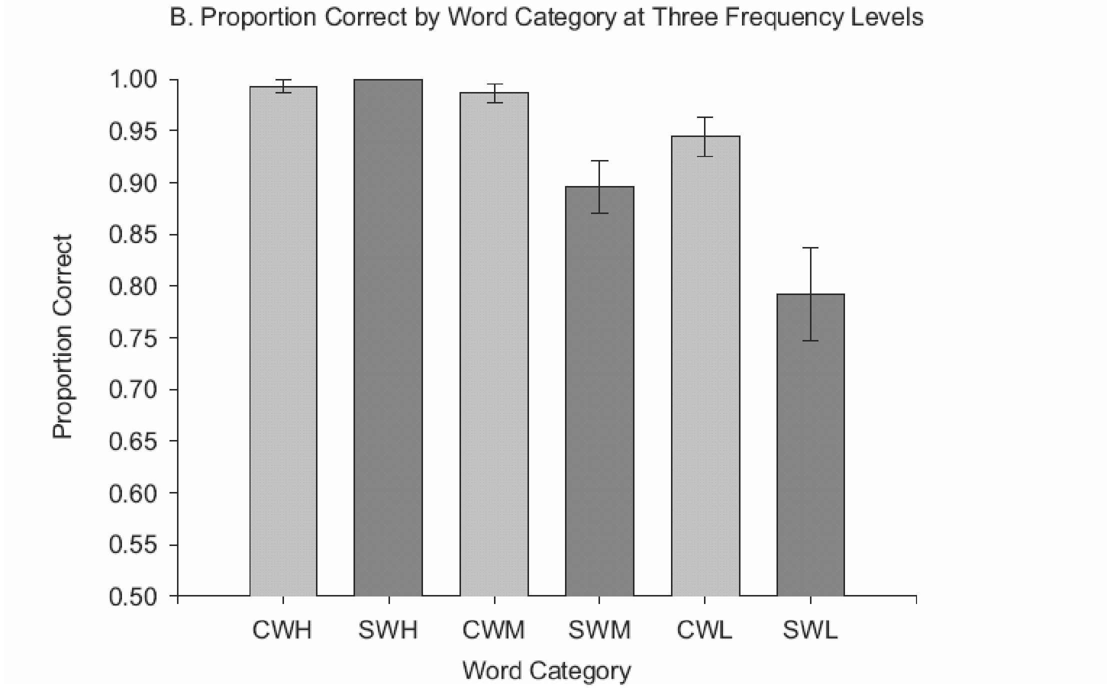
facilitation for high frequency Compounds (*M* = 624) relative to Single words (*M* = 678) (*F*(1,11) = 11.943, *MSE* = 1429.44, $p<0.006$), significant RT facilitation for middle frequency Compounds (*M* = 670) relative to Single words (*M* = 749) (*F*(1,11) = 28.431, *MSE* = 1344.702, $p<0.001$), and marginal RT facilitation for low frequency Compounds (*M* = 731) relative to Single words (*M* = 774) (*F*(1,11) = 4.198, *MSE* = 2640.962, $p<0.066$).

Table 3 Response Time and Accuracy at Three Frequency Levels

Condition	*Mean RT (ms)*	*SE*	*Accuracy (%)*
Compound Word High	624	23	99%
Single Word High	678	30	100%
Compound Word Medium	670	32	99%
Single Word Medium	749	39	90%
Compound Word Low	731	36	94%
Single Word Low	774	42	80%

Figure 8 Response Time and Accuracy at Three Frequency Levels


A. Response Time by Word Category at Three Frequency Levels


B. Proportion Correct by Word Category at Three Frequency Levels

Subsection 5: Accuracy Time at Three Frequency Levels

The ANOVA for accuracy among the three frequency subsets (2 word structures X 3 frequency levels) revealed significant effects of word structure ($F(1,11) = 13.644$, $MSE = 0.008$, $p<0.005$), of frequency level ($F(2,22) = 15.293$, $MSE = 0.007$, $p<0.001$), and a significant Structure X Frequency interaction ($F(2,22) = 11.396$, $MSE = 0.003$, $p<0.001$). The effect of accuracy was significant in planned comparisons among high vs. mid frequency words ($F(1,11)=18.526$, $MSE = 0.002$, $p<0.002$, with a significant interaction by word structure ($F(1,11) = 13.146$, $MSE = 0.009$, $p<0.005$), and for mid vs. low frequency words ($F(1,11) = 8.741$, $MSE = 0.007$, $p<0.014$), with a non-significant interaction ($F(1,11) = 3.667$, $MSE = 0.013$, $p<0.083$). Planned comparisons among Compounds and Single words at each frequency level show a non-significant accuracy difference for high frequency Compounds ($M = 99\%$) relative to Single words ($M = 100\%$) ($F(1,11) = 1.000$, MSE = 0.000, $p<0.340$), but a significant effect for middle frequency Compounds ($M = 99\%$) relative to Single words ($M = 90\%$) ($F(1,11) = 10.385$, $MSE = 0.005$, $p<0.009$), and for low frequency Compounds ($M = 90\%$) relative to Single words ($M = 80\%$) ($F(1,11) = 14.011$, $MSE = 0.01$, $p<0.004$).[13]

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[13] We also report the results of a replication study with 12 additional participants, in Appendix III. The pattern of results is identical to that of the current experiment, both in a by-participants and in a by-items analysis. Further, these data were reanalyzed excluding six single-word items which might be analyzed as complex (opaque/bound forms); the patterns were the same. These data are reported in Appendix IV.

Subsection 6: Discussion of Psychophysical Results

The behavioral results, in summary, support a decompositional view of morphological processing. The response times to compound words were faster, reflecting the influence of morphemic constituent properties rather than only whole-word properties. The fact that the response time facilitation for compounds persisted even among the highest overall frequency compounds is particularly challenging to full-storage models like Bybee (1995) that predict more whole-word and less decomposition-like processing as surface frequency increases, as whole-word representations will be strengthened and relations with morphemes will be weakened (Bybee, 1995). They will also be challenging for versions of the dual-route model which take surface frequency as a determiner of decomposability (e.g., Stemberger and MacWhinney, 1986, among others). Moreover, compound words were accurately judged as 'word' stimuli at significantly higher rates, suggesting a qualitative difference in the items by word structure. The findings support the view of morphologically complex items processed as internally structured representations in the mental lexicon. Access to morphemic constituents facilitated response time and resulted in higher accuracy for compounds relative to overall matched single words. Word-nonword foils, however, resulted in delayed RT but high accuracy, as has been reported previously for this type of item (and for word-word novel compounds). This suggests a role for decomposition even in the parsing of known compounds, as proposed by early decomposition first/full-parsing accounts.

As argued above, it is difficult to place this effect as early or late in time course using lexical decision data alone, although the pattern of effects strongly suggests some version of early decomposition, and it would be difficult for a late, decomposition-second view to capture these effects. If the electrophysiological signal shows an early difference favoring the compound constituents in the cascade of components thought to underlie lexical access, however, the results may be more conclusive in suggesting that the decomposition into constituents occurs during the initial stages of lexical processing. Further, identifying a component in the electrophysiological signal sensitive to constituent access would be of value in that it would provide an index of a subcomponent of decompositional processing that may not always be detectable at lexical decision, again which would be of value in determining exactly how decomposition is affected by factors such as transparency, productivity, frequency, etc. which are thought from some points of view to play a critical role in whether items are treated as complex or simplex in lexical processing. In the following, we analyze the electrophysiological signals leading to the lexical decision response with respect to their sensitivity to constituent, rather than whole-word properties, as a test for the presence and locus of decompositional effects in compound word processing.

Section 4: Neuromagnetic Responses

Subsection 1: Analytical Method

Analysis of the magnetoencephalographic signal across conditions and across participants revealed three consistent components appearing in cascade from the onset of the visual stimulus through the first 500ms post-onset; see Figure 9 for an example of these components. The occurrence of this series of components, appearing at approximately 170, 250, and 350 ms post-onset has also been attested in a growing cohort of neuromagnetic studies (see Pylkkänen and Marantz, 2003, for a recent review); see also the MEG experiment reported in Chapter 8 of this dissertation, for another set of findings eliciting this set of components and showing that the 350 ms (M350) component is sensitive to further aspects of lexical activation involving lexical representation in two types of ambiguous word (also reported in Beretta et al., 2005).

Figure 9 Magnetic Field Contours (A) and Averaged Waveform (B) Elicited by Presentation of Visual Words (from Visual Word Onset to First 500 ms Post-Onset)

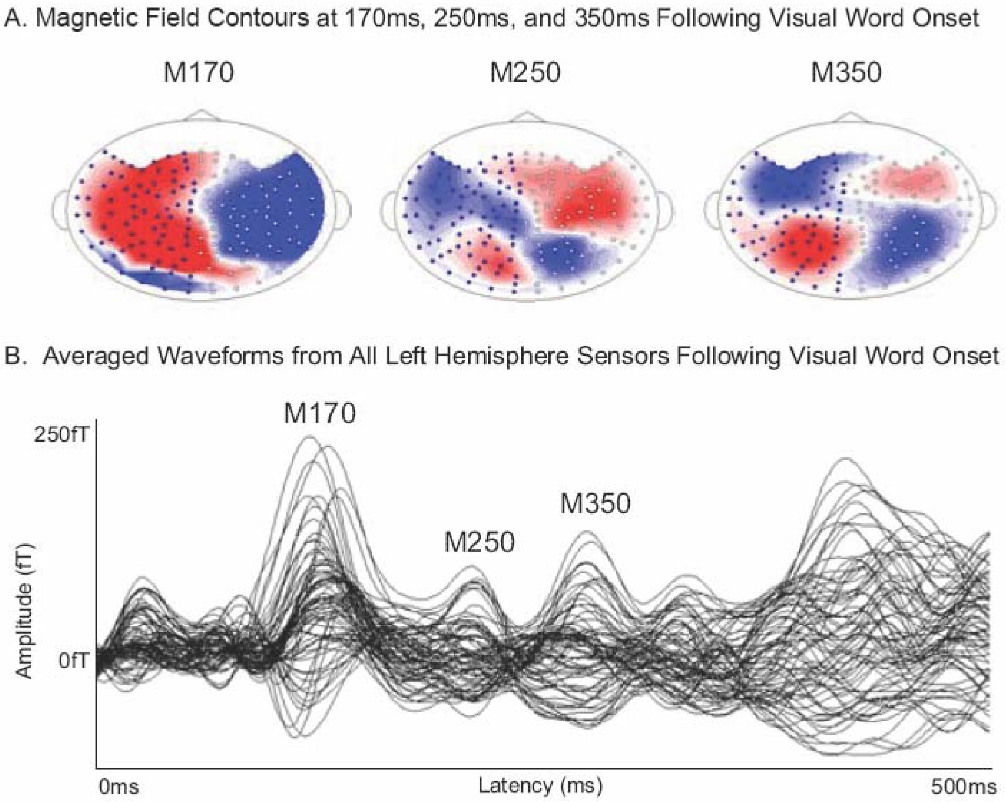
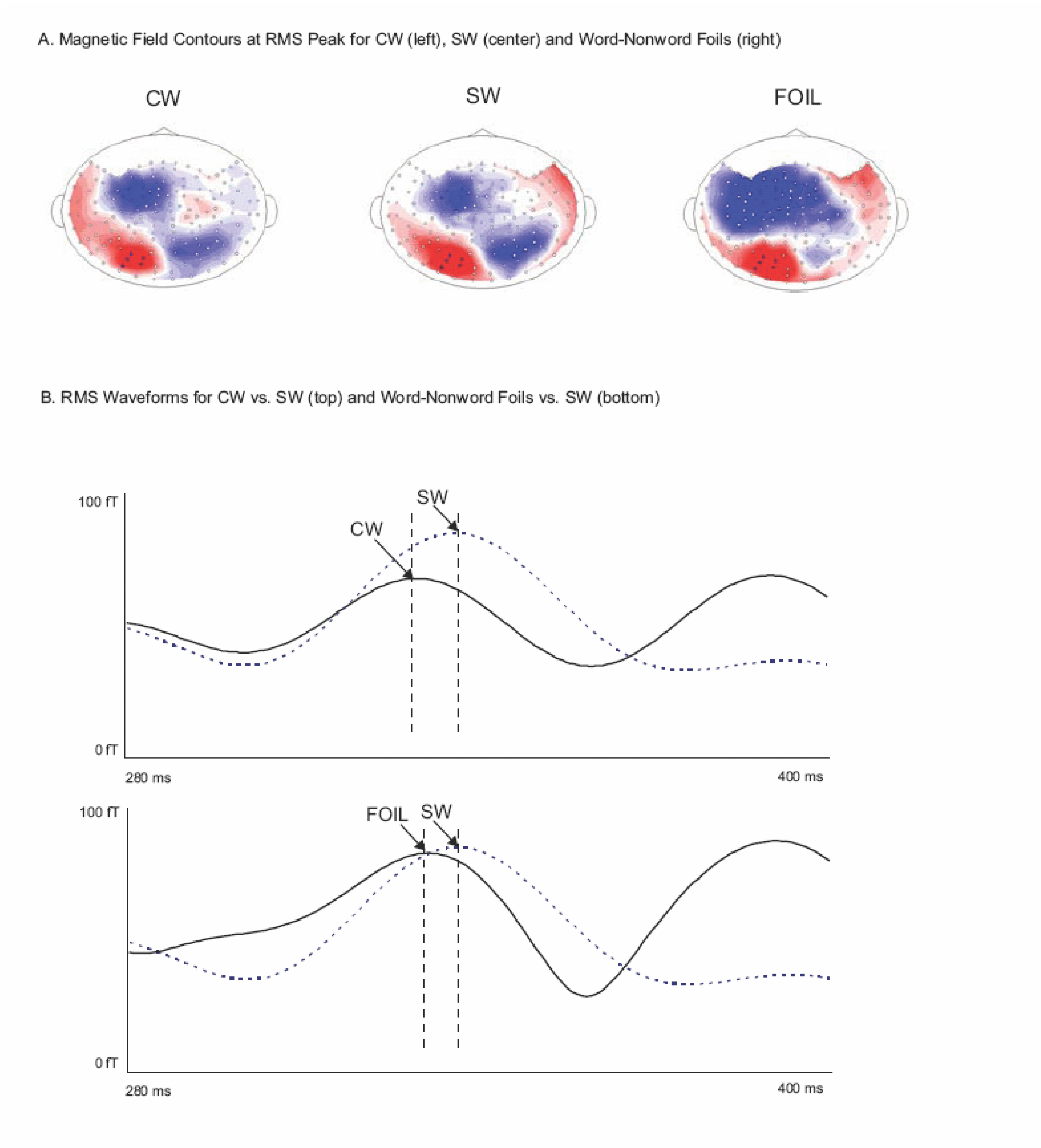


Figure 10 Magnetic Field Contours (A) and RMS Averaged Waveforms (B) for Compounds, Single Words, and Word-Nonword Foils



Root mean square (RMS) analysis. The peak latency and amplitude for each component was determined by selecting 5 channels from the sink (ingoing) and five channels from the source (outgoing) portion of the magnetic field contour; the latency of the peak from a root mean square (RMS) analysis on these 10 channels was entered into by-condition statistical comparisons, which are presented in the next section.

Subsection 2: Neuromagnetic Results

The third source component in the pattern of distributions was the first component sensitive to the compound versus single word comparison. This component, peaking around 350 ms, yielded a significant effect of condition in ANOVA ($F(2,22) = 8.532$, $MSE = 288.114$, $p<0.003$). Planned comparisons show a significantly earlier peak latency for the Compound words ($M = 333$ ms) than the Single words ($M = 360$ ms) ($F(1,11) = 12.732$, $MSE = 354.223$, $p<0.005$). Word-nonword foils ($M = 340$ ms) did not differ significantly from compound words ($F(1,11) = 1.394$, $MSE = 186.587$, $p<0.264$). Single word latency was significantly longer than Word-nonword Foil latency ($F(1,11) = 8.049$, $MSE = 323.53$, $p<0.017$). Table 4 shows the mean differences in M350 latency, and the MEG waveforms are shown in Figure 10.

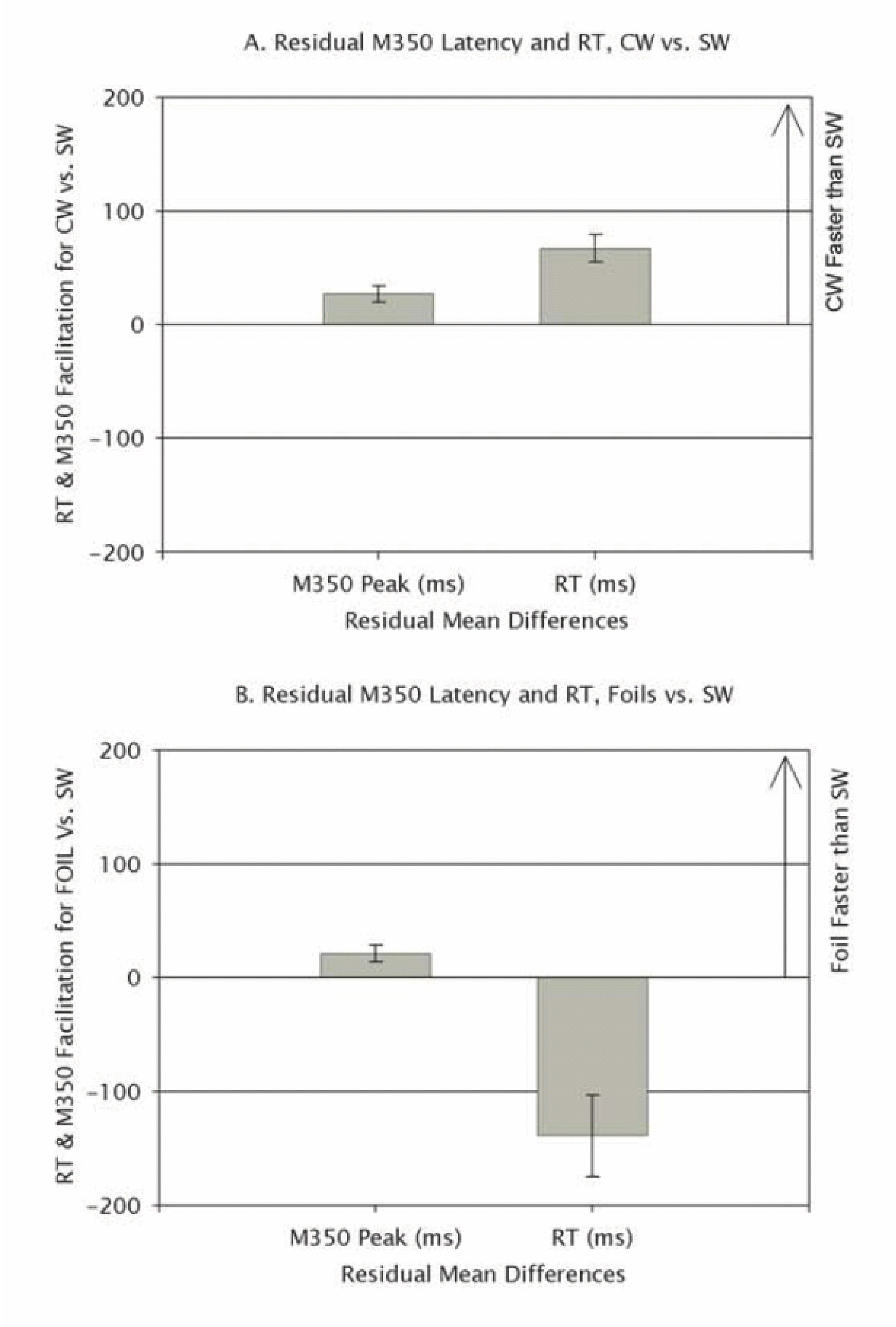
As for the behavior of the two earlier components typically observed in the data, around 170ms and 250 ms post-onset respectively, analysis of these two components yielded no significant latency differences by condition (all F's<1).

Likewise, amplitude did not differ at M170, M250, or M350 (all F’s<1). The direction of M350 latency and response time differences across conditions are depicted in Figure 11 below.

Table 4 M350 Latency For Compounds, Single Words, and Foils

Condition	*Mean RT (ms)*	*SE*
Compound	333	29
Single Word	361	36
Word-Nonword Foils	340	12

Figure 11 Relation among Response Time and M350 Latency for Compounds, Single Words, and Word-Nonword Foils


A. Residual M350 Latency and RT, CW vs. SW

B. Residual M350 Latency and RT, Foils vs. SW

Summary of Electrophysiological Results. Three components in the averaged evoked MEG waveform were observed consistently across conditions and participants, one peaking around 170 ms (M170), one peaking around 250 ms (M250), and a third peaking around 350 ms post-onset of the visually presented words (M350). Of these, only the third component showed a significant effect of word structure in the RMS analysis, the M350 component. While these results support a particular *timing* prediction, namely that M350 peak latency should show an effect of facilitation due to the properties of compounds' morphemic constituents when contrasted with disyllabic single words, these results leave open the precise nature of the underlying sources for the M350 and the other components consistently observed in the dataset.

Several studies have specifically addressed the underlying sources of these components. Tarkiainen et al. (1999), Helenius et al. (1999), and others have explored the localization of the responses before 200 ms in response to visual words and symbol strings; from these studies, the activation around 170 ms has been attributed to inferior occipito-temporal cortex. Helenius et al. (1999), among others, have also explored the source localization of the magnetic N400. Typically, this component has been localized broadly to left superior temporal locations, but with large individual differences (see, e.g., Helenius et al., 1999, for one example, and Van Petten and Luka, 2006, for a recent review of source localization findings regarding the N400m response). For example, in Helenius et al. (1999), a number of sources contributing to the N400-like response to semantically-anomalous sentence-ending words were clustered around left superior temporal regions (anterior, middle and/or posterior), but context sensitive responses also appeared in many different regions— for two subjects in left frontal regions, for five subjects in regions posterior to the Sylvian fissure, and for five subjects in right-side STG (superior temporal gyrus) (localized with 100 trials/condition). Halgren et al. (2002) also characterized the underlying sources of the responses to visual words over time in MEG using a variant of SPM (Statistical Parametric Mapping), again suggesting that the responses to visual words after 200 ms are quite diffuse in source localization in the left hemisphere and bilaterally; Marinkovic et al. (2003) also report distributed activation after 200 ms throughout anterior through posterior superior temporal regions, as well as inferior and medial prefrontal activation, as well as right hemisphere prefrontal and superior temporal activation. This has also been the case in previous attempts to localize the M350, in particular, as well as the M250 (see, e.g., Pylkkänen et al., 2006), both of which components showed diffuse and variable source localization across participants, including areas around left and right superior temporal regions, regions posterior to the Sylvian fissure, occipital regions, and left frontal regions (localizations from grand-average of 252 trials).

An exploratory source analysis of our data (using single equivalent current dipoles) suggests that, consistent with the previous studies, the M350 source tends to localize to left temporal regions, but with large individual variability. We do not pursue the analysis of the underlying sources of these components further here, considering the following limiting factors for the current dataset in this respect. In our experience, given that our study required careful stimulus control to allow for testing of our psycholinguistic hypothesis, this is not a dataset that is well-suited for a detailed source analysis of these complex components; the experiment was not designed to test for this, but to test a hypothesis about the timing of the peak activation of the M350 component in the evoked waveform. As previous studies have shown that they involve massive individual differences in source localization, it is clear that further MEG experiments testing the underlying sources of these components are necessary. And indeed, MEG is particularly well-suited among electrophysiological methods for undertaking this, but it will require higher numbers of trials and different stimuli, in order to obtain the optimal signal-to-noise ratio to permit believable source reconstruction for the components whose timing behavior was measured in the current study.

Section 5: General Discussion

The response time and magnetoencephalographic results from this study favor a decompositional account of lexical processing and a model of word recognition incorporating early decomposition into morphemic constituents. The visual lexical decision results show (i) a response time advantage for the compound words over matched single words, as predicted under a model in which morphemic constituents are accessed during the initial stages of lexical processing, and (ii) accurate though delayed responses to pseudomorphemic nonwords. The former provides new evidence for morpheme-based lexical processing, and the latter reinforces the conclusion that the effect of morphological structure for compound response time is not just word finding in words.[14] The decompositional effects found in the current study support one fundamental aspect of the *full-parsing* approach, which is decomposition even for *lexicalized* words. The direction of the effect (facilitation) can be handled by positing the storage of internally-structured entries which can be activated by prior access to constituents, and it is also consistent with a version of full-parsing without stored complex entries, namely one in which morpheme combination is not costly in the lexical decision task. With the behavioral measures, thus, we can argue for a qualitative difference among compounds, single words, and word-nonword foils motivated by their distinct processing profiles. These data provide further evidence for the decomposition of morphologically complex forms, using a method directly comparing complex and simplex words matched on overall properties, but contrasting in morphemic constituent properties. Our results are broadly consistent with the morphemic constituency effects reported in several studies, including Pollatsek and Hyönä (2005), Andrews et al. (2004), Juhasz et al. (2003), Shoolman and Andrews (2003), Zwitserlood (1994), and Andrews (1986), among others. In the following sections, we consider the implications of these results within the broader morphological processing literature.

The electrophysiological dependent measure (in particular, M350 latency) was hypothesized to track lexical access, with shorter, higher–frequency items expected to show earlier activation via peak latency. This allowed us to locate an effect of decomposition in time course previous to the overt response, since the same compound word suggests very different predictions for M350 latency in terms of its

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[14] Compound non-words with morphemic constituents consistently elicit long response times (e.g., Taft and Forster, 1976, among others)

morphemic constituent properties and its whole-word properties. The compound words were significantly earlier in peak latency for this component than the single words, as predicted by the constituent properties rather than solely by the whole word properties; the MEG response patterns for word-nonword foils looked more like that of compound words than single words. The results suggest that this component reflects the specific aspect of the computation of compound structure which involves activation of morpheme-level constituents.

Morphological parsing

Finding a facilitative effect of internal structure in processing is consistent with the notion from recent studies that an early morphological parser is active in word recognition (Feldman, 2000, Feldman, 1999, Frost et al., 1997, Frost et al., 2000a, Frost et al., 2000b, Longtin et al., 2003, Marslen-Wilson et al., 1994, Rastle et al., 2000, Rastle et al., 2004). Rastle et al. (2004) show this result in English in a masked priming paradigm using a short (42 ms) stimulus onset asynchrony (SOA). In masked priming, 'brother' primes 'broth', but 'brothel' does not prime 'broth'. Longtin et al. (2003) tested items with superficial morphological complexity in French and found priming whenever there is at least a surface string containing a legal root, even when the complex structure was only apparent and not accurate: *baguette* (gloss: little stick) is monomorphemic, but primes *bague* (gloss: ring). In contrast, there was no facilitation for words sharing only orthographic overlap without the apparent possibility of an exhaustive morphological parse (e.g. *abricot* – *abri*; gloss: apricot – shelter; -*cot* is not a suffix in French). In both the English and the French studies, the priming effect for morphologically complex and apparently complex words is seen both for semantically transparent morphologically-structured primes (*departure – depart*) and semantically opaque primes (*department – depart*); in contrast, cross-modal priming tasks show that this priming only persists in cross-modal tasks for transparent items, at least in English and French (Marslen-Wilson et al., 1994) and (Longtin et al., 2003, Experiment II), respectively. These results together argue for an early structural morphological segmentation system. A similar pattern emerges for stem homograph priming. Badecker and Allen (2002) show that in masked priming for stem homographs results in facilitation for the target. This effect holds for stem homographs: priming for *cerrar – cerro*; gloss: to close – hill, and is also dissociable from effects of semantic overlap (*puerta – cerro*; gloss: door – to close), while there is no significant facilitation for pairs with only orthographic overlap: *cerdo – cerro* (gloss: pig – hill). However, in longer-lag overt priming tasks, the previously facilitative stem homograph effect becomes one of inhibition (Allen and Badecker, 1999). Do the findings from this line of research in fact generalize to compounds? As noted above, two recent masked-priming studies with compounds suggest that this effect indeed holds for compounds, Shoolman and Andrews (2003) and the experiments in Chapter 4, which further supports the idea of an early morphological parse.

Other evidence comes from a recent production study (Roelofs and Baayen, 2002) which shows a preparation effect in the production of morphologically complex words, both semantically transparent ('input') and semantically opaque ('invoice'), but not monomorphemic words ('insect'). As concerns compounding, see also a recent set of studies on compound production in Dutch showing both first and second constituent frequency effects in the facilitation of naming latencies (Bien et al., 2005, cf. Jannsen et al., ms.). Additional support for a morphological but non-semantic effect in production comes from a study in Italian by Burani and colleagues (1999), who show that pseudowords with morphological constituency are named more easily than pseudowords without morphological constituency (and see Badecker, 2001 for effects of compound structure in a case of acquired naming deficit).

The emerging picture suggests that an early morphological parser is operative (as shown in studies of naming, masked priming, overt constituent repetition priming, fixation times in eye tracking, latency of the 350 ms MEG component), with initial parsing regardless of semantic transparency; effects of transparency begin to emerge, if at all, in measures which can also reflect subsequent stages of processing (such as cross-modal priming, semantic priming contrasting transparent and partially transparent vs. opaque compound primes, gaze duration in eye tracking, lexical decision).

Constraints

In addition to testing decompositional versus non-decompositional approaches, this experiment was able to test two putative constraints on the morphological influence in compound processing. The first is word length. Some previous studies (e.g. Bertram & Hyönä, 2003) suggested that word or constituent length may modulate morphological versus whole-word processing of compounds, and that the morphological effects seen for longer but not shorter words may be a non-structural effect arising from visual acuity (e.g. likelihood of needing two fixations versus one). The stimuli in our experiment were ‘short’ by the standard in Bertram & Hyönä (2003). Nevertheless, the effects of early access to constituents in the current study were as predicted under an early decomposition model, both in the electrophysiological and response time measurements. One advantage of the visual lexical decision/MEG method is that the starting points of processing and measurement (onset of visual stimulus) are clear and synchronized. In the eye-tracking methodology, both context and parafoveal preview likely play a role in affecting looking times; as regards parafoveal preview, the amount of information in the parafoveal view differs in size by condition in that study by virtue of the stimulus manipulation. While it may be complicated to directly compare the results among the two studies, the results together suggest some decompositional processing, and the results of the current study suggest that, at least in lexical decision, even shorter compound words undergo early morphological decomposition.

The second constraint explored was lexicalization. Contradictory effects in previous studies have given rise both to lexicalization-invariant and novel-compound-only positions on decomposition (e.g., Van Jaarsveld and Rattink, 1988). However, the effects reported in the current study were all elicited with lexicalized compounds orthographically written as single words. The current study thus suggests that lexicalized compounds undergo early decomposition. As noted above, some models seek to capture putative morphemic constituency effects as effects of lexical relatedness, and predict that these relationships should be weaker for whole-word forms as their whole-word frequency increases (e.g., Bybee, 1995). Such models would have particular difficulty with the morphemic constituency effects observed for lexicalized compounds at the highest frequency level (e.g. *rainbow*, *baseball*) in the current study.

Naturally, more studies are necessary to further investigate the effects reported here. Some of the major outstanding issues are briefly discussed in turn.

Which constituent(s) drive the effect? In the current study, both the first and second constituents of the compounds were of higher frequency, shorter length, and fewer syllables than the whole-words. One could independently manipulate constituent properties by position to locate the effects for compounds as arising from first, second, or both constituent positions; the current data are agnostic on this point. However, there are constituency effects reported for both constituents in previous experiments manipulating frequency of compound constituents. For example, Juhasz et al. (2003) found effects for both first and second constituents of lexicalized English compounds in lexical decision, naming, and eye-tracking experiments, including particularly robust second constituent effects (see also Andrews et al., 2004, Hyönä and Pollatsek, 1998, Jarema et al., 1999, Pollatsek et al., 2000, Pollatsek and Hyönä, 2005)[15]

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[15] Juhasz et al. (2003) presume that the relative pervasiveness of second position effects in their studies is because the second constituent position is where constituent and whole-word meanings converge in English (i.e. it is the head position).

Which properties of the constituents might drive the effect? Three factors were used to bias the constituents over the whole words: length, frequency, and syllabicity. Syllabicity has been shown to facilitate naming for difficult mono- and poly-syllabic words (see Henderson, 1982, Taft, 1991, for some discussion). Length effects have been attested in both behavioral (Gill and McKeever, 1974, Lavidor and Ellis, 2002, among others) and neurolinguistic studies (Cornelissen et al., 2003, Tarkiainen et al., 1999, among others). The MEG literature, for example, typically shows detection of word-length effects around 150-200 ms post-onset of visual word stimuli. However, frequency is the factor most often assumed to drive the effect in paradigms like the one used in the current study. Indeed, it has been common in the literature on lexical processing to contrast base and surface frequency of complex words (Baayen et al., 1997, Bertram et al., 2000b, among many others). In the literature on compounds, several studies which we have reviewed above have manipulated constituent frequency of compound words (Andrews, 1986, Bien et al., 2005, Juhasz et al., 2003, Pollatsek and Hyönä, 2005, among others). Many of these studies report base frequency effects on response times. However, accounting for the lack of base frequency effects under some circumstances has in turn led to various dual-route models or full-storage models in various cases (for some discussion, see, e.g. Bertram et al., 2000b, Hay and Baayen, 2005, New et al., 2004, Schreuder and Baayen, 1997, Taft, 2004), although we have raised questions regarding the conclusion that a lack of base-frequency effects entails a non-decompositional processing route

Is there an independent index of composition as opposed to decomposition? It would be valuable to identify potential electrophysiological indices of composition in the MEG signal, and to investigate possible compositional effects for both novel and existing complex words. In the psycholinguistic literature, there have been some studies which speak to the role of composition for novel items ('parse time' in the Morphological Race Model; Schreuder & Baayen, 1995; for some linguistic analyses, see e.g. Levi, 1978; Downing, 1977); for some experimental results, see e.g. Gagné, (2002), Van Jaarsveld & Rattink (1988), among others. Shoolman and Andrews (2003) suggest that 'combination' effects of the latter type can also be detected by increasing the proportion of nonwords with lexical routes, as suggested by the attenuation of base-frequency facilitation and priming for RT (Shoolman & Andrews, 2003).

We do not report results on an electrophysiological component indexing composition here. However, two possibilities from the MEG literature are worth briefly speculating on here. The first is the possibility that a subsequent iteration of an M350-like distribution in the 400ms range may be involved in this kind of process (Pylkkänen and Marantz, 2003). The second, intriguing possibility is that the index of this kind of combinatorics lies in the higher-frequency brain response (such as the gamma response, in the 20-50 Hz range). This response has been linked to binding in cognitive tasks in other domains, such as the visual domain (e.g. Tallon-Baudry and Bertrand, 1999). Some recent studies using EEG and MEG have begun exploring possible indices of linguistic properties in the gamma band (Braeutigam et al., 2001, Eulitz et al., 2000, among others). If complex words are complex lexical items with internal structure computed in real time, these stimuli may be of use in testing general properties of decomposition and composition in brain-level computation.

Processing models

The current processing models prominently featuring a decompositional component, the MRM (Morphological Race Model), AAM (Augmented Addressed Morphology model), and the supralexical model of Giraudo and Grainger (2000), face problems accounting for the range of data in the literature in a principled way. A decomposition-second model would have trouble accounting for the data presented here and elsewhere without further stipulations. The data would potentially be consistent with a dual route model such as MRM, since the data here support a class of models incorporating minimally a parallel decompositional component. As a model, MRM has the advantage of parallel availability of both options, but in order to accommodate the data in the literature, must direct traffic via constraints; further, at least some variants of the model do not predict decomposition for the items tested (lexicalized compounds). The effect of word structure, even among the highest-frequency compounds supports full-parsing models, such as that by Taft (1991, 2004), see also Stockall and Marantz (in press); however, the facilitative effect relative to the single words requires a principled account under full-parsing. The findings of the current study are also compatible with some parallel dual-route or segmentation-through-recognition models which posit a stored representation with internal morphological structure which can be accessed via initial activation of morphemic constituents.

Semantic Transparency

The focus of the present experiment was to test for the presence of decomposition in visually presented, lexicalized English compounds. Our behavioral and neural results suggest a role for early decomposition in the recognition of known compound words. While we did not test specifically the property of semantic transparency/opacity, it would be potentially informative to explore the role of transparency in compound representation and processing under similar conditions to those of the current study. The loci of decompositional effects on the one hand, and any transparency effects on the other hand, may be differentiable by measuring not only response time but also neural components involved in lexical activation, which may be informative regarding how we should incorporate such constraints into the parsing model.

Further, showing constituency effects regardless of transparency would seem to be at odds with the supralexical model (Giraudo and Grainger, 2000) which posits constituent access after initial contact with whole-word representations and only for transparent words (see also Diependaele et al., 2005, for more discussion in terms of the supralexical model and transparency). Such findings may also present challenges to distributed-connectionist approaches to constituency effects, since those models seek to capture such effects as form-meaning overlaps. In the next chapter, we address this issue directly, reporting response time facilitation in masked priming both for constituents of transparent and of opaque lexicalized compound primes; for further compound-constituency effects independent of semantic transparency, see also Shoolman and Andrews (2003) (masked priming from constituents to compounds), Zwitserlood (1994) (overt visual priming from compounds to constituents), Libben et al. (2003) (overt visual priming from constituents to whole compounds), and Pollatsek and Hyönä (2005) (morphemic-frequency effects on fixation durations in eye tracking regardless of transparency).

As noted, we will return to the role of semantic transparency in compounding specifically (and its implications for lexical representation more generally) in the next chapter, investigating this issue using the technique of masked priming. In future research, we will also extend the testing of effects of constituency and semantic transparency using the MEG method presented above in the following way. First, to address the interpretation of the MEG component as reflecting constituent properties independent of whole-word properties such as lexicalization, we will test the MEG (and psychophysical) responses elicited by novel compound words with the same morphological constituents as the compounds tested in the above experiment. Adding this stimulus category allows tests of whether there is indeed facilitation in the MEG component around 350 ms post-onset, even though the whole-word is novel (and may, like the word-nonword stimuli tested above, result in contrastingly longer, not shorter, RTs). Second, we will test directly whether there is any effect in the latency of the MEG component around 350 ms with respect to semantic transparency (and whether there are other effects related to transparency evident in the MEG signal) when other lexical properties are held constant, by comparing responses to compounds with the same constituent-level properties, but contrasting significantly in level of semantic transparency (we will utilize the stimuli in Experiments II-III below for the basis of this experiment, as they well satisfy these requirements, being tightly matched in morphemic properties and whole-word lexical properties, but contrasting by condition in semantic transparency; see the item descriptions in Chapter 4 for more information on these item controls).

Visual vs. Auditory Processing

The evidence provided by our first experiment came from visual lexical processing (as does much of the evidence we cite above). The question then arises whether such effects would also hold in the auditory domain, and what information in the speech signal may affect whether a word is processed holistically or by positing internal morphological structure. Two studies in German, (Isel et al., 2003) and (Koester et al., 2004), investigate the processing of spoken compounds and the role of prosodic information in analyzing a spoken word as a potential compound. In Chapter, 5, we address the issue of morphological-level processing in spoken words directly, using the interesting case of Japanese compounds which undergo the morpho-phonological alternation called *rendaku*, or sequential voicing. Again, we show activation of constituent morphemes in novel Japanese compounds, providing evidence from a version of cross-modal fragment priming suggesting that spoken compound comprehension involves morphological-level processing (those results are also reported in Sakai et al., 2006).

Section 6: Summary

The addition of simultaneous MEG recording to the lexical decision task offers a new way to investigate a deep property of lexical representation and processing, morphological decomposition, and points to a method for testing and constraining time course predictions on the role of decomposition in lexical processing. The behavioral and electrophysiological results support the growing variety of studies that suggest a role for morphological-level representations in lexical processing, consistent with a view of lexical representation and processing involving structurally-mediated computations over abstract lexical representations.

This study presents one way forward in enriching the information available from lexical decision data (overt response data such as RT and accuracy), by the addition of a set of time-sensitive dependent variables using simultaneous MEG recordings of brain activity. In the following three chapters, we pursue the possible interpretation of the data in this chapter as reflecting morphological decomposition during processing, and the challenges we have raised in objection to the notion that types of idiosyncrasy such as those introduced by limited transparency, productivity, frequency, preclude decomposition for some or all words (for which some evidence in the literature, mainly from lexical decision, has been adduced).

In the next chapter, we directly pursue the claim that morphemic constituents are automatically activated during the processing of lexicalized compounds, and directly challenge the notion that *semantic transparency* constrains the operation of decomposition. In Chapter 5, we address the issue of whether *spoken words* are processed as atoms or whether internal morphological structure is considered during the online processing of spoken words, and also directly challenge the notion that *surface form* constrains the operation of decomposition. In Chapter 6, we return to visual processing, testing whether derivationally-affixed words also show effects of automatic morphological decomposition, for the purpose of directly challenging whether *productivity* constrains the operation of decomposition. In Chapter 7, we return to the methodology of simultaneous MEG and lexical decision, applying the method to a new domain in which a distinction in the internal structure of lexical representation is at issue: that of the nature of lexical representations under two types of lexical *ambiguity*. Before moving on to the next chapter, we briefly present the results of a replication study to verify the replicability of the psychophysical results by-participants and by-items in a new group of participants.

Section 7: Psychophysical Replication Study (Experiment IB)

Subsection 1: Design and Results

In order to validate the replicability of the psychophysical results of the first experiment with a similar sample size, we conducted a separate lexical decision study with additional participants who did not participate in the MEG/lexical decision experiment reported above. Twelve additional undergraduate students from the

University of Maryland College Park (native speakers of American English; 7 females, ages 18-24, mean age 20) completed the lexical decision experiment, for which they received payment. The items were those of Experiment I. Participants were tested individually in a quiet experiment room (outside the MEG scanner). Items were presented in white text on a black background on a computer monitor; 'Word' responses were indicated by clicking a button with the index finger of the dominant (right) hand; 'Nonword' responses were indicated by clicking a button with the middle finger of the same (dominant) hand. The pattern of results in the replication study was virtually identical to that of the main experiment, as is summarized in Table 5 below. This pattern of results held both in by-participants and by-items analyses; full details, statistical tests, and comparison of statistical results with the main experiment are all provided in Appendix III. The results of this replication study suggest that the psychophysical findings are robust and replicable, and hold both by participants and by items.

Further, as noted above, unlike the responses elicited in the MEG scanner, both the 'word' and 'nonword' responses were elicited on the dominant (right) hand in this replication study, with the same pattern of results. This suggests that response hand does not strongly bias the results in this dataset.

Table 5 Response Time and Accuracy, Psychophysical Replication Study

OVERALL COMPARISON		RESPONSE TIME (ACC %)
Compound Words		605 (92%)
Single Words		678 (82%)
Word-Nonword Foils		722 (86%)
SUBANALYSES AT THREE FREQUENCY LEVELS		RESPONSE TIME (ACC %)
High Frequency	Compound Words	557 (98%)
	Single Words	623 (99%)
Mid Frequency	Compound Words	609 (96%)
	Single Words	690 (88%)
Low Frequency	Compound Words	667 (81%)
	Single Words	766 (67%)

Subsection 2: Re-analysis with Six Items Removed

We further analyzed the replication study, removing six items of potential concern. We identified these six items, all from the single word list, that are most likely to be taken as pseudo-derived or opaque complex forms (*grievance, stretcher, creature, substance, merchant, pleasure*). The pattern of results remained virtually identical to that in the full analysis, both by participants and by items, as reported in detail in Appendix IV below. This suggests that, while these forms should be avoided to the greatest extent possible to make the clearest complex vs. simplex word comparison, these items did not significantly interfere with the intended compound vs. single word contrast in the current study.

Chapter 4: Automatic Morphological-level Decomposition: Masked Priming of Compound Constituents

Section 1: Introduction

The results of the lexical decision/MEG study presented in the last chapter suggest that compound constituents are activated automatically during the processing of compound words, including lexicalized compounds, as is shown in a direct comparison of words with compound structure vs. simplex words matched on overall properties. Further, the MEG results provide supporting evidence suggesting that this effect holds true of the initial stages of lexical activation. In the studies presented in this chapter, we will turn to the investigation of constituent access in compounding using the task of masked priming. As we will show below, these studies will allow us to examine the findings from Experiment I as concerns the following three fundamental and related issues: (i) the extent to which morphologically complex forms are processed in terms of their constituents, (ii) the extent to which the presence and processing of morphological complexity is constrained by factors such as semantic transparency, word position of morpheme, word frequency, and productivity, among many other candidates, and (iii) the extent to which apparent effects of morphological processing can be accounted for as effects of formal or semantic similarity – or how, alternatively, such effects would fit into a model of lexical processing incorporating a morphological level (see Frost et al., 2005, McQueen and Cutler, 1998, Sandra, 1994, for reviews).

Recently the technique of *masked priming* has generated interest in the context of this debate, as evidence from this paradigm has been put forth to argue for morphological constituency effects which diverge from formal and semantic effects, and which may not be constrained by factors such as semantic transparency, which are often evident in overt cross-modal priming studies such as Marslen-Wilson et al. (1994). As such, the masked priming paradigm has become a critical testing ground for the competing accounts of whether or when decomposition plays a role in lexical processing, since competing accounts of lexical representation and processing predict distinct patterns of effects in this domain. The aims of the current studies are to present new findings that address and clarify some fundamental questions raised by our own results from the last chapter, as well as from the previously-reported findings from masked priming with derivational morphology which were used to argue for early and across-the-board morphological constituency effects. We argue that the evidence, taken together, supports the notion of an early morphological-level decomposition process in the recognition of complex words, and that the constraint we will test, semantic transparency, does not preclude initial decomposition. Such a conclusion about morphological structure requires that there *is* morphological structure, and argues against recent conceptions of word representations that deny the role of morphology in lexical representation and processing (e.g., Gonnerman et al., ms., Hay and Baayen, 2005, Seidenberg and Gonnerman, 2000).

Some recent masked-priming studies have reported rapid automatic segmentation of complex words into constituent morphemes (e.g., Longtin et al., 2003, Rastle et al., 2004). These studies have found significant masked partial-repetition priming whenever the surface-string is consistent with a morphological parse, both for semantically transparent morphologically-structured primes (*departure – depart*) and opaque primes (*department – depart*), and even for pseudo-derived words (*brother/broth*), although not for words without the possibility of internal morphological structure, regardless of orthographic overlap, such as (*brothel/broth*). These results may be taken to reflect a stage of initial morpheme-based segmentation. However, since these studies focused on affixation, a major question which is raised by the studies is whether the effects would generalize to other kinds of morphologically complex words, or whether they are due to the salience of the highly frequent closed-class suffix (see, e.g., Longtin et al., 2003, for some discussion). Further, it remains controversial whether these decompositional effects are indeed free from constraints by semantic transparency, as predicted under some models of lexical processing (e.g., Giraudo and Grainger, 2000), in which initial contact with the lexicon is always through whole-word representations, and as predicted by models without internal structure, which would seek to explain seeming effects of constituency in terms of formal or semantic overlaps (e.g., Seidenberg and Gonnerman, 2000). At the root of these concerns are fundamental questions (i) about when decomposition takes place under competing decompositional accounts (immediately vs. only after contact with a whole-word representation), (ii) what, if anything, constrains initial decomposition into constituent morphemes (whether all complex words, or only transparent words, decompose), and (iii) whether putative morphological-level effects can be reduced to regularities of form/meaning pairings (morphological constituency accounts vs. similarity-based accounts).

Given these concerns and questions, testing compounds becomes important, and perhaps crucial, as compounding is a word-formation process adjoining *open-class* morphemes – allowing tests of whether stripping of a salient affix is prerequisite for decompositional effects, and is a process yielding complex words with a wide variation in how closely semantically related the parts and the compound word are. Thus, in the current studies, we investigate the priming of constituents of English transparent (*teacup)* and opaque (*bellhop*) compound words in a masked priming paradigm closely matching those which have previously yielded significant priming for roots of derivationally-complex items (e.g., Longtin et al., 2003, Rastle et al., 2004).

Masked priming and morpho-orthographic segmentation

Using the technique of masked priming (Forster and Davis, 1984), a recent series of studies has lent support to the notion that an early morphological parser is active in visual word recognition (e.g., Badecker and Allen, 2002, Boudelaa and Marslen-Wilson, 2005, Feldman and Soltano, 1999, Feldman, 2000, Frost et al., 1997, Frost et al., 2000a, Frost et al., 2000b, Longtin et al., 2003, Longtin and Meunier, 2005, Rastle et al., 2000, Rastle et al., 2004, among others). These studies, in the main, report facilitation in response time for the lexical decision to a target when it can be morphologically parsed from the masked prime, using very short presentation times (~40-50 ms), which are thought not to be sufficiently long to permit conscious recognition in the general case. Importantly, semantic or orthographic overlap without the possibility of an exhaustive morphological parse are shown not to cause significant or equal facilitation. Monomorphemic word pairs (like *tinsel - tin*) do not facilitate response times (e.g., Badecker and Allen, 2002, Diependaele et al., 2005, Drews and Zwitserlood, 1995, Giraudo and Grainger, 2000, Grainger et al., 1991, Longtin et al., 2003, Rastle et al., 2004, Segui and Grainger, 1990, among others).[16] In contrast, the morphological priming effect is said to hold both for semantically transparent morphologically structured primes ('departure'-'depart') and semantically opaque primes ('department'-'depart') (e.g., Boudelaa and Marslen-Wilson, 2001, 2005, Feldman and Soltano, 1999, Feldman, 2000, Longtin et al., 2003, Rastle et al., 2004, among others) These results together suggest an early process of segmentation into morphological-level parts, in cases where semantic or orthographic overlap do not yield similar effects.[17]

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[16] For additional evidence for lack of facilitation for prime-target pairs possessing only formal overlap in other paradigms, see also Marslen-Wilson et al., (1994), Meunier et al., (2000) (*overt cross-modal immediate repetition priming*), Zwitserlood, 1994 (1994), Allen & Badecker, 1999 (1999) (*overt visual-visual immediate repetition priming*), and Murrell & Morton, (1974) (*long-lag visual-visual priming*), among many others. For dissociation of morphological and semantic effects, see also Stolz & Besner, (1998) (*priming with letter search task*), among others.

[17] The pattern regarding semantic transparency differs somewhat for cross-modal tasks. For example, Marslen-Wilson et al. (1994) found that only the transparent derivationally-complex primes ('departure') showed a facilitative effect. Longtin et al., (2003), Experiment II, showed the same in their cross-modal task, contrasting with their Experiment I (masked priming). Similarly, Badecker and Allen, (2002) show that masked priming from stem homographs is facilitative and separable from both orthographic and semantic overlap. However, in overt visual priming with longer SOA, the stem homograph effect is inhibitory (Allen and Badecker, 1999).

Taking one example, Longtin et al. (2003) tested items with apparent morphological complexity in French and found priming only if there is at least a surface string that could be exhaustively parsed into a legal root ('bague') and suffix ('-ette'), even when this structure would not be accurate for this item, referred to as ‘pseudo-derived’, e.g. ‘baguette’ is monomorphemic, but primes ‘bague’. Using a masked priming paradigm with a 46ms prime duration, Longtin et al. (2003) tested semantically transparent morphologically complex words, semantically opaque complex words, pseudo-derived words (e.g. baguette), and words with only orthographic overlap. Transparent pairs (gaufrette/GAUFRE ‘‘wafer/waffle’’) yielded significant facilitation (38 ms). The opaque pairs (fauvette/FAUVE ‘‘warbler/wildcat’’) yielded significant facilitation (43ms). Pseudo-derived pairs (baguette/BAGUE ‘‘little stick/ring’’) yielded significant facilitation (26ms). In contrast, orthographic overlap (abricot/ABRI ‘‘apricot/shelter’’) showed the opposite result, of 26 ms inhibition (Longtin et al., 2003).

Rastle et al. (2004) developed a very similar paradigm using English stimuli and a comparably brief prime duration of 42 ms. They tested these findings using English stimuli of three types: 1) semantically transparent morphological relationship, e.g. cleaner-CLEAN; 2) apparent morphological relationship (like the ‘pseudo-derivation’ in Longtin et al., 2003), e.g. corner-CORN; 3) orthographic form overlap without apparent morphological relationship, e.g. brothel-BROTH. The results again showed a significant effect of priming for both semantically transparent complex words (27 ms), and words with apparent morphological complexity (22 ms), although not for the orthographic overlap condition (brothel-BROTH) (4 ms, *n.s.*).

Cumulatively, the main thrust of these findings is that the segmentation side of morphological-level decomposition operates rapidly and automatically, facilitating response times to constituents in an environment where neither semantic overlap nor orthographic overlap yields similar facilitation (see Feldman and Soltano, 1999, Feldman, 2000, Longtin et al., 2003, Rastle et al., 2004, among others, for further discussion). If these generalizations are correct, it suggests that there is considerable morphological decomposition that cannot be captured simply by (i) direct *form-meaning mappings* or (ii) constraints on decomposition making reference to *semantic transparency*.

As such, this research continues to generate interest with respect to opposing fundamental conceptions of the representation and processing of complex words, e.g. distributed-connectionist vs. localist, dual route vs. full decomposition, sublexical vs. supralexical models. From at least Murrell & Morton (1974) and Taft and Forster (1975, 1976) on, evidence has been amassing which shows that effects of morphological structure are detectable using methods such as lexical decision, priming, naming, and eye-tracking methods. These effects were offered as evidence of morphological decomposition, contrary to the Full-Listing model proposed by Butterworth (1983), a model focusing on observations about distinctions in transparency and productivity, for example, in suggesting that automatic decomposition should not be expected to occur in the general case (see, e.g., Manelis & Tharp, 1977, for early evidence put forth to support a full-listing type of approach). Since then, distributed-connectionist approaches, decomposition-second (e.g. supralexical models) models, and dual-route (e.g. whole word vs. constituent race) models of lexical processing have incorporated, at least in part, the essence of the Full-Listing approach by positing whole-word processing under certain circumstances, in contrast to a decomposition-first view in which words are processed immediately and automatically in terms of their morphological-level constituents, as we have mentioned in Chapter 3 above.

Distributed-connectionist accounts seek to capture ‘morphological’ internal structure effects without reference to any abstract morphological level, handling these effects as arising from statistical regularities of form and meaning pairings (Seidenberg and Gonnerman, 2000). According to this type of approach, relations among words and their ‘parts’ will be evident only insofar as there is a transparent form and meaning-based relation which is built up among them over time (implemented as weight adjustments between connectional primitives). As such, the distributed-connectionist approach does away with the notion of abstract morphological representation, and predicts that so-called constituency effects arise based on these form-meaning similarities (see also Elman, 2004). Although it is often said that the distributed-connectionist model cannot handle effects like those cited above, in which opaque complex words show morphological constituency effects (see, e.g., Rastle et al., 2004, Stolz and Besner, 1998, for some discussion), Plaut and Gonnerman (2000) offer an account suggesting that a distributed-connectionist model taking into account the overall level of transparent ‘morphological’ complexity in a language might model the constituency effects for opaque forms in morphologically rich languages.[18] Since their approach predicts that a language like English, with relatively impoverished morphology (Plaut and Gonnerman, 2000), should not show such effects, masked priming results from such languages become especially interesting.

A second class of models recognizing at least in part a role for morphological-level representation and a role for whole-word processing can be broadly construed as dual-route (whole-word and constituent) models of lexical access. Under these approaches, various constraints (such as semantic transparency) mediate whether a word will be accessed in terms of its parts or whether the word will be accessed and stored as a full-form (Bertram et al., 2000b, Schreuder and Baayen, 1995, among others). Within these models, there are versions which view the process as parallel, and versions which view decomposition as an effect subsequent to whole-word access, as in the *supralexical model* (e.g., Giraudo and Grainger, 2000). In the supralexical model, for example, priming effects from opaque items are not expected, as the first contact for complex words is through the whole-word representation, later proceeding to constituent representations in case there is a semantically transparent relationship among parts and the whole word (see, e.g., Diependaele et al., 2005, Giraudo and Grainger, 2000, for recent discussion). Some empirical results are consistent with full-listing for precisely such items, such as the lack of cross-modal priming for roots of semantically opaque derivationally complex words in Marslen-Wilson et al. (1994), lack of base frequency effects for certain derived words such as those with

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[18] While Plaut and Gonnerman (2000) do not offer a speculation on how to classify quantitatively languages as morphologically-rich and poor languages, the authors explicitly place English in the latter category.

homonymous suffixes in Finnish, discussed in Bertram et al. (2000b), further discussed in Vannest et al. (2002); cf. Taft (2004).

The two previous approaches differ from one in which complex words are expected to be decomposed into their constituents during lexical access regardless of the semantic relations involving the constituents, which could be called an *early structure-based decompositional approach*. This approach suggests that the morpheme is a privileged level of initial parsing in the general case, in contrast to the distributed-connectionist model and dual-route models, which predict morpheme-like effects only under certain circumstances, such as when a semantically-transparent relation applies. The decompositional view has received considerable support from recent studies of masked priming in derivationally-complex words, along the lines reviewed above; see Stockall & Marantz, (in press), for a full-decomposition treatment of the English irregular past tense, and Taft (2004) for another implementation of a full-decomposition approach.

The results of the recent masked priming studies reviewed above thus offer the potential of speaking directly to specific, distinct predictions expected under these differing approaches to the representation and on-line processing of complex words, and the paradigm seems to hold promise for generating interesting new testable predictions adjudicating among these views. However, some questions regarding the results of these masked priming studies remain.

Morpho-orthographic segmentation and Compounding

The first question involves the generalizability of the effects. For example, could the rapid segmentation into constituents in the derivationally-complex words used in Rastle et al. (2004) and Longtin et al. (2003) be epiphenomenal, arising from the presence of a saliently high-frequency, short, closed-class suffix morpheme that may be especially easy to detect? Since nearly all of the masked priming studies on morphological constituency have tested affixation, it is not clear from these studies whether this particular aspect of formal regularity plays a role in eliciting root priming effects. However, compounding allows for a direct test of this. In English compounding, two open-class roots are combined and represented as a single word (e.g. *tea+pot* yields *teapot*), without any overt linking morphology. If responses to constituents can be facilitated by masked priming using whole compounds such as *teapot* or *bellhop* as a prime, it suggests that the morphological segmentation underlying the 'morphological' masked priming effects are not reliant on the salience of the closed-class affix, but indeed generalize to other morphologically complex word structures.

Second, it remains controversial whether semantic transparency plays a fundamental role in when morphological constituency effects should hold (Plaut and Gonnerman, 2000, Seidenberg and Gonnerman, 2000). Distributed-connectionist accounts would not predict priming for cases in which the compound is semantically opaque, if the relation among the prime word and its 'constituent' is only defined in terms of formal and semantic similarity (e.g. if the relationship of *teacup* and *tea* arises from the partial overlap of the sounds (or letters) of *teacup* and *tea*, as well as their partial similarity in meaning). Recall that formal similarity by itself does not result in significant facilitation. Further, as noted above, decomposition-second approaches such as the supralexical model also suggest semantic transparency as a constraint on constituent access, claiming that access to constituent information occurs *only after contact with whole-word representations*, *and only in case the semantic relation among the whole and parts is transparent*. Recently, based on results from masked cross-modal and incremental priming paradigms, Diependaele et al. (2005) have suggested that semantically-transparent morphemes may be facilitated more strongly and on an earlier time course than semantically-opaque words in French. The fundamental distinction between distributed-connectionist and supralexical accounts on one hand, and structure-based decomposition-first accounts on the other, with respect to how semantically opaque words should behave, recommends testing for priming of compound constituents under two conditions, one in which the prime is a transparent compound, and one in which the prime is an opaque compound.

Previous Research on compounding

As reviewed above, several studies have investigated compound processing using lexical decision, as also discussed in the previous chapter (e.g. Andrews, 1986, Experiments 2 & 3; Juhasz et al., 2003, Experiment 1), priming (e.g., Monsell, 1985, Sandra, 1990, Shoolman and Andrews, 2003, Zwitserlood, 1994), and eye-tracking paradigms (e.g., Andrews et al., 2004, Bertram and Hyönä, 2003, Pollatsek and Hyönä, 2005). As for priming from compounds to their constituents, one piece of evidence, mentioned in the previous chapter, is Zwitserlood (1994), who tested immediate constituent repetition priming and semantic priming with unmasked primes and longer durations and prime/target asynchronies than is typical in masked priming (200 ms prime, target presented 100 ms after disappearance of the prime), to study the processing of semantically transparent, partially-transparent, and opaque compounds in Dutch. The results of the two experiments indeed show constituent priming by all types of compound word, regardless of transparency, although only the totally- and partially-transparent items showed semantic priming of constituents (e.g., priming for the Dutch equivalents of examples like *butterfly→bread*) (cf. Sandra, 1990, regarding semantic priming from the opaque constituent of partially-transparent compounds).

Shoolman and Andrews (2003) studied priming in compounds using compounds as targets in a masked priming paradigm. Their study focused on the masked priming of compound targets (*bookshelf*), pseudo-structured words (*hammock*), and various types of nonword using constituents as primes (56 ms duration), and found both first and second constituent priming of compounds regardless of semantic relatedness. Libben et al., (2003) also showed priming for both transparent and opaque compound targets by their first and second constituents in an overt, longer-lag repetition priming task. As reviewed in the previous chapter, eye-movements have also been used to test for constituency effects in compounding. As regards semantic transparency effects, Pollatsek and Hyönä (2005) notably demonstrated clear constituent effects in eye fixations, regardless of semantic transparency, in a study of Finnish compounds presented in sentential context using an eye-tracking paradigm.

Principally, the results of the studies reviewed above suggest a role for morphological-level complexity in processing both transparent and opaque compound words, although the results are not totally conclusive, and many of the mixed results come from overt priming tasks susceptible to strategic effects; nevertheless, they suggest the potential that compound processing is consistent with a distinction among morphological constituency and semantic relatedness. In the current study, we report a set of studies relying on masked priming, using the whole compounds themselves as primes, as this has the potential to demonstrate that constituents of compounds are activated automatically, regardless of semantic association, even when the complex word primes are not likely to be consciously observed. Finding significant facilitation of constituents in this paradigm would lend support to the notion of early access to constituents during lexical access, extended to compounds, and providing more conclusive arguments for decomposition as a general, across-the-board initial process.

Current Study

Given the concerns outlined above the possible reliance of morpho-orthographic segmentation on salient surface forms or semantic transparency, it remains controversial to what extent the previously-observed findings counter accounts predicting that morphological-level decomposition is constrained by factors like salience of the affix, semantic transparency (e.g., Giraudo and Grainger, 2000), or other constraints typical of dual-route models (e.g., Schreuder and Baayen, 1995), and to what extent morphological-level explanation is needed at all (recall the distributed-connectionist approaches such as Seidenberg and Gonnerman, 2000, among others); see also Hay & Baayen, (2005) for an approach making reference to 'graded' morphological structure. Hence, we explore these topics by studying English compounding, taking advantage of its properties of combining open-class roots without overt linking morphology and showing wide variations in semantic transparency among lexicalized compounds.

In the two priming studies reported, we ask (i) whether constituents of compounds will show significant priming in the masked-priming paradigm, and (ii) whether effects of priming are constrained by semantic transparency. The results have specific implications both for clarifying the locus of the effects previously observed with affixed primes, and for modeling the online processing of compound words. In the next section, we turn to the current studies.

Section 2: Rating Study

In order to obtain a measure of the semantic transparency of compound words relative to their constituent morphemes, for the purpose of selecting stimuli for the following two priming studies, a rating study was conducted on the semantic transparency of an initial set of 188 candidate compound words.

Stimuli and Design. The questionnaire consisted of 188 compound words, selected such that many compounds were likely to be rated as clearly transparent or opaque. Among all 188 compounds, no morpheme was ever repeated; this ensures that any subset of compounds from this list with the desired transparency ratings can be selected for use in the main experiments without concern about repeating morphemes across items. The 188 words were presented in pairs with one member of the pair always the compound word, and the other either its left or right constituent morpheme, varied using a Latin Square design. Further, each list was divided into two sections of 94 items each; one block consisted of word pairs comprised of compounds and their non-head constituent; the other, compounds and their head constituent. Head constituent vs. non-head constituent block order was also counterbalanced in a Latin Square design. This yielded four lists (counterbalancing whether a participant saw a given compound with its head or non-head constituent, and whether a participant saw a block of word pairs comprised of compounds with head or non-head constituents in the first or second section of the list). Items were pseudorandomly ordered within each block for each list. No participant saw any compound more than once. The participants were instructed that the experiment consists of a list of word pairs, and that the task was to rate, on a 5-point scale, how related they judged the two members of the word pair to be.[19] Participants were also informed that they could circle any unfamiliar word and did not have to provide a relatedness rating for that word (this allowed us to identify any unfamiliar compounds or constituent morphemes, so that these would not be used in the main experiment).

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[19] For semantic transparency rating study designs similar to this, see e.g., Marslen-Wilson et al., (1994), among others.

Participants. Forty undergraduate students from the University of Maryland College Park, all native speakers of American English, completed the rating questionnaire for course credit.

Data analysis. The rating for each compound/constituent pair was averaged across participants, and lists of the most transparent and most opaque compounds were extracted according to the averaged responses. (Looking at response patterns over all rating responses, no effects of List or Head/Non-head section order were revealed in statistical analyses.) Lists of 44 transparent and 44 opaque compounds were selected from among the highest- and lowest-rated compounds, for testing priming of the non-head (initial-position) morpheme (Experiment I) and head (final-position) morpheme (Experiment II). The properties of these items including statistical tests of differences in transparency ratings, frequency, length, syllabicity, are reported separately for each experiment below.

Section 3: Experiment II: Introduction

Masked priming of the non-head of lexicalized compounds is particularly interesting considering that much of the decomposition evidence coming from masked priming has tested priming of the root of a derivationally-complex suffixed word (e.g., Diependaele et al., 2005, Longtin et al., 2003, Rastle et al., 2004, among many others). Thus, in Experiment II, we test the priming of the non-head constituent of compounds such as (*tea*) or (*bell*), using the whole compound (*teacup*) or (*bellhop*) as a prime (see also Shoolman & Andrews, 2003, for the priming of whole compound targets by using either their first- or second-constituent as primes, and Zwitserlood, 1994, for priming of constituents of Dutch compounds at longer latencies). Probing for constituent priming in the non-head position (e.g. *teacup-tea*) allows the most direct comparison with the masked priming studies of Longtin et al. (2003), and Rastle et al. (2004), each of which tested constituent priming of a derivational root in initial position (e.g. *government-govern*). The method of the current study closely matches those of the derivational morphology studies cited above.

Section 4: Experiment II: Methods

Subsection 1: Stimuli and Designs

Transparency Ratings. For the compounds selected as non-head constituent primes, ratings for the opaque group were significantly lower than those of the transparent group, both with respect to the target morpheme (transparent 4.40, opaque 1.99; paired t-test, $t(43) = 34.722$, $p<0.001$) and in averaged ratings among both morphemes (transparent 4.13, opaque 2.49; paired t-test, $t(43) = 14.278$, $p<0.001$). We carried these 44 candidate items forward for online testing. These items were matched on overall length across the transparent and opaque lists (8.4 vs. 8.5 letters, *n.s.*; paired t-test, $t(43) = 0.765$, $p<0.45$).

Lexical properties. The transparent and opaque compound primes were matched on overall frequency (0.19 vs. 0.17 log frequency, *n.s.*; paired t-test, $t(43) = 1.732$, $p<.10$), as well as on first (1.77 vs. 1.69 log frequency, *n.s.*; paired t-test, $t(43) = 0.127$, $p<0.90$), and second constituent frequency (1.74 vs. 1.90 log frequency, *n.s.*; paired t-test, $t(43) = 0.685$, $p<0.50$), as well as on both first (4.1 vs. 4.2 letters, *n.s.*; paired t-test, $t(43) = 0.363$, $p<0.72$) and second constituent length (4.3 vs. 4.3 letters, *n.s.*; paired t-test, $t(43) = 0.408$, $p<0.69$), and are identical on first constituent syllabicity (1.1 syllables) and matched on second constituent syllabicity (1.0 vs. 1.1 syllables, *n.s.*; paired t-test, $t(43) = 1.000$, $p<0.33$). The compounds were also matched on syllable number (CW-transparent mean = 2.14, CW-opaque mean = 2.16; *n.s.*; paired-t-test, $t(43) = 0.274$, $p<0.79$), and all compounds followed the same primary stress pattern (e.g. *cámpsite*). The item controls for primes, targets and controls are summarized in Table 6 below, and a complete list of items for our first priming experiment is reported in Appendix V.

Each non-head target constituent was then matched with an unrelated control item as follows. Constituents and their control morphemes were identical in length (*transparent* 4.1 letters; *opaque* 4.2 letters) and syllable number (*transparent* 1.1 syllables; *opaque* 1.1 syllables). They were also matched for frequency, both among transparent targets vs. controls (1.77 vs. 1.77 log frequency, *n.s.*; paired t-test, $t(43) = 0.127$, $p<0.90$) and opaque targets vs. controls (1.69 vs. 1.68 log frequency, *n.s.*; paired t-test, $t(43) = 0.368$, $p<0.72$).

Table 6 Item controls (Priming of non-head constituent by compound prime).

Item	*Letter Length*	*Log Frequency*	*# of Syllables*
Transparent Prime Compound	8.4	0.19	2.1
Opaque Prime Compound	8.5	0.17	2.1
Transparent Target Morpheme	4.1	1.8	1.1
Transparent Control Morpheme	4.1	1.7	1.1
Opaque Target Morpheme	4.2	1.7	1.1
Opaque Control Morpheme	4.2	1.8	1.1

Subsection 2: Lexical Decision Norming Study (Experiment IIA)

Before conducting the priming study, we conducted a lexical decision pre-test for the target non-head morphemes vs. their control morphemes. These results allowed the identification of outlier target and control morphemes for the analysis of the priming results, and to ensure that any effects of priming would not be due to across-target differences. Twenty-one undergraduate students from the University of Maryland College Park (native speakers of American English; 15 females, ages 18 to 22) completed a lexical decision experiment, for which they received payment. The items consisted of the 88 non-head constituent morphemes taken from the 44 transparent and 44 opaque compounds, the 88 control morphemes, and 176 pronounceable nonwords. We identified six transparent and opaque pairs with large mean differences among target and control morphemes and removed them from further analyses to reduce the effect of baseline differences on any reported priming effects.

Response time. The response time results do not show any significant effects by participants or items in the overall comparison of non-head morphemes vs. their control morphemes ($F_1(1,20) = 0.005$, *MSE* = 249.870, $p<0.943$; $F_2(1,75) = 0.001$, *MSE* = 660.372, $p<0.975$), in direct comparisons of transparent targets vs. controls ($F_1(1,20) = 1.292$, *MSE* = 333.661, $p<0.270$; $F_2(1,37) = 1.531$, *MSE* = 561.098, $p<0.225$) or in direct comparisons of opaque targets vs. controls (F_1(1,20 = 0.798, *MSE* = 465.749, $p<0.383$; $F_2(1,37) = 1.276$, *MSE* = 729.145, $p<0.267$).

Accuracy. There were no significant effects of accuracy in the comparisons of targets and controls, transparent targets vs. controls, and opaque targets vs. controls, by participants and items. The overall comparison of non-head morphemes vs. their control morphemes was non-significant ($F_1(1,20) = 0.521$, *MSE* = 0.001, $p<0.480$; $F_2(1,75) = 0.065$, *MSE* = 0.004, $p<0.800$); differences were also non-significant in direct comparisons of transparent targets vs. controls ($F_1(1,20) = 3.049$, *MSE* = 0.001, $p<0.097$; $F_2(1,37) = 0.525$, $p<0.474$) and in opaque targets vs. controls ($F_1(1,20) = 0.033$, *MSE* = 0.001, $p<0.859$; F_2 $(1,37) = 0.005$, *MSE* = 0.006, $p<0.945$).

Subsection 3: Masked Priming Procedure (Experiment IIB)

We now turn to the masked priming of the non-head compound constituents in order to address the two main questions discussed above: whether constituents of compounds will show significant facilitation of response times in masked priming, and whether effects of priming are constrained by semantic transparency.

The prime-target pairs included 44 semantically transparent English compounds with the compound (e.g. *teacup*) as prime and its initial, or non-head, morpheme (e.g. *tea*) as target, and 44 semantically opaque English compounds with the compound (e.g. *bellhop*) as prime and its initial morpheme (e.g. *bell*) as target. 44 additional pairs utilized a transparent compound as prime, and a single word matched to the compound's initial morpheme, as control, and 44 pairs utilized an opaque compound as prime, and a single word matched to the compound's initial morpheme, as control, as shown in Table 7 below. Eighty-eight compound words of varying semantic transparency, matched in length and frequency to the compounds which primed the word targets served as primes for one hundred seventy-six pronounceable nonword targets, half of which had some orthographic overlap with the prime word, included to make the word:nonword ratio 1:1, and such that neither lexicality nor transparency of the prime predicted the lexicality of the target.

Table 7 Example Stimuli (Priming of non-head constituent by compound prime).

Condition	*Example Prime*	*Example Target*
Transparent Prime	TEACUP	tea
Transparent Control	TEACUP	fog
Opaque Prime	BELLHOP	bell
Opaque Control	BELLHOP	chin

Transparent vs. opaque primes, and targets vs. controls were matched on length, frequency, and syllabicity, as previously discussed and summarized in Table 6 above.

Stimuli were visually presented in the center of the screen in Courier New font, with black text on a white background using DMDX software (Forster and Forster, 2003), in a randomized order. The experiment began with 6 practice trials to familiarize the participant with the task. Participants were instructed to decide whether each item was a word or a nonword. Each trial was initiated with a 426 ms mask ("#####") equal in letter-length with the prime to follow, in the center of the screen, followed by visual presentation of prime for 49 ms, and then immediately by the target stimulus, remaining on the screen until participant's response via button press or 2500 ms timeout. A typical trial thus looks like (######-TEACUP-tea).[20] 'Word' responses were made by button-press using the index finger of the dominant hand, 'Nonword' responses by button-press with the middle finger of the dominant hand. Three short rest periods were offered (on 88-trial intervals). Response times were recorded from the onset of the target stimulus. The response time data were

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[20] This trial structure is patterned after the studies most closely related to the current study (e.g. Longtin et al., 2003; Rastle et al., 2004). The case change manipulation (upper vs. lower case), used in those studies, was also adopted for our study, to make the prime and target *physically* different (e.g., Forster, 2003); we also followed those studies in not introducing a backward mask following the prime word, as it would have increased the prime-target SOA preventing a comparison with those studies, and we wished to avoid the concern that backward masking can lead to increased detection of the prime (for discussion of these methodological concerns, see e.g. Forster, 2003; Forster, 1999; Masson & Bodner, 2003; Masson & Isaac, 1999).

analyzed after removal of trials with incorrect responses and those in which the response time was outside 2.5 standard deviations from the mean.

Subsection 4: Participants (Experiment IIB)

Twenty-one undergraduate students from the University of Maryland College Park, native speakers of American English with normal or corrected-to-normal vision (11 females; ages 18 to 27 years old), provided their written informed consent to participate in this experiment. The participants were paid or offered course credit for their participation. None of the participants in this or subsequent experiments/pre-tests participated in any of the other pre-tests or experiments.

Section 5: Experiment II: Results

Response time. The response time results show a significant effect of prime vs. control in the overall comparison of non-head morphemes vs. their control morphemes by participants and items ($F_1(1,20) = 52.104$, $MSE = 319.477$, $p<0.001$; $F_2(1,75) = 45.137$, $MSE = 1352.635$, $p<0.001$), and significant effects by participants and items in direct comparisons of transparent target vs. control by participants and items ($F_1(1,20) = 43.326$, $MSE = 490.078$, $p<0.001$; $F_2(1,37) = 42.095$, $MSE = 968.176$, $p<0.001$) and in direct comparisons of opaque target vs. control by participants and items ($F_1(1,20) = 30.566$, $MSE = 403.972$, $p<0.001$; $F_2(1,37) = 12.559$, $MSE = 1733.777$, $p<0.002$), as summarized in Table 8 below. Direct comparisons of magnitude of priming effects (Control – Prime RT) across transparent and opaque conditions were non-significant by participants and items ($F_1(1,20) = 2.414$, $MSE = 496.599$, $p<0.137$; $F_2(1,37) = 1.358$, $MSE = 2172.929$, $p<0.252$).

Accuracy. The accuracy results show a small but significant effect in the overall comparison of non-head morphemes vs. their control morphemes in the participant analysis though not the item analysis ($F_1(1,20) = 8.475$, $MSE = 0.001$, $p<0.01$; $F_2(1,75) = 1.640$, $MSE = 0.004$, $p<0.205$), a significant effect by participants and items in the direct comparison of transparent target vs. control ($F_1(1,20) = 17.356$, $MSE = 0.001$, $p<0.001$; $F_2(1,37) = 8.899$, $MSE = 0.001$, $p<0.006$), but not in opaque targets vs. controls ($F_1(1,20 = 0.038$, $p<0.848$; $F_2(1,37) = 0.005$, $MSE = 0.006$, $p<0.945$). Direct comparison of differences in error rates (Control – Prime error rate) is significant by participants though not by items ($F_1(1, 20) = 6.923$, $MSE = 0.001$, $p<0.017$; $F_2(1,37) = 1.582$, $MSE = 0.006$, $p<0.217$). Response times and Accuracy rates are summarized in Table 8 below, along with the results of the lexical decision pre-test for comparison.

Table 8 Priming of non-head constituent (by participants).

PRIMING STUDY	*Response Time in ms. (error %)*		*Mean Difference (Priming)*
Condition	*Target*	*Control*	
All Primes vs. Controls	586 (2%)	625 (4%)	39**
Transparent Primes vs. Controls	576 (1%)	621 (3%)	45**
Opaque Primes vs. Controls	596 (4%)	630 (4%)	34**

** = significant at *p*<0.01

* = significant at *p*<0.05

LEXICAL DECISION PRE-TEST	*Response Time in ms. (error %)*		
Condition	*Target*	*Control*	*Mean Difference*
All Primes vs. Controls	553 (3%)	553 (2%)	0
Transparent Primes vs. Controls	549 (2%)	555 (2%)	7
Opaque Primes vs. Controls	559 (4%)	553 (4%)	-7

** = significant at *p*<0.01

* = significant at *p*<0.05

Section 6: Experiment II: Conclusion

Significant priming was observed in the current study for non-heads of lexicalized compounds, under the same conditions in which priming was observed for the root of derivationally suffixed words in languages such as English (e.g. Rastle et al., 2000, 2004) and French (e.g. Longtin et al., 2003), and for which neither formal priming (Badecker & Allen, 2002; Diependaele et al., 2005; Giraudo & Grainger, 2000; Longtin et al., 2003; Rastle et al., 2000, 2004, among many others) nor semantic priming (e.g. Feldman, 2000, among others) can account for the effects. Our results converge also with the findings on Dutch compounds by Zwitserlood (1994) who tested overt partial-repetition priming, with longer prime-target latencies. We obtained robust facilitation in the priming task (IIB) while no such differences were evident in the lexical decision pre-test (IIA), and participants did not report conscious recognition of the prime words in the debriefing following Experiment IIB. We conclude from these results that the segmentation process underlying morphological decomposition, which was identified in priming in the above studies for derivationally complex words, is not epiphenomenally occurring due to the salience of a high-frequency, closed class suffix, as priming is observed in the current study from compound primes (made up of only open-class morphemes). Further, in the current study, priming was significant both for transparent and for opaque compounds, suggesting that semantic transparency does not strongly constrain the initial decomposition into constituent morphemes. Experiment II has provided the basic answers to our two experimental questions: (i) whether decompositional effects would be evident for complex words formed by compounding, as they were for derivationally complex words in Longtin et al. (2003) and Rastle et al. (2004), among others, and (ii) whether the effects would be constrained by transparency. We found strong evidence for decompositional effects, and these effects held both for transparent and for opaque items. The findings from Experiment II also suggest that these effects can be elicited in a within-subjects design like the one applied in the current study.

Experiment II was designed to test for decompositional effects on the non-head (initial) morpheme. Since the compounds, unlike derivationally complex words, have not one but two open-class roots, one can test for root activation effects on the head (final) position as well as the initial position of the word. In Experiment III, we test for the priming of the head constituent using transparent and opaque compound primes, as in Experiment II. To do so, we selected the best items from the rating study introduced above in overall transparency/opacity and transparency/opacity with respect to the target morpheme. Thus the stimulus set for Experiment III was selected with the aim of maximizing item controls for testing priming on the head morpheme, instead of simply carrying forward the identical item set from Experiment II. The goal is again to directly test our two questions: (i) decomposition into constituent morphemes, and (ii) whether or not transparency constrains decomposition in this paradigm. Thus, in Experiment III we directly test our two research questions using the final morpheme. This experiment will show whether or not significant priming effects hold for the final morpheme, and whether decompositional effects are mediated by semantic transparency.

Section 7: Experiment III: Introduction

The results of Experiment II suggested that priming holds for the non-head constituent of compound words in English, as it does for the root of derivationally-suffixed words. In Experiment III, we test for the priming of the head (non-initial) morpheme (e.g. the priming of *cup* by *teacup*, or of *hop* by *bellhop*).

Section 8: Experiment III: Methods

Subsection 1: Stimuli and Designs

Transparency Ratings. We selected a list of 44 transparent and 44 opaque compounds from among the highest- and lowest-rated compounds, for testing priming of the head (final morpheme), from the rating study introduced above. The compounds selected had the following properties.[21] For the compound primes, ratings for the opaque group were significantly lower than those of the transparent group, both with respect to the target morpheme (transparent 4.30, opaque 1.97; paired t-test, $t(43) = 30.312$, $p<0.001$) and in averaged ratings among both morphemes (transparent 4.03, opaque 2.41; paired t-test, $t(43) = 12.242$, $p<0.001$). We carried these 44 candidate items forward for online testing.

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[21] Since we utilize partially non-overlapping transparent/opaque prime lists for each study, maximized not only for overall difference in transparency but also for maximal transparency difference with respect to the target constituent, this limits the direct numerical comparison of head vs. non-head position in constituent priming, which is an interesting related issue in compound processing; see, e.g. Jarema et al. (1999). This choice allows the strongest test of constituent priming in the current study, within each position, controlling for semantic transparency and other important lexical factors thought to influence recognition (frequency, length, syllabicity, etc.).

Lexical properties. These items in the transparent and opaque lists were matched on overall length (8.5 vs. 8.3 letters, *n.s.*; paired-t-test, $t(43) = 1.145$, $p<0.26$). Within the head prime lists, the transparent and opaque compound primes were matched on overall frequency (0.19 vs. 0.17 log frequency, *n.s.*; paired-t-test, $t(43) = 0.179$, $p<0.86$), on first (1.98 vs. 1.71, *n.s.*, paired-t-test, $t(43) = 1.647$, $p<0.11$) and second constituent frequency (1.67 vs. 1.78, *n.s.*, paired-t-test, $t(43) = 0.960$, $p<0.35$), as well as on both first (4.2 vs. 4.2 letters, *n.s.*, paired t-test, $t(43) = 0.247$, $p<0.81$) and second constituent length (4.3 vs. 4.1 letters, *n.s.*, paired t-test, $t(43) = 1.354$, $p<0.19$), on first constituent syllabicity (1.2 vs. 1.1 syllables, *n.s.*, paired t-test, $t(43) = 0.771$, $p<0.45$) and second constituent syllabicity (1.0 vs. 1.0 syllables, *n.s.*, paired t-test, $t(43) = 0.443$, $p<0.66$). These compounds were also matched on syllable number (*transparent* 2.25 syllables, *opaque* 2.20 syllables; *n.s.*; paired-t-test, $t(43) = 0.443$, $p<0.66$), and all compounds followed the same primary stress pattern (e.g. *báthrobe*).

Each head target constituent was then matched with an unrelated control item as follows. Constituents and their control morphemes were identical in length and syllable number. They were also matched for frequency for both transparent targets (1.67 vs. 1.67 log frequency, *n.s.*; paired t-test, $t(43) = 0.370$, $p<0.72$) and opaque targets (1.79 vs. 1.79 log frequency, *n.s.*; paired t-test, $t(43) = 0.612$, $p<0.55$). These item controls are summarized in Table 9 below; a full list of items for Experiment III is included in Appendix VI.

Table 9 Item controls (Priming of head constituent by compound prime).

Item	*Letter Length*	*Log Frequency*	*# of Syllables*
Transparent Prime Compound	8.5	0.19	2.2
Opaque Prime Compound	8.3	0.17	2.2
Transparent Target Morpheme	4.3	1.7	1.0
Transparent Control Morpheme	4.3	1.8	1.0
Opaque Target Morpheme	4.1	1.7	1.1
Opaque Control Morpheme	4.1	1.8	1.1

Subsection 2: Lexical Decision Norming Study (Experiment IIIA)

We conducted a separate lexical decision pre-test for the target head morphemes vs. their controls, respectively. These results allowed the identification of outlier target and control morphemes for the analysis of the priming results, and ensure that any effects of priming would not be due to across-target differences. Twenty-one undergraduate students from the University of Maryland College Park (native speakers of American English; 15 females, ages 18-22) completed a lexical decision experiment, for which they received payment. The items consisted of 88 head constituent morphemes taken from the 44 transparent and 44 opaque compounds, 88 control morphemes, and 176 pronounceable nonwords. We identified eight transparent and opaque pairs with large mean differences among target and control morphemes and removed them from further analyses to reduce the effect of baseline differences on any reported priming effects.

Response time. The response time results show no significant effects of target vs. control in the overall comparison of head morphemes vs. their control morpheme by participants or items ($F_1(1,20) = 0.768$, $MSE = 235.962$, $p<0.326$; $F_2(1,71) = 1.171$, $MSE = 770.255$, $p<0.284$), and no significant effects in direct comparisons of transparent target vs. control by participants or items ($F_1(1,20) = 1.754$, $MSE = 524.565$, $p<0.201$; $F_2(1,35) = 2.453$, $MSE = 734.965$, $p<0.127$) and opaque target vs. control by participants or items ($F_1(1,20) = 0.029$, $MSE = 322.903$, $p<0.868$; $F_2(1,35) = 0.000$, $MSE = 801.814$, $p<1$).

Accuracy. There were no significant effects of accuracy. Differences in accuracy were non-significant in the overall comparison of non-head morphemes vs. their control morphemes by participants and items ($F_1(1,20) = 2.092$, $p<0.165$; $F_2(1,71) = 1.078$, $p<0.304$), and non-significant in direct comparisons of transparent target vs. control by participants and items ($F_1(1,20) = 3.649$, $p<0.072$; $F_2(1,35) = 0.766$, $p<0.388$) and opaque target vs. control by participants and items ($F_1(1,20 = 0.370$, $p<0.551$; $F_2(1,35) = 0.302$, $p<0.587$).

Subsection 3: Masked Priming Procedure (Experiment IIIB)

Analogously to Experiment IIB, we now turn to the masked priming of the head compound constituents in order to explore whether constituents of compounds will show significant facilitation in response times, and whether such effects of priming will be constrained by semantic transparency, when measuring priming for the head (final) position of English compound words.

The prime-target pairs included 44 semantically transparent English compounds with the compound (e.g. *teacup*) as prime and its final, or head, morpheme (e.g. *cup*) as target, and 44 semantically opaque English compounds with the compound (e.g. *bellhop*) as prime and its final morpheme (e.g. *hop*) as target. 44 additional pairs utilized a transparent compound as prime, and a single word matched to the compound's final morpheme, as control, and 44 pairs utilized an opaque compound as prime, and a single word matched to the compound's final morpheme, as control, as shown in Table 10 below. Eighty-eight compound words of varying semantic transparency, matched in length and frequency to the compounds which primed the word targets, served as primes for one hundred seventy-six pronounceable nonword targets, half of which had some orthographic overlap with the prime word, included to make the word:nonword ratio 1:1, and such that lexicality or transparency of the prime did not predict lexicality of the target.

Table 10 Example Stimuli (priming of head constituent by compound prime).

Condition	*Example Prime*	*Example Target*
Transparent Prime	MOUSETRAP	trap
Transparent Control	MOUSETRAP	dish
Opaque Target	HONEYMOON	moon
Opaque Control	HONEYMOON	fate

As before, transparent vs. opaque primes, and targets vs. controls were matched on length, frequency, and syllabicity. Mean values of these properties are listed in Table 9 above. Stimuli were presented in the same manner as described for Experiment II.

Subsection 4: Participants (Experiment IIIB)

Twenty-one undergraduate students from the University of Maryland College Park, native speakers of American English with normal or corrected-to-normal vision (16 females; ages 18 to 22 years old), native speakers of American with normal or corrected-to-normal vision provided their written informed consent to participate in this experiment. Participants were paid or offered course credit for their participation.

Section 9: Experiment III: Results

Response time. The response time data were analyzed as in Experiment II. The response time results again show a significant effect of prime vs. control in the overall comparison of head morphemes vs. their control morpheme by participants and items ($F_1(1,20) = 15.619$, $MSE = 439.518$, $p<0.002$; $F_2(1,71) = 28.476$, $MSE = 1086.186$, $p<0.001$), and significant effects in direct comparisons of transparent target vs. control by participants and items ($F_1(1,20) = 4.560$, $MSE = 1833.226$, $p<0.046$; $F_2(1,35) = 18.044$, $MSE = 1230.856$, $p<0.001$) and opaque target vs. control by participants and items ($F_1(1,20) = 8.193$, $MSE = 748.231$, $p<0.011$; $F_2(1,35) = 10.597$, $MSE = 937.772$, $p<0.004$), as summarized in Table 11 below. Direct comparisons of magnitude of priming effects (Control - Prime RT) across transparent and opaque conditions were non-significant by participants and items ($F_1(1,20) = 0.049$, $MSE = 3538.851$, $p<0.828$; $F_2(1,35) = 1.188$, $MSE = 2048.758$, $p<0.284$).

Accuracy. The accuracy results for comparisons of targets and controls, transparent targets vs. controls, and opaque targets vs. controls are as follows: the overall comparison of head morphemes vs. their control morphemes showed a small but significant effect in ($F_1(1,20) = 16.615$, $MSE = 0.001$, $p<0.002$; $F_2(1,71) = 10.650$, $MSE = 0.002$, $p<0.003$), as well as in direct comparisons of transparent target vs. control ($F_1(1,20) = 12.089$, $MSE = 0.001$, $p<0.003$; $F_2(1,35) = 8.033$, $MSE = 0.002$, $p<0.009$); the effect was marginal in the comparison of opaque target vs. control ($F_1(1,20) = 4.231$, $MSE = 0.001$, $p<0.054$; $F_2(1,35) = 2.825$, $MSE = 0.001$, $p<0.103$). The direct comparison of the difference in accuracy scores (Control – Prime error rate) was not significant by participants or by items ($F_1(1,20) = 2.373$, $MSE = 0.002$, $p<0.140$; $F_2(1,35) = 1.266$, $MSE = 0.006$, $p<0.269$). Response times and Accuracy rates appear in parentheses in Table 11 below, along with the lexical decision pre-test results for comparison.

Table 11 Priming of head constituent (by participants).

PRIMING STUDY	*Response Time in ms. (error %)*		*Mean Difference*
Condition	*Target*	*Control*	*(Priming)*
All Primes vs. Controls	626 (2%)	652 (4%)	26**
Transparent Primes vs. Controls	622 (2%)	651 (5%)	29**
Opaque Primes vs. Controls	629 (2%)	654 (3%)	25**

** = significant at $p<0.01$

* = significant at $p<0.05$

LEXICAL DECISION PRE-TEST	*Response Time in ms. (error %)*		
Condition	*Target*	*Control*	*Mean Difference*
All Primes vs. Controls	584 (2%)	588 (3%)	4
Transparent Primes vs. Controls	580 (2%)	589 (3%)	9
Opaque Primes vs. Controls	587 (2%)	587 (3%)	0

** = significant at $p<0.01$

* = significant at $p<0.05$

Section 10: Experiment III: Discussion

Significant priming was achieved in Experiment III for the head morpheme of lexicalized compounds, as in Experiment II for non-head morphemes. As discussed above, this priming holds under the same conditions in which priming was observed for the root of derivationally suffixed words in previous studies. This reinforces the conclusion that the decomposition effect previously observed for derivationally-complex words is not epiphenomenally due to the salience of a high-frequency, closed class suffix. The results of Experiment III also show that this effect is not limited to the constituent in the word-initial (onset) position.[22] In Experiment III, priming was again significant both for transparent and for opaque compounds, consistent with the suggestion that semantic transparency does not strongly constrain initial morphological decomposition. No significant differences were evident in the lexical decision pre-test (IIIA), and participants did not report conscious recognition of the prime words in the debriefing following Experiment IIIB. The numerically smaller priming effects overall for the second constituent suggest the possibility of a position and/or head-modifier distinction in the overall level of priming. For the purpose of the present study, the results crucially show significant and non-distinct priming from transparent and opaque compounds to their final morpheme. Further, while the numerical differences with respect to Experiment II suggest further exploration of possible effects of position and/or structure, two factors argue for caution: (i) the two experiments reported here involve different participants and partially different item sets, making direct numerical comparison across these two experiments complicated (they were not designed to test this question), and (ii) such effects have not been evident in many studies that did try for direct tests of position effects (cf. Jarema et al., 1999 for an interesting cross-linguistic approach to position/head-modifier differences in compound processing).

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[22] This shows a further reason to re-visit the previous results which have tested derivationally-complex words, using compounds: the previous results from derivationally-complex words mainly concern priming of a root constituent which sits in the word-initial (onset) word position. With compounds, one can straightforwardly probe for decomposition in both word-initial and word-final positions.

Section 11: Overall Conclusions

Subsection 1: General Discussion

The data demonstrate that English compounds prime their morphological constituents, both in non-head (initial) and head (final) position, in a masked priming paradigm with a short, 49ms prime duration. Thus, the answer to the first question, whether compounds prime their constituents under the same conditions in which derivationally complex words have been shown to prime, is affirmative. These results converge with previous findings (e.g. Longtin et al., 2003; Longtin & Meunier, 2005; Rastle et al., 2000, 2004, among many others), yielding further evidence of automatic activation of morphological units in masked priming, and addressing the concerns about affixal salience— the presence of a salient closed-class affix is *not* a necessary condition for yielding this type of evidence for automatic morphological decomposition. Since we found robust priming both for transparent and for opaque compound constituents, the current dataset also answers our second question in the affirmative: the compound constituent priming effect is *not* strongly constrained by semantic transparency. These results shed light on the scope of morphological segmentation effects, and also demonstrate how the effects can be elicited in a within-subjects design amenable to neuroscientific research applications. We now turn to the implications of these findings for the modeling of morphological processing, in context of previous results in compounding and derivational morphology.

Converging results with previous compounding studies

The current results add further evidence to the findings from previous research on compounding cross-linguistically from experimental paradigms such as naming, lexical decision, and eye-tracking suggesting a role for constituency in the processing of compounds. While Andrews (1986) supported the notion that compound constituency effects may be post-lexical, since the composition of the stimulus set in the lexical decision task affects the detection of constituent-frequency effects in derived words, further evidence from a variety of paradigms suggests that constituency effects originate in the early stages of lexical processing (which does not exclude the possibility of post-lexical influences on whether these effects remain evident in late measures like lexical decision). For example, Pollatsek and Hyönä (2005) found reliable effects of the constituent-frequency manipulation in eye-movements both for transparent and opaque compounds presented in sentence context in Finnish, but no reliable effects of transparency on first-pass reading times or other measures of fixation on the compound word (see also the Finnish studies by Pollatsek et al., 2000 and Hyönä & Pollatsek, 1998, for constituent frequency effects in eye-movements). Those results match those of the current study in demonstrating a role for constituents in online processing and in that constituent activation is not constrained by transparency. Similar results, attesting some role for constituents in compound processing, obtained in studies such as Andrews et al., 2004, for English compounds in sentence context, and Juhasz et al. (2003) for constituency effects in English compounds in naming, lexical decision, and eye movement studies (see, e.g., Libben et al., 1999, Lima and Pollatsek, 1983, Van Jaarsveld and Rattink, 1988, among others). As mentioned above, these results also converge with the findings on Dutch compounds at longer prime/target latencies, by Zwitserlood (1994). In the current study, we observed rapid constituent priming regardless of transparency when the prime was shown for a brief duration (49ms), supporting the notion common to the studies cited, that *constituents of compounds are activated rapidly and automatically and influence the processing of the compound word*.

Morpho-orthographic segmentation and models of morphological processing

In the introduction to this set of experiments, we raised some possible concerns with the interpretation of previous results mainly coming from the masked priming of suffixed words (e.g. Longtin et al., 2003; Rastle et al., 2004, among many others), namely that the root activation may arise because of the presence of a high-frequency, short, salient, closed-class affix (see, e.g. Longtin et al., 2003, for some discussion), and the controversy over whether the effects are constrained by semantic transparency (see Diependaele et al., 2005; Feldman, 2000; Rastle et al., 2004; Stolz & Besner, 1998; and Seidenberg & Gonnerman, 2000, for related discussion from differing viewpoints). By testing the priming of compound constituents, we were able to investigate the rapid priming of constituents in a case where all morphemes were open-class roots.

Having found robust priming of compound constituents, regardless of semantic transparency, we conclude that the salience of a high-frequency, closed-class affix is not necessary to obtain the effects. Thus, we have removed one possible account of these effects, and lend support to the notion that morpho-orthographic effects indeed hold in the general case. Further support for this comes from the findings on the masked priming of abstract morphological constituents in cases where morphological structure is discontinuous, such as the priming of roots in Semitic languages (e.g., Boudelaa and Marslen-Wilson, 2001, 2004, 2005, Frost et al., 1997, Velan et al., 2005). Together, these results suggest an automatic parse into abstract morphological units, supporting the basic contention of the previous studies on morpho-orthographic segmentation, that these finding reflect early structure-based activation of morphological constituents regardless of semantic relationships.

These results would be difficult to handle on distributed-connectionist approaches (e.g. Seidenberg & Gonnerman, 2000), in which morphological effects are captured as form-meaning associations. While the transparent compounds have semantic similarity with their constituent ‘morphemes’, which may lead to facilitation, and formal similarity, which does not lead to facilitation, the opaque compounds lack semantic relationships, yet contain formal similarity which should not yield facilitation – but inhibition, if any effect. While it is debatable whether an alternative non-morphological view could predict robust priming for transparent items like *teacup*, for which simultaneous semantic facilitation and formal inhibition are predicted, at a minimum, a similarity-based account would face difficulties with predictions on robust priming for *opaque* items (they should yield no facilitation from semantics, nor facilitation based on formal similarity). Under these conditions, compounds like *bellhop* should fail to prime just as opaque words like *spinach* which overlap formally with a real morpheme (*spin*). However, we obtained robust and statistically equivalent priming for transparent and opaque compounds, in both priming experiments reported here. These results directly challenge a similarity-based account, which does not carry commitments to abstract morphological representation. Instead, the current results are consistent with a structural account in which early access to constituents is not strongly constrained by semantic transparency, but rather operates as an automatic process identifying morphological constituents regardless of semantic relationship.

Further, these results are not consistent with decomposition-second psycholinguistic models which claim that decomposition into constituents is strongly governed by semantic transparency (such as the supralexical approach, e.g. Giraudo & Grainger, 2000; see also the account in Marslen-Wilson et al., 1994, among others). Instead, the data are consistent with the growing masked priming literature showing rapid structure-based parsing into constituent morphemes. Likewise, this set of data presents challenges for constraint-based dual-route models or approaches in which morphological structure is seen as a gradient phenomenon (e.g. Hay & Baayen, 2005) in which full-form storage is commonly attributed to semantically-opaque, less-productive, homonymous-affixed, and other instances of complex words showing some kind of idiosyncrasy (see e.g., Bertram et al., 2000, among others). The current results, in context of the findings across languages from derivational morphology support the view that all words are initially and rapidly parsed into their abstract morphological constituents: *early structure-based decomposition*/*full decomposition*. Once again, this is in support of a conclusion in which those constraints thought to engender full-form processing may not contravene initial decomposition, but instead should be accounted for as effects on post-decompositional processing (cf., Bertram et al., 2000b, Hay and Baayen, 2005)

Subsection 2: A note on experimental methodologies

For these priming studies, we have adopted a fully-within subjects design (Experiments IIB and IIIB). Thus, it is crucial that our target and control morphemes are matched closely on lexical statistics, but to be certain that across-target differences cannot account for any priming results, we also conducted lexical decision pre-tests without priming to show that the targets and controls are responded to at the same latencies (Experiments IIA and IIIA). This allows us to take measurements of both the target and control within one subject, and measure priming effects with good precision in controlling unwanted variation that may lead to noise in the priming data.

Previous studies have often used an identical target, but compared the response to this target across participants (one participant contributing response to the target preceded by the related prime, and another participant contributing the response to the target preceded by an unrelated prime; e.g. *government*→*govern* and *building*→*govern*). In our design, the same participant contributes both the target and control response, the target and control are closely matched and pre-tested to yield the same RT without priming, and the prime is identical (*teacup*→*tea* and *teacup*→*sin*, for example). This method resulted in closely matched targets and controls, with very close response times (e.g. 0 ms mean difference in Experiment IIA) in the pre-test. This allows us to be rather confident in attributing any effects in the priming task to priming. A second concern, however, regards the use of the identical prime in the two conditions. Although ideal as far as stimulus-matching goes, it raises concerns about repetition and recognizability effects. It is important to note that the repeated prime is always masked, minimizing the possibility that it be recognized consciously by the participant. The order of appearance (target vs. control) was fully randomized. Finally, as we report below, no problems of recognizability of primes in general seemed to have occurred based on the repeated prime.

While this method has the benefits of collecting fully-within subject data (no unintended differences from between-subjects), and as we show below, seem to engender no unintended effects, the methodological choices always constitute a trade-off. We aimed to test whether the masked priming effects hold for compounds, but also to investigate whether it is possible to develop this within-subjects design for masked priming, considering that ultimately, such designs are needed if the important masked priming method is to be extended to simultaneous psychophysical and electrophysiological methods (see, e.g., Brown et al., 2000, Deacon et al., 2000, Dien et al., 2006, for applications of priming in ERP experiments).[23] Desirably, the findings now being generated psycholinguistically will lend themselves to neuroscientific testing, with an eye toward answering some of the hardest questions surrounding the literature (e.g. pinpointing exactly where in the time course of processing masked priming effects hold, with the overall aim of a fully temporally-specified cognitive model of lexical processing). The goal of the current study is to

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[23] These studies used a variety of priming designs, and some included repetition of unmasked primes and/or targets, in some cases multiple repetitions. In the current study, the only repetition is of a masked prime (1 repetition); no consciously presented item is repeated.

provide a set of psycholinguistic results investigating one aspect of masked morphological priming, with the aim of continuing research in this domain using a method which is possible to implement in a cognitive neuroscience approach requiring fully within-subjects designs. We are now pursuing the electrophysiological testing of these priming effects using MEG, testing both full repetition priming and the constituent priming paradigm presented in this chapter (i.e., priming from compounds to their morphemic constituents, while contrasting semantic transparency).

Undoubtedly, however, it would be important to investigate whether the same pattern of effects holds in a Latin-square type of priming paradigm as well. Under such a design, for example, one participant would respond to *tooth* following the masked prime *toothpaste*, and another would respond to *tooth* following a masked control such as *grapefruit*. Further, we have assumed that formal (i.e., orthographic) overlap would not result in robust priming in the masked priming paradigm, as evidenced by the multitude of studies we discussed below, but it will be an important confirmatory step to develop a direct test of this using compound stimuli in the masked priming paradigm; one way to do so is to compare the priming of *teacup→tea* and *bellhop→bell* on the one hand, with cases like *cartwheel→car*, where all three stimulus types are compounds, but only the first two involve a morphological constituency relation with the target, the third involves only an orthographic overlap. In an overt priming study (100 ms prime duration) from compounds to constituents in Dutch (Zwitserlood, 1994), this type of orthographic condition was included, and showed inhibition, as predicted, while morphological constituents were facilitated.

In current work, we are pursuing replications of the masked priming studies reported here using a Latin-Square design and including the above-mentioned orthographic control, in the manner described above, in order to directly address these concerns and further validate the results presented here.

Subsection 3: Summary

The results from the current study converge with previous findings using masked priming that show rapid, automatic segmentation into morphological units, regardless of affixal salience, across languages (e.g. English, French, Spanish, Dutch, Arabic and Hebrew), across kinds of morphologically complex word, including derivationally-complex words and compounds, and across semantically transparent and opaque complex word forms. These results favor an interpretation in which words are initially and automatically analyzed in terms of their morphological-level constituency in the general case, and not initially constrained by factors such as semantic transparency. This runs counter to approaches which either seek to reduce morphological representation to effects of similarity in form and meaning, as in distributed-connectionist accounts, or which suggest that words are only sometimes decomposed, depending on properties of the complex word (transparency, productivity, ambiguity, etc.) as in many dual-route and supralexical accounts of complex word processing. Instead, the results are consistent with a view that morphological complexity is recognized early and automatically by rule, not by exception.

Chapter 5: Rapid Structure Prediction in Lexical Access: *Rendaku* in the Processing Japanese Spoken Compounds[24]

Section 1: Introduction

Subsection 1: Word Structure and Spoken Word Perception

So far, we have been making the case that lexical processing involves access to internal representations below the ‘word’ level, regardless of surface form or semantic relations, using evidence from the processing of visual words. However, the question invariably arises whether the same holds true for spoken words – that is, whether internal structure is indeed posited incrementally online during speech perception. At first glance, we seem to be asking whether ‘tea’ is activated when hearing ‘teacup’. However, in this section we look at a more complex, yet potentially more informative case involving the processing of spoken compounds, namely the processing of Japanese compounds containing *rendaku* (which, as we discuss below, is a voicing alternation observed on the first segment of the second constituent of a compound). As we will see below, looking at *rendaku* in Japanese compounds will allow us to test whether word-internal morphemic structure is indeed considered incrementally online, even when a morpho-phonological process (*rendaku*) alters the

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[24] This section is based on collaborative research with Dr. Hiromu Sakai of Hiroshima University, Dr. Nina Kazanina of the University of Ottawa, and Megumi Yoshimura and Junichi Tanaka, of Hiroshima University; see, e.g. Sakai et al. (2006).

second constituent such that it is not ‘there’ in the surface phonology any longer. In these interesting cases, the surface and underlying forms are only abstractly related. Showing constituent activation in such cases, as we will discuss further below, would make a strong case for the notion that internal morphological structure is posited incrementally in spoken word recognition, and would further support the notion that such activation does not rely on surface formal similarity or semantics. Thus, positive findings would reinforce the conclusion that there *is* abstract morphological structure in lexical processing, and provide further challenges to alternative views which do not make this commitment, but rather attempt to recast morphological-level effects are epiphenomena of surface formal similarity or semantic overlap.

Subsection 2: *Rendaku* in Japanese Morpho-phonology

In this section, we briefly present the phenomenon of *rendaku* in Japanese morpho-phonology, which will be useful for the understanding of how *rendaku* allows an interesting test of morphological-level processing in spoken words.

Licensing of rendaku. Briefly, *rendaku* is a morpho-phonological operation which applies to the second morpheme in a compound containing a voiceless initial segment, causing the voiceless initial segment to become voiced. This phenomenon is shown in the examples in (1) and (2) below.

(1) shiro + kani → shiro***ga***ni Gloss: *white* + *crab* → *white crab*

(2) take + sao → take**za**o Gloss: *bamboo* + *pole* → *bamboo pole*

To summarize, the application of *rendaku* changes the voiceless initial segment of the second member of a compound into its voiced counterpart. Thus, the surface form of the second member within a compound involving *rendaku* has been changed from its form in isolation, due to this operation occurring at the word-internal morpheme boundary. This process can occur not only in frequent, lexicalized compounds, but also occurs in less frequent and truly novel compounds; the compound in (1) is an example.

Constraints on rendaku. The application of *rendaku* is blocked, however, under certain circumstances. The application of *rendaku* to the second morpheme of a compound is blocked when the second morpheme already contains a voiced obstruent, as can be seen in the examples in (3) and (4) below.

(3) aka+huda → akahuda *aka-buda Gloss: *red tag* (Kubozono, 2005)

(*4*) aka+huta → akabuta Gloss: *red lid*

A further constraint on *rendaku* is that it applies to native Japanese (Yamato) vocabulary and typically not to Sino-Japanese vocabulary or loan words, although there are some examples of Sino-Japanese or borrowed words which undergo *rendaku*, as pointed out in Otsu (1980), among others.

Exceptions to the rendaku rule. Many exceptions to the *rendaku* rule have led some to conclude that *rendaku* is unpredictable or purely lexically specific (e.g., McCawley, 1968, Vance, 1980). Exceptions (more and less systematic) to the rule include effects of properties of the immediately preceding mora mediating whether *rendaku* applies in the *ta*/*da* voicing alternation (i.e. effects outside the expected domain to which *rendaku* should be sensitive), for which there are some potential explanations (see, e.g., Kubozono, 2005), lack of *rendaku* in Dvanda compounds, lack of *rendaku* typically on Sino-Japanese morphemes (although there are exceptions), and some cases which seem to not follow a pattern at all, such as that the Japanese word '*hiragana*' (*hira*+*kana*) allows *rendaku*, but the word '*katakana*' (*kata*+*kana*) does not (a contrast with example (2) presumably shows that this contrast is not due to the voicing in the non-head morpheme).[25] We will not go into detail about these or other exceptions, but note that while *rendaku* seems to be productive, and in current use, it is not straightforward to say that it applies across the board without exceptions. What *will* be crucial for us below is that *rendaku* is possible during online processing, yielding lexical activation for candidates otherwise not predicted to be activated during the processing of certain words, not that *rendaku* be an exceptionless requirement.

Rendaku in complex compounds. It is worth noting that in cases in which the compound has more than two morphemes, one can see that *rendaku* is sensitive to the

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[25] Another example may be:

a) mae+kami→mae**ga**mi (front+hair→bangs) (*Rendaku*, as expected)

b) kuro+kami→kuro**ka**mi (black+hair→dark hair) (*Rendaku* does not occur) organization of the internal morphological structure, as is shown in the following examples, in (5) and (6) below. These examples show the case in which a compound is formed from three morphemes, with the latter two morphemes both capable in principle of undergoing *rendaku* according to the constraints sketched above. In such a case, the pattern of *rendaku* (in particular, whether the second member of the compound undergoes *rendaku*) will be a reflection of whether the compound is left or right branching, as described in the generalization in (7) below.

(5) Right Branching Trimorphemic Compound

Compound: [nuri] [[hashi] [***ba***ko]]

Constituents: nuri + hashi + hako

Gloss: *lacquered chopsticks-box* (chopstick box which is lacquered)

(6) Left Branching Trimorphemic Compound

Compound: [[nuri] [***ba***shi]] [***ba***ko]

Constituents: nuri + hashi + hako

Gloss: l*acquered-chopsticks box* (box for lacquered chopsticks) (Otsu 1980)

The relevant observation is that *rendaku* will apply to the second member of a pair of adjacent morphemes only if the second member is on the right branch of the structure. This constraint is often referred to as the Right Branch Rule, following the observations of Otsu, 1980.

(7) *Right Branch Rule* schema (*Rendaku* candidate positions underlined and bolded) (Otsu, 1980)

a. Left-branching structure [[X **Y]** **Z]**

b. Right-branching structure [X [Y **Z**]]

There have been a number of discussions of *rendaku* phenomena in the theoretical literature (e.g., Ito and Mester, 1986, Kubozono, 2005, Otsu, 1980, Vance, 1980, among others), and considerable attention has been paid to the adequate handling of seeming exceptions and counterexamples. While these studies have sought to clarify whether the basic conditions sketched above are sufficient or necessary conditions for the occurrence of *rendaku*, the basic observation important for our study is that the presence of a word-internal voiced segment is compatible with (i.e. raises the possibility of) an application of *rendaku* occasioned by the presence of a morpheme boundary, for the sake of exploring whether the possibility of an internally-structured compound word is considered online, thus affecting the set of lexical candidates activated.

In what follows, we present an initial study intended to probe this issue. We adopt a variant of the fragment-completion technique to test whether there is indeed activation of lexical candidates which are consistent with a *rendaku*-marked compound-structure continuation, but are not part of the onset cohort based solely on surface form. We test for this using novel Japanese compounds in which, according to the conditions described above, *rendaku* should occur on the initial segment of the second morpheme of the compound (e.g. *shiro*+***ka****ni* → *shiro****ga****ni*), so that we can test whether auditory presentation of the initial morpheme plus the initial CV of the second morpheme (e.g., *shiroga_*) will result in activation of the target word *kani*, despite both the lack of surface identity of the initial segment, and the lack of any particular semantic boost from the meaning of the first morpheme or a lexicalized whole-compound meaning. We explore the design in more detail below.

Subsection 3: Fragment Completion and Lexical Activation

For the purposes of this study, we utilize a variant of the cross-modal fragment completion task. In this task, a portion of a word is presented auditorily to the participant, who must make a subsequent lexical decision to a visually presented word (e.g., Marslen-Wilson, 1990, van Donselaar et al., 2005, Zwitserlood, 1989, among others). The intuition behind this task is that the auditory presentation of a fragment (e.g. *bea_*) will result in activation of compatible continuations (in Marslen-Wilson's terms, its cohort, e.g. *beaker*, *beetle*, etc.), and findings using this paradigm indeed show that there is a resulting facilitation for a lexical decision to the related target word, e.g. *beetle*), relative to an unrelated prime, e.g. *ra_*. A study using Spanish (Soto-Faraco et al., 2001) has suggested that, while compatible continuations are facilitated in the fragment-completion paradigm, partially congruent fragments with a mismatching segment, in contrast, yield inhibition, relative to completely unrelated controls. For example, a prime-target pair in which the vowel segment mismatches, such as the prime-target pair cab***e***l_→cab***a***llero will result in longer lexical decision response times for the target (*caballero*), than will the control prime-target pair *sol_→caballero* (see also van Donselaar et al., 2005, for a replication of those findings in Dutch).

We now ask how these findings will extend to complex words, in particular to Japanese compounds in which *rendaku* is licensed. Specifically, we will test whether a fragment containing the first morpheme of a novel compound and the first CV of its second morpheme (to which *rendaku* should apply, due to the lack of another voiced obstruent in the second morpheme), e.g. shiroga_, will result in activation for the second morpheme presented in isolation (thus, in non-*rendaku* form), e.g. *kani* (crab). The second morpheme (*kani*) should be activated if a parse of the fragment in which a morpheme boundary after *shiro* is considered, and a possible application of *rendaku* is undone (i.e. considering that the *ga_* may be underlyingly *ka_*, thus broadening the cohort to include *ka_* onset words).

Put more broadly, we would like to examine how the matching of the auditory speech input is matched to potential lexical representations, and have found a case in which the relation among the input stream (at least at the segment level) and the underlying structure is 'complicated' in an interesting way, i.e., the surface form of a constituent is altered from its form in isolation by an operation changing its onset segment, due to a particular operation holding at morpheme boundaries under certain circumstances. Given a way to test for this activation, we can then ask whether the matching of candidate lexical representations to an auditory speech input is indeed constrained solely by *surface form*, or whether this activation is indeed mediated by the possibility of *internal structure at the morpheme level* (i.e. the possibility of compounding) and the form-changing morpho-phonological alternation that may be licensed in that environment, altering the cohort of potential lexical candidates in this way.

Subsection 4: Allomorphy/Morpho-phonology in Cross-modal priming

There is some motivation for thinking that at some point during processing, roots whose surface form has changed due to some allomorphic alternation are indeed activated. For example, in the Marslen-Wilson et al. (1994) cross-modal priming studies, derived words undergoing a stem change, such as *sanity*, presented auditorily in full (these were not fragment-completion studies) resulted in facilitation to the visually presented target *sane*. However, it is not clear when during processing this activation takes place, as the word is presented in full, and whether this activation depended on the lexical status of the prime. Further, these cases are arguably different from the more productive application of *rendaku* (e.g., while the stem change in derived words such as those with the suffix *–ity* concerns a very circumscribed class of roots, *rendaku* potentially applies to any native Japanese morpheme with a voiceless initial segment not possessing a voiced obstruent elsewhere).

Subsection 5: Koester et al. (2004): Linking Elements in German Compounds

Is there evidence that compound structure is in fact considered as a possibility during the online processing of spoken words? Some results from the auditory processing of compounds in German suggest that compound structure is indeed considered online during processing (Koester et al., 2004). In one experiment, Koester et al. (2004) show that a gender mismatch among a preceding determiner and both the non-head and head morpheme of the following nominal compound's non-head and head elicit LAN-like negativities in the ERP signal (for both transparent and opaque compounds). They interpret this to reflect online decomposition into morphological constituents in German. Interestingly, in two follow-up studies, Koester et al. test agreement in number among a determiner and a subsequent nominal compound containing a linking element which is formally identical with a plural; an example of a compound with the linking element (*-en*), homophonous with a plural marker in German, is shown in example (8) below.

(8) ein$_{sg}$ Ohr**en**$_{\mathbf{pl}}$ – zeuge$_{\mathbf{sg}}$
a/one ears witness (Koester et al., 2004)

Koester et al. (2004) find that the linking element attached to the non-head morpheme elicits a negativity in the ERP signal, but only if the prosody of the non-head morpheme fails to follow that of a compound, instead following a single-word pattern (the items differed physically such that the morphemes in the compound non-head condition were shorter in duration and differed in pitch contour compared with the same morpheme in the single-word condition). These results together are taken to indicate both that German compounds are decomposed into morphological constituents, and that compound structure is considered online (as attested by the linking element not taken as a head plural-marker) as far as the prosody is consistent with the morpheme being the non-head of a compound.

Subsection 6: Current Study: Experiment IV

Thus, in the current study, we adapt the cross-modal fragment priming method to the study of complex words, testing for the activation of a lexical target in Japanese (e.g. *kani* 'crab') immediately following the presentation of a spoken fragment consisting of one morpheme (e.g. *shiro* 'crab') and the first CV fragment of the second morpheme (e.g. *ga_*), taken from a spoken novel compound such as *shirogani* ('white crab'). Crucially, the CV fragment (***ga***) mismatches segmentally with the target presented in isolation (***<u>ka</u>***ni), but this voicing alternation is licensed by the morpho-phonological alternation *rendaku* at a compound's morpheme boundary under certain circumstances. Thus, if only segmental information is guiding the initial activation of lexical candidates, a target with an unvoiced initial segment, such as *kani*, would not be expected to be activated, whereas if the possibility of a morphemic boundary is considered (and thus, the possibility of *rendaku* comes into play), then it is possible that candidates consistent with the *rendaku* alternation (i.e., words with an unvoiced alternate of the voiced segment in the fragment) should also be activated and thus added to the cohort of activated lexical candidates. Evidence for the latter would argue for a role for compound structure consideration in spoken word processing, making a strong case for morphological-level representation and decomposition, and demonstrating that surface formal identity is not solely responsible for the observed activation. Let us now turn to the experimental design.

Section 2: Method

Subsection 1: Stimuli and Design

36 sets of items were recorded on Digital Audio Tape by a female native speaker of Japanese, and truncated to include either the first morpheme plus the first CV of the second morpheme (e.g. *shiroga_*, or to include solely the first morpheme (e.g. *shiro_*). Thus, for each target (e.g. *kani*), two primes were created, one with the *rendaku*-compatible CV following the first morpheme (*experimental condition, e.g. shiroga_*→*kani*), and one with solely the first morpheme (*control condition, e.g. shiro_*→*kani*). A third condition (*repetition priming, e.g. shirogani*→*kani*) was also added in which the auditory prime was the whole compound (e.g. *shirogani*), with the second morpheme in isolation as the visual target (e.g. *kani*).

Subsection 2: Procedure

The participants were tested in quiet experimental room. The fragment primes were presented auditorily by headphones at a comfortable presentation level, and visual targets were presented in the center of the screen on an experiment computer. For each trial, the visual target was presented immediately following the offset of the auditory fragment prime (ISI of 0 ms). The visual stimulus remained on the screen until the participant's response was recorded. Response time and accuracy were measured for the lexical decision response to the visual target. The stimuli were presented using DMDX software (Forster and Forster, 2003). Participants were instructed to respond whether the visual target was a real word of Japanese as quickly and accurately as possible.

Subsection 3: Participants

36 students from Hiroshima University, all native speakers of Japanese with normal hearing and normal or corrected-to-normal vision, provided their written informed consent to participate in this experiment. The participants were paid for their participation.

Section 3: Results

Subsection 1: Response Time for Fragment Priming Condition and Repetition Priming Condition

The comparison among response times for the experimental condition (Table 12), control condition, and repetition priming condition (Table 13) resulted in a significant difference as shown by a repeated-measures ANOVA (p<0.001). Direct comparison of the fragment priming experimental condition (M=640 ms) and the control condition (*M*=668 ms) revealed a significant effect of priming for the *rendaku*-compatible target by the fragment prime (*p*<0.01), despite the mismatch in surface form among the fragment prime and target. The repetition priming condition, in which the whole compound was auditorily presented in full prior to the visual target (and in which the *rendaku*-caused sound change remains), also showed significant facilitation for the response to the target (*p*<0.01). The magnitude of the effect was much larger in the full repetition priming condition than in the fragment priming condition.

Table 12 Response Time: Japanese Fragment Priming vs. Control

Condition	*Example*	*Mean RT in ms*
First morpheme + CV Fragment	shiroga_ kani	640
First morpheme (Control)	shiro_ kani	668
	Priming Effect	28**

** = significant at *p*<0.01

Table 13 Response Time: Japanese Repetition Priming vs. Control

Condition	*Example*	*Mean RT in ms*
Whole compound	shirogani_ kani	565
First morpheme (Control)	shiro_ kani	668
	Priming Effect	103**

** = significant at *p*<0.01

Section 4: Discussion

Subsection 1: Summary of the Results

In sum, the findings of this study show that responses to a visual target are facilitated by a fragment of a novel compound, consisting of the first morpheme and the first CV of the second morpheme, even when there is a segmental mismatch from the fragment to the target (caused by *rendaku*). These results suggest that the target is indeed activated as a morpheme-level lexical candidate (*rendaku* is in a sense undone, adding the voiceless continuations to the potential lexical candidates), despite the surface segment mismatch in the final CV of the fragment (e.g., shiro*ga_*) as compared with the target (e.g. *ka*ni). The repetition priming condition further confirmed that the second morpheme is significantly activated despite the segment-level mismatch caused by the operation of *rendaku*. Together, these results show that not only are morphemes activated in cross-modal repetition priming contrast despite a segmental mismatch occasioned by the morpho-phonological alternation, but lexical candidates compatible with a *rendaku*-altered compound continuation are considered as possible continuations even in the fragment priming condition despite a segment-level mismatch (*shiro**ga_*** → ***ka**ni*). Recall that these results mirror the facilitation results typical in fragment priming for lexical candidates (e.g. *bea_*→ *beaker*), and contrast, as predicted, with the typical findings from these studies regarding segmental mismatch in single words (cab***e***l_ → cab***a***llero), which do not lead to facilitation but to inhibition (Soto-Faraco et al., 2001, among others).

Subsection 2: Tentative Conclusions

These findings suggest at least three major conclusions regarding the nature of lexical representation and the positing of internal morphological structure for these representations. Each conclusion is consistent with the arguments we have drawn from the previous visual lexical studies regarding the nature of internal structure and the putative constraints on its presence, as we will discuss below.

First, the results of this experiment once again argue for *structure and abstraction* in the lexical processing system. We have shown that lexical candidates which are compatible with a spoken fragment only insofar as that fragment is taken to possibly have a compound structure (and thus licenses the *rendaku* voicing alternation) are indeed activated online during the processing of Japanese spoken words. This shows that the possibility of internal structure is considered, and that lexical representations which are compatible with the incoming speech stream only given a morpheme boundary and the application of a morpho-phonological rule are activated. This suggests again that activation of abstract morphological representations is *not* exclusively constrained by surface form, and that the processing of these words is sensitive to the relation between the underlying morphological and phonological structure and the surface representation.[26,27]

Second, the results of the current study, in which novel Japanese compounds were tested, once again suggest that *semantic relationship* and *lexicalization* cannot account for the facilitation found for the targets here. As regards semantic relationship, the only information in the prime is the first morpheme embedded before the first CV of the second morpheme in the auditory fragment (e.g. *shiroga_*). There is no whole compound in the auditory stimulus to semantically prime the target, and the activation for the *rendaku*-compatible target cannot be accounted for via semantic priming from the onset morpheme (to the extent that there happens to be any semantic relation among them at all) because it is also present in the control condition (e.g. *shiro_* → *kani* Gloss: *white* → *crab*).

Third, these results again reinforce our conclusion that having internal structure is not reliant on exceptionless systematicity. Even though *rendaku* does not apply without exception in Japanese compounds, the possibility of a *rendaku*-occasioned voicing alternation at a morpheme boundary seems to be considered

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[26] It is interesting to consider fitting structure-based hypothesis generation at these levels into a model of speech perception involving internal forward models/analysis-by-synthesis (Halle, 2002).

[27] It is also important to note here that we do not address in this dissertation cases of full suppletion of the *go/went* type. We note here that even these cases allow analyses which do not entail atomic representations, and that it remains open to what extent such cases are similar to other forms of allomorphy; nevertheless, such cases undoubtedly raise interesting questions regarding how they are processed under a full-decompositional approach. For an experimental approach investigating the nature of decomposition in irregular allomorphy, see Stockall and Marantz (in press).

online during the processing of Japanese spoken words. Thus, this evidence from compounds undergoing *rendaku*, which is a fairly productive but not exceptionless phenomenon, once again shows that the positing of internal morphological structure is not limited to fully productive cases. Even in the processing of spoken words, the exceptions do not disprove the rule.

Subsection 3: Limitations of Conclusions

While the findings of our study suggest that a compound continuation involving the application of *rendaku* is indeed considered online, our major intended goal, the findings leave several interesting and important factors for further research. For example, all of the fragment items in the current study involved prosody (pitch-accent) compatible with a compound continuation (e.g. rising vs. falling pitch over the fragment prime); thus, this data does not address the question of whether compound-compatible prosody is a necessary condition for the consideration of compound structure, as may be suggested by the German findings of Koester et al. (2004), among others. Previous studies on the effects of prosody in the fragment completion priming of single words have argued that compatible prosody is necessary. For example, the study cited above regarding segmental mismatches in Spanish fragment priming showed an inhibition effect not only for segmental mismatches (e.g.), but also for mismatches in stress, e.g., the matching stress prime *prinCIp__* facilitates the lexical candidate *prinCIpio* (Gloss: *beginning*), but the fragment mismatching the candidate's stress pattern, e.g., *PRINCI_*, does not, (Soto-Faraco et al., 2001). Further, it has been shown in Dutch that the unstressed prime *ok_* which matches in stress with the target *october* facilitates responses to that target, although the stressed prime *OK_* does not (van Donselaar et al., 2005). Finally, there is evidence that native speakers of Japanese are sensitive to pitch accent in fragment priming tasks such as forced-choice and gating tasks (Cutler and Otake, 1998).

To explore the potential role of prosody in the paradigm we have utilized in the current study, we will pursue a straightforward extension of the current study which is to test the priming of *rendaku*-compatible targets such as *kani* (crab), under two priming conditions, as follows:

(9) Prosody compatible w/compounding (pitch rising on 2nd syllable)

Example: shiroga_→kani (white+ga→crab)

(10) Prosody not compatible w/compounding (pitch falling on 2nd syllable)

Example: shiroga_→kani (white+ga→crab)

As regards models of how an initial set of potential lexical candidates is activated, more tests are also needed to adjudicate among competing accounts of which candidates are activated during speech processing. For example, while the activation of *kani* may not be consistent with the cohort model under Marslen-Wilson's hypothesis, in which the cohort is solely determined by phonological identity beginning with the onset, additional tests are needed to determine whether the vowel ending among the fragment prime (e.g. shirog**a**_ and k**a**ni) is sufficient to result in facilitation for a lexical candidate simply due to the shared vowel, which may be consistent with other spoken word access models which do not rely solely on onset-consistent candidates as part of the cohort, such as TRACE (McClelland and Elman, 1986). It would strengthen the arguments made from the current study to know whether the vowel is sufficient to obtain priming in our paradigm; however, the Spanish results from Soto-Faraco et al. (2001) and other results from the fragment-priming literature on segment mismatch suggest that facilitation solely due to the vowel overlap would not result in facilitation in our task. For example, Soto-Faraco et al. (2001, Experiment III) directly tested for consonantal mismatch, keeping the vowel constant, and found virtually identical patterns of priming for fully-overlapping prime-target pairs, and *no* facilitation from the consonant-mismatching prime-target pairs which shared a fragment-final vowel, e.g. *pa**t**i_ pa**p**illa*). This evidence may suggest that our priming effect would not be accounted for solely due to the fragment-final vowel overlap. Nevertheless, in order to directly address this, we will pursue a follow-up experiment which contrasts two surface-mismatching cases, one in which the surface mismatch among prime and target is compatible with the application of *rendaku* (11) and another in which the surface mismatch among prime and target is in the same position, but is not compatible with the application of rendaku (12). Examples from these two target conditions are shown below:

(11) *Rendaku*-compatible surface mismatch (target condition from above study)

Example: shiro**g**a_→kani (white+ga→crab)

(12) *Rendaku*-incompatible surface mismatch

Example: shiro**b**a_→kani (white+ba→crab)

If the priming effect identified in the current study were to have arisen purely due to the overlapping vowel segment, then similar facilitation effects should be observed in both conditions; however, if morphological structure-based prediction plays a role in facilitating the response to the target, as we have concluded from the current study, then the rendaku-compatible and rendaku-incompatible prime-target pairs should pattern in divergent ways.

The results presented in this chapter raise also the possibility of further interesting experiments designed to test whether internal-structure information such as *rendaku* feeds into other aspects of structure processing. While it is beyond the scope of the current discussion, it is worth pointing out that the cue to internal structure discussed here, *rendaku*, also potentially serves to indicate to some extent, the head status of a morpheme. For example, in multi-morphemic compounds (as discussed in Section 1 above), the presence or absence of *rendaku* in a *rendaku*-compatible morpheme may serve as a cue to its relation in the internal structure. Consider the following two compound fragments:

(13) kuro hashi… (black chopsticks…)

(14) kuro bashi… (black chopsticks…)

Only the second is a potential head morpheme, given the observation that the second morpheme will undergo *rendaku* (all other conditions satisfied) if it is in the right branch of the structure (i.e. if it is the head among two sisters locally merged in the tree). While *bashi* in the second example does not need to be the head (the compound could be more than two morphemes), e.g. *kuro bashi bako* [[black chopsticks] box], the *hashi* in the first example cannot be the head *[[kuro hashi] bako]. This potentially yields at least two kinds of prediction (i) whether a given morpheme can be the head of the complex word, and (ii) whether a head must be upcoming; that is, in the case of *kuro hashi*… it must be the case that the structure is minimally [X [Y Z], allowing the forward prediction of Z. We do not make any specific claims here, but simply raise the possibility that this environment is potentially fruitful one for examining further issues regarding the nature and kinds of information applied to the processing of speech word-internally (see, e.g., Frazier, 1987, Krott et al., 2004, among others).

Finally, the findings on morphological activation in fragment priming in Japanese *rendaku* cases suggests further cross-linguistic extensions to this line of research to other cases of morphologically-conditioned variation among surface and underlying form in complex words. One case which we will explore is the processing of multisyllabic/multimorphemic words undergoing *tone sandhi* (conditioned variation in the surface tone) in various tone languages. Like *rendaku* in Japanese, tone sandhi in Chinese compounding results in cases in which the surface form and underlying morphological representation no longer share surface form identity, but are nevertheless related abstractly. Thus, on analogy to the *rendaku* case, one can test for underlying morpheme activation when surface tone is altered by a morpho-phonological process such as tone sandhi, using the fragment priming task which was applied to the Japanese *rendaku* case in the current study. On analogy to *rendaku*, if the tone sandhi rules are in a sense undone online in consideration of possible compound structure, morphemes mismatching in tone with the surface realization but compatible with it given a tone sandhi operation, may indeed be activated as can be tested in a fragment priming task. In fact, exploring tone sandhi in a similar way to *rendaku* may be further informative given that in some dialects of Chinese, the relation among surface tone and underlying tone can be more or less complex, whereas the *rendaku* alternation is such that the underlying morpheme segment (unvoiced) and surface morpheme segment (voiced) are related by the single feature change in voicing. These results may also speak to specific questions on the lexical specification of tone and the perceptual effects of sandhi rules varying in productivity and sensitivity to word-internal structure.

Chapter 6: Decomposition, Productivity, and Affix Representations: Morphological Decomposition in Japanese De-Adjectival Nominals

Section 1: Introduction

Subsection 1: Root and Affix Representations and Morphological Decomposition

While much attention in the lexical processing literature has been paid to the representation of root morphemes in derivational and inflectional morphologically-complex words, little to no direct evidence has been provided for the independent representation of affix morphemes[28] or regarding the composition of root-affix combinations. Thus, while arguments can be made for a morphological-level relationship among a complex word and its root (e.g. *government* and *govern*), there are few arguments in the literature which can point directly at mental representations for affixes themselves. This is a notable absence, since these affix representations are assumed in approaches to morphology and its psycholinguistic implementation taking seriously the notion of abstract morphological representation of pieces and their combination into complex structures (although arguably, no such commitment is needed for approaches to lexical representation and its implementation which make no reference to internal structure, such as network models like Bybee (1995) and

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[28] Kazanina, in preparation, which examines masked priming across *–er* affixed words, is the first study to directly address this that we are aware of.

other approaches which consider a broadly non-decompositional approach to be plausible; see Hay and Baayen (2005) for a recent argument in this favor).

In this pilot experiment, then, our goals will be twofold. First, we intend to extend the findings from masked priming which argue for a morphological-level relationship among a complex word and its root morpheme (e.g. *government-govern*), to examine whether affixes also yield facilitation under the same circumstances (recall the findings from Rastle et al., 2005, Longtin et al., 2003, among others, showing that complex words are decomposed, activating their root morpheme even under conditions of unconscious masked priming, in which neither semantic nor orthographic relationship yields equivalent facilitation). To do so, we will test whether a prime and target pair sharing only an affix will result in facilitation, as predicted if they overlap morphologically, but not if their overlap is solely orthographic or semantic. However, we will use this priming relationship to address a second goal related to our overall project, namely whether productivity indeed serves as a factor which contravenes initial decomposition and results in atom-based representation and processing. Thus, we will test for affix-to-affix priming not only for a highly productive affix, but for a highly unproductive affix, for the reasons described in the following subsection.

Subsection 2: Putative Role of Productivity in Morphological Complexity

By testing masked affix priming among not only productive affix morphemes, but also less productive affixes, one can explore whether, as is often claimed, *productivity* indeed constrains whether so-called complex words will be decomposed, or treated as atomic. Such a distinction among productive and unproductive 'complex' words has been posited under several accounts. For example, under the recent proposal by Hay and Baayen (2005), a 'graded' view of morphological complexity is adopted in which 'morphemes' do not play a privileged role in lexical representation and processing; however, under such a view, taking something like an exemplar approach to representation, more highly productive complex words receive more paradigmatic support, and under their speculation, will consequently show more 'decomposition-like' effects of relation among the 'complex' word and its 'root'.

Positing whole-word storage and processing of non-productive 'complex' words is often taken to follow from some of the following properties of the non-productive morphemes— they tend to be more susceptible to semantic drift (extended or idiosyncratic meaning) and to sound changes, and do not readily contribute to the formation of new words in the lexicon. However, whether these kinds of word engender whole-word storage and processing remains an empirical issue. Indeed, it has been speculated that the distinction among productive and unproductive derivational affixation recapitulates the regular/irregular distinction in inflection which led to the Pinker-style dual-route account in which regularly inflected forms are decomposed, but irregular forms are associatively related (see, e.g., Hagiwara et al., 1999, Sugioka, ms., for this speculation concerning Japanese de-adjectival nominalizing affixes). Undoubtedly, productive and unproductive affixation engender differences of the kind sketched above, but is not straightforward whether the differences in productivity imply that only productive complex words are *decomposed*, since, as we have argued elsewhere in this dissertation, constraints such as productivity (and semantic transparency, and frequency, etc.) may hold over decomposed representations at some level (i.e. in composition/combination among morphemes in a decomposed representation) and do not *a priori* imply non-decomposed or atomic representations (see e.g., Yang, 2005, for a computational model).

Crucially, the effect of productivity as a constraint on decomposition is a testable hypothesis, which, we will show, can be pursued along the same lines as has been done for the representation of root morphemes. In the current study, then, we test for the priming of affix representations among two affixes serving the same function (de-adjectival nominalization) but which differ drastically in their productivity. We will borrow methodologically from the larger literature on the priming of root representations, focusing on the technique of masked priming, as presented in the sections to follow.

Subsection 3: Properties of Japanese De-Adjectival Nominalizers *–mi* and *–sa*

In this experiment, we will examine the affix representations of two de-adjectival nominalizing suffixes in Japanese, *–sa* and *–mi*, one of which is highly productive (*–sa*) and the other highly unproductive (*–mi*). The *–sa* affix applies extremely widely in Japanese, forming nouns from adjectives; we show some examples of *–sa* affixation below.

(15) mezurashisa (mezurashi+sa) (Gloss: *rare+ness*; *rareness/novelty)*

(16) utsukushisa (utsukushi+sa) (Gloss: *pretty+ness*; *beauty)*

The productivity of the *–sa* affix also extends to borrowed words, as is shown in the example below with the borrowed word *sexy* from English.

(17) sexy-sa (sexy+sa) (Gloss: *sexy+ness*; *sexiness)*

In contrast, the de-adjectival nominalizer *–mi* is highly restricted in Japanese, and is attested in fewer than 40 Japanese words, as cited in Sugioka, (1986), and which we also observed in our own corpus search using the NTT lexical database of Japanese, discussed further as regards our stimuli below. Some examples of *–mi* de-adjectival nominalization are as follows.

(18) atatakami (atatakai+mi) (Gloss: *warm+ness*; *warmth*)

(19) omoshiromi (omoshiroi+mi) (Gloss:*interesting+ness*; *interestingness*)

While there are some adjectives which can take either the *–sa* and *–mi* affix, like the examples in (18)-(19) above (more examples shown below), the adjectives which combine with the *–mi* affix are quite limited; some that cannot combine with mi are shown in (20)-(23) below.

(20) kashikosa (Gloss: *wise+ness*; *wisdom*) *-mi:* *kashikomi

(21) nagasa (Gloss: *long+ness*; *length*) *-mi:* *nagami

(22) yosa (Gloss: *good*+*ness*; *goodness*) _-mi:_ *yomi

(23) oishisa (Gloss: *delicious*+*ness*; *deliciousness*) _-mi:_ *oishimi

Further, *–mi* affixation cannot typically be applied to borrowed words. It has been argued that there are subtle differences in meaning among the *–sa* and *–mi* nominalized forms of adjectives which can take both *–sa* and *–mi*, and it has been claimed that *–mi* is more likely to carry unpredictable or extended meanings. For example, as concerns adjectives which take both *–mi* and *–sa*, Sugioka (1986) claims that these *–mi* and *–sa* forms also show different meanings, as shown below for the example of *hukai (deep)*, which can take either *–sa* or *–mi* (however, we leave aside the question of how robust these judgments are, and how significant the meaning differences are). Sugioka (1986) uses the following evidence to show that in the case of *hukai*, the de-adjectival nominal *huka-mi* reflects a place ('deep point'), whereas *huka-sa* reflects the abstract property of 'depth' (Sugioka, 1986).

(24) hukai (Gloss: *deep*) Examples: _-mi:_ hukami _-sa:_ hukasa

(25) Kawa no huka-mi / *huka-sa ni hamat-ta.

River GEN depth LOC fall-PAST

Gloss: 'I fell into the deep point of the river'

(26) Kawa no *huka-mi / huka-sa ni odoroku.

River GEN depth LOC be surprised.

Gloss: '(I) am surprised by how deep the river is.' (Sugioka, 1986)

As mentioned above, it has been speculated that this distinction may recapitulate the regular/irregular distinction in a *Words-and-Rules* account, in which the productive affix *–sa* will be treated in a decomposed form, but the *–mi* affixed word will be stored (Sugioka, ms., Hagiwara et al., 1999). Indeed the experimental results of the Hagiwara et al., 1999 study with aphasics supported a distinction among these two types of word, which was consistent with their hypothesis based on a words-and-rules account. See also Clahsen et al., (2003), for a review of these findings and a similar intuition regarding the relation of derivation and inflection under a *Words-and-Rules* type of account.

The Japanese de-adjectival nominalizers are reminiscent of the *–ness*/*–ity* affixes in English (e.g., *darkness*, *brevity*); one distinction worth pointing out due to its advantage for examining the Japanese nominalizers rather than the English ones, is that in Japanese, the less productive nominalizer *–mi*, which would be the counterpart of the English *–ity*, does not alter the orthography/phonology of the root, unlike many cases with *–ity*. From the experimental standpoint in contrasting priming of the productive and the unproductive affix, the Japanese case allows us to hold this root-changing process equal across the two affixes, something that could not be achieved in English (e.g., *dark-darkness* does not involve a stem change, but *brief-brevity* does).

Subsection 4: Current Study: Experiment V

In this experiment, we thus aim to test whether the masked priming paradigm, which was used in the studies with derivational affixes reviewed earlier in this dissertation (and used in Experiments II-III above) to argue for the facilitation of root morphemes in complex words, will also yield evidence of independent affix representations, may be predicted under a decompositional view of derivational morphology, in which derivationally-complex words are comprised of internal morphological representations. Here, we will examine whether a complex word with one of the Japanese de-adjectival affixes (*–sa*/*–mi*), facilitates responses to another complex word with a different root, but sharing the same affix. Testing both *–sa* and *–mi*, it becomes possible to test whether the productivity of the affix constrains whether a complex word is decomposed or processed as if it were an atomic representation.

Section 2: Method

Subsection 1: Stimuli and Design

Test conditions. The test conditions consisted of the *–sa* priming condition, in which one root with the productive *–sa* affix or a matched control serves as a prime, and another root with the *–sa* affix served as targets; the *–mi* priming condition was that in which one root with the unproductive –*mi* affix or a matched control serves as a prime, and another root with the –*mi* affix serves as a target. Examples of these test conditions are as follows.

(27) -*sa* priming: 異常さ (ijyoo-sa; *abnormality*) → 貴さ(tooto-sa; preciousnss)

(28) -*sa* control: 切り傷 (kirikizu; *scar*) → 貴さ(tooto-sa; *preciousness*)

(29) -*mi* priming: 哀れみ (awaremi; *pity*) → 黒み (kuromi; *blackness*)

(30) -*mi* control: 宮参り (miyamairi; *shrine visit*) → 黒み (kuromi; *blackness*)

The number of existing –*mi* suffixed words in Japanese is extremely low, as mentioned above. Searching the NTT Lexical Database, we were able to find sufficient numbers of items (judged by native speakers to be acceptable) to test 36 –*mi* affixed words, which, while allowing a clear test of productivity, severely limits the number of trials per condition in the current experiment. Since the –*mi* priming condition ((29) above) requires a set of –*mi* words as primes, a set of –*mi* words as targets, and a set of –*mi* words as targets to be preceded by unrelated controls, we were limited to 24 –*mi* targets (12 primed by –*mi* primes, and 12 primed by unrelated controls in each of two counterbalanced lists). To directly compare –*mi* and –*sa* priming effects from the same sample size, we thus also tested 24 –*sa* targets (12 preceded by –*sa* primes, and 12 preceded by unrelated controls in each counterbalanced list).

In addition to these test conditions, the experiment included the following eight filler conditions, to control for prime/target relatedness and lexicality of responses in the following ways.

Additional Control Conditions. First, we included conditions in which words with *–mi* and *–sa* affixes[29] served as primes, and nonwords with word-final *–mi* and *–sa*, respectively, served as targets. These conditions served three related functions: (i) to remove the predictability of the response based on the ending sound of the prime, (ii) to remove the prediction of the response based on the appearance of *–mi* or *–sa* on the target, and (iii) to remove the prediction of the response based on the overlap of *–mi* or *–sa* among prime and target. An equal number of additional control trials were added, with unrelated real word primes, and nonwords ending in *–mi* and *–sa* respectively, to balance the number of related and unrelated prime and target pairs across word and nonword targets, again, to avoid any imbalance that might bias responses based on proportion of prime-target relatedness. Each condition included 12 targets (every trial appeared in both lists, as no counterbalancing was needed). Examples of these conditions are as follows.

(31) Root-mi → nonword -mi: 縮み (chiji-mi; shrinkage)→ 車み

(32) Unrelated control → nonword –mi 水位 (suii; water-level) → 駅み

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[29] Given that the number of *–mi* deadjectival nominals is vanishingly small in Japanese (such that we have utilized nearly every *–mi* de-adjectival found in the NTT database judged acceptable by native speaking informants, in our *–mi* priming test condition), we take advantage of the presence of the de-verbal nominalizing homophone/homograph /*–mi*/ for constructing these primes.

(33) Root-sa → nonword –sa: 確かさ (tashika-sa; certainty) → 呂さ

(34) Unrelated control → nonword –sa 捨て身 (sutemi; desperation) → 佐さ

Finally, we included two conditions with word primes lacking both *–mi* and *–sa*, serving as primes, and words and nonwords lacking both *–mi* and *–sa*, respectively, serving as targets. These two conditions were added to reduce the proportion of primes and targets in the experiment containing either *–mi* or *–sa*; reducing this proportion minimizes the likelihood that the *–mi* and *–sa* words become particularly salient to the participants. Each condition included 72 targets (every trial appeared in both lists, as no counterbalancing was needed). Examples of these conditions are as follows.

(35) Real word without *–mi* or *–sa*, unrelated real word without *–mi* or *–sa*:

骨膜 (kotsu maku; connective tissue) → 下顎 (shita-ago; lower jaw)

(36) Real word without *–mi* or *–sa*, unrelated nonword without *–mi* or *–sa*:

自棄 (jiki/yake; being reckless/desperate) → 无め

Table 14 shows all of the experimental conditions, with example stimuli for each condition. See Appendix VII for a full list of stimuli.

Table 14 Experimental Conditions and Examples.

Condition		**Example**			
Prime type	**Target type**	**Prime**	***Translation***	**Target**	***Translation***
Root_1+*mi* suffix	Root_2+*mi* suffix	哀れみ	pity	黒み	blackness
Unrelated Control	Root_2+*mi* suffix	宮参り	shrine visit	黒み	blackness
Root_2+*sa* suffix	Root_2+*sa* suffix	異常さ	abnormality	貴さ	preciousness
Unrelated Control	Root_2+*sa* suffix	切り傷	scar	貴さ	preciousness
Root+deverbal *mi* homophone	Nonword with word-final *mi*	縮み	shrinkage	車み	*nonword*
Unrelated Control	Nonword with word-final *mi*	水位	water level	駅み	*nonword*
Root+*sa*	Nonword with word-final *sa*	確かさ	certainty	呂さ	*nonword*
Unrelated Control	Nonword with word-final *sa*	捨て身	desperation	佐さ	*nonword*
Non *mi*/*sa* word	Unrelated Non *mi*/*sa* word	骨膜	connective tissue	下顎	lower jaw
Non *mi*/*sa* word	Unrelated Non *mi*/*sa* nonword	自棄	being reckless	无め	*nonword*

Item controls. Within the target conditions (*–mi* priming and *–sa* priming), Prime vs. Control frequency, and Prime vs. Control character length were controlled. The primes and controls in the *–mi* condition were not significantly different in log frequency ($t(11)=-0.470$, $p<0.65$) and were identical in length; the primes and controls in the *–sa* condition were not significantly different in log frequency (t(11)=1.077, *p*<0.31) and length (*t*(11)=-1, *p*<0.34). Across *–mi* and *–sa* priming conditions, Prime, Control, and Target frequency and character length were also controlled, to allow across-condition comparison (all *n.s.* comparisons).[30] Table 15 below summarizes the properties of the items in each of the test conditions.

Table 15 Properties of Target Stimuli

Condition		Properties of Prime		Properties of Target	
Prime type	**Target type**	**Prime Frequency**	**Prime Length**	**Target Frequency**	**Target Length**
Root$_1$+*mi* suffix	Root$_2$+*mi* suffix	-0.15	3	-0.207235	2.3
Unrelated Control	Root$_2$+*mi* suffix	-0.15	3		
Root$_2$+*sa* suffix	Root$_2$+*sa* suffix	-0.21	2.8	-0.157324	2.5
Unrelated Control	Root$_2$+*sa* suffix	-0.22	2.8		

Prime-target lexicality and word:non-word ratios. The total number of trials was 240. Half of the targets across the experiment were words, and half nonwords; thus, the word:nonword ratio was 1:1. Since all primes were words, the lexicality of the prime would not predict the lexicality of the target. Word:nonword ratios for *–mi* and *–sa* words specifically were also 1:1, as achieved via the control conditions outlined above.

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[30] In addition, care was taken to avoid as much as possible having prime-target pairs which involve semantically similar properties (i.e., with the aim of avoiding prime-target pairs such as *bitterness→ sweetness*).

Subsection 2: Procedure

This experiment utilized a masked priming design (Forster and Davis, 1984). Each trial was initiated with a 480 ms forward mask ("######"), presented in the center of the screen in 12-point font. The forward mask was immediately followed by the visual presentation of prime for 48 ms, which was then immediately replaced by the target stimulus, which remained on the screen until participant's response via button press or the 3000 ms automatic timeout.[31] The prime and target stimuli were presented in different MS fonts, with different font sizes (11-point and 12-point respectively). The manipulation of font and size is done simply to add some physical difference among prime and target; in languages like English, this is typically done by using a case change; in languages like Chinese and Japanese, however, the case-change option is not available, thus font and/or size manipulations are typically used.[32] The stimuli were presented in black text on a white background, using DMDX stimulus presentation software (Forster and Forster, 2003).

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[31] This trial structure uses a very similar mask-prime-target pattern and timings to previous studies on masked morphological priming (Longtin et al., 2003, Rastle et al., 2004) and to our own studies on masked priming of compound constituents, reported as Experiments II-III in this dissertation. We note here that the trial structure is also similar to Hino et al. (2003) who test masked priming across scripts in Japanese (Hino et al., 2003). Like the current study, Hino et al. (2003) utilize a six-character string of hashmarks as a forward mask.

[32] While in Japanese (unlike, say, Chinese) there are multiple scripts (Kanji, Hiragana, and Katakana), it is not straightforward to alter the script among prime and target on analogy with upper/lowercase alternation in English; among the many complications are massive differences in ambiguity in words when represented in Hiragana or

Participants were tested in a quiet experiment room. They first received written instructions presented on the computer screen, with follow-up by the experimenters to make sure that the task was clear. Participants were instructed to decide as quickly and accurately as possible whether each item was a word or a nonword. 'Word' responses were made by button-press using the index finger of the dominant hand, 'Nonword' responses by button-press with the middle finger of the dominant hand. Response times were recorded from the onset of the target stimulus. The participants were not informed of the presence of the masked prime. The experiment then began with 6 practice trials to familiarize the participant with the task. The response time data were analyzed after removal of trials with incorrect responses and those in which the response time was outside 2.5 standard deviations from the mean (and below 1500 ms, to remove exceptionally long responses).

Subsection 3: Participants

Thirty students from Hiroshima University, all native speakers of Japanese with normal or corrected-to-normal vision, provided their written informed consent to participate in this experiment. The participants were paid for their participation.

Katakana (syllabic scripts) as compared with Kanji (Chinese-character morphograms), lexically-specific case typicality effects (i.e. words typically written in either Kanji, Hiragana, or Katakana); differences in character length in syllabic-script representations across words which have the same number of characters when represented in Kanji, etc.

Section 3: Results

Subsection 1: Response Times

In the analysis of Response Time, a significant effect of Prime vs. Control was observed in the by-participant analysis ($F(1,29)=4.56$, $p<0.041$), reflecting an overall facilitation for suffix-related targets vs. those primed by unrelated controls. While there was also a significant word type effect, reflecting overall faster response times to *–mi* suffixed targets vs. *–sa* suffixed targets ($F(1,29)=8.321$, $p<0.008$), no significant interaction was found among priming and word type ($F<1$). However, separate planned direct comparisons of *–mi* prime vs. control and of *–sa* prime vs. control conditions did not show strong effects ($p<0.16$ and $p<0.09$, respectively), which makes the overall results much more difficult to draw conclusions from, as they stand now. In the Discussion section, we discuss the tentative conclusions and remaining issues suggested by this initial study.

Subsection 2: Accuracy Rates

In the analysis of Accuracy by participants, no a significant effect of Prime vs. Control was observed in the by-participant analysis ($F<1$), nor was there a significant word type effect. ($F(1,29)=1.851$, $p<0.477$), but a significant interaction was found among priming and word type ($F(1,29)=10.585$, $p<0.005$); *–mi* controls were responded to with higher accuracy than targets, but –*sa* targets showed the opposite trend. Response Time and Accuracy are also shown in Table 16 below.

Table 16 Response Time and Accuracy: Affix Priming in Japanese

	Response Time in ms. (error %)		*Mean Difference*
Condition	*Target*	*Control*	*(Priming)*
-*mi* Primes vs. Controls	578 (4%)	591 (1%)	13
-*sa* Primes vs. Controls	594 (3%)	609 (5%)	15

Section 4: Discussion

Subsection 1: Summary of Results and Tentative Conclusions

The current study found a small, but significant priming from affix-to-affix in a masked priming paradigm, consistent with a view in which not only roots but affixes have independent representations, and consistent with the view that complex words are decomposed automatically into morphological-level constituents in the time course of lexical processing. Observing significant priming for affixes, without a distinction among the highly productive –*sa* affix and the highly unproductive –*mi* affix suggests that productivity does not constrain initial decomposition into morphological-level constituents. This would run counter to the view (e.g. Hay and Baayen, 2005), in which productivity governs whether a given word will be decomposed into parts or perceived holistically, but would instead be consistent with a version of morphological processing in which not only productive (or transparent or frequent, tested in other studies in the dissertation) complex words are treated as complex: under this view, all complex words are initially decomposed into constituent morphemes immediately during lexical processing, regardless of productivity. This raises interesting issues, already mentioned elsewhere for semantic transparency and frequency in this dissertation, regarding how and when effects of productivity arise during the course of lexical processing, and accordingly, how they should be accommodated into a model of how complex words are represented and processed. Although views of productivity and processing models vary greatly, a fairly widely accepted answer is that unproductive 'complex' words are treated as simplex words— however, the results of the current study do not support that solution; instead they open the possibility that even unproductive complex words are treated as complex, and that effects of productivity arise at later stages (presumably involving the licensing of the root-affix combination).

We have previously argued from similar evidence that semantic transparency effects may hold at later stages, as evidenced by lack of semantic transparency constraints on masked priming, while under certain circumstances, they emerge in longer-lag tasks including cross-modal priming. In parallel with this, it is interesting to examine the experimental evidence for priming of affix representations across tasks, and effects of productivity across tasks. However, the extant literature is not so large as it is for semantic transparency. (There is one report from a conference proceedings arguing that words with the productive English *–ness* prime other words with *–ness* in a cross-modal task (Marslen-Wilson et al., 1996)).

Hagiwara et al. (1999) argued that the case we are examining (Japanese de-adjectival nominalization) may recapitulate the regular-irregular distinction under a dual-route account put forth by Pinker and others; productive *–sa* and unproductive *–mi* would be formed by rule and association, respectively (Hagiwara et al., 1999). (There is similar evidence from English irregular inflection that has been used to support a similar rule/storage dichotomy; see, e.g., Ullman et al. (1997), among others.) While their evidence from performance of Japanese aphasics supports a distinction among these two types of de-adjectival nominalizer, it is interesting to think about where this distinction arises, and whether it is compatible with the hypothesis that at some initial stage, both are treated as complex, and that the difference (which must be a part of every model, in some form) does not clearly rule out the less productive form as being 'complex'.

Subsection 2: Remaining Concerns and Future Research

Of course, many further studies are required to investigate whether the trend in the current data indeed reflects an initial facilitation for affixes, regardless of productivity. First, more studies are required in order to compare the facilitation found in the current study with effects of purely orthographic overlap, which are predicted to go in the opposite direction. In practice, it is difficult to construct the relevant test items in Japanese, since when using kanji/kana, it is difficult to find sufficiently matched cases of Kanji plus word-final *–mi* words without internal morphological structure to compare with the test conditions. Some ways forward would be to use control words which are typically written in Japanese in hiragana only, with a word-final *–mi* that does not correspond to the *–mi* morpheme. If the intuition is on the right track that orthographic overlap in itself tends toward *inhibition*, then the comparison which we have used here (affix-overlapping prime vs. unrelated control) would in fact have *underestimated* any morphological-level effect, because the control condition would not factor out the effect of orthographic overlap, thus masking to some extent the effect of morphological-level activation; it has been argued elsewhere that this kind of intuition may account, at least in part, for the relatively robust masked priming effect in languages with discontinuous morphology, such as Hebrew and Arabic (e.g. Forster, 1998, among others).

Second, more data is needed to verify whether the findings of the current study hold up, considering the following two issues. (i) The current data come from a relatively small set of items (constrained by the number of *–mi* words in the Japanese lexicon); with a small number of samples from each participant, and a relatively low number of participants in comparison with other studies on the masked priming of root morphemes (Longtin et al., 2003, Rastle et al., 2004, among others), the relatively weak effects obtained so far are perhaps to be expected. One way forward which we will pursue is to simply collect data from more participants, which would at least allow us to know whether the effects become clearer with more samples. (ii) We do not know how large or robust affix priming effects *should* be, given the dearth of studies. The effects obtained in the current study are clearly smaller than those of masked repetition or partial repetition from roots (and mainly, from onset position). It would be important to gather data from more experiments, to get a better sense of whether such effects consistently appear, and to draw some conclusions about the relative magnitude and robustness of those effects relative to those of root priming studies.

Finally, given that we know very little about whether and how effects of shared affix should be manifested in masked priming (which was one reason we conducted this exploratory pilot), it would make sense to test for root-priming effects for these two word types, which we will pursue in our next studies. Looking at the priming effects from these complex words to their root morphemes would also allow us to test whether there is indeed a distinction among more and less productive words in 'how decomposable' they are (cf., Hay and Baayen, 2005).

Additional experiments are also called for which can also potentially tease apart interesting aspects of the de-adjectival morphemes, the roots they take, and the relations among the two affixes. Thus, in our next studies we will test for priming effects from *–mi* to *–sa* affixed words and vice versa, in which function (de-adjectival nominalization) is shared across prime and target, but not morphological identity; priming across roots (that is, from one root which takes the restricted-productivity morpheme, *–mi,* to another that also takes *–mi*); this will be tested to explore possible relations among roots which are listed/marked for licensing the combination with the *–mi* affix. Presenting these future studies in more detail is beyond the scope of the current dissertation, but their brief mention points to some ways forward which we will pursue in subsequent studies, for the purpose of better understanding the nature of root and affix representations, and the relation among roots and affixes under different circumstances (e.g. under differing levels of productivity).

Section 5: General Summary

In sum, we have provided some tentative evidence to suggest that affix representations behave like root representation in the masked priming task, yielding facilitation due to morphological identity. If these findings are on the right track, this would add to the considerable evidence for root priming from complex words, complex word priming from roots, and the suggestive findings from Marslen-Wilson et al. (1994) (who found that, unlike the just-cited permutations, a derived form like *manager* inhibits another derived form with the same root such as *management* in the cross-modal task, taken to reflect affix-affix competition, and thus, indirectly, internally-structured representation involving affix morphemes), that suggests that complex words are treated as internally morphologically structured representations. If these results are on the right track, they may also suggest that the decomposition of derivationally-complex words into constituents is not strongly constrained by productivity, finding facilitation both for the more- and the less-frequent de-adjectival nominalizers in Japanese. This again argues for automatic decomposition into constituent morphemes, and raises interesting questions about the role of constraints such as productivity, transparency, frequency, etc., which have commonly been thought to constrain whether decomposition into parts occurs.

Chapter 7: Psycholinguistic-Electrophysiological Cross-Method Research in a New Domain: Representation of Lexical Roots and Lexical-Semantic Ambiguity[33]

Section 1: Introduction

Subsection 1: Background

In the previous studies presented in this dissertation, we have explored psychophysical and neural evidence for the processing of lexical representations under alternative views on the nature of those representations (e.g. by examining whether they are initially treated as complex internally-structured representations or as atoms). In the following, we explore both psychophysical and neural reflections of lexical processing in a new domain, that of lexical semantics. In this domain, we would like to show once again that fundamental differences in views of the nature of lexical representations can be tested (both psycholinguistically and neurally) in environments in which they make specific divergent predictions about an aspect of their behavior (e.g. timing) in a certain process (e.g. retrieval of lexical items from memory). Just as in the MEG/lexical decision study on compounding presented in Chapter 3, where we tested for a putative distinction among compounds being comprised of two morphemes under one set of approaches, or of one atom under a

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[33] Portions of this chapter have been adapted from our published manuscript (Beretta, Fiorentino, and Poeppel, 2005)

second set of approaches, here we will test for a putative distinction on the representation of ambiguous words, which are alternatively claimed to have single or multiple lexical entries.

Again, supporting the claim that two kinds of ambiguous word have distinct representations at the level of lexical entry (in which a multiplicity of senses, unlike a multiplicity of homonymous meanings, is accounted for by virtue of internal structure) points to a lexicon in which there *are* abstract lexical entries, and consequently, distinct consequences for ‘multiplicity’ of meanings depending on the organization of the abstract representations. In the next subsection, we will focus on the properties of the ambiguous words under study (namely *polysemy* and *homonymy*) and their putative representational distinctions, before turning to the experimental investigation of the putative representational distinction among these two word types using psychophysical (lexical decision) and electrophysiological (MEG) evidence.

Subsection 2: A Distinction Among Kinds of Lexical Ambiguity: *Polysemy* and *Homonymy*

It is common to draw a distinction among two kinds of ambiguous word: polysemous words and homonymous words. Homonymous words are those in which the meanings of an ambiguous word are unrelated, save for their orthographic/phonological overlap. A typical example is the English word *bank*, which carries the following unrelated meanings, as in (37)-(38):

(37) Meaning 1: *Financial Institution*

Example: Jan deposited $50 at the bank yesterday.

(38) Meaning 2: *Side of River*

Example: In order to find the biggest fish, we often fished from the muddiest part of the bank along this river.

Polysemous words on the other hand have multiple related meanings or 'senses'. Consider the example of the English word 'door'. Two related senses can be seen in the examples in (39)-(40):

(39) Sense 1: *Physical Object*

Example: The door fell off its hinges

(40) Sense 2: *Aperture*

Example: The child ran through the door. (Beretta et al., 2005)

Returning to the example of *bank* above, we can see that a single homonymous meaning can itself carry multiple polysemous senses. Consider the examples in (41)-(42) below.

(41) Meaning / Sense: *bank (Financial Institution) / Institution/entity*

Example: The bank apologized to its customers.

(42) Meaning / Sense: *bank (Financial Institution) / Building*

Example: The bank was destroyed in an earthquake.

These examples demonstrate that words can carry two types of ambiguity: polysemy and homonymy. Further, words can be both homonymous and carry multiple polysemous senses. (It is further worth noting that across words in a language, the words in a language can vary in the number of unrelated meanings and number of polysemous senses; we will take advantage of this property in the experiment below).

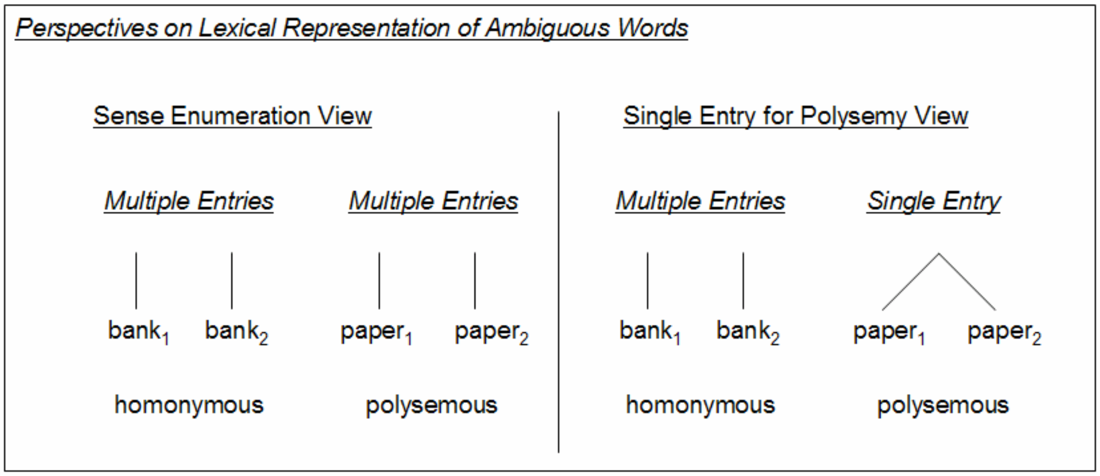
Subsection 3: A Distinction at the Level of Lexical Entry?

To what extent, if any, do the distinctions we have used above to describe these two types of lexical ambiguity make claims about distinctions in the mental lexicon? As regards homonymy, it is typically claimed that homonymous words have separate lexical entries for their unrelated meanings. Thus, for example, there will be separate lexical entries for *bank*, the financial institution, and for *bank*, the side of a river. What is less clear (and where a controversy over the nature of lexical representations arises) is what kind of lexical entries the related (polysemous) senses have. One alternative that has been considered is that each polysemous sense is itself a separate lexical entry, on a par with the unrelated meanings of homonymous words (this has been termed a Sense Enumerated Lexicon approach).

However, another alternative is that unlike unrelated meanings, the senses of a polysemous word are part of a single lexical entry. An account of polysemy associated with this view is the Generative Lexicon view proposed by Pustejovsky (1995). Similar views are involved in the accounts of polysemy in Nunberg (1979), Caramazza & Grober, (1976), and Lehrer (1990), among others, each of which posit that multiple senses may be derived from forms of lexical rule or meaning extension.

Both the sense-enumerated view, in which multiple unrelated meanings and multiple polysemous senses result in multiple lexical entries, and the single-entry views of polysemy, in which only unrelated meanings, and not multiple polysemous senses result in multiple lexical entries, are potential candidates for the organization of the mental lexicon. In what follows, we will consider whether and how one can test this possible distinction among polysemy and homonymy in terms of lexical representation in lexical processing; see Figure 12 for a schematic representation of these two competing representational proposals.

Figure 12 Two Perspectives on the Representation of Ambiguous Words



Subsection 4: Processing of Lexical Ambiguity in the Lexical Decision Task

In fact, there have been many psycholinguistic studies on how ambiguity affects processing time. The perhaps surprising finding from the initial studies using lexical decision, for example, pointed to an *advantage* for ambiguous words— that is, ambiguous words were responded to more quickly than unambiguous words (e.g., Borowsky and Masson, 1996, among others). While studies in this vein relatively consistently found an "ambiguity advantage", these early studies did not specifically investigate the contribution of the kinds of ambiguity (polysemy and homonymy) to this effect, as argued by Rodd et al. (2002); thus it is not clear, from the previous studies, what the source of the observed 'ambiguity advantage' was. When specifically investigated, the findings showed that the advantage holds for polysemous words, and not for homonymous words (Rodd et al., 2002). Indeed, the results of a set of lexical decision studies by Rodd et al. (2002) showed that while polysemy resulted in faster response times, the opposite held for homonymous words, as we will see below. These results seem to suggest a distinction among polysemy and homonymy: in lexical access, having more polysemous senses is different from having more homonymous meanings.

Subsection 5: Current Study: Experiment VI

Given the potential interest of this finding, in the current study we seek to replicate and extend the findings of Rodd et al. (2002) in the following ways, pursuing the research methodology adopted in Chapter 3 (simultaneous MEG/lexical decision). Following Rodd et al. (2002), we examine responses to words with either few or multiple senses, and a single or multiple unrelated meanings, to once again explore whether having more senses has similar consequences for lexical access as having more unrelated meanings, as would be predicted if both kinds of ambiguity engendered multiple lexical entries, or whether having multiple polysemous senses is indeed different from having multiple unrelated meanings as predicted under accounts in which polysemous words have a single lexical entry, while homonymous words have separate lexical entries for each unrelated meaning.

However, we will also utilize simultaneous MEG recordings in the following way, as in the experiment in Chapter 3. As discussed in Chapter 3, MEG recordings allow the measurement of brain activity time-locked to the onset of a visual word, with millisecond-resolution in timing. The addition of these brain-level recordings adds additional time-sensitive dependent measurement capability *before* the lexical decision response, making possible the detection of effects occurring prior to the response, and the comparison of these earlier effects with the psychophysical response (e.g. lexical decision times). Based on the findings of the MEG study with compounds (Chapter 3), and on the previous MEG studies reviewed therein (see Pylkkänen and Marantz, 200, for a review) it is hypothesized that, in the MEG evoked averaged waveform, a particular cascade of peaks of activity should be elicited in the first 500 ms following the onset of the visual word. Notably, three peaks of activation, termed M170, M250, and M350 based on their characteristic peak activation time, should be consistently elicited. Of these, the third component, peaking around 350 ms, has been hypothesized to index aspects of lexical activation.

This leads to a testable hypothesis about M350 activation and its relation to response time in the current study, as follows (details of experimental items and method to follow in the next section).

Response time: predictions. If having multiple homonymous meanings is the same as having multiple senses (i.e. both engender multiple lexical entries), then multiple polysemous senses and multiple homonymous meanings should affect response times in a similar way (contra Rodd et al., 2002). If having multiple homonymous meanings is distinct from having multiple senses (i.e. only homonymous meanings engender multiple lexical entries), then multiple polysemous senses and multiple homonymous meanings should affect response times in distinct ways (following Rodd et al., 2002).

MEG (evoked waveform): predictions. If the hypothesis that the latency of the peak activation around 350 ms post-onset of the visual word (M350) is sensitive to aspects of lexical activation, then if there is no distinction among having multiple polysemous senses and having multiple homonymous meanings at the level of lexical candidates, no distinction in the timing of the M350 peak activation is predicted (if the response time nevertheless shows an effect, this may suggest a post-lexical locus of the response time effect). However, if the distinction among having multiple polysemous senses and multiple homonymous meanings is a distinction at the level of activating lexical candidates, then it is predicted that having multiple polysemous senses and multiple homonymous meanings should have distinct effects on M350 peak latency, paralleling the response time results. As regards the earlier MEG components, M170 and M250: the words across condition are controlled for visual word-form properties thought to affect the first distribution (M170), such as letter-length, so no differences are predicted there. From the extant results, which do not show any clear sensitivity of the M250 to aspects of visual lexical processing, no straightforward predictions follow for the activation at M250.

Section 2: Methods

Subsection 1: Stimuli and Design

The set of stimuli tested in this experiment are those from Experiment II of Rodd et al. (2002). A brief description of the properties of these items follows; see also Rodd et al. (2002) for further details on these items. The target items fall into four categories: (i) words with few senses and a single meaning, (ii) words with many senses and a single meaning, (iii) words with few senses and multiple unrelated meanings, and (iv) words with many senses and multiple unrelated meanings. Number of unrelated meanings (homonymy) was measured for this stimulus set via counts of entries in the Wordsmyth dictionary (Parks et al., 2003). Number of senses (polysemy) was calculated for this stimulus set via number of senses listed in the WordNet lexical database (Felbaum, 1998). These four conditions were matched for lexical properties including word frequency, using the CELEX lexical database (Baayen et al., 1993), number of syllables, concreteness ratings, and familiarity ratings; numbers of words differing from one another by only a single letter were also controlled across conditions (Rodd et al., 2002). Examples of stimuli from each condition are shown in Table 17 below, and a full list of items is listed in Appendix VIII.

Table 17 Examples of Items: Lexical Ambiguity Experiment

	Polysemy	
Homonymy	Few Senses	Many Senses
Single Meaning	farm	hook
Multiple Unrelated Meanings	calf	bowl

Subsection 2: Procedure

Psychophysical Procedure. The stimuli were visually presented using Psyscope (Cohen et al., 1993) in four blocks of 64 items, each with the same number of items from each of the four stimulus conditions. The experimental paradigm was continuous lexical decision. Participants were instructed to respond as quickly and accurately as possible whether the stimulus presented was a word or a nonword. Each trial began with a 500 ms fixation point in the center of the screen, followed by visual presentation of the stimulus, lasting until the participant's response. Each trial was followed by an interstimulus interval varied pseudorandomly from 500-1000 ms (at 50 ms intervals). 'Word' responses were made with the right (dominant) hand, and 'nonword' responses with the left (non-dominant) hand. The order of the four blocks of items was randomized across subjects, and for each subject the order of items within lists was also randomized. Each block was preceded with 10 practice stimuli not included in the analysis of target items, and each block was followed by a brief rest period before the next block. The nonwords were comprised of pseudohomophones which were matched for length with the word stimuli. The ratio of words to nonwords was 1:1. The experimental session was preceded by a practice session comprised of 64 practice trials which were not included in the analysis of target items.

During this experiment, participants lay in dimly-lit magnetically-shielded room (Yokogawa Electric Corporation, Tokyo, Japan), viewing items presented on a screen fixed 37 cm above the participant's eye-level. The target stimuli subtended 1.4º of visual angle vertically and 3.5º horizontally, (range 2.3º to 4.6º). The stimuli were presented in Geneva font, size 48, in yellow letters on a black background. Button-press responses were made using a two-pad non-magnetic fiber-optic response-button system (Current Designs, Inc., Philadelphia, PA).

Neuromagnetic recording procedure. Neuromagnetic signals were recorded continuously with a 160-channel whole-head axial gradiometer MEG System (Kanazawa Institute of Technology, Kanazawa, Japan). Prior to the recording, five electromagnetic coils were positioned on the participant with respect to anatomical landmarks: the nasion, preauricular flaps, and two forehead positions. The nasion and pre-auricular points were then digitized, as was the location of each of the five coils. The location of these coils with respect to the sensors was recorded immediately before and after the experimental recording for subsequent coregistration with digitized headshape or MRI images, to make possible analyses of this data which may involve source localization.

Data were recorded at a sampling rate of 1000Hz, filtered online with a band-pass filter of 1-200Hz and a band-elimination filter at 60Hz. The continuous data file was then noise-reduced relative to three reference magnetometer coils using the Continuously Adjusted Least Squares Method (CALM) (Adachi et al., 2001). Trials were then averaged by condition with epochs beginning 100 ms before stimulus onset and extending to 500 ms post-onset, and level-rejected at +/-2.0 pT to remove trials with eye-blinks or other artifacts, if any. The averaged data were baseline-corrected relative to a 100 ms prestimulus interval, and low-pass filtered at 20Hz.

Subsection 3: Participants

Nineteen right-handed, monolingual American English-speaking adults with normal or corrected-to-normal vision (13 females; ages 18 to 31) provided their written informed consent to participate in this experiment. Participants were paid for their participation.

Section 3: Psychophysical Results

Subsection 1: Psychophysical Data Analysis

Response times and accuracy were analyzed for each participant as described in the following two subsections. The mean response times and accuracy rates are discussed in these sections, and summarized in Table 18 below.

Subsection 2: Response Times

Response times and accuracy were analyzed for each participant as follows. The response time data revealed a significant effect of Polysemy, in both by-participants ($F(1,17) = 15.616$, $p< 0.002$) and by-items analyses ($F(1,31) = 4.325$, $p< 0.046$). Words with more polysemous senses were responded to more quickly than words with fewer senses. The data also revealed a significant effect of Homonymy, significant in the by-participants analysis ($F(1,17) = 7.832$, $p<0.013$), marginal in the by-items analysis ($F(1,31)=3.508$, $p<0.089$). Words with more unrelated meanings were responded to more slowly than those with a single meaning. The Polysemy X Homonymy interaction was not significant in by-participants or by-items analyses (F’s <1).

Subsection 3: Accuracy

The accuracy data also revealed a significant effect of Polysemy, in both by-participants ($F(1,17) = 39.085$, $p< 0.001$) and by-items analyses ($F(1,31) = 11.332$, $p< 0.003$). Words with more polysemous senses were responded to more accurately than words with fewer senses. The data also revealed no significant effect of

Homonymy, either in the by-participants analysis (*F*(1,17) = 1.946, *p*<0.182), or in the by-items analysis (*F* <1). Words with more unrelated meanings were responded with approximately equivalent accuracy compared to words with a single meaning. The Polysemy X Homonymy interaction was not significant in by-participants (*F*(1,17) = 1.068, *p*<0.317) or by-items analyses (*F*<1).

Table 18 Response Time (ms.) and Accuracy (%): Polysemy vs. Homonymy

	Polysemy		
Homonymy	Few Senses	Many Senses	*Mean*
Single Meaning	626 (5.2)	611 (1.2)	619 (3.2)
Multiple Unrelated Meanings	648 (7.3)	622 (1.6)	635 (4.45)
Mean	637 (6.25)	617 (1.4)	

Section 4: Neuromagnetic Responses

Subsection 1: Analytical Method

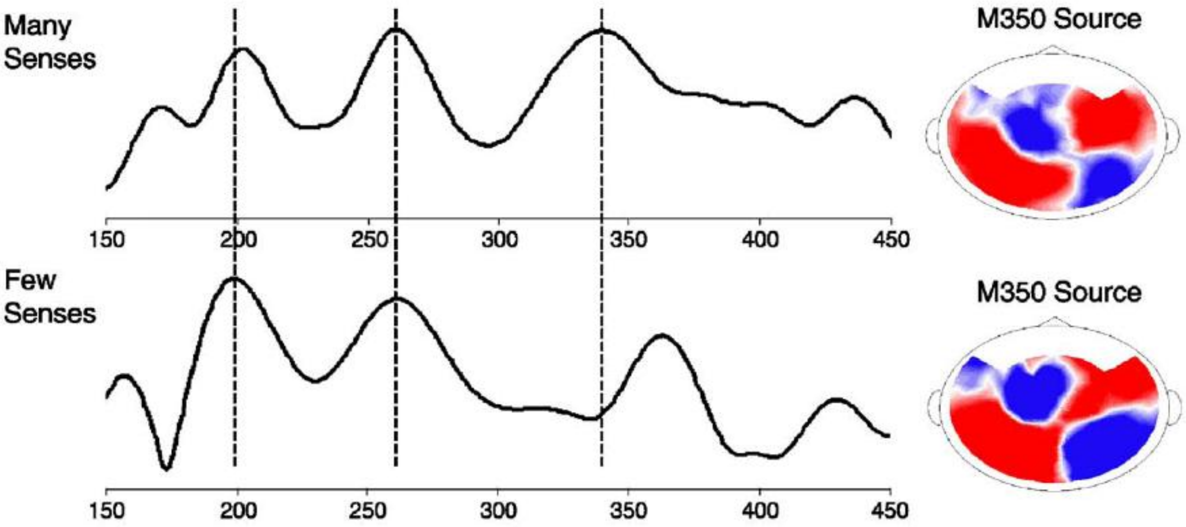
As in Experiment I, three components in the MEG waveform were observed across conditions and participants following the onset of the visual stimulus, appearing at approximately 170 ms (M170), 250 ms (M250), and 350 ms (M350), respectively. As remarked above, these components have been observed in several studies on responses to words presented in isolation using MEG (e.g., Embick et al., 2001, Pylkkänen et al., 2002, as well as the study in Chapter 3 of this dissertation). Six participants who failed to show one or more of these components in one or more condition (M350, 3 participants; earlier components, 3 participants), and thus precluded across-condition comparisons on the properties of the respective components, were excluded from the MEG analysis, as was one participant with very high error rates in the lexical decision task. Thus, the data from twelve participants was carried through to the waveform analysis.

As in Experiment I, the peak latency and amplitude for each component was determined by selecting 5 channels from the sink (ingoing) and five channels from the source (outgoing) portion of the magnetic field contour; the latency of the peak from a root mean square (RMS) analysis on these 10 channels was entered into by-condition statistical comparisons. In this experiment, which was focused on detecting the sensitivity of the M350 component, the channel selection was made based on the magnetic field contour of the M350 component; since this channel selection also captured a large portion of the contour for the earlier components, with identifiable peaks in the RMS waveform, this channel selection was applied not only to the M350 but as a (coarse) measure of potential effects on the earlier two components.

Subsection 2: Neuromagnetic Results

Analysis of M350 peak latency revealed a marginal effect of Polysemy ($F(1,11)=4.018$, $p<0.071$) by participants; words with multiple senses elicited earlier M350 peak latency than those with few senses. There was also a marginal effect of Homonymy ($F(1,11)=3.514$, $p<0.089$); words with multiple meanings elicited later M350 peak latencies than words with a single meaning. The interaction of Polysemy and Homonymy was not significant (*F*<1).Planned direct comparisons of the main effects of Polysemy and Homonymy revealed significant effects of Polysemy (*t*(23)=2.071, *p*<0.05, two-tailed), and Homonymy (*t*(23)=2.209, *p*<0.038). The peak latency values for the M350 component are shown in Table 19 below. The RMS averaged waveforms for the comparison of Many vs. Few Senses for one participant are illustrated in Figure 13 below.

Figure 13 MEG Waveform: Many vs. Few Senses (Single Participant Data)



A marginal effect of Polysemy was also detected in M350 peak amplitude (*F*(1,11)=4.037, *p*<0.071) by participants; no effect of Homonymy on amplitude was observed (*F*<1). The interaction among Polysemy and Homonymy in M350 peak amplitude was marginal (*F*(1,11)=4.12, *p*<0.068). (No clear pattern of effects on peak latency or peak amplitude was elicited on the earlier components; thus, we do not pursue their analysis more deeply in this paper.)

Table 19 M350 Latency (ms.): Polysemy vs. Homonymy

	Polysemy		
Homonymy	Few Senses	Many Senses	*Mean in ms. (SE)*
Single Meaning	345	328	336 (5.70)
Multiple Unrelated Meanings	359	349	354 (5.96)
Mean in ms. (SE)	352 (6.12)	338 (5.76)	

Section 5: General Discussion

Subsection 1: Discussion

The current study utilized a simultaneous MEG/lexical decision methodology to probe for distinctions in the nature of lexical representations, this time not by looking at morphologically-complex words, but by exploring a putative distinction in the lexical representation of words with two kinds of lexical ambiguity: polysemy and homonymy. On one set of accounts, both having multiple polysemous senses and having multiple homonymous meanings results in separate lexical entries, whereas on an alternative view, only homonymous meanings are listed as separate lexical entries, and polysemous senses involve only a single lexical entry. In this study, we confirmed, following Rodd et al. (2002), that, holding other properties thought to affect lexical retrieval from memory equal (frequency, length, etc.), having multiple polysemous senses had distinct, opposite effects from having multiple unrelated meanings. Words with multiple polysemous senses were responded to more quickly, and yielded earlier M350 peak latency, compared with words with few polysemous senses, while homonymous words were responded to more slowly, and yielded longer M350 latency, compared with unambiguous words.

The response time findings replicate the findings of Rodd et al. (2002), who showed that polysemous words were responsible for the ambiguity advantage, and that homonymous words, in contrast, were associated with slower response times than unambiguous words. Further, using MEG, we have shown that this distinction holds not only of response time, but also of the MEG component around 350 ms (M350), thought to index initial lexical activation (and which was the first component found to be sensitive to the activation of morphological constituents in Experiment I in this dissertation). We did not find evidence suggesting that the effects were post-lexical (which we would expect would incur equivalent M350 latencies but response time differences). Instead, we found that a difference was indeed significant in M350 latency in the same direction as that of response times— multiple senses were *faster*, but multiple meanings were *slower*.

Taken together, these results support a distinction in the nature of lexical representations for polysemous words and homonymous words. These findings seem to be at odds with views of lexicon in which both kinds of word involve multiple lexical entries, e.g., sense enumeration, and to be consistent with a view in which the two kinds of words are represented differently, e.g. in which homonymous words engender multiple entries while polysemous words involve a single entry. Further, the

MEG results suggest that this distinction holds several hundred milliseconds before the overt response is made, as demonstrated by a significant effect of latency at the M350. Consistent with the hypothesis that this component reflects initial lexical activation, the distinction among polysemous and homonymous words seems to be evident at the stage of lexical activation, and not solely at later stages of processing. (It is also worth noting that this set of MEG findings is also consistent with the findings from a number of studies on the evoked waveform in MEG during visual word processing in attesting components around 170, 250, and 350 ms following the onset of the visual word, and the sensitivity to the third component, M350, to lexical properties.)

Subsection 2: Converging Evidence

It is worth noting briefly here that a recent MEG study has observed the same distinction among homonymous and polysemous words on the M350 MEG component (Pylkkänen et al., 2006). In that study, priming among senses was facilitative, resulting in reduced latency of the left-hemisphere M350 latency, whereas the effect among homonyms was one of longer latency. Like the current study, the authors take these findings to reflect a representational distinction among polysemy and homonymy at the level of lexical activation (Pylkkänen et al., 2006).

Subsection 3: Remaining Issues

In sum, the results offer an answer to the question that motivated the experiment reported here. By conceiving of linguistic models of polysemy in terms of single-entry vs. multiple-entry processing accounts, as we have done, we have further confirmed that it is possible to consider the relative effects of homonymy and polysemy in the time course of lexical processing, and have added electrophysiological evidence to suggest that these effects hold in a brain response thought to reflect properties of lexical activation, hundreds of milliseconds before the overt response. Although the results together argue for a fundamental distinction among polysemous words and homonymous words, in which a multiplicity of meanings has different representational consequences than does a multiplicity of senses, further work is needed to uncover precisely how this representational distinction interacts with retrieval from lexical memory.

While the predicted representational distinction was borne out in our measures of lexical activation, it is not wholly clear why homonymy and polysemy show the direction of effects that they do. That is, while there is a straightforward theoretical interpretation of the fact that homonymy and polysemy manifest distinct processing profiles, why should words with more than one meaning (homonyms) *slow* access relative to words with one meaning (non-homonyms), and why should words with many polysemous senses *speed* access relative to words with few polysemous senses?

First, let us consider the problem posed by the homonymy disadvantage. Why should there be longer latencies for words with more than one meaning (homonyms) compared to words with one meaning (non-homonyms)? Network models of word recognition that implicate competition between words to activate meaning representations may argue that different meanings of homonyms ought to result in slower recognition than for single-meaning non-homonymous words. In this sort of model, each word is represented as a unique pattern of activation across a set of orthographic/phonological and semantic units. Orthographic patterns of words are linked to more than one semantic pattern if a word is homonymous. When the network encounters an orthographic pattern of a homonymous word, both of its meaning representations will compete with each other. The consequence of this competition is that it will take longer to arrive at a stable activation pattern.

Regardless of whether a network architecture is adopted, a version of a competition account can be articulated. The basic intuition is that presumably, readers are at some level comparing alternative interpretations, and this process of comparison in itself engenders processing cost. While competition is certainly a possibility with regard to the processing of homonymy, any account will have to capture why more closely related, but separate form-meaning pairings in the case of polysemy do not compete if they are also separate entries.

However, there is another kind of account that can be put forth to account for the effects in the present study. Assuming words with more than one meaning (homonyms) do have separate entries, frequency alone could constitute an explanation of the homonymy disadvantage. Since the stimulus items were matched for form frequency, each entry for a homonym must be less frequent than a single-meaning non-homonym entry. Since frequency is known to affect both RTs and

M350 responses, it should be expected that homonyms matched for form frequency will slow access relative to non-homonyms. This would straightforwardly account for a homonymy disadvantage. When we turn to the problem of the many senses advantage (why words with more senses have a processing advantage over words with few senses), the first thing to point out is that again a separate-entries account of polysemy would predict that having more senses would engender this type of frequency-caused disadvantage. That is, every separate sense would by consequence have lower frequency than the whole word form, and we would predict that more senses should have slower response times and longer M350 latencies.

A problem for both the competition accounts and the frequency accounts arises when trying to accommodate the sense advantage. For example, under the frequency account, if the senses of a word are really stored as a single entry, then the form frequency should be a good predictor of these measures, and would not predict an advantage per se in retrieving these items based on frequency. The same line of reasoning holds for competition accounts; while lack of competition surely can account for a lack of sense disadvantage, it is not likely to be informative regarding a sense advantage.

Here, it is worth reinforcing that the failure of both of these accounts to apply across polysemous words and homonymous words follows straightforwardly from what he have concluded to be the case: that there is a *representational distinction* among the two types of word. The present study has yielded data that are consistent with the claim that while homonyms have separate entries, polysemous words do not. The fact that frequency and competition can explain the homonymy disadvantage but cannot explain the many senses advantage may be seen as further confirmation of this claim. While it is true that either competition or frequency differences attendant on separate homonymous entries may explain the homonymy disadvantage, competition or frequency do not explain the many senses advantage, which difficulty follows from the single vs. multiple-entries conclusion.

There have been several intuitive proposals which seek to point a way forward to a solution. For example, Rodd et al. (2002) consider several candidates, including the possibility that words with many senses may be semantically richer than words with fewer senses, or that words with many senses are used in a wider range of contexts than words with few senses and so develop context independent representations. Since the present study was not designed to tease apart the various theoretical models of single-entry polysemy, further experimentation is indicated. However, what the present study has addressed is the prior question of whether or not a single-entry lexical model of polysemy is a viable proposition. The findings in this respect are rather clear: this study provides firm behavioral and neural support for a single-entry model of polysemy.

There are many other problems which remain to be addressed, in addition to those sketched above, and interesting extensions of the present study. We briefly note two of them, before moving on to the concluding remarks in the next chapter. The first issue that we note is that in the current study we did not draw a distinction among *kinds* of polysemy in the stimuli that we tested. Undoubtedly, a deeper exploration of these effects with respect to finer distinctions among kinds of polysemy (e.g. regular polysemy, such as type/token polysemy, vs. irregular polysemy, i.e. meaning extensions that border on unrelated meanings) may shed more light on to what extent polysemous senses group together under a single entry or constitute multiple lexical entries. For example, Klein and Murphy (2001) found evidence that senses which are less related (i.e. look more like the unrelated meanings of homonymy), pattern as though the senses were separate entries. This suggests that it may not be all kinds of polysemy which result in single-entry representation, but rather the effect may be circumscribed to more closely related senses or regular polysemy. This raises interesting possibilities for future research, the most straightforward of them being a test of whether the ambiguity advantage for polysemous words in lexical decision (and MEG) holds only for regular polysemy or more broadly. The second, related issue is that, in the current study, we have not considered homonymy or polysemy relative to grammatical category. While it is possible that grammatical category should be taken into account in testing these items, we do not speculate on any possible role or mediating factor related to grammatical category here.

Section 6: Summary

In sum, the findings of the current study, taken together, argue for a representational distinction among two types of ambiguous word: polysemous words and homonymous words. Utilizing a set of stimuli in which lexical properties other than ambiguity were kept equal, it was shown that, as found by Rodd et al. (2002), having more senses has a distinct effect from having more homonymous meanings, counter to expectations given a model in which each type of word engenders listing of separate entries. Adding the simultaneous MEG measure, this distinction was detected also in the latency of the MEG component around 350 ms post-onset, consistent with previous findings (and Experiment I of this dissertation) which show that this component is sensitive to aspects of lexical activation, and further indicating that the distinction among polysemous and homonymous word representations held at the early stages of lexical activation.

This study also serves to demonstrate, in a domain other than morphological complexity, that using psycholinguistic and neurolinguistic measures together, one can test for fundamental distinctions among lexical representations in terms of specific divergent hypotheses about how they should behave in terms of *timing* under alternative views. Like the previous studies presented here, where keeping all things equal which tend to affect retrieval from lexical memory, we were able to reveal morphological-level distinctions in the timing of lexical processing, the current study supports a distinction in kind among the two types of word— having more senses is different from having more meanings, both in the overt response and at the initial stages of lexical activation, in contrast to a singleton approach by which both types of word would engender separate listings.

Chapter 8: Conclusion

Section 1: Decomposition and the Nature of Lexical Representations

Subsection 1: Decomposition and Lexical Representation: Concluding Remarks

In this dissertation, we have addressed the fundamental issue of whether so-called 'complex' words are indeed treated as internally-structured representations, compatible with views of lexical representation (and linguistic representation more generally) as involving abstract representations. As concerns lexical representation specifically, we tested in various ways, a view of the lexicon in which the morpheme, rather than the whole-word, is treated as a basic unit of representation and processing, arguing that such a view, if supported empirically, runs counter to a view of the lexicon which is not committed to the notion of morpheme (and indeed, not committed to the notion of abstract internal representation).

Our way into this problem in the core studies of this dissertation was to (i) explore, under highly controlled circumstances, whether so-called complex words are indeed decomposed into morphological parts online during the course of lexical processing, (ii) in the course of testing for decomposition, to test whether a host of factors thought to engender whole-word (i.e. atomic) storage and processing, including whole-word frequency, semantic transparency, and productivity, indeed preclude decomposition, counter to the predictions of automatic, across-the-board decomposition, and (iii), focus on contrasts which would be potentially informative regarding whether putative effects of decomposition could be accounted for based on formal or semantic overlaps without recourse to abstract morphological representation.

In the concluding sections of this dissertation, we will review the evidence which we have accumulated to address the issues in (i-iii) above, from a variety of experimental methods and across languages. Then, we will consider the place of decomposition in lexical representation and processing, and the evidence which has called it into question, focusing on the nature of the evidence which has been used to argue for both sides. Finally, we will consider the implications of adopting a view of the lexicon as consisting of morpheme-level basic units and initial across the-board decomposition, before concluding this report.

Subsection 2: What Have We Shown?

We argued in the core chapters of the dissertation that investigation of the processing of compound words has the potential to serve as a wedge into many of the foundational issues we have raised above. In Experiment I (Chapter 3), we provided a direct test for effects of internal word structure in compounding by the direct comparison of the effects of morphological-level vs. whole-word (atomic) properties on lexical decision. Given the well-known findings regarding factors affecting retrieval from lexical memory (such as frequency of occurrence), we tested whether constituent properties would affect responses to compounds, or whether the compounds would be processed as whole-words. We showed facilitation for compounds, predicted by access to constituents, and counter to the non-decompositional view, but questioned whether relying on lexical decision alone would be sufficient for this kind of investigation, given the following concerns. Under a decompositional view, decomposition is expected to be only one stage in processing, and post-decomposition effects could also affect lexical decision times, which by their very nature, have the potential to reflect aspects of processing throughout all stages of lexical access and decision. As a way into localizing the facilitation effects in *timing*, we simultaneously recorded time-sensitive measurements of brain activity using MEG, with findings suggesting that the facilitation effects were in the predicted direction in an MEG component sensitive to initial lexical activation (M350).

Thus, in Experiment I we supported a decompositional view of compound processing, counter to the view in which there is a bias, even an initial bias, to treat the word rather than morpheme level as a primitive as predicted on non-decompositional (or late decompositional) views of the lexicon (via challenges to the specific processing models which commit to these views). Using a whole-word frequency manipulation, we also verified that these effects held across whole-word frequency categories, suggesting that a view in which relatively frequent so-called complex words are treated as atomic (and which seeks to explain decompositional effects for low-frequency words under a paradigmatic whole-word view, e.g. Bybee, 1995, who proposes a 'neurally plausible' network view of morphology including these predictions), would face challenges accounting for the current data.

However, Experiments II and III (Chapter 4) were designed to test for converging evidence for the view that compounds are indeed decomposed into morphological parts automatically, adopting the psycholinguistic paradigm of masked priming, which had been used to test for morphological segmentation mainly in derivationally complex words. Because in this paradigm the prime word is presented so briefly that participants cannot detect it consciously in the general case, it has been claimed that this paradigm is well suited to testing for automatic activation at earlier stages, with inherent avoidance of late, strategic effects which may complicate interpretation of the priming effects; further it has been observed that morphological-level overlap results in a pattern of facilitation that is distinct orthographic or semantic overlap, a further attraction for teasing apart whether these factors, without recourse to abstract morphological structure, could account for apparent morphological-level processing evidence.

We adopted this paradigm to test for morphological-constituent activation in compounds (Experiments II-III), in order to test whether constituents of compounds would show predicted facilitation under a morphological view— but also addressing some concerns regarding the generalizations we have just presented for masked priming, namely that previous root priming effects might have been epiphenomena, resulting from affixal salience, not across-the-board decomposition. We showed that indeed morphological constituents were robustly primed by compounds, suggesting that these constituents are automatically activated during processing of compounds, arguing directly against an affixal-salience account of the masked-priming effects. Further, we tested whether semantic transparency constrained whether facilitation would occur, as predicted under views in which ‘complex’ words with semantic idiosyncrasy would engender atomic storage and processing, and showed equivalent priming regardless of transparency (we also verified that these effects hold of both initial and final position in compounds).

We then turned to a novel domain in which to test the effects of morphological-level structure in lexical processing, using an extension of the fragment priming technique typically applied to single-word research, and examining the activation of lexical candidates in Japanese compounds (Experiment IV). As we argued in Chapter 5, we were able to test directly whether the possibility of internal structure is considered online during spoken word processing, by showing the activation of lexical candidates from the fragment primes which are not consistent with being a continuation of the fragment prime based on the mismatch in phonological segments across the prime and target in voicing. Such priming was predicted under an abstract morphological structure-based view, since this mismatch crucially could be ‘undone’ if the possibility that the fragment included a morpheme boundary was considered during processing, since the *rendaku* morpho-phonological alternation changes the initial segment of the second member of Japanese compounds in some environments. Again, by building on basic findings regarding the properties of lexical activation, this time in the fragment priming paradigm, we were able to provide new evidence that indeed the possibility of a compound continuation is considered online, activating possible morphemic constituents which otherwise would not receive significant activation based on surface (i.e. phonological segment) features alone. Further, since we tested this on novel compounds and kept the initial morpheme constant across prime and control, we could carefully rule out the possibility of a semantic rather than morphological-level account of the activation in these findings.

Following these core studies, we reported two experiments outside the domain of compounding, first turning to affixation, and then to lexical semantics. In Chapter 6, we tested a pilot study to (i) test for a further constraint on whether words are processed as atomic or decomposed representations, namely productivity, and (ii) to test for possible effects of affix representation in the masked priming paradigm. Following the masked priming studies cited above, we tested whether affix-to-affix facilitation could be obtained across Japanese de-adjectival nominals with different roots, but sharing the same nominalizing suffix (Experiment V). Crucially, Japanese has two such suffixes, one of which (*-sa*) is very productive, and another (*-mi*) which is very restricted. On analogy with the root priming studies, we reasoned that if affix representations are activated automatically during the processing of complex words, then it may be possible to detect using masked priming (as argued by Kazanina, in preparation), and further, the properties of the Japanese nominalizers would then allow a test of whether productivity would constrain whether these words are treated as atomic or decomposed. While the results suggested a trend in which both kinds of word are decomposed, more research is called for to verify these effects.

Finally, we turned to a quite different environment in which we could also test for putative distinctions in lexical representation, in which under one view, polysemous words involve a single entry, with senses arising due to internal complexity, but homonyms engender separate lexical entries, counter to an alternative view where each instance engenders a separate lexical entry. Following recent results from lexical decision (Rodd et al., 2002), which provided an empirical challenge to the view that all ambiguity is the same in its consequences for lexical representation, we replicated the findings of that study and adopted the methodology of the compound study in Experiment I of this dissertation to again test whether these effects hold at the earliest component in the MEG signal sensitive to lexical activation (M350). Consistent with the view that the lexical decision results reflect distinctions in the activation of morphological roots; the predicted effects from the lexical decision results were indeed reflected in the latency of this component's peak activation, further localizing the locus of this effect in time prior to the overt response.

Subsection 3: Conclusions on Morphological Decomposition

The following main findings from each experiment are taken to support a view of the lexicon including *automatic across-the-board decomposition* into morphological parts. We consider how these effects fit into a broader view of the lexicon in the remainder of the discussion.

From Experiment I (English, Visual, Lexical Decision/MEG):

- Decomposition of compound words, contrary to non-decomposition
- Localized to initial lexical activation (MEG)
- Decomposition regardless of surface word frequency

From Experiments II and III (English, Visual, Masked Priming):

- Automatic decomposition of compounds, contra whole-word view
- Applies regardless of orthography and of surface position
- Applies regardless of semantic transparency

From Experiment IV (Japanese, Auditory, Fragment Priming):

- Compound-compatible activation online during lexical processing
- Morphological-level representation in spoken processing
- Applies regardless of surface form mismatch (segment mismatch)
- Applies regardless of semantic relationship

From Experiment V (Japanese, Visual, Masked Priming):

- Possibility of automatic decomposition into affix as well as root
- Applies regardless of orthography and, applies in non-onset position
- Possibility of application regardless of extreme productivity distinction

From Experiment VI (English, Visual, Lexical Decision/MEG):

- Distinct representation for two types of ambiguous word
- Localized to initial activation using MEG

Subsection 4: Putting it All Together

All of the evidence in this dissertation is naturally incomplete. I hope to have pointed out some points in which crucial data is needed to validate findings or strengthen arguments, and of course each study leads to further predictions that must be tested.

However, taken together, and taken within the context of the larger literatures with which it engages, this body of findings points to a conclusion at odds with the fundamental view in which word structure can be captured fully or in part in terms of unstructured atomic representations (and thus, the findings run counter to views of the lexicon which make no specific claim to abstraction or morpheme-level representation). Instead, the results together support a view in which the ‘word’ is not a privileged level of representation – instead of a bias toward treating words as an unstructured, basic unit, our evidence and reading of the literature supports a view in which ‘words’ are decomposed automatically, across-the-board, into morphological-level representations which combine to form more complex structures. This view *does* commit to abstract morphological-level representations, and is consistent with a view of the lexicon that is organized in terms of morphological-level distinctions.

Throughout the dissertation, we have compared morpheme-based and non-morphemic accounts of lexical representation and processing via comparisons of competing processing models which commit to one or the other foundational view, and our evidence has consistently pointed to morphological-level decomposition, while presenting challenges to specific non-decompositional approaches and non-morphological accounts put forth to capture seeming decomposition effects (e.g. via semantic or formal overlaps); whole-word based approaches were not supported across the studies presented here. The question naturally arises to what extent this line of argument from the data extends to adjudicating among competing morphological theories. Our results argue for a piece-based processing model, and would thus fit naturally with morphological theories assuming a piece-based architecture, such as Distributed Morphology (Halle and Marantz, 1993), and would seem to present challenges to word-based morphological theories such as A-morphous Morphology (Anderson, 1992). Arguably, making such arguments depends, however, on how the alternative morphological theories would be spelled out as processing predictions. For example, if an implementation of a word-and-paradigm based morphology were to involve a process of identifying stems as an initial step toward hypothesizing which word-formation rule may account for the surface form, it is conceivable that, for example, activation of stems may follow (see e.g., Anderson, 1988, for some discussion of a parsing implementation along those lines). If that approach were taken, presumably experiments such as the one presented in this dissertation regarding affix representation become highly relevant, since neither the theory nor the kind of implementation sketched here seems to commit to independent morpheme-level representations of affixes, while such representations fit in nicely, arguably, with potential implementations of piece-based theories. While we will leave aside more detailed discussion of this particular issue, it is worth pointing out that, to the extent that such ideas would be fleshed out, the array of approaches presented in the dissertation does present a potential source of experimental evidence by which one can empirically investigate what the relevant representations are really like.

Returning to our 'bird's eye view', we support a conclusion in which there are *three* types of word in the mental lexicon, not two, and not one. Two of the three types are treated as complex, internally-structured representations, those with morphological but not semantic relations among whole and parts (*bellhop*), and those with both morphological and semantic relations among whole and parts (*teacup*). Again, this commits us to a view of linguistic representation in which there *are* abstract structured representations, which is where these specific distinctions we have concerned ourselves with in one domain, word structure, speak directly to issues on the nature of mental representation, taking linguistic representation as our example.

It is worth considering, as we will do in the discussion to follow, exactly *how* we can come to this conclusion from the domain of word structure, where intuitions mainly about idiosyncrasies and their consequences seem to call for the alternate conclusion (e.g., as famously argued by Butterworth, 1983).[34] Recall that the various viewpoints on lexical representation (both in bird's eye view and as concerns specific implementation models) which do not make the commitments we are making here, accord with the intuition that in a domain such as word structure, idiosyncrasy of one kind or another (semantic, formal, frequency-based) has been taken to implicate a storage, rather than a computational, view of word structure. However, we are arguing that this *does not have to be* the case. Notably, our evidence suggests that it is *not* the case. Where do such constraints fit in, then?

Subsection 5: Role of Constraints

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[34] Although we are claiming that the intuition regarding lexical idiosyncrasy in favor of atomism is strong, it may be worth noting, as regards the idiosyncrasy of meaning involved in idiomatic phrasal expressions, the view that even phrasal idioms have internal syntactic structure has already, arguably, won the day.

In the current dissertation we have often made reference the difficulty of drawing inferences from lexical decision regarding the localization of effects in time course during lexical processing. Since a good portion of the evidence for effects such as productivity, affix homonymy, effects of formal regularity which are claimed to influence whether so-called complex words are handled via decomposed or whole-word lexical access comes from such evidence (e.g., Baayen et al., 1997, Bertram et al., 2000b, Schreuder and Baayen, 1995, Vannest et al., 2002), there is some cause to question whether the effects speak directly to whether the given words undergo decomposition at the initial stages of lexical activation. Given that lexical decision has the potential to reflect various stages of processing (and is susceptible to strategic effects), the inference from lexical decision results which fail to find effects, say, of root frequency, do not by themselves rule out the possibility of initial decomposition (see, e.g., Taft, 2004, for similar arguments). One way under an across-the-board decompositional account to address these effects is to attribute them to post-decompositional processing, which carries the following two expectations (i) one would expect to find decompositional effects if one could target earlier stages of lexical processing, and (ii) there is some account of why there is a different pattern of effects at later stages.

As for the first point, we have pointed toward some ways in which this can be tested. In the first experiment, we introduced a simultaneous lexical decision/MEG brain imaging method, showing that the decompositional effect, which in this case was reflected in lexical decision time for compounds, held also in the timing behavior of the first MEG component sensitive to properties of lexical activation, such as word frequency (Embick et al., 2001). In further experiments, we adopted masked priming methods thought to be sensitive to rapid, automatic activation of parts, showing that both semantically transparent and opaque compounds primed their constituents, despite evidence from some longer-lag overt measurements, such as lexical decision, (Coolen et al., 1991, Libben et al., 2003, Schreuder and Baayen, 1995) and cross-modal priming (e.g., Marslen-Wilson et al., 1994), which suggest differences in the processing of these two word types, a difference which has often been attributed to decompositional vs. whole-word processing for transparent and opaque words, respectively. We also attempted to apply this technique to test the hypothesis that both more- and less-productive derivationally-affixed words would show priming effects in masked priming, despite less clear results from later measures such as lexical decision, which again have previously motivated views of whole-word processing mediated by productivity (see, e.g., Bertram et al., 2000c). While the results are still not clear, the trend suggested some priming regardless of productivity, which should be pursued further.

As for the second point, further work is needed to better understand the dynamics of morpheme combination (i.e., composition, in addition to decomposition). At a basic level, it is clear that any account of the lexicon must take into consideration effects of transparency, productivity, frequency, and other constraints resulting in some kind of idiosyncrasy, such as form-changing irregularities. While some of the alternative views of the lexicon, which we have challenged on the basis of decomposition, offer a straightforward account – full storage for these items – our data has failed to support those assumptions. Although it is beyond the scope of this dissertation to provide a full account of the nature of these constraints on composition, we note that an alternate view, compatible with across-the-board decomposition, is one in which constraints operate post-decompositionally, constraining morpheme combination. We have suggested that our data is consistent with the decomposition side of this argument, i.e., that constraints such as semantic transparency, surface frequency, and productivity do not preclude decomposition of complex words into morphemic parts. What such an approach owes in further research, then, is a theory of *composition*. Just as we have suggested that perhaps the standard view that the 'word' is the basic unit in the lexicon must be reconsidered, arguing for a primary role instead for morphological-level primitives, it may be the case that as more evidence accumulates along the lines we have sketched out above, perhaps the focus must eventually move from the question of *decomposition*, to that of *composition*.

Subsection 6: Morphological Processing in Sentence Context

We have argued from single-word data that a view of the lexicon in which the morpheme, not the word, is the basic unit. While single-word tasks undoubtedly contribute to our understanding of the nature of lexical representations and lexical retrieval, further research along the lines sketched in this dissertation, but extended to sentential context, may clarify the extent to which the morphological-level effects found across single-word tasks indeed hold in connected speech and text. At present, there is no consensus on this, and further research is needed to clarify to what extent the morphological-level effects are measurable in those contexts. To date, there are reports of morphological-level effects present in reading but not lexical decision, lexical decision but not reading, and both reading and lexical decision (e.g., Bertram et al., 2000a, Hyönä et al., 2002, and Juhasz et al., 2003, respectively). Further, questions also arise whether previous conclusions on the absolute and relative time course of lexical activation indeed apply in sentence context (Sereno et al., 1998). To begin to untangle these questions with regard to derived words and compounds, it would be useful to consider at least the following areas. First, under what linguistic conditions and to what extent do constituency effects such as constituent-frequency manipulation emerge in measures such as eye movements for derived words and compounds (Andrews et al., 2004)? Second, to what extent are morphological facilitation effects most akin to single word tasks preserved in English multimorphemic words in sentential context? This may be approachable via tasks such as fast priming (e.g. Trueswell and Kim, 1998, for one application of this technique) and cross-modal lexical priming (CMLP) in sentence context (see, e.g., Hillert and Swinney, 2001, for an interesting use of CMLP technique to test for compound constituency in German compounds with idiosyncratic meanings). Third, to what extent are morphological-level processes such as the assignment of internal structure to multimorphemic words influenced by the context in which they appear? The latter is perhaps the most challenging to test (see Libben and de Almeida, 2005, for one attempt), but a better understanding of the role of context may aid in understanding why the previous literature shows variable results in testing morphological structure in sentences, and for clarifying how and when morphological information interacts with other aspects of structure building and interpretation.

Section 2: Overall Summary

The current dissertation has presented several lines of research testing specific linguistic hypotheses which also speak directly to the representational inventory and functional organization of language using a cross-linguistic approach involving psychophysical and neuroimaging methods as called for by the specific research question. At the very least, we hope that this work has sketched the outline of a research program concerning the internal structure of complex words at the interface of linguistics and neuroscience, which in turn, offers the possibility to explore foundational issues in the scientific study of mind.

Appendices

Appendix I Target Items, Experiment I (Compounds, Single Words, and Foils)

Compound Words

- AIRPLANE
- ARMBAND
- BARBELL
- BIRTHDAY
- BULLFIGHT
- CORNFLAKE
- COURTYARD
- DOORSTEP
- EARLOBE
- FLAGSHIP
- FLOORMAT
- GANGLAND
- GIRLFRIEND
- HEADACHE
- NORTHEAST
- PAYROLL
- RAILWAY
- SEALINK
- SHOWCASE
- SKINCARE
- SNOWFLAKE
- SOUTHWEST
- TEASPOON
- TREETOP
- BASEBALL
- BATHROOM
- COWBOY
- FORTNIGHT
- GUIDELINE
- HOUSEHOLD
- LANDMARK
- POSTCARD
- RAINBOW
- SPOTLIGHT
- SUNSHINE
- WORKSHOP
- BEELINE
- CLUBMATE
- FOGHORN
- HUMPBACK
- KEYWORD
- LIFERAFT
- LOGJAM
- MAILBAG
- OXTAIL
- RAGTIME
- SOAPBOX
- TAPEWORM
- BOMBSHELL
- BOOKSTORE
- CREWMAN
- FANFARE
- FOOTPATH
- HAIRCUT
- HANDGUN
- HEATWAVE
- LOOPHOLE
- SIDEWALK
- SOYBEAN
- WOODCHIP

Single Words

- CASSETTE
- CHAUFFEUR
- CHEETAH
- CHIMNEY
- CRESCENT
- CREVASSE
- DISCOURSE
- FOUNTAIN
- GRIEVANCE
- MEMBRANE
- MERCHANT
- MISSILE
- PAMPHLET
- PARLANCE
- PHEROMONE
- PLEASURE
- PRATTLE
- PRESTIGE
- SCOUNDREL
- SYNAPSE
- TRESTLE
- TRINKET
- TROMBONE
- TRUNCHEON
- BASKET
- CHOCOLATE
- CREATURE
- FRACTION
- FRAGMENT
- FRANCHISE
- GRAMMAR
- PLAINTIFF
- PLATFORM
- SANCTION
- SEQUENCE
- SUBSTANCE
- ANDROID
- DERVISH
- FRISBEE
- HARLOT
- HYDRANT
- KERCHIEF
- MASSEUSE
- QUININE
- SPROCKET
- STURGEON
- THIMBLE
- WOMBAT
- BOUTIQUE
- KNUCKLE
- MIGRAINE
- PALETTE
- PLACARD
- ROULETTE
- SARDINE
- SEMBLANCE
- STRETCHER
- TEMPLATE
- THROTTLE
- TURBINE

Subsets: Three Frequency Levels

High Frequency

Compound	**Single Word**
BASEBALL	BASKET
BATHROOM	CHOCOLATE
COWBOY	CREATURE
FORTNIGHT	FRACTION
GUIDELINE	FRAGMENT
HOUSEHOLD	FRANCHISE
LANDMARK	GRAMMAR
POSTCARD	PLAINTIFF
RAINBOW	PLATFORM
SPOTLIGHT	SANCTION
SUNSHINE	SEQUENCE
WORKSHOP	SUBSTANCE

Mid Frequency

Compound	**Single Word**
BOMBSHELL	BOUTIQUE
BOOKSTORE	KNUCKLE
CREWMAN	MIGRAINE
FANFARE	PALETTE
FOOTPATH	PLACARD
HAIRCUT	ROULETTE
HANDGUN	SARDINE
HEATWAVE	SEMBLANCE
LOOPHOLE	STRETCHER
SIDEWALK	TEMPLATE
SOYBEAN	THROTTLE
WOODCHIP	TURBINE

Low Frequency

Compound	**Single Word**
BEELINE	ANDROID
CLUBMATE	DERVISH
FOGHORN	FRISBEE
HUMPBACK	HARLOT
KEYWORD	HYDRANT
LIFERAFT	KERCHIEF
LOGJAM	MASSEUSE
MAILBAG	QUININE
OXTAIL	SPROCKET
RAGTIME	STURGEON
SOAPBOX	THIMBLE
TAPEWORM	WOMBAT

Foils

- CANTRESK
- CHAIRMIG
- CROWSKEP
- DRABSKEN
- FOOTBAWP
- FRAYGRET
- FRETSDOP
- HATFOSH
- HILLSIJE
- MOUTHPEEM
- NUTSHEP
- PANCABE
- POTDASK
- ROPEWAST
- TRAYBLESH
- WEARPLATZ

Appendix II Item Control Statistics, Experiment I

Appendix IIa. Morphemic vs. Whole-word Properties: Overall Comparison

Morphemic vs. whole-word properties in the overall comparison of Compound vs. Single Words

Whole Compounds and Single Words were matched on letter length, frequency, and syllabicity (all $t<1$ by paired two-tailed t-test). Compound words were selected such that morphemic frequency, length, and syllabicity contrasted with the whole Compounds and Single Words. Statistical tests are summarized below.

a. *Morphemic Frequency (constituents higher than whole words.* Analysis of Variance (ANOVA) for overall CW, overall SW, C1, and C2 frequency ($F(3,236)=104.778$, $MSE=.438$, $p<0.001$; all planned contrasts: CW vs. C1, CW vs. C2, SW vs. C1, SW vs. C2, $p<0.001$)).
b. *Morphemic Length (constituents shorter than whole words).* ANOVA for length of overall CW, overall SW, C1, and C2 significant, $F(3,236)=525.646$, $MSE=.577$, $p<0.001$; all planned contrasts: CW vs. C1, CW vs. C2, SW vs. C1, SW vs. C2, significant at $p<0.001$).
c. *Morphemic Syllabicity (constituents shorter than whole words).* All constituent morphemes were monosyllabic, and all whole words disyllabic.

Appendix IIb. Morphemic vs. Whole-word Properties: Subanalyses

Morphemic vs. whole-word properties in the comparison of Compound vs. Single Words: Subanalyses at three frequency levels

Compounds and Single Words were matched on letter length, frequency, and syllabicity (all $t<1$ by paired two-tailed t-test) within three bins of twelve words each: one for high frequency words, one for middle frequency words, and one for low frequency words. Statistical tests for morphemic vs. whole-word properties are summarized below.

HIGH FREQUENCY

a. *Morphemic Frequency (constituents higher than whole words).* ANOVA for the whole-word vs. morpheme frequency manipulation (whole CW, whole SW, C1, and C2) was significant ($F(3,44)=23.092$, $MSE=.150$, $p<0.001$; all planned contrasts: CW vs. C1, CW vs. C2, SW vs. C1, SW vs. C2, significant at $p<0.001$).
b. *Morphemic Length (constituents shorter than whole words).* ANOVA for the length mismatch as also significant ($F(3,44)=107.498$, $p<0.001$; all planned contrasts as above, significant at $p<0.001$).
c. *Morphemic Syllabicity (constituents shorter).* All constituents monosyllabic, all whole words disyllabic.

MIDDLE FREQUENCY

a. *Morphemic Frequency (constituents higher than whole words).* ANOVA on the frequency mismatch was significant $F(3,44)=51.324$, $MSE=.183$, $p<0.001$; all planned contrasts significant at $p<0.001$).
b. *Morphemic Length (constituents shorter than whole words).* ANOVA showed a significant mismatch ($F(3,44)=168.015$, $MSE=.373$, $p<0.001$; all planned contrasts significant at $p<0.001$).
c. *Morphemic Syllabicity (constituents shorter).* All constituents monosyllabic, all whole words disyllabic.

LOW FREQUENCY

- a. *Morphemic Frequency (constituents higher than whole words).* ANOVA on the frequency mismatch was significant *F*(3,44)=50.397, *MSE*=.354, *p*<0.001; all planned contrasts significant at *p*<0.001).
- b. *Morphemic Length (constituents shorter than whole words).* ANOVA showed a significant mismatch (*F*(3,44)=102.898, *MSE*=.481, *p*<0.001; all planned contrasts significant at *p*<0.001).
- c. *Morphemic Syllabicity (constituents shorter).* All constituents monosyllabic, all whole words disyllabic.

ADDITIONAL TESTS OF LETTER-LENGTH ACROSS FREQUENCY BINS

Whole-word length across frequency bins. The compounds and single words were matched identically for length within each bin. There was a small length difference across bins (*F*(2,33)=4.092, *MSE*=.631, *p*<0.027); only the high- and low-frequency items differed significantly in a planned contrast (t(33)=2.826, *p*<0.009).

Morphemic Length across frequency bins. Within the high frequency bin, first and second compound constituent letter lengths were 4.00 and 4.08 (t<1), within medium frequency bin 3.42 and 3.75 (t<1), and within low frequency 3.83 and 3.92 (t<1). First constituent lengths differed by a fraction of a letter across frequency bins (*F*(2,33)=3.906, *MSE*=.348, *p*<0.031); only medium and low frequency first-constituents differed significantly in a planned contrast (t(33)=2.766, *p*<0.01). Second constituent lengths did not differ significantly across frequency bins.

Appendix III Replication of Experiment I (N=12)

Appendix IIIa. Overall Response Time and Accuracy

Overall comparison		Response Time (Acc %)
Compound Words		605 (92%)
Single Words		678 (82%)
Word-Nonword Foils		722 (86%)
Subanalyses at Three Frequency Levels		**Response Time (Acc %)**
High Frequency	Compound Words	557 (98%)
	Single Words	623 (99%)
Mid Frequency	Compound Words	609 (96%)
	Single Words	690 (88%)
Low Frequency	Compound Words	667 (81%)
	Single Words	766 (67%)

Appendix IIIb. Statistical Analyses of the Data in Appendix IIIa above

	Response Time		*Accuracy*	
Overall comparison	ANOVA By-Participants	ANOVA By-Items	ANOVA By-Participants	ANOVA By-Items
CW vs. SW. vs. Foil	$F_1(2,22)=24.856$, $p<0.001$	[a]	$F_1(2,22)=10.901$, $p<0.002$	[a]
CW vs. SW	$F_1(1,11)=20.182$, $p<0.002$	$F_1(1,59)=23.324$, p<0.001	$F_1(1,11)=18.140$, $p<0.002$	F_2 (1,59)=11.934, p<0.001
CW vs. Foil	$F_1(1,11)=35.487$, $p<0.001$	[a]	$F_1(1,11)=7.096$, $p<0.023^{*}$	[a]
Subanalyses at Three Frequency Levels	ANOVA By-Participants	ANOVA By-Items	ANOVA By-Participants	ANOVA By-Items
Structure (CW vs. SW)	$F_1(1,11)=17.786$, $p<0.002$	$F_2(1,11)=15.596$, $p<0.003$	$F_1(1,11)=11.249$, $p<0.007$	$F_2(1,11)=9.888$, $p<0.010$
Frequency (High, Mid, Low)	$F_1(2,22)=34.125$, $p<0.001$	$F_2(2,22)=11.479$, $p<0.001$	$F_1(2,22)=47.680$, $p<0.001$	$F_2(2,22)=20.318$, $p<0.001$
Interaction	$F_1(2,22)=0.610$, $p<0.553^{\dagger}$	$F_2(2,22)=0.273$, $p<0.764^{\dagger}$	$F_1(2,22)=6.156$, $p<0.009$	$F_2(2,22)=5.236$, $p<0.015$
High vs. Mid	$F_1(1,11)=16.504$, $p<0.002$	$F_2(1,11)=14.416$, $p<0.004$	$F_1(1,11)=14.865$, $p<0.004$	$F_2(1,11)=16.036$, $p<0.003$
Interaction	$F_1(1,11)=0.333$, $p<0.577^{\dagger}$	$F_2(1,11)=0.583$, $p<0.462^{\dagger}$	$F_1(1,11)=10.170$, $p<0.010$	$F_2(1,11)=7.932$, $p<0.018$
Mid vs. Low	$F_1(1,11)=30.323$, $p<0.001$	$F_2(1,11)=14.416$, $p<0.004$	$F_1(1,11)=50.005$, $p<0.001$	$F_2(1,11)=12.558$, $p<0.006$
Interaction	$F_1(1,11)=0.265$, $p<0.618^{\dagger}$	$F_2(1,11)=0.483$, $p<0.502^{\dagger}$	$F_1(1,11)=2.647$, $p<0.133^{\dagger}$	$F_2(1,11)=0.533$, $p<0.474^{\dagger}$
CWH vs.SWH	$F_1(1,11)=12.581$, $p<0.006$	$F_2(1,11)=10.714$, $p<0.008$	$F_1(1,11)=2.200$, $p<0.167^{\dagger}$	$F_2(1,11)=0.550$, $p<0.475$
CWM vs. SWM	$F_1(1,11)=8.037$, $p<0.017$	$F_2(1,11)=8.483$, $p<0.015$	$F_1(1,11)=8.250$, $p<0.016$	$F_2(1,11)=6.838$, $p<0.025$
CWL vs. SWL	$F_1(1,1)=11.063$, $p<0.008$	$F_2(1,11)=6.352$, $p<0.029$	$F_1(1,1)=8.105$, $p<0.017$	$F_2(1,11)=8.737$, $p<0.014$

[†] n.s.

[a] Foils not entered into by-items due to the large difference in number of samples.

[*] n.s. in main experiment.

Appendix IV Re-Analysis of Replication Study with Six Items Removed

The following analyses were conducted after six items were removed to reduce the possibility that some single words were also treated as complex (*grievance, stretcher, creature, substance, merchant, pleasure*). The pattern of results is virtually the same as in Appendix III. Differences (3 cases in which a statistical result became marginal rather than significant) are marked with the †† mark, as mentioned below the table.

	Response Time		*Accuracy*	
OVERALL COMPARISON	ANOVA BY-PARTICIPANTS	ANOVA BY-ITEMS	ANOVA BY-PARTICIPANTS	ANOVA BY-ITEMS
CW vs. SW. vs. Foil	$F_1(2,22)=26.845$, $p<0.001$	[a]	$F_1(2,22)=13.932$, $p<0.001$	[a]
CW vs. SW	$F_1(1,11)=26.138$, $p<0.001$	$F_2(1,59)=29.732$, $p<0.001$	$F_1(1,11)=20.822$, $p<0.002$	$F_2(1,59)=13.549$, $p<0.002$
CW vs. Foil	$F_1(1,11)=35.487$, $p<0.001$	[a]	$F_1(1,11)=7.096$, $p<0.023^{*}$	[a]
SUBANALYSES AT THREE FREQUENCY LEVELS	ANOVA BY-PARTICIPANTS	ANOVA BY-ITEMS	ANOVA BY-PARTICIPANTS	ANOVA BY-ITEMS
Structure (CW vs. SW)	$F_1(1,11)=20.228$, $p<0.002$	$F_2(1,11)=16.776$, $p<0.003$	$F_1(1,11)=11.807$, $p<0.007$	$F_2(1,11)=7.832$, $p<0.018$
Frequency (High, Mid, Low)	$F_1(2,22)=36.575$, $p<0.001$	$F_2(2,22)=11.053$, $p<0.001$	$F_1(2,22)=46.448$, $p<0.001$	$F_2(2,22)=20.520$, $p<0.001$
Interaction	$F_1(2,22)=0.427$, $p<0.659^{\dagger}$	$F_2(2,22)=0.134$, $p<0.875^{\dagger}$	$F_1(2,22)=.5.949$, $p<0.009$	$F_2(2,22)=4.313$, $p<0.027$
High vs. Mid	$F_1(1,11)=19.603$, $p<0.002$	$F_2(1,11)=15.314$, $p<0.003$	$F_1(1,11)=15.223$, $p<0.003$	$F_2(1,11)=12.077$, $p<0.006$
Interaction	$F_1(1,11)=0.092$, $p<0.768^{\dagger}$	$F_2(1,11)=0.274$, $p<0.612^{\dagger}$	$F_1(1,11)=10.727$, $p<0.008$	$F_2(1,11)=4.592$, $p<0.056^{\dagger\dagger}$
Mid vs. Low	$F_1(1,11)=29.275$, $p<0.001$	$F_2(1,11)=4.719$, $p<0.054^{\dagger\dagger}$	$F_1(1,11)=47.651$, $p<0.001$	$F_2(1,11)=14.862$, $p<0.004$
Interaction	$F_1(1,11)=0.299$, $p<0.597^{\dagger}$	$F_2(1,11)=0.008$, $p<0.932^{\dagger}$	$F_1(1,11)=2.107$, $p<0.176^{\dagger}$	$F_2(1,11)=1.505$, $p<0.247^{\dagger}$
CWH vs. SWH	$F_1(1,11)=16.263$, $p<0.003$	$F_2(1,11)=16.263$, $p<0.003$	$F_1(1,11)=1.678$, $p<0.223^{\dagger}$	$F_2(1,11)=0.305$, $p<0.593$
CWM vs. SWM	$F_1(1,11)=9.621$, $p<0.011$	$F_2(1,11)=9.621$, $p<0.011$	$F_1(1,11)=8.932$, $p<0.013$	$F_2(1,11)=3.713$, $p<0.081^{\dagger\dagger}$
CWL vs. SWL	$F_1(1,1)=11.063$, $p<0.008$	$F_2(1,11)=11.063$, $p<0.008$	$F_1(1,1)=8.105$, $p<0.017$	$F_2(1,11)=7.139$, $p<0.023$

[†] n.s.

[††] marginal here, significant in main & replication experiments.

[a] Foils not entered into by-items due to the large difference in number of samples.

[*] n.s. in main experiment.

Appendix V Items for Priming Non-head Compound Constituents (Experiment II)[†]

Transparent Prime	*Morphemic Target*	*Unrelated Target*	*Opaque Prime*	*Morphemic Target*	*Unrelated Target*
NEWSPAPER	news	bill	HONEYMOON	honey	fluid
TEACUP	tea	sky	KINGPIN	king	loss
SAILBOAT	sail	bend	HOGWASH	hog	tar
BACKBONE	back	find	HALLMARK	hall	song
CAMPSITE	camp	boss	BOOTLEG	boot	mill
BUBBLEGUM	bubble	gossip	PASSPORT	pass	rule
CLASSROOM	class	match	PINEAPPLE	pine	bail
FLOORMAT	floor	queen	LANDLORD	land	drug
MOUSETRAP	mouse	chill	DASHBOARD	dash	tent
CORNFIELD	corn	nest	TAILGATE	tail	drum
DRAINPIPE	drain	fleet	TURNCOAT	turn	love
TABLECLOTH	table	style	BANDWAGON	band	ring
SHOEBOX	shoe	milk	JOYSTICK	joy	pan
VIDEOTAPE	video	motor	BRAINCHILD	brain	youth
PAINTBRUSH	paint	shock	FORTNIGHT	fort	reed
TOMBSTONE	tomb	deed	STAGECOACH	stage	march
BEEFSTEAK	beef	mask	SPREADSHEET	spread	weight
SHIPWRECK	ship	farm	SWEATSHOP	sweat	patch
SANDSTORM	sand	roof	MASTERMIND	master	object
TEARDROP	tear	poll	CROWBAR	crow	mint
RACEHORSE	race	list	FLOODLIGHT	flood	trick
DOGHOUSE	dog	kid	FOLKLORE	folk	tube
TOOTHPASTE	tooth	brand	GANGPLANK	gang	tool
SNOWFLAKE	snow	chip	BEDROCK	bed	oil
FLAGPOLE	flag	poem	SIDESHOW	side	game
ROSEBUD	rose	jail	COURTYARD	court	price
HAIRSPRAY	hair	wine	BUTTERFLY	butter	fabric
EARPLUG	ear	cat	CROSSWORD	cross	judge
LAMPSHADE	lamp	junk	EGGPLANT	egg	bay
MAILBAG	mail	wood	PENPAL	pen	toy
EYELID	eye	law	GODFATHER	god	art
TREETOP	tree	card	CATCHPHRASE	catch	drink
KEYHOLE	key	ban	GRAPEFRUIT	grape	thumb
FOOTPRINT	foot	wall	REINDEER	rein	claw
HEALTHCARE	health	action	SOULMATE	soul	path
MUDSLIDE	mud	web	NOSEDIVE	nose	text
BIRTHPLACE	birth	lunch	PADLOCK	pad	inn
TEAMWORK	team	kind	CELLPHONE	cell	task
DOORKNOB	door	wife	HAMSTRING	ham	cue
BULLFIGHT	bull	vice	TYPEFACE	type	host
OATMEAL	oat	dew	FORKLIFT	fork	stud
FINGERTIP	finger	status	FIBERGLASS	fiber	satan
HAYSTACK	hay	peg	JELLYFISH	jelly	basil
ANTHILL	ant	gem	HANDGUN	hand	cent

[†] Experiment 2A included only morphemic and control targets, in a lexical decision pretest. Experiment 2B tested priming of the morphemic and unrelated targets by the CW. The final six items in each condition are those removed from the analyses as described in the Procedure.

Appendix VI Items for Priming Head Compound Constituents (Experiment III)[††]

Transparent Prime	*Morphemic Target*	*Unrelated Target*	*Opaque Prime*	*Morphemic Target*	*Unrelated Target*
NEWSPAPER	paper	human	HALLMARK	mark	view
SHOEBOX	box	kid	RAGTIME	time	work
CORNFIELD	field	stock	PINEAPPLE	apple	mayor
TEACUP	cup	art	HONEYMOON	moon	fate
CLASSROOM	room	fact	HAMSTRING	string	priest
BACKBONE	bone	sink	JOYSTICK	stick	dance
MOUSETRAP	trap	dish	BANDWAGON	wagon	bible
HEADACHE	ache	howl	HOGWASH	wash	golf
TABLECLOTH	cloth	marsh	TURNCOAT	coat	bike
PAINTBRUSH	brush	stamp	DASHBOARD	board	staff
SHIPWRECK	wreck	sting	BOOTLEG	leg	guy
TOOTHPASTE	paste	guild	TAILGATE	gate	bowl
SAILBOAT	boat	seed	KINGPIN	pin	lap
DOORKNOB	knob	ramp	TYPEFACE	face	help
VIDEOTAPE	tape	will	BRAINCHILD	child	state
BEEFSTEAK	steak	gloom	SUGARCANE	cane	frog
SANDSTORM	storm	wheel	LOGJAM	jam	spy
HAIRSPRAY	spray	flame	LANDLORD	lord	size
DRAINPIPE	pipe	mess	WINDFALL	fall	term
FLAGPOLE	pole	luck	CRACKPOT	pot	lip
AIRPLANE	plane	youth	ROLLERBLADE	blade	quest
SEATBELT	belt	mask	BOTTLENECK	neck	root
BATHROBE	robe	cart	BOMBSHELL	shell	crown
HOMETOWN	town	drug	SOUNDTRACK	track	doubt
FAIRYTALE	tale	fuel	WARPATH	path	meal
TINFOIL	foil	glue	DOUGHNUT	nut	cop
RATTLESNAKE	snake	thumb	RAINBOW	bow	pen
BASKETBALL	ball	mile	DAREDEVIL	devil	lemon
BODYGUARD	guard	waste	ARMPIT	pit	fax
DAYDREAM	dream	score	DATABASE	base	club
STOPWATCH	watch	sense	STOREFRONT	front	whole
SOULMATE	mate	rank	PAYROLL	roll	bear
HANDGUN	gun	bid	COPYCAT	cat	bus
CELLPHONE	phone	train	JAILBIRD	bird	pain
PADLOCK	lock	cast	BOOKWORM	worm	bulb
NOSEDIVE	dive	glow	CUFFLINK	link	date
BEEHIVE	hive	duct	FORTNIGHT	night	house
BUBBLEGUM	gum	pea	PASSPORT	port	hell
RACEHORSE	horse	crime	WHIPLASH	lash	hike
SEAFOOD	food	girl	TREADMILL	mill	snow
STREETCAR	car	job	GUIDELINE	line	bank
POSTCARD	card	tree	FROSTBITE	bite	hook
SUNFLOWER	flower	expert	WINGSPAN	span	bolt
GRAPEFRUIT	fruit	stake	WHEATGERM	germ	loaf

[††] Experiment 3A included only morphemic and control targets, in a lexical decision pretest. Experiment 3B tested priming of the morphemic and unrelated targets by the CW. The final eight items in each condition are those removed from the analyses as described in the Procedure.

Appendix VII Target Items: Japanese Affixation Experiment*

	Japanese Stimuli			English Gloss		
Condition	Prime	Control	Target	Prime	Control	Target
Root+*mi*	楽しみ	伸び率	痛み	pleasure	progress rate	pain
	楽しみ	伸び率	重み	pleasure	progress	weight
	明るみ	奥さん	悲しみ	brightness	wife	grief
	明るみ	奥さん	苦しみ	brightness	wife	suffering
	親しみ	紫外線	強み	familiarity	ultra violet	strength
	親しみ	紫外線	厚み	familiarity	ultra violet	thickness
	憎しみ	太もも	弱み	hatred	thigh	weakness
	憎しみ	太もも	深み	hatred	thigh	depth
	温か	気兼ね	甘み	warmth	hesitation	sweetness
	温か	気兼ね	緩み	warmth	hesitation	looseness
	とろみ	ご法度	丸み	jelly-likeness	taboo	roundness
	とろみ	ご法度	苦み	jelly-likeness	taboo	bitterness
	面白	日照り	高み	interestingness	sunlight	height
	面白	日照り	赤み	interestingness	sunlight	redness
	おかし	かがり	辛み	funniness	bonfire	spiciness
	おかし	かがり	渋み	funniness	bonfire	bitterness
	惜しみ	かき氷	臭み	regret	crushed ice	skinkiness
	惜しみ	かき氷	軽み	regret	crushed ice	lightness
	哀れ	宮参り	青み	pity	shrine visit	blueness
	哀れ	宮参り	黒み	pity	shrine visit	blackness
	えぐみ	克己心	有り難	bitterness	self restraint	valuableness
	えぐみ	克己心	柔らか	bitterness	self restraint	softness
	白み	忌引	凄み	whiteness	mourning	grimness
	白み	忌引	旨み	whiteness	mourning	umami
Root+*sa*	豊かさ	第三者	長さ	pleasure	third party	length
	豊かさ	第三者	大きさ	pleasure	third party	bigness
	広さ	うそ	厳しさ	brightness	lie	strictness
	広さ	うそ	難しさ	brightness	lie	difficulty
	深刻さ	味わい	速さ	familiarity	flavor	fastness
	深刻さ	味わい	怖さ	familiarity	flavor	fear
	太さ	随筆	便利さ	hatred	essay	convenience
	太さ	随筆	安さ	hatred	essay	cheapness
	大変さ	ひいき	正確さ	warmth	favor	accuracy
	大変さ	ひいき	鋭さ	warmth	favor	sharpness
	異常さ	切り傷	狭さ	abnormality	scar	narrowness
	異常さ	切り傷	貴さ	abnormality	scar	preciousness
	短さ	迷宮	寛容さ	interestingness	labyrinth	generosity
	短さ	迷宮	熱さ	interestingness	labyrinth	hotness
	しぶと	釣りざ	浅さ	funniness	fishing rod	shallowness
	しぶと	釣りざ	細かさ	funniness	fishing rod	fineness

だるさ	狙い目	多彩さ	regret	target	variety
だるさ	狙い目	醜さ	regret	target	ugliness
詳しさ	息ぬき	賢さ	pity	break	wisdom
詳しさ	息ぬき	律儀さ	pity	break	diligence
冷徹さ	秋まつ	疑わし	bitterness	fall fiesta	suspicion
冷徹さ	秋まつ	がんこ	bitterness	fall fiesta	stubbornness
善さ	弓術	脆さ	whiteness	archery	fragileness
善さ	弓術	嫌さ	whiteness	archery	unpleasantness

[*] Note that, due to the extremely low productivity of *–mi* affixed words, we used each *–mi* prime and matched unrelated control for two *–mi* targets, but crucially, since we used a Latin-square counterbalanced design with two lists, no *–mi* prime or unrelated control was ever repeated for a given participant. The schematic below shows how this is done, using the first two *–mi* targets, 痛み and 重み, showing which prime each of the first two participants would see with each target. The same approach was used for the *–sa* targets.

Schematic for Latin Square Design:

Latin Square List 1	Participant 1 Prime	Participant 1 Target	*Latin Square List 2*	Participant 2 Prime	Participant 2 Target
Item 1	楽しみ	痛み	Item 1	伸び率	痛み
Item 2	伸び率	重み	Item 2	楽しみ	重み

Additional Control Stimuli: Japanese Affixation Experiment[†]

Condition		Japanese Stimuli		English Gloss	
Prime	Target	Prime	Target	Prime	Target
Root+deverbal *mi* homophone	Nonword with word-final *mi*	営み	呉み	business	-
		恨み	塊み	grudge	–
		好み	山れみ	favorite	-
		囲み	格びみ	surrounding	-
		仕込み	げみ	preparation	–
		進み	ぱみ	progress	-
		絡み	橋み	connection	-
		縮み	車み	shrinkage	-
		慎み	島み	prudence	-
		悩み	館み	suffering	-
		休み	けみ	break	-
		微笑み	桐み	smile	-
Unrelated Control	Nonword with word-final *mi*	水位	駅み	water level	-
		熱心	梟み	zeal	-
		街頭	にみ	street	-
		愛唱	ひみ	favorite song	-
		育ち	窓み	growth	-

		殺し	てみ	killing	-
		張り	めみ	strain	-
		社用	ぴみ	on business	-
		吉日	公げこみ	lucky day	-
		半ば	原輿笹み	half/middle	-
		限界	ねみ	limit	-
		楕円形	ぬみ	oval	-
Root+*sa*	Nonword with word-final *sa*	寒さ	之さ	coldness	-
		貧しさ	包りさ	poverty	-
		慎重さ	変貼さ	prudence	-
		硬さ	察めさ	solidness	-
		確かさ	呂さ	certainty	-
		不思議さ	埜さ	wonder	-
		真剣さ	巻めさ	seriousness	-
		若さ	はさ	youth	-
		潔さ	旗すさ	braveness	-
		見事さ	ぺさ	splendidness	-
		低調さ	づさ	bad-conditioned	-
		不用意さ	ろさ	unpreparedness	-
Unrelated Control	Nonword with word-final *sa*	互い	校惇さ	mutuality	-
		売上金	のさ	sales	-
		心待ち	ぶさ	expectation	-
		司令	楓ゆさ	command	-
		勝ち目	淵機さ	chance to win	-
		受け持ち	亥さ	take charge	-
		捨て身	佐さ	desperation	-
		挫折	符行さ	sprain	-
		ねぎ	近まもさ	scallion	-
		見覚え	禄いへさ	recognition	-
		丸焼き	壬さ	fully grilled	-
		敷き布団	ざさ	mattress	-
Non *mi*/*sa* word	Unrelated Non *mi*/*sa* nonword	寝相	ぬざ	body move during sleep	-
		自棄	无め	recklessness	-
		獄中記	策れけ	diary in jail	-
		姿焼き	特枯ろ	whole grill	-
		適応性	西薬ぬ	adjustability	-
		数の子	るへび	herring roe	-
		社交性	八ほ矛	sociality	-
		皮むき	香ぼづ	peeling	-
		音さた	貴鰯あ	contact	-

私立探偵	桑銀損き	private detective	-
非常手段	翼むおれ	emergent solution	-
空き巣	刷ざひ	thief	-
歯医者	遥ち寸	dentist	-
解剖学	絹労腎	anatomy	-
行進曲	堂罠い	marching music	-
昆布	俯め	seaweed	-
裏切り	蟻車お	betrayal	-
束縛	らろ	binding	-
三角形	印ふえ	triangle	-
腹痛	りぐ	stomachache	-
機関銃	完筆寸	machinegun	-
山小屋	桐ぼ肉	cabin	-
はやり	つさも	trend	-
親指	べほ	thumb	-
しわ	もけ	wrinkle	-
がれき	てさぬ	debris	-
衰え	すど	wither	-
楽譜	わぺ	music score	-
乗務員	へみろ	crew	-
表彰式	寧げあ	commendation	-
走り	らへ	running	-
買い手	をみで	buyer	-
汚れ	ぺか	impurity	-
祈り	めむ	prayer	-
宿題	れが	homework	-
電池	げと	battery	-
人格	をろ	personality	-
沈黙	毘ご	silence	-
やる気	雛ぬそ	motivation	-
格付け	雲えげ	ranking	-
闘い	だご	battle	-
踊り	狗ろ	dance	-
幸せ	要鵜	happiness	-
絵本	るぎ	picture book	-
動物園	昼耳ぜ	zoo	-
皮切り	獅ぶ抗	start	-
かに	ぽも	crab	-
負け	舵び	defeat	-
我慢	肝べ	patience	-
炭坑	紺お	coal mine	-

		台所	ごぬ	kitchen	-
		問い	斤ら	question	-
		誕生日	三け観	birthday	-
		香り	業ど	scent	-
		漏れ	せへ	leak	-
		制服	覧い	uniform	-
		肝臓	也う	liver	-
		日記	花づ	dairy	-
		高速道路	藩蚊葬さ	highway	-
		倉庫	百ぬ	storage	-
		貧困	邪お	poverty	-
		日曜日	牝舶せ	Sunday	-
		続き	盂め	sequel	-
		呼びかけ	志稟けの	call	-
		電話番号	省邦凶る	phone number	-
		入り口	門れむ	entrance	-
		牛肉	ひは	beef	-
		太陽	ぬろ	sun	-
		支持者	乗はべ	supporter	-
		重要性	納へ赤	importance	-
		セット	甲ぐほ	set	-
		医学部	九函め	medical school	-
Non *mi*/*sa* word	Unrelated Non *mi*/*sa* word	骨膜	下顎	connective tissue	lower jaw
		三角錐	呵責	cone	blame
		耳学問	換言	fake knowledge	rephrase
		手づる	縦じわ	hand bail	vertical wrinkle
		地動説	字余り	heliocentric theory	additional letters in haiku
		笑い顔	電磁力	smile	electromagn-tic energy
		金魚鉢	扇状地	goldfish bowl	valley
		缶詰め	肉付け	canned food	enrich
		断トツ	早死に	exceeding	early death
		潜在意識	つわり	unconsciousness	morning sickness
		人形遣い	非行少年	puppeteer	delinquency
		国粋主義	釣りざお	patriotism	fishing rod
		作り話	人込み	fiction	crowd
		無秩序	山並み	chaos	mountains
		駆け足	偽り	run	deceit
		劣等感	占い	complex	fortune telling

縄張り	竜巻	territory	tornado
売り手	はしご	seller	ladder
持ち物	土手	belongings	bank
吹雪	浴室	blizzard	bathroom
手すり	時差	hand trail	time lag
紀元前	持ち前	B.C.	natural
最寄り	髪の毛	closest	hair
こぶし	眠り	fist	sleep
いとこ	くせ	cousin	habit
叫び	備え	shout	preparation
ずさん	空き	sloppy	empty
飾り	脅し	decoration	threat
輝き	救い	shining	rescue
真っ先	舞台裏	at the very beginning	backstage
励まし	手だて	encouragement	arrangement
作り方	償い	recipe	compensation
借り手	話し	borrower	story
宝くじ	半島	lottery	peninsula
群れ	喜劇	group	comedy
辞書	花火	dictionary	fireworks
始め	田舎	beginning	countryside
薬局	右手	pharmacy	right hand
偏差値	有害	Standard deviation	harmful
物理学	偏見	physics	prejudice
手作り	見送り	handmade	sending off
手がかり	友だち	clue	friend
受け付け	ふた	reception	lid
同級生	別れ	classmate	separation
長距離	信仰	long distance	faith
上積み	独身	pile	single
食べ物	時計	food	clock
暗殺	運命	assassination	fate
暴動	旅館	riot	inn
頼り	女王	reliance	queen
わいろ	助手	bribe	assistant
集まり	栄養	gathering	nutrition
取り消し	気候	cancel	climate
科学者	砂漠	scientist	desert
締め切り	滑走路	deadline	runway
社会福祉	副作用	social welfare	side effect
社会保障	哲学	social	philosophy

		guarantee	
体育	なべ	PE	cooking pan
子育て	遺産	raising children	legacy
まとめ	文明	summary	civilization
着陸	温度	landing	temperature
車いす	人びと	wheelchair	people
売れ行き	ゆとり	sales	space
繰り返し	女の子	repeat	girl
届け出	後ろ	administrative process	behind/back
向こう	幼稚園	over there	kindergarten
郵便局	観察	post office	observation
思い出	誤り	memory	mistake
生命保険	拍手	life insurance	applause
植民地	先行き	colony	future
農産物	東日本	agricultural products	East Japan
駐車場	飛行機	parking	airplane

[†] Please note also that the control conditions were designed such that every participant saw every prime-target pair listed above; Latin-square counterbalancing was used only for the target *–mi* and *–sa* conditions.

Appendix VIII Items from Lexical Ambiguity Experiment*

Multiple Meanings		*Single Meaning*	
Few Senses	*Many Senses*	*Few Senses*	*Many Senses*
ash	angle	ant	belt
calf	bark	bandage	bend
chap	blow	bet	bite
cricket	boil	bone	burn
cuff	bowl	bulk	dip
fleet	bust	cage	drain
fudge	clip	cake	feather
hide	clutch	carton	flash
lime	compound	crew	grip
loaf	duck	crude	hammer
loom	flush	deaf	hang
mint	fold	farm	hook
mole	gag	feast	load
novel	gum	foam	loop
page	hail	harsh	mask
pen	jam	heap	nest
pine	jar	hinge	pinch
poach	lap	hurdle	roll
port	lean	join	saddle
prune	lock	lump	scan
pupil	pitch	path	shade
rare	scale	profit	slice
rash	seal	request	slide
rifle	slip	rust	smash
stable	spell	silk	sour
stern	stall	slim	spin
stunt	stem	slot	steam
tend	strain	snake	sway
tense	strand	soap	thread
toast	stud	spy	tread
utter	swallow	stain	whip
yard	tap	trot	wire

*Adapted from Rodd et al. (2002)

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