Semantic Interpretability in German Morphological Decomposition:

Evidence from a primed visual lexical decision task

Submitted in fulfillment of the requirements for Paper B(v) (Psycholinguistics and Neurolinguistics) under the M.Phil. in General Linguistics and Comparative Philology

Prerna Nadathur

Trinity 2013

Contents

1 Introduction

1.1 Theories of the mental lexicon

The role played by morphology in word recognition and processing is a central issue for models of lexical access and representation. While the idea that the words of a language like English can be segmented into atomic units (stems and affixes) is robustly supported in the theoretical literature, from a psycholinguistic perspective this is relatively meaningless if such units play no role in language processing. Investigations into the structure and organization of the mental lexicon can thus be seen to be investigations, simultaneously, into the psychological reality of morphological theory.

Theories of the mental lexicon have mostly situated themselves on the continuum between two extremes: full listing and full decomposition. Full listing models (e.g. Manelis & Tharp 1977, Butterworth 1983) hold that each word has an independent lexical entry, regardless of morphological relationships into which it enters. At the other end of the spectrum, full decomposition models (e.g. Taft & Forster 1975) argue that lexical entries comprise single morphemes, while polymorphemic words occur as part of clusters in which stems are linked to the affixes with which they grammatically combine.[1] Full decomposition therefore regards morphological structure as the underlying principle of lexical organization, holding that complex words are obligatorily segmented in comprehension. Proponents of full listing have challenged this view on grounds of processing inefficiency, arguing, for instance, that a mechanism which obligatorily strips the suffix *-er* from *reader* will also waste effort by incorrectly segmenting *simmer*. Against this, decompositional models provide an immediate explanation for the production and comprehension of polymorphemic innovations such as *unfaxable* (example due to Rastle et al 2004), which full listing cannot treat.

These conflicts have been extensively examined at the empirical level. Experimental data on the whole appears to support some notion of decomposition, and consequently full listing approaches have largely been set aside. Data primarily come from studies employing the lexical decision task, in which subjects are asked to determine the lexical status (word or nonword) of a target item, ostensibly in their native language. Some of the earliest evidence for a morphologically structured lexicon comes from Taft & Forster (1975), who found that real nonword stems such as *juvenate* (from *rejuvenate*) took longer to be rejected by subjects than fake (nonmorphemic) stems such as *pertoire* (from *repertoire*). On Taft & Forster's view, this reflects the fact that *juvenate*, as a legal stem, has a lexical entry, while *pertoire* does not: successful location of the entry prolongs decision time for the former.

This is not conclusive: to begin with, Taft & Forster's explanation makes the implicit claim that unsuccessful lexical search is necessarily faster than successful search followed by consideration of the information presumably contained in the entry for *juvenate*. This is insufficiently supported by the available evidence. The case for decomposition, however, is significantly strengthened by a large volume of more nuanced data from primed lexical

[1] "... *unlucky* is stored in conjunction with *luck* (along with *lucky, luckily, luckless*, and so on), and there is no separate lexical entry for the word *unlucky*, this word being constructed from the entry *luck* by addition of the affixes *un-* and *-y*." (Taft & Forster 1975; p638)

decision studies, in which an additional (prime) stimulus is presented (visually or auditorily) before the decision target. Studies such as Henderson (1985) have found that a morphologically complex prime such as *softly* reduces decision time to its stem *soft* (see also Taft 1991, Feldman 1992, Frost et al 1997, Marslen-Wilson & Tyler 1997, Rueckl et al 1997). These findings have been taken to indicate that the complex prime activates the lexical entry for its stem, a picture which is compatible with a decompositional model involving monomorphemic lexical entries.

1.2 Complications for full decomposition

Despite the attractiveness of this interpretation, it is not uncontroversial to designate morphological structure as the locus of observed facilitation (Seidenberg 1987, Marslen-Wilson et al 1994). Interpretation is complicated by the fact that morphological relatedness in English (and other concatenative languages) is tightly correlated with phonological, orthographic, and/or semantic relatedness (consider again *softly* and *soft*). What appears as morphological priming may be attributable to one or more of these factors. In addition, a fully decompositional "affix-stripping"-type model leaves a number of issues unaddressed. Notably, morphemes do not necessarily behave in a semantically compositional fashion. They are not necessarily semantically invariant across contexts (see Aronoff 1976). Consider, for instance, the contribution of *-mit* to *submit*, as compared to *permit* and *admit*: if *-mit* is to have a single independent lexical entry, this ought to contain semantic as well as grammatical information, yet it is far from clear what might be encoded to achieve the correct results. Thus, while priming effects do seem to support decomposition, other sources must also be considered.

Marslen-Wilson et al (1994) systematically address these issues in a series of experiments designed to isolate the effects of morphology, phonology, and semantics. Their study uses the cross-modal paradigm, in which the prime is presented auditorily and the target visually. This choice was intended to reduce or eliminate orthographic effects, a presumption which is shared across much of the psycholinguistic literature. In their first experiment, Marslen-Wilson et al covaried prime-to-target morphological and phonological relatedness to investigate the independent effects of these factors.[2] They found that [+morphological, +phonological] and [+morphological, -phonological] pairs showed comparable statistically significant priming, while [-morphological, +phonological] pairs were comparable to the unrelated control pairs. This pattern indicates that facilitation by morphologically related words is morphological rather than phonological, as phonology appears to make no statistical difference (either in the presence or absence of morphological relatedness).

Marslen-Wilson et al also investigated semantic and morphological interaction, and uncovered a more complicated pattern. Purely semantic priming (between prime-target pairs such as *dolphin-WHALE*) had been found previously (Collins & Loftus 1975, Becker 1979,

[2] A pair such as *happiness-HAPPY* was considered to be both phonologically and morphologically related, while *sanity-SANE* were morphologically but not phonologically transparent due to the stem vowel change. Pairs like *tinsel-TIN* were regarded as phonologically but not morphologically related.

Lupker 1984). By varying the semantic transparency of the relationship between a morphological prime and its stem, Marslen-Wilson et al sought to determine the extent to which semantic association plays a role in morphological priming. Pairs such as *casualty-CASUAL* represent a morphological relationship which is semantically opaque, while pairs like *punishment-PUNISH* have a transparent semantic relationship. Results showed priming between [+morphological, +semantic] pairs and, significantly, *no* priming between [+morphological, -semantic] pairs. This suggests a significant role for semantic relatedness in word recognition and processing, and led Marslen-Wilson et al to formulate a theory of the mental lexicon in which decomposition is only partial. On this view, morphology structures the mental lexicon only insofar as it correlates with transparent semantic meaning. Pairs where the semantic relationship is obscured do not occur in linked clusters, but rather have independent lexical entries. A number of other researchers have also proposed "hybrid" decompositional approaches, for instance to handle the issues presented by regular vs. irregular inflection patterns (see Clahsen et al 2003, Colé et al 1989, and Frauenfelder & Schreuder 1992).

1.3 A time course model of decomposition

The Marslen-Wilson model faces one immediate challenge: the results give no *a priori* reason to suppose that priming is due to the convergence of morphology and semantics, rather than to semantics alone. Subsequent studies, including Rastle et al (2000), have addressed this. Investigating the time course of visual word recognition, Rastle et al varied both the prime exposure duration (PED) as well as the stimulus onset asynchrony (SOA, the interval between prime and target). For those trials in which the prime was consciously perceived, semantically transparent morphological pairs (e.g. *departure-DEPART*) showed statistically greater facilitation than merely semantically related pairs (e.g. *cello-VIOLIN*). This indicates, in keeping with the Marslen-Wilson et al picture, that semantic information and morphology work together in facilitation.

At the shortest PEDs (at which primes were "masked," or not consciously perceivable), Rastle et al also found that semantically opaque derived forms prime their stems to the same extent as semantically transparent derived forms. This goes against Marslen-Wilson et al and suggests the existence of purely morphological links at some level of word recognition and processing. Rastle et al propose that the difference here relates to the difference between visual and cross-modal priming; and, specifically, to the difference between the time-course points accessed by the two tasks. In particular, early visual processing (prior to conscious prime perception) may be governed by morphology alone, while the later (conscious) stages of perception bring semantic considerations online as well. Semantic information may indeed be *required* at later stages, as per Marslen-Wilson et al.

This picture is further elaborated by Rastle et al (2004), who examined whether the semantically-blind results could be attributed to a purely form-sensitive decompositional process, rather than a morphological one. Using masked priming, they compared effects in morphological and transparent pairs such as *cleaner-CLEAN* to those from "fake" morphological pairs like *corner-CORN* (where *corner* appears to contain a real stem, *corn*, and a real suffix, *-er*, but is actually monomorphemic), and from form-only pairs like *brothel-BROTH* (in which the prime again appears to contain a real stem, but not a real suffix). If decomposition is form-based, all three conditions should show comparable facilitation, while if decomposition is morphological but semantically blind, the first two conditions ought to pattern together, while the third shows no facilitation. Finally, if decomposition is semantic (and morphological), priming would be expected only from the first condition, while the second two should pattern together. The *cleaner-CLEAN* pairs and *corner-CORN* pairs showed significant facilitation, while the *brothel-BROTH* pairs showed none: this supports the Rastle et al (2000) early time-course view.

Full listing models have largely been abandoned due to their incompatibility with data of the type described here. Indeed, these data fit extremely well with the picture outlined so far, involving a lexicon structured at one level (accessed by the shorter visual tasks) by morphology, and at a higher level (accessed by more conscious processing) by semantics as well. Nevertheless, this is not the only existing model which could explain the experimental results presented here, and this point is worthy of some consideration.

Just as Marslen-Wilson et al's partial decompositional model can be regarded as the successor to full decomposition models, so can connectionist accounts be thought of as heir to full listing. Models such as Rumelhart & McClelland (1989) hold that lexical entries are full words (polymorphemic or otherwise), but depart from full listing in that they allow morphology to provide "interlevel" structure (Caramazza et al 1988, Rueckl & Raveh 1999). In particular, learned association (and association frequency) forge connections between words in the mental lexicon. On such a view, the high semantic association between morphologically related pairs such as *departure/depart* would create a strong activation link, while the disconnect between *casualty* and *casual* leads to a lower association frequency and thus explains the relative weakness (or absence) of a link between those two. It is easy to see as well how the masked priming task might tap into a more visually-oriented network of activation links than the cross-modal task, thus explaining the semantically-blind results in early processing discussed above.[3]

1.4 The use of pseudoword primes

A particularly useful means of distinguishing between the decompositional time course model and the connectionist approach is to use pseudowords in the priming task – that is, words that are morphologically and/or phonologically plausible, but do not actually exist. Connectionist models explain facilitation by links between whole-word lexical entries: as a morphologically complex pseudoword like *happiful* does not have a lexical entry, this view predicts no facilitation from *happiful* to *happy*. Facilitation would indicate the activation of *happy*, which could only come about if *happiful* were decomposed into its ostensible components during processing. Any priming from morphological pseudowords, then, would argue for decomposition.

[3]Somewhat harder to handle on this picture is the pseudo-morphological result between a prime-target pair such as *corner-CORN*, but activation links attuned to an orthographic representation of morphological structure might be able to explain this on a connectionist framework.

Longtin & Meunier (2005) used this approach in the masked priming paradigm in French. They showed that pseudowords consisting of two legal morphemes, such as *rapidifier* (from *rapide* and *-ifier*), facilitated decision to their roots (*rapide*, here), whereas nonmorphological pseudowords, comprising a legal stem and a nonexistent suffix (e.g. *rapiduit*) did not. Moreover, facilitation in the first condition was comparable to facilitation from an existing derived prime (e.g. *rapidement*). These results suggest that morphological pseudowords *do* prime their stems in the same manner as real derived words, and support decomposition over connectionist models in early visual processing.

Longtin & Meunier made a further experimental distinction which highlights an interesting avenue for exploring the role of semantics in lexical access. They divided morphological pseudowords into two categories: one in which the nonexistent combination of stem and suffix yielded interpretable results (e.g. *rapidifier*(=to make quicker)), and one in which the combination was not interpretable (e.g. *sportation*).[4] In keeping with Rastle et al (2000, 2004), Longtin & Meunier found no role for semantics in masked priming: both pseudoword conditions primed their stems, and the effects were comparable.

Meunier & Longtin (2007) conducted a follow-up study in which the same conditions were used, but in the cross-modal paradigm. This served two purposes: it investigated the latter part of the time course picture, and evaluated this against a connectionist approach in the cross-modal task, an important consideration insofar as masked priming and cross-modal priming are widely agreed to access different levels of the word recognition process. Meunier & Longtin found that semantically interpretable pseudowords primed their stems to the same extent as existing derived primes. By contrast, uninterpretable pseudowords did not facilitate their stems, and indeed gave results comparable to nonmorphological pseudoword and unrelated primes. As a connectionist model would predict nopriming from pseudowords across the board, observed facilitation in the interpretable condition is sufficient to point away from this approach, and towards one in which the prime need not have an actual lexical entry in order to activate its stem.

As far as the Rastle et al (2000, 2004) time course model goes, Meunier & Longtin show a significant role for semantics in the later stages of processing. Crucially, an interpretable pseudoword gets its meaning precisely from the combination of its components: *rapide*(=quick) and *-ifier*(=to make so) combine to form *rapidifer*(=to make quicker). Such words *must* be somehow decompositionally parsed to be interpreted, and this process must activate at least the semantic information relating to the stem. That semantically-motivated decomposition is the source of stem activation and priming is supported by the fact that uninterpretable pseudowords do *not* prime their stems – the early visual activation of the stem seems to be inhibited at a later stage by the uninterpretability of the pseudoword. This ties together well with the Marslen-Wilson et al results for semantically transparent vs semantically opaque pairs in the cross-modal tasks (suggesting that a similar inhibition takes place in both cases), as well as with the description of the later stages of the processing

[4] An illustrative English example of this difference would be the following: compare *rapidify* (to make rapid) with *rapidless*. Neither word exists in English, although both are morphologically and phonologically plausible; the former is readily interpretable, while the latter has no immediately accessible interpretation.

time course as proposed by Rastle et al (2000, 2004).

1.5 Present aims

Two particularly interesting questions at this point are first, how semantically-motivated "inhibition" comes about in the uninterpretable condition, and second, at what point this occurs. The first is difficult to answer with the experimental methods available; however, the second is eminently approachable. Drews & Zwitserlood (1995), although primarily investigating a different issue, provide some relevant data. In a Dutch experiment comparing orthographic to morphological relatedness, they included a morphological pseudoword condition: pseudowords were formed from "an illegal combination of the target word and an existing Dutch suffix" (p1106). In the masked paradigm, results duplicated those from Longtin & Meunier; however, in the unmasked visual paradigm (at a PED commensurate with conscious processing), they found inconsistent priming from pseudowords to their roots. This could be caused by a couple of considerations. First, Drews & Zwitserlood did not distinguish between interpretable and uninterpretable combinations of stems and suffixes, but simply considered morphological pseudowords as a group. If the stimulus set used included both interpretable and uninterpretable pseudowords (in the sense of Longtin and Meunier), it is possible that priming results may have been obscured by this lack of specificity. In addition, the conscious visual task might tap into a level of lexical access that differs from the masked visual and/or cross-modal paradigms. Indeed, the PED in Drews & Zwitserlood was long enough to permit conscious perception, but might for some subjects not yet be long enough to wholly bypass visually-determined effects.

The experiment described in this report is intended to provide a continuation of the investigation into the partial-decomposition time course model proposed by Rastle et al (2000, 2004) (see also Rastle & Merkx 2011). Using the visual unmasked priming paradigm, I consider both interpretable and uninterpretable pseudoword primes in German. I use the parameters set by Longtin & Meunier for distinguishing between the types: both comprise nonexistent combinations of legal stems and legal suffixes. Interpretable pseudowords are formed by a grammatical combination which lends itself to interpretation via a simple composition of component meanings (as with *rapidifier*); uninterpretable words are formed by an ungrammatical combination, which therefore precludes semantic composition (as with *sportation*).

These choices were made with a few different aims in mind. First, distinguishing between interpretable and uninterpretable pseudowords follows up on the Longtin & Meunier and Meunier & Longtin results, but in a different language, thereby adding some cross-linguistic depth to the picture established in those studies. Secondly, the use of pseudowords provides further evidence helpful in adjudicating between connectionist and decompositional models in the manner described in section 1.4. Third, the choice of the unmasked paradigm allows investigation of a different (and possibly intermediate) level of the time course of word recognition and processing, and therefore promises to shed some additional light on the Rastle et al (2000, 2004) model. As a side issue, the paradigm choice paired with the clear distinction between pseudoword types may help to clarify the locus of indeterminacy in the unmasked Drews & Zwitserlood results.

2 Predictions, Materials, and Method

This experiment used German to examine the visual priming effects of interpretable and uninterpretable morphological pseudowords on their stem morphemes. Following the method established in Longtin & Meunier (2005), morphological pseudowords were formed by selecting a novel pairing of an existing German stem and an existing German suffix. The words thus created were therefore not real German words, but were both morphologically and phonologically plausible.

Interpretable pseudowords were created by choosing a stem and suffix that grammatically combine in German: for instance the noun *Sturm*(=storm) and the adjectival suffix *-ig*(=like) combine to form the nonexistent word *sturmig* (which has the apparent meaning "stormy"). As Longtin & Meunier point out, this type of process is responsible for lexical innovation in many languages (consider *googling*, in English), as it results in a word that is grammatically formed, phonologically plausible, and has existing morphological and semantic parallels (p29): compare *sturmig* to the existing word *eckig*(=angular), which is derived from the noun *Ecke*(=corner) and the suffix *-ig*.

By contrast, uninterpretable pseudowords were formed from ungrammatical combinations of stems and suffixes: the morphemes were chosen from incompatible classes. For instance, the verb *rennen*(=to run) and the suffix *-los*(=without) cannot grammatically give *rennlos*, as *-los* attaches exclusively to nouns (e.g. *herzlos*(=heartless), from *Herz*(=heart)). As a result, *rennlos* is morphologically composed in that both stem and suffix are legal morphemes, and is also phonologically plausible, but it cannot be assigned a meaning in the same way as *sturmig*, because there is no way of composing the semantic contribution of *los* with that of *rennen* (compare to the English pseudoword *runless*, from *run* and *-less*).

For each target in this experiment, two different primes were used: an unrelated control and either an interpretable or uninterpretable "derived" pseudoword. Priming in the related conditions was thus compared to the unfacilitated baseline given by the control results.

Based on the time course model described here, the results of Meunier & Longtin (2007), and the evidence from Marslen-Wilson et al (1994) and Rastle et al (2000, 2004), I predicted that semantically interpretable pseudowords would be found to prime their roots in the unmasked visual paradigm, whereas uninterpretable pseudowords would not. Meunier & Longtin show this pattern for the cross-modal paradigm, and this coheres with results from real word primes in the other experiments which show that semantically transparent derived primes facilitate their roots over semantically opaque primes. If Rastle et al (2000, 2004) are correct to attribute the difference between masked and cross-modal priming results to the activation of semantic information with conscious perception of the prime, then the visual unmasked paradigm would be expected to pattern with cross-modal results. This is predicted here. In particular, I predicted that the PED and SOA chosen for the unmasked task in this experiment would allow complete processing of the prime prior to the target, and thus permit realization of the semantic effects associated with conscious perception on the time-course model.

2.1 Materials

In order to avoid frequency and/or word class effects, all targets were chosen to be verbs, and were frequency-matched using the CELEX database. This was supplemented by judgments from two native speakers of German (regarding the relative salience of the words chosen). 48 targets were selected in all.

To create interpretable pseudowords, a number of suffixes that attach to verbs were examined for frequency, morphological productivity, and the relative constancy of their semantic contribution. Frequency was determined by comparing the number of tokens in the CELEX database which used the suffix in question. One further consideration was applied at this point: the availability of frequency-matched existing words containing the relevant suffix (as these provided appropriately matched control primes). Based on these criteria, the suffixes *-nis* and *-ung* were selected. Both attach to verbs and produce nouns, the first typically representing something with the quality of its stem verb (like *-ness* in English), and the second typically giving an instance of the verbal act associated with its noun stem (as with *-ing* or *-ment* in English).

A list of potential interpretable pseudowords was created by appending both suffixes to the verb targets, as in the examples below:

(1) a. *empfinden*(=to feel sthg.) → *Empfindnis, Empfindung*

b. *raten*(=to advise sthg.) → *Ratnis, Ratung*

All existing words (e.g. *Empfindung*(= feeling)) from this list were then removed, and the others checked against CELEX, the Duden online dictionary (www.duden.de), and in Google (www.google.de) to verify their nonexistence as real words or recent neologisms. Once this was done, two native speakers were asked to select the most plausible of the remaining candidates, leaving a list of phonologically and orthographically acceptable pseudowords which were also regarded as easily semantically interpretable.

For the uninterpretable pseudowords, suffixes were chosen that do not attach to verbs. As with the other suffixes, these were matched for productivity and frequency. In addition, in order to match word class across primes, the suffixes chosen were both nominal: *-heit* and *-tum* attach to nouns and adjectives to produce nouns (e.g. *Kindheit*(=childhood), from *Kind*(=child)). As with the interpretable pseudowords, a list was then generated by attaching both suffixes to the target verbs, as in the examples below:

(2) a. *basteln*(=to create) → *Bastelheit, Basteltum*

b. *ordnen*(=to arrange) → *Ordheit, Ordtum*

These were then submitted to the native speaker judges to verify uninterpretability and to screen for phonological plausibility (they were asked to select the "better" candidates).

Out of the lists of potential interpretable and uninterpretable pseudowords remaining, 24 of each were selected, one for each of the 48 targets. This was done at random. Within each interpretability condition, half were selected with each suffix. Overall, this gave 12 pseudoword primes with each of the four suffixes (*-heit*, *-nis*, *-tum*, *-ung*), across the list of 48 pairs. Real word control primes were selected to be unrelated to the targets, and were chosen to "match" the pseudoword primes in that they were real words ending with the chosen suffixes. Suffixes were evenly distributed amongst the controls. Table 1 contains sample stimuli in each condition. A complete list, including target glosses, can be found in Appendix A.

Table 1: Sample stimuli

Pseudoword condition	*Test pair (prime/target)*	*Control pair (prime/target)*	*Prediction*
Interpretable	BRENNUNG/brennen	BEWEGUNG/brennen	priming
	SIEGNIS/siegen	ZEUGNIS/siegen	
Uninterpretable	DIENTUM/dienen	WACHSTUM/dienen	no priming
	GREIFHEIT/greifen	DOPPELHEIT/greifen	

2.2 Stimulus lists

The 48 test pairs were split, at random, into two lists of 24 pairs each. Each list contained 12 interpretable and 12 uninterpretable primes, distributed evenly between the suffixes. At this point, each list contained exactly half the target verbs; the remaining targets in each case were added with the controls, paired so that 6 controls with each suffix appeared in each list. Thus, each of the 48 verb targets occurred in each list, once each, and in a different priming condition across lists.

Each list was then supplemented with 48 filler pairs. All filler targets were nonwords following the verbal pattern in German (e.g. *dremen*), to counterbalance the real word targets in the test and control conditions. Both lists contained the same set of 48 filler targets, but the primes were varied across list. In each list, 24 primes were "derived" suffixed items (e.g. *Dremnis*, from *dremen*) and hence were nonwords, while the remaining filler primes were existing suffixed words (e.g. *Ärgernis*(=irritation)). As before, the assignment of pairs to lists was done so that each list contained 12 filler pairs with a prime ending with each suffix, 6 in the "related" condition and 6 in the unrelated condition. Nonword (filler) targets were verified by the native speaker judges for orthographic and phonological plausibility and suitable distance from existing words.

The two lists thus generated therefore each contained 96 pairs, 12 in the interpretable pseudoword test condition, 12 in the uninterpretable test condition, 24 in the unrelated control condition, and 48 in the filler condition, of which half appeared to be related and half were unrelated. Each subject therefore performed 96 lexical decision trials, with 48 word targets and 48 nonword targets; no subject saw any prime or target word twice. They also saw equal numbers of word and nonword primes, equivalently distributed across target status: 12 prime-target pairs each of word-word, word-nonword, nonword-nonword, and nonword-word status. Each list was pseudorandomized, so that no more than three of any particular condition appeared consecutively. This was done to minimize the possibility of "learned" responses.

2.3 Procedure

This experiment used the visual unmasked priming paradigm, with a PED of 300ms, a target exposure of 600ms, and a within-trial SOA of 1106ms (leaving a 806ms gap between prime offset and target onset). Each target was followed by a 400ms pause before the start of the next trial, meaning that subjects had a total of 1000ms for response after the target onset. Reaction times (RTs) were measured from target onset. Trials began with a pause of 906ms, meaning that the total pause between target offset and the onset of the following primes was 1306ms. After each 12 trials, a longer pause of 5804ms was given. PED was chosen to be comparable to Drews & Zwitserlood (1995) (see experiment 3B), but slightly longer (300ms instead of 200ms).

Contrary to usual visual priming practice, primes were presented in block capitals and targets in lower case. This was due to the fact that all primes were either nouns or resembled nouns (due to the chosen suffixes), which are obligatorily capitalized in German, and could thus not have been presented in lower case without causing confusion. All stimuli were presented in white letters (in font "System," 36pt), and were centered on a dark grey background on a computer monitor (ViewSonic 17" PerfectFlat™ CRM Monitor E70f) in a quiet room. The experiment was controlled using *Splice*,[5] from a Macintosh Pro computer (OS 10.5.8). Response times were measured with purpose-built hardware (Reetz, 2008). Subjects responded by pressing one of two buttons (labelled "yes" and "no") on a two-button box; they were instructed to use their dominant hand for "yes."

Subjects were given written instructions outlining the task. These were then verbally summarized by the experimenter. All instructions were given in English. Subjects were then seated before individual monitors and given 10 practice trials. The total duration of the experimental process was approximately 10 minutes; the experiment itself (96 trials) took 5 minutes and 35 seconds.

2.4 Participants

32 native speakers of German participated in the experiment. All live and work or study in the vicinity of Oxford, England. All had normal or corrected-to-normal vision, and none were dyslexic. None of them participated in the stimulus selection judgments.

[5] *Splice* is a signal-processing program developed by Henning Reetz. The version used was last updated in 2008.

All participants spoke English at a high level; other languages in which they reported fluency included French (6), Spanish (4), Norwegian (2), Russian (2), and Arabic, Danish, Dutch, Italian, and Romanian (1 each). None were left-handed. The mean and median ages of the participants were 23.78 and 23.5, respectively.

3 Results

Due to a systematic software error, no RTs over 600ms were recorded.[6] Outlying responses below 250ms were discarded, giving a range of 350ms. Incorrect and missing responses were excluded from the final analysis. One participant was excluded due to a correct response rate of less than 50%.[7] Additionally, 12 target stimuli were excluded from the final analysis; the excluded stimuli were correctly identified as words by less than 60% of participants.[8]

Data was modeled using a mixed analysis of variance (ANOVA). An Fmin REML (reduced emphasis maximum likelihood) analysis listed subjects as a random variable, in addition to target nested under the interpretability condition of the associated pseudoword prime. This was done to minimize potential systematic variation between individuals, and between the targets of the interpretable vs uninterpretable primes. The dependent variable for analysis was reaction time (RT); independent variables were condition (test prime vs. control prime), pseudoword interpretability, and combined condition and pseudoword interpretability.[9]

Least square mean RTs for each independent variable are reported in Tables 2-4. Overall, there was a significant main effect of condition, $F(1, 816.5) = 104.8190, p < 0.0001$. The effect of pseudoword interpretability was not significant ($F(1, 33.6) = 0.9943, p = 0.3258$), nor was the interaction between condition and pseudoword interpretability ($F(1, 815) = 0.0024, p = 0.9610$).

On the whole, test primes in both interpretability conditions produced a facilitation effect of 40.39ms (see Table 2 for error margins). An analysis of interaction shows that uninterpretable primes produced a facilitation effect of 40.20ms (over corresponding controls), while interpretable primes produced a facilitation effect of 40.58ms (see Table 3 for error margins); as noted, these did not differ significantly. The observed 6.04ms difference between targets of

[6]The software used to transmit and record response data incorporated a lag of 400ms between the actual response provided by the participant and the writing of this data to a results file. A response at 250ms, for example, would have been written (as 250ms) to the results file at 650ms. Similarly, any RTs over 600ms would have been written after 1000ms; the experiment design, however, permitted only 1000ms for the recording of data. Consequently, no RTs of over 600ms were successfully recorded. This error was systematic and affected all participants; it was not discovered until testing was complete.

[7]No participants had an error (wrong response) rate of higher than 5%; however, both error and correct response rates are likely to have been artificially low, due to the missing data between 600ms and 1000ms. As a result, participant exclusions were determined according to a relatively low correct response bar (50%), rather than an error or nonresponse rate.

[8]As with participant exclusions, the correct response rate bar was set lower than normal to account for missing data.

[9]Thanks are due to Adam Roberts (Language & Brain Lab, Oxford) for his assistance with statistical analysis.

Table 2: Average RTs (in ms) by prime interpretability

Interpretability	*Average RT*	*Std dev*
Yes	493.07	± 6.73
No	487.03	± 7.02

Table 3: Average RTs (in ms) by condition

Prime condition	*Average RT*	*Std dev*
Test	469.86	± 6.44
Control	510.25	± 6.52

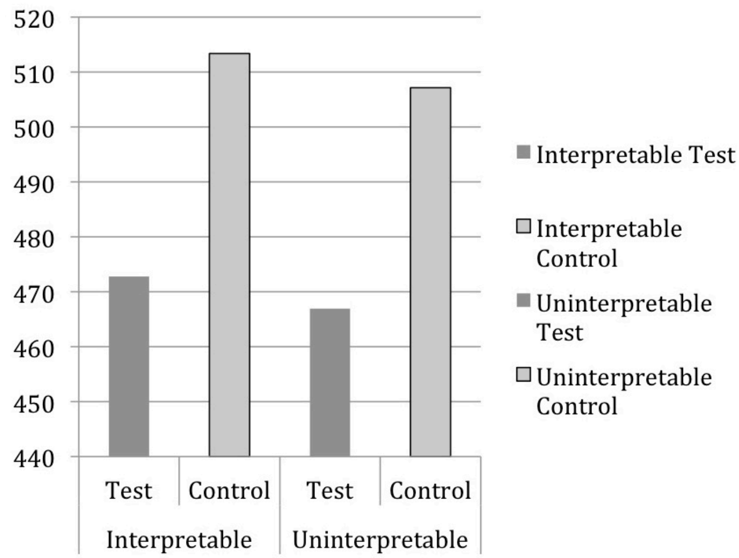
Table 4: Average RTs (in ms) by condition and prime interpretability

	Test		**Control**		
Pseudoword condition	*Average RT*	*Std dev*	*Average RT*	*Std dev*	*Difference*
Interpretable	472.78	± 7.16	513.36	± 7.30	40.58*
Uninterpretable	466.93	± 7.53	507.13	± 7.70	40.20*

interpretable primes and targets of uninterpretable primes was again insignificant (see Table 4 for error margins). Figure 1 provides a visual representation of the effect of pseudoword priming, sorted by interpretability condition.

The results of a planned comparison to examine the effect of prime interpretability status on RT confirm these findings; they show no interpretability effect. Facilitation was significant in both interpretability conditions, $t(815.4) = 7.7431, p < 0.0001(3 \times 10^{-14})$ for interpretable primes and $t(815.4) = 6.8301, p < 0.0001(2 \times 10^{-11})$ for uninterpretable primes.

Figure 1: Average RTs (in ms) for condition, by corresponding pseudoword prime interpretability



4 Discussion

4.1 The time course of decomposition

This study investigated the effect of semantic interpretability on the decomposition of morphological pseudowords in visual recognition and processing. Priming effects between interpretable pseudowords (formed from a grammatically legal but nonexistent combination of a real stem and real suffix) and their roots were compared to priming effects between uninterpretable pseudowords (formed from a grammatically prohibited combination of a real stem and a real suffix) and their roots. The goal was to see if interpretable primes produced a larger facilitation effect than uninterpretable primes. The prediction was that interpretable primes would facilitate their roots, and uninterpretable primes would not.

The data do not support this prediction. All pseudoword test primes facilitated their roots; the size of the facilitation effect was significant and statistically identical across prime interpretability. Semantic interpretability apparently played no role in target recognition: facilitation can be wholly attributed to the morphological nature of the pseudoword primes.

These results parallel the findings of Longtin & Meunier (2005) for morphological pseudowords in the masked priming paradigm. They also found no role for semantic interpretability; both interpretable and uninterpretable pseudoword primed their roots. This was claimed to be a result of the particular stage of processing accessed by the masked priming task. Specifically, Longtin & Meunier argue that the early (preconscious) visual stage is "sensitive only to the morphological structure of the pseudoword (whether it is parsable into morphemes or not)," (p35) and not to grammaticality or semantic interpretability.[10]

The prediction that facilitation effects would vary according to prime interpretability status was based on the time course model of morphological decomposition and word recognition as proposed by Rastle et al (2000, 2004). This model takes into account evidence that early visual word recognition is sensitive only to morphology and argues that the semantic effects observed in studies such as Marslen-Wilson et al (1994) are due to the longer time frame associated with the cross-modal paradigm used in those experiments. In particular, masked priming accesses a preconscious level of word recognition, while cross-modal tasks take place with both prime and target consciously perceived. The time-course model relies on the idea that semantic information comes online with conscious perception, after a certain amount of time has passed.

This experiment aimed at an intermediate time-course point in order to investigate this model further. PED was chosen to fall in the unmasked range (allowing for conscious perception), but was faster than auditory presentation. Based on the notion that conscious perception corresponds to the activation of semantic mechanisms, I predicted that results would pattern with those from the cross-modal task in Meunier & Longtin (2007). As stated, this was not the case; instead they patterned with the preconscious masked results from Longtin & Meunier (2005).

These results can be interpreted in two ways. First, it may be the case that the PED and/or SOA were insufficiently long to permit semantic activation; that is, while PED *was* long enough for conscious perception, it may be the case that semantic considerations come online a certain amount of time *after* conscious perception begins. If semantic processing was temporally precluded, priming would be expected to pattern with early (masked) time-course effects, as observed. This of course raises the question of when precisely semantic considerations come online.

The second interpretation of the results has to do with a reinterpretation of the proposed decomposition model. It is possible that what has been construed as a time-course effect may actually be a modality effect. That is, it may be the wholly visual nature of the masked paradigm that permits morphological decomposition and precludes semantic information, while the cross-modal task accesses a different level of representation. Switching between an auditory and visual input mode plausibly accesses a more abstract level of the lexicon than a purely visual task; this level incorporates decomposition but additionally includes semantic information in its representations of morphological relatedness. This idea is not

[10]Rastle et al (2000, 2004) also characterize early time-course effects in this way.

altogether new: Marslen-Wilson et al (1994) centered in part around the notion that different modalities might produce different results by accessing different representation levels. If the role played by semantic information can be attributed to the combined auditory and visual input in the cross-modal task, unmasked priming would again be expected to pattern with masked priming (as a visual task), as observed.

This study, unfortunately, does not provide sufficient grounds for adjudicating between these two possibilities. It is nevertheless illuminating with respect to the time course model in that it shows that semantic processing does not simply come online concurrently with conscious perception: the actual link between perception and semantic information must be more complicated. Further investigation will, of course, be needed to complete this picture. To begin with, a careful time-course visual study, along the lines of Rastle et al (2000), but using pseudoword primes, could resolve the issue of whether semantic processing comes online at a time-delay from conscious perception. Observed facilitation by interpretable in the absence of facilitation by uninterpretable pseudowords at a specific point in the time course would corroborate this view; the absence of such a difference would support the second, modality-based explanation I have offered.

This experiment was also designed with the hope of providing clarity about the inconclusive pseudoword results from Drews & Zwitserlood (1995). This has not been achieved in the manner expected. As results here show clear priming in both intepretability conditions, the lack of consistent priming from pseudowords in Drews & Zwitserlood is unlikely to be due to an insufficient interpretability distinction. I shall not attempt to find another explanation here; however, it is worth observing that the results of this experiment as well as Drews & Zwitserlood both suggest that the "consciousness" distinction in the time course model as proposed is insufficiently nuanced to account for the interaction between morphological and semantic information.

4.2 Potential issues

The most significant potential issue with the experiment conducted here was the software error leading to a loss of RT data. After exclusions were calculated (see section 3), a tally of the number of target tokens in each prime interpretability condition was taken: 50.5% of target tokens with uninterpretable primes remained in the final sample, while 62.2% of target tokens with interpretable primes remained. It is possible that the full data set would have shown a difference between interpretable and uninterpretable primes, and that this has been obscured by the unequal loss of targets; however, given the statistically identical priming across interpretability conditions, this seems fairly unlikely. Moreover, the usual practice of discarding data outside two standard deviations from the mean would likely have eliminated a similar proportion of targets in each prime interpretability condition. A repeat of this experiment is, of course, in order; this would conclusively resolve these concerns.

In terms of wider effects, it is worth observing that this study has used morphological ungrammaticality as a proxy for determining semantic uninterpretability. There is no way to determine whether the uninterpretable primes are unintepretable because they are grammatically ill-formed or only because they are semantically ill-formed. An interesting and relevant follow-up would find a way of distinguishing these cases: this might be achieved, for instance, by using words containing bound morphemes, particularly those which have a potentially variable contribution, such as *-mit* in the *submit, permit* examples from section 1.2. Given a morpheme (stem or affix) with sufficient variability, it seems possible that semantic interpretability could fail due to the inability to fix a compositional meaning, without the need to incorporate grammatical incompatibility.

Finally, all of the studies cited here using pseudowords have been restricted to suffixed derived pseudowords. Marslen-Wilson et al (1994) found differentiable results with prefixed and suffixed (real) words, some of which have since been challenged (see Rastle & Merkx 2011). No conclusion on this point has yet been reached; pseudoword primes could provide relevant information about prefixed words. Such a follow-up might, additionally, serve to inform us about the nature of the "automatic" morphological parser proposed by the time course model for early processing.

5 Conclusion

This study investigated the role that semantic interpretability plays in a visual processing task with pseudowords. Priming from interpretable pseudowords to their stems was directly compared to priming from uninterpretable pseudowords and unrelated control words. The main finding was that both interpretable and uninterpretable pseudoword primes facilitate their roots. This shows that semantic interpretability does not interact with morphologically-based decomposition (as established by Rastle et al 2004, Longtin & Meunier 2005, Meunier & Longtin 2007) in visual word processing.

This experiment provides illuminating data with respect to the time course model of morphological decomposition proposed by Rastle et al (2000, 2004), and in particular argues for a more nuanced picture. Specifically, results show that the semantic effects observed in cross-modal priming experiments may not simply be due to the longer time course associated with conscious perception; there may be either a more complicated temporal relationship between perception and semantic information than has so far been proposed, or modality (visual vs auditory-visual) may genuinely access different levels of representation in the mental lexicon, as suggested by Marslen-Wilson et al (1994).

Taking these modifications into consideration, the results obtained here are compatible with a time-course model, and in particular with a picture where purely morphological information plays a role at the early stages of word recognition and processing. At this stage, which is accessed by the masked priming task, and also apparently by the chosen PED and SOA of the unmasked task conducted here, an automatic parser decomposes words with apparent morphological structure (*rapidify*) into the morphemes of which they appear to be composed (*rapid, -ify*). This is not simply an orthographic process, but relies on the presence of existing morphemes in the presented word.

Early visual processing is not sensitive to semantic information: results are achieved solely on the morphological basis described, with morphological pseudowords facilitating their targets regardless of their interpretability status (Longtin & Meunier 2005, this study).

A number of studies support the notion that semantic information comes online at a separate stage of processing, and the results here are compatible with this, subject to the proposed modification: the availability of semantic input, which can inhibit some of the purely morphological results from early processing, appears to occur either after a certain amount of time has passed after the conscious perception threshold in visual processing, or at an alternative level of morphological representation accessed by the need to translate between auditory and visual input in the cross-modal task. The nature of this "switch" is a matter for further research, and could be investigated in the first instance by a visual time-course study as proposed in section 4.2, or additionally by delayed repetition (and other long-lag visual tasks).

Finally, the fact that morphological pseudowords facilitate their roots in any way is a point against connectionist models of the mental lexicon. A morphological pseudoword cannot have a lexical entry, and is therefore incapable of activating its stem through connectionist links between lexical entries; rather, it must be decomposed in order for the stem to be recognized and then activated. The observed facilitation argues for a decompositional model of word recognition and processing, and is compatible with the time course model as described above. Further study will serve to pin down the processes and levels of representation and information involved with decomposition.

A Appendix

Table 5: Test and control stimuli

Primes		**Targets**	
Interpretable pseudoword	*Unrelated control*	*German*	*English gloss*
ANALYSIERUNG	ACHTUNG	analysieren	to analyze
BEREITNIS	SÄUMNIS	bereiten	to prepare
BEWEISUNG	FÖRDERUNG	beweisen	to prove
BRENNUNG	BEWEGUNG	brennen	to burn
DISKUTIERUNG	DROHUNG	diskutieren	to discuss
DRÄNGNIS	BEDÜRFNIS	drängen	to push, crowd
EMPFINDNIS	ERLAUBNIS	empfinden	to feel (sthg)
FANGNIS	ERLEBNIS	fangen	to capture
GRÜNDNIS	BEFUGNIS	gründen	to establish (sthg)
HEIRATUNG	ERINNERUNG	heiraten	to marry
LEERNIS	KENNTNIS	leeren	to empty
MALUNG	HOFFNUNG	malen	to paint
MERKNIS	GEFÄNGNIS	merken	to perceive (sthg)
RATNIS	HEMMNIS	raten	to advise (sthg)
REDUNG	MELDUNG	reden	to talk
SCHAUUNG	WOHNUNG	schauen	to see
SCHLAFNIS	KÜMMERNIS	schlafen	to sleep
SCHÜTZUNG	STIMMUNG	schützen	to protect
SIEGNIS	ZEUGNIS	siegen	to win, conquer
STERBUNG	WERBUNG	sterben	to die
VERGESSNIS	GESCHEHNIS	vergessen	to forget
WERTNIS	VERZEICHNIS	werten	to assess (sthg)
ZITTERUNG	FORSCHUNG	zittern	to tremble
ZWEIFELUNG	ZEICHNUNG	zweifeln	to doubt (sthg)

Table 6: Test and control stimuli (continued)

Primes		**Targets**	
Uninterpretable pseudoword	*Unrelated control*	*German*	*English gloss*
ÄNDERHEIT	ALLEINHEIT	ändern	to change
ATEMHEIT	SICHERHEIT	atmen	to breathe
BASTELTUM	ALTERTUM	basteln	to create
BRECHHEIT	BLÖDHEIT	brechen	to break
DIENTUM	WACHSTUM	dienen	to serve
FLIEGHEIT	DICHTHEIT	fliegen	to fly
GREIFHEIT	DOPPELHEIT	greifen	to grab (sthg)
IRRHEIT	FEINHEIT	irren	to be wrong
KLAGTUM	EIGENTUM	klagen	to sue
KLAPPHEIT	EBENHEIT	klappen	to clap
KLINGTUM	HEIDENTUM	klingen	to sound, ring
LACHTUM	HEILIGTUM	lachen	to laugh
LAUTHEIT	SELTENHEIT	lauten	to acclaim
MESSTUM	EIGENTUM	messen	to measure
MISCHTUM	BISTUM	mischen	to mix (sthg)
ORDTUM	STREBERTUM	ordnen	to arrange
PFEIFTUM	FAKTUM	pfeifen	to whistle
RAUCHHEIT	MEHRHEIT	rauchen	to smoke
RÄUMTUM	ZARENTUM	räumen	to clear (sthg)
RENNHEIT	FREIHEIT	rennen	to runn
SCHWEIGHEIT	GOTTHEIT	schweigen	to be silent
STREBHEIT	GESUNDHEIT	streben	to aspire (to)
WANDELTUM	ERBTUM	wandeln	to alter (sthg)
ZAHLTUM	NARRENTUM	zahlen	to pay (for)

Table 7: Fillers

Primes		**Targets**
Related nonword	*Unrelated word*	
AKTUIERTUM	VOLKSTUM	aktuieren
BEIFELUNG	HEBUNG	beifeln
BLASCHNIS	ÄRGERNIS	blaschen
BLUNUNG	ABARTUNG	blunen
BRADERUNG	DEUTUNG	bradern
DASCHHEIT	WEISHEIT	daschen
DOTSUNG	BAUCHUNG	dotsen
DREIGUNG	TRAUUNG	dreigen
DREMNIS	BEGÄNGNIS	dremen
DRULLTUM	REICHTUM	drullen
FLAGHEIT	DUNKELHEIT	flagen
FRASSERTUM	BRAUCHTUM	frassern
FRÜMHEIT	GEMEINHEIT	frümen
GIELHEIT	ECHTHEIT	gielen
GLEBUNG	BINDUNG	gleben
HÄUSTNIS	BESORGNIS	häusten
KLADERNIS	GLEICHNIS	kladern
KLEFNIS	EREIGNIS	klefen
KLOSTNIS	GESTÄNDNIS	klosten
KRUSSUNG	EINLADUNG	krussen
LIENTUM	DIKTUM	lienen
LOCHTUM	HELDENTUM	lochten
LÜPSTHEIT	KLUGHEIT	lüpsten
MALDTUM	FÜRSTENTUM	malden

Table 8: Fillers (continued)

Primes		**Targets**
Related nonword	*Unrelated word*	
MEITNIS	BÜNDNIS	meiten
NEUZELUNG	FORMUNG	neuzeln
NORTHEIT	DÜNNHEIT	norten
PFURHEIT	REINHEIT	pfuren
PIELNIS	WIRRNIS	pielen
RAUSTUM	KÖNIGTUM	rausten
REUFUNG	KÜRZUNG	reufen
SCHARZTUM	RITTERTUM	scharzen
SCHLEDHEIT	BEDINGTHEIT	schleden
SCHURBHEIT	BESONDERHEIT	schurben
SIENHEIT	MINDERHEIT	sienen
SPÖLNIS	VERMÄCHTNIS	spölen
STORZUNG	KREUZUNG	storzen
STRABTUM	ABSTRAKTUM	straben
STURFTUM	CHRISTENTUM	sturfen
TEPFERUNG	LOSUNG	tepfern
TREBNIS	GELÖBNIS	treben
TRUFTUM	KAISERTUM	trufen
TRUSCHNIS	BILDNIS	truschen
WARDERUNG	SENDUNG	wardern
WIERTHEIT	BLINDHEIT	wierten
WURSCHTUM	SIECHTUM	wurschen
ZWALNIS	ERTRÄGNIS	zwalen
ZWUCKHEIT	NÜCHTERNHEIT	zwucken

References

[1] Aronoff, M. (1976). *Word Formation in Generative Grammar*. Cambridge, MA: MIT Press.

[2] Becker, C. (1979). Semantic content and word frequency effects in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance* 5: 252-259.

[3] Butterworth, B. (1983). Lexical representation. In B. Butterworth (ed), *Language Production*. San Diego, CA: Academic Press, 257-294.

[4] Caramazza, A., A. Laudanna & C. Romani (1988). Lexical access and inflectional morphology. *Cognition* 28: 297-332.

[5] Clahsen, H., I. Sonnenstuhl & J. Blevins (2003). Derivational morphology in the German mental lexicon: a dual mechanism account. In H. Baayen and R. Schreuder (eds), *Morphological Structure in Language Processing*. Berlin: Mouton de Gruyter, 125-155.

[6] Colé, P., C. Beauvillain, & J. Segui (1989). On the representation and processing of prefixed and suffixed words: a differential frequency effect. *Journal of Memory & Language* 28: 1-13.

[7] Collins, A. & E. Loftus (1975). A spreading-activation theory of semantic processing. *Psychological Review* 82: 407-428.

[8] Drews, E. & P. Zwitserlood (1995). Morphological and orthographic similarity in visual word recognition. *Journal of Experimental Psychology: Human Perception and Performance* 21(5): 1098-1116.

[9] Feldman, L. (1992). Morphological relationships revealed through the repetition priming task. In Noonan, Downing & Lima (eds), *Linguistics and Literacy*. Amsterdam: John Benjamins, 239-254.

[10] Ferrand, L. & B. New (2003). Semantic and associative priming in the mental lexicon. In Bronin (ed), *Mental Lexicon: Some words to talk about words*. New York: Nova Science Publications, 25-43.

[11] Fischler, I. (1977). Semantic facilitation without association in a lexical decision task. *Memory & Cognition* 5: 335-339.

[12] Frauenfelder, U. & R. Schreuder (1992). Constraining psychological models of morphological processing and representation: the role of productivity. In Booij & van Marle (eds), *Yearbook of Morphology 1991*. Dordrecht: Kluwer Academic, 165-183.

[13] Frost, R., K. Forster, & A. Deutsch (1997). What can we learn from the morphology of Hebrew? A masked-priming investigation of morphological representation. *Journal of Experimental Psychology: Learning, Memory & Cognition* 23: 829-856.

[14] Gonnerman, L., M. Seidenberg & E. Andersen (2007). Graded semantics and phonological similarity effects in priming: evidence for a distributed connectionist approach to morphology. *Journal of Experimental Psychology: General* 136(2): 323-345.

[15] Henderson, L. (1985). Towards a psychology of morphemes. In Ellis (ed), *Progress in the Psychology of Language*, Vol. 1. London: Erlbaum, 15-72.

[16] Longtin, C-M. & F. Meunier (2005). Morphological decomposition in early visual word processing. *Journal of Memory & Language* 53: 26-41.

[17] Longtin, C-M., J. Segui & P. Halle (2003). Morphological priming without morphological relationship. *Language & Cognitive Processes* 18: 313-334.

[18] Lupker, S. (1984). Semantic priming without association: a second look. *Journal of Verbal Learning & Verbal Behavior* 23: 709-733.

[19] Manelis, L. & D. Tharp (1977). The processing of affixed words. *Memory & Cognition* 5: 690-695.

[20] Marslen-Wilson, W., L. Tyler, R. Waksler & L. Older (1994). Morphology and meaning in the English mental lexicon. *Psychological Review* 101: 3-33.

[21] Meunier, F. & C-M. Longtin (2007). Morphological decomposition and semantic integration in word processing. *Journal of Memory & Language* 56: 457-471.

[22] Rastle, K., M. Davis, W. Marslen-Wilson & L. Tyler (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language & Cognitive Processes* 15: 507-537.

[23] Rastle, K, M. Davis, & B. New (2004). The broth in my brother's brothel: morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review* 11(6): 1090-1098.

[24] Rastle, K. & M. Merkx (2011). Semantic constraints on morphological processing. In G. Gaskell & P. Zwitserlood (eds.), *Lexical Representation: a multidisciplinary approach.* Berlin: Mouton de Gruyter, 13-32.

[25] Rueckl, J. & M. Raveh (1999). The influence of morphological regularities on the dynamics of a connectionist network. *Brain & Language* 68: 110-117.

[26] Rumelhart, D. & J. McClelland (1986). On learning the past tenses of English verbs. In McClelland, Rumelhart, & the PDP Research Group (eds), *Parallel Distributed Processing: Explorations in the Microstructure of Cognition, Vol. 2: Psychological and Biological Models.* Cambridge, MA: MIT Press, 216-271.

[27] Seidenberg, M. (1987). Sublexical structures in visual word recognition: access units or orthographic redundancy? In Coltheart (ed), *Attention and Performance XII*. London: Erlbaum, 245-263.

[28] Seidenberg, M. & J. McClelland (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, 96(4): 523-568.

[29] Stolz, J. & L. Feldman (1995). The role of orthographic and semantic transparency of the base morpheme in morphological processing. In Feldman (ed), *Morphological Aspects of Language Processing*. Hillsdale, NJ: Erlbaum.

[30] Taft, M. (1981). Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior* 20: 289-297.

[31] Taft, M. (1991). *Reading and the Mental Lexicon*. Hove, UK: Erlbaum.

[32] Taft, M. & K. Forster (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior* 14: 638-647.