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Lexical Gaps and Morphological Complexity:

The Role of Intermediate Derivational Steps

A thesis submitted for the degree of

Doctor of Philosophy

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Swetlana Schuster

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ABSTRACT

Swetlana Schuster *Doctor of Philosophy*

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Lexical Gaps and Morphological Complexity:
The Role of Intermediate Derivational Steps

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In this thesis, we present a multi-method investigation of how lexical gaps, defined here as morphologically and phonologically viable formations, are processed in derivational chains. Due to a focus on the processing of single-affixed words in the experimental literature, little is known about the role of intermediate steps of derivation during morphological decomposition.

In a series of four behavioural experiments, we show that while all morphologically well-formed items activate a base word that is two derivational steps away, speakers are sensitive to the internal composition of visually matched novel forms. Items like **Spitzung* (*spitz* > *spitzen* > **Spitzung*) primed their stem more than pseudowords containing two lexical gaps in their derivational chain such as *hübsch* > **hübschen* > **Hübschung*. Similar patterns emerged in an ERP (Event-related potentials) experiment using cross-modal priming: novel forms in the **Spitzung* set displayed

significantly stronger attenuation of the N400 response to the target *spitz* than items for which the intermediate position in the derivational chain is a lexical gap such as **Hübschung*, thereby demonstrating a stronger link between pairs without a lexical gap in the intermediate position.

Building on previous neuroimaging research on the processing of derivational depth in morphological complexity (cf. Meinzer et al., 2009; Pliatsikas et al., 2014), we subsequently turned to a functional magnetic resonance imaging investigation of the neural correlates of morphological complexity processing with lexical gaps. Both sets of pseudowords showed greater activation in the left inferior frontal gyrus relative to existing complex words as an index of prolonged lexical search. A direct comparison between the two sets of novel forms revealed stronger activation in the right superior parietal lobule and precuneus for pseudowords with lexical gaps in the intermediate position.

These findings lend support to the idea that morphological decomposition involves the inspection of intermediate levels of morphological composition as a step-wise procedure that is informed by the structural rules of the language.

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1. RESEARCH QUESTIONS AND MOTIVATIONS

An important question in psycholinguistic research touches on the recognition and interpretation of words in real time. The task seems deceptively straightforward and could be equated to the successful retrieval of an entry from a long list of entries encountered over a lifetime. Yet, intuitively, we could hypothesize that some words are more complex than others, thereby taxing our recognition and interpretation capacities more than simpler words.

Complexity can be expressed in a myriad ways, but in the present thesis the term will be used to refer to morphological complexity that we define as a measure of the internal structural complexity of different words. The research questions pursued in the present thesis relate to the possibility that modulations of internal morphological structure will have measurable processing consequences that will extend to novel formations without an existing lexical representation. The intuition that morphological structure is discernible in extant and non-existent formations alike was introduced in Schuster (2015). We noted the pervasiveness with which processes of morphological structure analysis can be expected to play a role in day-to-day life: when a local business in Germany is called *essBar* (see Figure 1.1), only a morphological analysis can reveal the availability of two concurrent interpretations to the customer: (1) a deverbal adjective 'edible' through suffixation with *-bar* to the verb *essen* (V., 'to eat') and (2) a compound referring to 'a bar to eat in'.

Figure 1.1 *Café* EssBar *(City Cards – Control Center)*

Crucially, while the derived adjective *essbar* is an existing word (and fairly frequent with 18 occurrences in CELEX (Baayen, Piepenbrock, & Gulikers, 1995)), the availability of two possible readings following the morphological analysis of a complex word is not restricted to existing words. Thus, the name selected by a company specializing in the rental of party equipment - *LEIHbar* - looks superficially parallel to our previous example (see Figure 1.2).

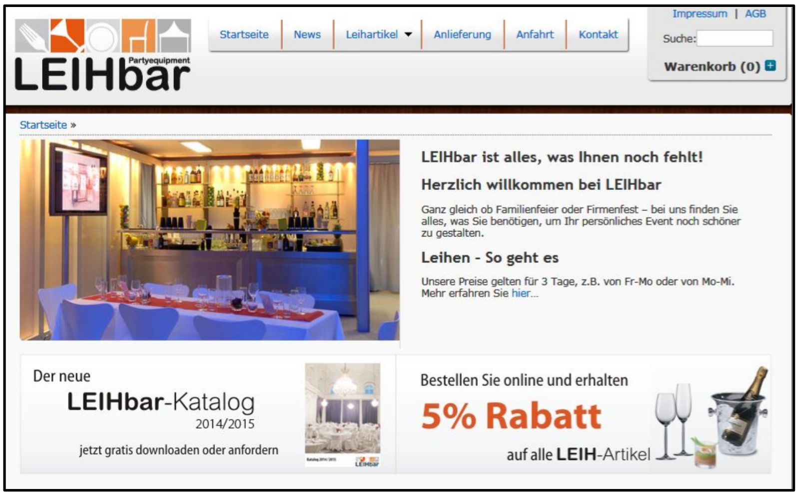

Figure 1.2 *Official website of "LEIHbar" (Lokales-Branchenbuch.net)*

Yet we find that *leihbar* itself as a deverbal adjective formed on the basis of the verb *leihen* (V., ‘to borrow’, ‘to lend’) is neither attested in CELEX (Baayen et al., 1995), nor in the DWDS database (Klein & Geyken, 2010). It is only through a morphological analysis of the novel form that the meaning of *leihbar* can be computed. The question could be raised, however, whether or not we only resort to these analyses when the effects of cunning marketing strategies draw our attention to this possibility in the first place. In many ways, the detection of morphological structure in a non-existent item such as *leihbar* is straightforward: a single operation, namely the identification of an existing stem *leih-* and a possible suffix *-bar* suffices. Maybe this is an explanation for the pervasiveness of the strategy? A Google search for **kochbar* - another derivation that does not yield an existing word - should convince us further that the novel formations derived for advertising purposes are not a rare occurrence. Alternatively, it could be the case that the analysis of morphological complexity is an integral part of the word recognition process and is not constrained by the number of morphological operations required and thus the degree of complexity.

Questions regarding the role of a possible morphological component in the word recognition process will guide the aims pursued in the present thesis. For this purpose, we will turn to the empirical investigation of the processing patterns induced by different sets of novel forms. Will native speakers of German detect morphological structures in non-existent items that require additional morphological operations to identify an existing base word? Is the base word *leihen* still identifiable when its non-existent derivate **leihbar* serves as the base to an additional derivation, yielding the non-existent noun **Leihbarkeit*? Crucially, does the lexical status of the intermediate position - here the non-existent form **leihbar* - affect the processing of its derivate **Leihbarkeit*? How will this differ for a non-existent formation such as **Denkbarkeit* (V., 'thinkability') that looks visually matched to **Leihbarkeit*, but for which the intermediate position *denkbar* (V., 'thinkable') is already an existing lexical representation? Will intermediate levels of derivation and thus the internal complexity of a novel formation affect processing? Using a series of behavioural and neurolinguistic techniques, we will probe into the role played by internal levels of morphological composition. This may in turn shown that word recognition in both existing and non-existent derived items is shaped by complexities that the straightforward retrieval of a surface form cannot reveal.

2. WORD RECOGNITION & MORPHOLOGICAL PROCESSING

2.1 Introduction

As established in Chapter 1, an important question in psycholinguistic research relates to the mechanisms underlying word recognition. This has been seen as a way to gain insight into (1) how reading is acquired; (2) how we map strings of characters into written words and subsequently into higher-level representations that carry meaning; and (3) how we convert acoustic signals into meaningful elements in speech. At the same time, it was hoped that studying the mechanisms that underlie word recognition would provide a more thorough understanding of the architecture of our mental lexicon as we gather more information on how the words we know are represented in relation to other words, especially those that are morphologically related to one another. Recall that the questions to be addressed in the present thesis pertain to the processing of novel formations that cannot be expected to possess a lexical representation of their own. Yet we hypothesize that formations that possess morphological structure might modulate the recognition process.

Before we can attempt to study the processing of morphological structure in non-existent words, we will need to give a brief overview of how the notion of morphological structure will be understood in the present thesis, as well as motivate our hypothesis that morphological structure can be expected to modulate the word recognition process. These points will be discussed in section 2.2. In section 2.3, we then turn to psycholinguistic approaches to morphological representation by introducing the main models of morphological processing before moving on to modality-specific aspects of morphological processing in section 2.4. In section 2.5, we will address the question whether the evidence for and against an autonomously morphological level of analysis surfaces differently in visual word recognition depending on the type of experimental task employed and how this may interact with other factors such as language-specificity, the type of morphological process investigated, or even the time-point of the recognition process. In order for speakers to decompose non-existent items based on their structure, tacit knowledge regarding the viability of morphological constructions based on constraints in the language has to be available. In section 2.6, we survey different kinds of constraints that may inform on-line language processing before we lay out the kinds of questions that we hope to address in this thesis.

2.2 Motivating morphological structure: linguistic structure and morphological constraints

As we suggested in Chapter 1, it is the ability to give structural analyses to words - real and novel - that is critical to the assignment of the intended meaning to a form that could take two meanings such as *essbar* (A., 'edible' or N., 'a bar to eat in'). In both cases, the surface segmentation of the whole form *essbar* is equivalent, as it is broken up into two parts *ess-* and *-bar.* It is, however, the function of the two parts in their composition that differs. For the adjectival meaning 'edible', the second part functions as a deverbal suffix *-bar* that gives the overall construction its syntactic category.

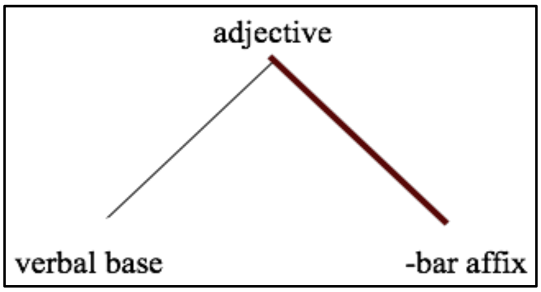

Figure 2.1 *Structural representation for deverbal adjectives such as essbar*

Under the second analysis, the second component carries more semantic substance as it is now not interpreted as an affix, but as the lexeme *Bar* (N., 'bar'), which enters the V-N compound *Essbar* as seen in Figure 2.2.

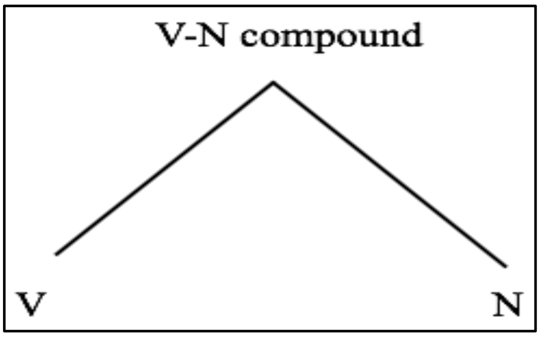

Figure 2.2 *Structural representation for V-N compound such as* Essbar

The word *essbar* is certainly just a particular example of how the interpretation of individual constituents within a complex morphological word may incline us one way or another. However, Figures 2.1 and 2.2 illustrate how a more abstract representation of the underlying processes may be represented. That an abstract representation is required to capture generalizations across the language already emerged in Chapter 1, where we showed that verbs such as *leihen* in German can be made to fit the templates in Figures 2.1 and 2.2 even though the forms *leihbar* (A., 'lendable', 'borrowable") and *Leihbar* (N, 'bar for lending/borrowing') are not attested (yet) as such.

In this particular instance, the differences in meaning were driven by the functions assigned to the second constituent in the overall composition without altering the structure of the construction as a whole. However, as soon as more than two constituents enter the composition, their arrangement with regard to one another becomes critical in the assignment of meaning. A typical textbook example (Haspelmath & Sims, 2010) is given in Figure 2.3 where the complex construction *undoable* can be shown to be interpretable in two different ways, depending how the morphological constituents are grouped together. In Figure 2.3, the structural analysis on the left yields the interpretation of a process that can be reversed (i.e undone) while the meaning assigned to the structure on the right would be appropriate for a situation in which one were to describe an action or process that cannot be carried out and which is therefore *un-doable*.

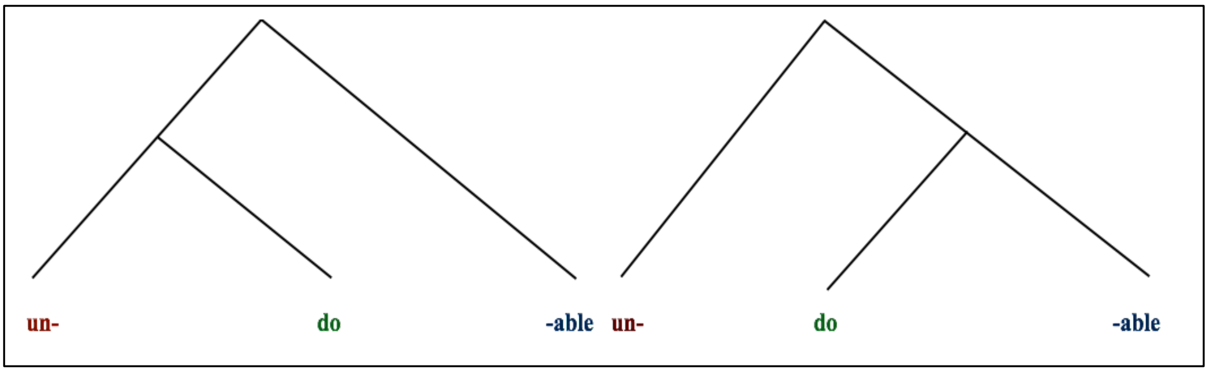

Figure 2.3 *Illustration of two possible structural analyses for* undoable *based on Haspelmath (2002)*

Even if one were to argue that instances in which two meanings can be extracted from a single complex construction are rare, it is nonetheless clear that it is the possibility of combining the prefix *un-* with both verbs and adjectives in English that gives rise to the possibility of entertaining two meanings in the first place.

As we shall see later in this chapter, a precise description of the kind of constraints that characterize the morphological system of a language needs to factor in many more aspects than just the syntactic category of the base to which an affix is attached. In order to capture the kind of generalizations on which native speakers rely during morphological complexity processing, it is nonetheless viable to consider which combinations between bases and affixes are never attested in a given language since this might give a first approximation of the kind of knowledge that we are interested in. Since the research to be presented in this thesis is on suffixation processes in German, Figure 2.4 is intended to serve as an overview of a number of word formation processes in German that involve suffixation. Not all word formation processes described in Figure

2.4 are equally productive - a notion to which we will return in later parts of this chapter. The number of suffixes used to derive different parts of speech in German is relatively substantial as can be gleaned in Figure 2.4, underscoring the complexity of the overall system. Some suffixes (in red font) trigger umlauting (vowel fronting) of the stem vowel as an originally phonologically conditioned process that can synchronically be considered epiphenomenal with regard to a number of morphological processes.

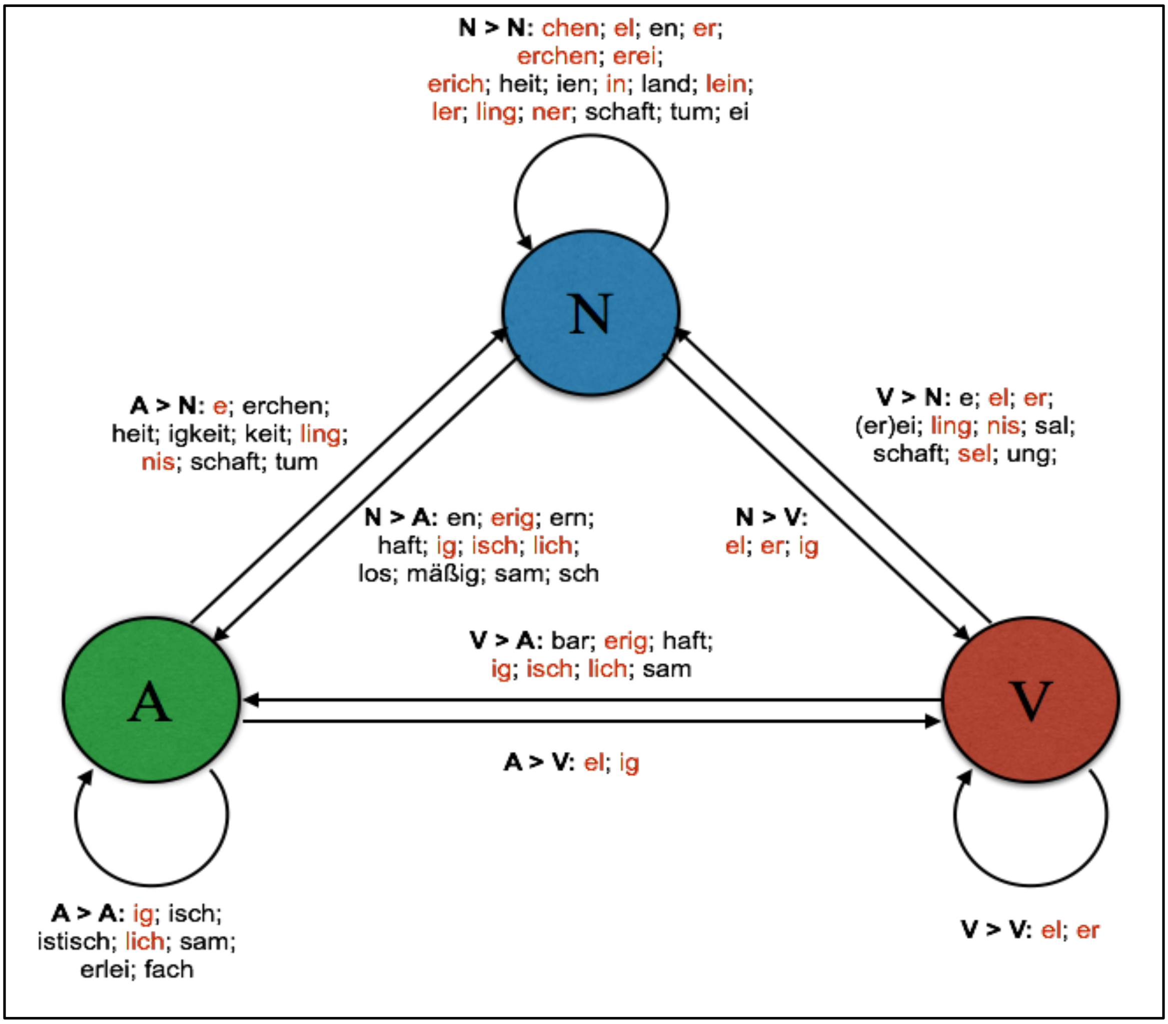

Figure 2.4 *Overview of suffixation processes in German (Fleischer (1975) and Schmid (2005))*

Note that Figure 2.4 - although comprehensive with regard to suffixation processes as possible - does not attempt to capture other modes of word formation in German such as prefixation or conversion, the latter being the formation of a morphologically related word in the absence of a change in phonological surface form as in *stehlen* (V., ‘to steal’) > *das Stehlen* (N., ‘stealing’). Further complexities arise in the derivation of forms that have non-native; that is, borrowed bases. In many cases, bases that are from the non-native stratum of the language necessitate non-native affixes. As an example, the complex noun *Modifikation* (N., ‘modification’) is derived from the verb *modifizieren* using the suffix -*ation* that does not feature in derivations from inherited verbs.

In view of the range of complexities that are revealed through the links between lexical entries sharing a morphological relationship, the question as to how native speakers represent morphologically complex words in their language seems particularly pertinent. A number of different approaches to this question have been advanced in the morphological processing literature and we shall present a subset of these in the following section.

2.3 Models of morphological processing

Over the last four decades of research into morphological processing, a number of models of word recognition have been proposed. In the following section, we will present a subset of these models. We will review differences in how these models account for decompositional processes during word recognition, but with a particular focus on the predictions made concerning the processing of novel complex forms. Very broadly, models of morphological processing can be divided into three major groups depending on whether decomposition is obligatory (*full-decomposition models*), non-essential (*full-listing models*) or to a certain degree context-dependent (*dual or mixed models*).

2.3.1 Full-decomposition models: affix-stripping and across-the-board decomposition

Taft and Forster (1975) proposed a model of morphological processing that is fully decompositional and highly reliant on the identification of the stem in morphologically complex words. In an unprimed lexical decision task with two sets of nonwords, nonwords that function as bound stems in existing prefixed words (e.g. *juvenate* in *rejuvenate*) led to slower reaction times and higher error rates than nonwords that were not classified as existing stems (e.g. *pertoire* from *repertoire*). The classification into stems (*juvenate*) and pseudostems (*pertoire*) was established on the basis of both etymological considerations and meaning compositionality. Taft and Forster (1975) argued that while the prefix *re-* "contributed to the meaning of the word" in *rejuvenate* (p. 640), this was not the case for *repertoire*. Response delays for items like *juvenate* were thus explained on the grounds that a match with an existent entry in the mental lexicon was instantiating an interference effect, suggesting that bound stems (e.g. *juvenate*) were directly represented in the mental lexicon. This interference effect was also observed when existing stems were combined with prefixes into novel complex forms such as *dejuvenate*. Classifying complex novel forms such as *dejuvenate* again led to longer response latencies and higher error rates than for nonwords such as *depertoire* in which the embedded fragment *pertoire* was considered a pseudostem. On the basis of these results, the model put forward by Taft and Forster (1975) included an obligatory morphological analysis that precedes the lexical search process for the whole word. Alternative models in which the order of application is reversed, meaning that a search for the whole word is instantiated first before morphological decomposition could apply, are also discussed. These are, however, considered incompatible with earlier results by

Taft, Forster and Garrett (1974) that revealed no differences in recognition latencies between prefixed words (e.g. *rejuvenate*) and nonprefixed words such as *somersault*. In this context, Taft and Forster (1975) make the *a priori* assumption that complex words such as *rejuvenate* must be stored under the stem *juvenate* and that an existing entry for *rejuvenate* is thus not available. On the other hand, if one were to suppose that *rejuvenate* can in principle also be retrieved holistically, the results reported by Taft, Forster and Garrett (1974) could also be reconciled with whole word retrieval.

This leads to an important consideration with regard to possible processing differences between existing complex words and nonwords. While Taft and Forster (1975) propose a full parsing model that involves morphological decomposition for all complex items, the empirical evidence advanced is based on the processing patterns seen for different types of nonwords. These include both prefixed and pseudo-prefixed nonwords (*dejuvenate* versus *depertoire*), as well as their embedded stems and pseudostems (*juvenate* versus *pertoire*), which also do not exist in the language. We will pre-empt the discussion of a possible caveat of this approach, namely that these conclusions are reached based on processing evidence from nonwords, rather than existing complex words.

As we shall see in 2.3.2, Butterworth (1983) contends that a morphological analysis of complex words is only warranted as a 'fall-back procedure'. In this context, it could be argued that the evidence seen for morphological decomposition in Taft and Forster (1975) is not necessarily reflective of the general mechanisms involved in word recognition, but emerges as a side effect of probing morphological decomposition in nonwords, rather than existing words that could be expected to have a lexical representation. Evidence against this view could be advanced based on the observation that the components that modulate the recognition process in Taft and Forster (1975) are stems and these have been shown to affect the recognition process in existing words as well. Thus, a number of studies have shown that lexical decisions are affected by lemma frequency as the summed frequency of all inflectional variants of the base (e.g. Alegre & Gordon, 1999; Burani, Salmaso, & Caramazza, 1984; Clahsen, Eisenbeiss, & Sonnenstuhl-Henning, 1997; Colombo & Burani, 2002). Similarly, for derived words, the frequency of the base has been shown to influence the processing of the complex word itself (Bradley, 1979; Meunier & Segui, 1999). Moreover, as demonstrated by Ford, Davis and Marslen-Wilson (2010), the base frequency effect is independent of morphological family size and thus an important independent factor in the processing of morphological complexity.

More recently, another variant of a *full-decomposition model* was put forward by Stockall and Marantz (2006) on the basis of two overt priming experiments (prime duration 200 ms) in which both MEG response latencies and RTs were recorded. Stockall and Marantz (2006) focused on effects of decomposition for regularly and irregularly inflected past tense forms in English and found that regularly and irregularly inflected forms led to equivalent priming effects of their roots. For Stockall and Marantz (2006), morphological priming is understood as facilitation through activation of the same root morpheme, regardless of whether a prime word takes a different surface form of the root than its target. Based on a previous cross-modal priming experiment by Allen and Badecker (2002), Stockall and Marantz (2006) selected two sets of irregularly inflected verbs that differed in the degree of overlap with their respective base words, in addition to identity controls and an orthographic control condition. The pairs in the orthographic condition mirrored common alternations in stem allomorphy for irregular verbs, but were not morphologically related such as (*book* - *bake*). An overview of the experimental conditions selected by Stockall and Marantz (2006) for Experiment 1 is given in Table 2.1.

Table 2.1 *Experimental conditions for Experiment 1 (Stockall & Marantz, 2006)*

Example Stimulus Set

Condition		**Prime**	**Target**
I	Irregular Low Overlap	taught	teach
II	Irregular High Overlap	gave	give
III	Identity	boil	boil
IV	Orthographic Overlap	curt	cart

Priming responses were measured (1) as the effect on M350 latencies and (2) as response latencies to the target. For the latencies of the M350 component, it was found that differences emerged for the identity condition, as well as the two morphological conditions with varying degrees of overlap. Orthographic controls only showed a trend towards facilitation ($p < .1$), which did not reach significance. In the reaction time analysis, an entirely different pattern was discernible. Reaction times were only significantly faster following related primes in the identity condition and the morphological condition with a high degree of overlap between prime and target. Orthographic controls exhibited the opposite pattern from the neural responses captured through the M350 component, whereby responses following related primes were in fact slowed down compared to unrelated controls. These patterns are argued to reflect separate stages of word recognition, in which an initial stage of root activation is succeeded by interference effects between lexical candidates. In a follow-up experiment, the direction of prime-target presentation was reversed and regularly inflected past tense forms and their base words were included (e.g. *date* - *dated*). There was no identity condition in this experiment, but orthographic controls were now selected to display both orthographic and semantic overlap without an inherent morphological relationship such as *boil* - *broil* and *screech* - *scream* (see Table 2.2 for an overview of conditions).

Table 2.2 *Experimental conditions for Experiment 2 (Stockall & Marantz, 2006)*

Example Stimulus Set

Condition		**Prime**	**Target**
I	Irregular Low Overlap	teach	taught
II	Irregular High Overlap	give	gave
III	Regular Verb	date	dated
IV	+S+O-M	boil	broil

The analysis of M350 latencies revealed that only for morphologically related pairs, but not in the semantic and orthographic control condition, did targets preceded by a related prime show an earlier evoked M350 response. In the RT data, all morphologically related pairs - whether or not their relationship was expressed through a high degree of formal overlap - led to significant priming effects. No such effect was observable for pairs that were related in meaning and form (e.g. *broil* - *boil*), but were not morphologically related. Crucially, the absence of any effects for the condition {+ S, + O, - M} suggests that the morphological effects observed could not be easily reduced to joint contributions from semantic relatedness and orthographic overlap.

2.3.2 Full-listing models: whole word storage and connectionism

Under a full-listing hypothesis as proposed by Butterworth (1983), the claim is made that the unit of lexical access is the whole word for both simple and morphologically complex words. All existing words are stored separately and in an undecomposed form. Proponents of full form representation models argue that given the capacity of our declarative memory – the part of our memory system that enables us to store factual knowledge – there is no reason to assume that questions pertaining to parsimony should carry any weight in the debate. Morphological information as such is thus not necessary in order to recognize morphologically complex words. As argued by Butterworth (1983), the implication is not that speakers possess no sensitivity to regularities in the relationships between words, but that the mental lexicon is not organized according to morphological criteria, especially for existing words. This point is important since the main focus of this thesis is on the processing of complex pseudowords, which are, by definition, not listed in the mental lexicon.

In view of growing evidence for the importance of the stem in visual word recognition (see 2.2.1), more recent *full-listing models* have suggested that these experimental findings can also be explained without invoking a purely morphological component in word recognition. Instead, many so-called *connectionist models* (cf. McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989; Seidenberg & Gonnermann, 2000) rely on the interaction between semantics and form overlap to account for priming effects between morphologically related items. In these models, morphological information plays no role in the representation and processing of existing words, but rather emerges as an epiphenomenon of the combined effects of semantics and phonology. Under these accounts, base frequency effects are argued to be reducible to the automatic activation of words in the lexicon that display a high degree of formal and semantic overlap with the base word. Inevitably, this will result in the activation of morphologically related words.

At the same time, surface frequency effects have also been reported in the literature, suggesting that the frequency of the whole word modulates processing (Taft, 1979; Clahsen, Sonnenstuhl, & Blevins, 2002). As with base frequency, effects of surface frequency are compatible with both *full-decomposition* and *full-listing* approaches. Under a *full-listing* account, surface frequency effects are expected given that the surface form is considered to be the unit of representation. In *supra-lexical models* (Giraudo & Grainger, 2000) of word recognition, for instance, complex words such as *dealer* are recognized based on their whole word representation. It is therefore expected that the surface frequency of the whole word would affect recognition. In these models, information about morphological structure only becomes available after lexical identification has taken place and therefore surface frequency effects inevitably modulate word recognition. Under decompositional accounts (e.g. Taft & Forster, 1975), it has been proposed that following obligatory decomposition and a search process for the stem in the mental lexicon, a recombination process ensues, whereby the validity of the construction composed of stem and affix is inspected. Surface frequency effects could arise as a result of the recombination procedure that checks the validity of a whole word form for the combination between stem and affix. Alternatively, an attempt at reconciling the joint contribution of both base and surface frequency effects has been made in so-called 'mixed' or 'dual-route' models as will be discussed in section 2.3.3.

2.3.3 Mixed or Dual-route: race models and concurrent routes for word recognition

As sketched out previously, a number of models can be placed somewhere along the continuum between the two extreme positions of *full-decomposition* versus *full-listing*.

The *AAM* (*Augmented Addressed Morphology*) model by Caramazza, Laudanna and Romani (1988), for instance, is based on the availability of two concurrent routes for word recognition. Words can be recognized both through direct access and through decomposition. An important aspect of the model centres on the idea that words are initially recognized holistically when they are familiar, but morphological constituents become available for complex items that speakers have not encountered before (Caramazza, Laudanna, & Romani, 1988; Laudanna & Burani, 1985). As both routes are available during word recognition, the *AAM* model accommodates both base and surface frequency effects. The predictions made with regard to the preferred processing route are clear: no morphological decomposition takes place for known (that is, previously encountered) words as the direct access route reaches the expected threshold for activation faster than a parsing procedure into its morphological units. Parsing is, however, triggered during the processing of nonwords (p. 301). The *AAM* model can be interpreted as a race model between the two routes, but with a clear separation in their applicability for word versus nonword processing. While both routes are available, there is no temporal overlap for the time frame at which the routes are operative. The direct route precedes morphological decomposition, which is only activated when no existing lexical entry is available. Under this view, real word and nonword processing patterns are both temporally and qualitatively distinct. Other race models such as the *Morphological Race Model* (Frauenfelder & Schreuder, 1992) permit the simultaneous activation of both processing routes, resulting in a less stringent separation of the cognitive processing routes for existing words versus nonwords. In the *Morphological Race Model*, both processing routes run in parallel. For certain morphologically complex words, either route can lead to successful word recognition. Heuristics for determining which route is preferred touch on the token frequency of the word, with higher-frequency words being accessed via the direct route. For the morphological parsing route, the "inherent (i.e. transparency) and the distributional (i.e. frequency) properties" (p. 176) of the complex word are argued to affect recognition times. These so-called "inherent" lexical patterns pertain to (1) the phonological transparency between a derived word and its base with regard to vowel quality, stress pattern etc. and (2) the semantic coherence as a measure of the predictability of the meaning of a derived word.

Frauenfelder and Schreuder (1992) also lay out the predictions that the *Morphological Race Model* makes with regard to the incorporation of novel morphologically complex words into the existing mental lexicon. Upon first exposure to a morphologically complex word, only the morphological parsing route is available for processing. Following a number of successive presentations of the item in question, the direct route takes precedence as a full-form representation emerges for the relevant morpheme combinations. For existing words, frequency as well as what the authors term the 'parsability' of the word and the cumulative frequency of its morphological constituents are argued to be deciding factors in the selection of one route over the other. Parsability is suggested to be highest for transparent morphologically complex words, which, as the authors point out, often coincides with their property of being derived on the basis of productive affixes. Moreover, a discussion of the relative merits and drawbacks of the two processing routes is put forward for languages other than English with the conclusion that the prevalence of one route over the other may differ depending on the morphological properties of the language. Thus, in agglutinative languages such as Turkish, speakers are encountering novel forms much more frequently than in English, and thereby arguably show a stronger reliance on the parsing route.

In other *Dual-Route models*, it is proposed that properties of complex words such as the regularity of their formation are crucial factors with regard to the preferred processing route. Pinker (1997), for instance, claimed that English verbs, whose past tense is formed through rule application with the *-ed* suffix are decomposed while irregular past tense forms in English verbs (e.g. *sang*; *thought*; *caught* etc.) are stored and accessed holistically. Again, properties relating to the affix in question are thus advanced as decisive with regard to the expected processing patterns. In other partial decomposition models, processing differences between different types of morphological processes are proposed. Based on the results of a repetition priming experiment, Stanners, Neiser, Hernon & Hall (1979) propose that the processing of inflected forms proceeds through the activation of the base word and is therefore fully decompositional while derived forms are retrieved directly from lexical representations that are separate from their base.

2.4 Modality-specific aspects of morphological processing

There are significant and obvious differences between visual and auditory word processing. These differences clearly relate to both the form and the time course during which the sensory information becomes available.

An auditory stimulus can only be presented to the listener in a strictly left-to-right fashion, meaning that disambiguating information becomes available incrementally. In visual word recognition, the incoming sensory information is presented holistically, giving the processor the possibility of evaluating information in a temporally less transient way. Even though the access routes towards a word vary between visual and auditory processing, they must eventually converge on the same representation, containing congruent information about the lexical entry.

In this section, the purpose is to review the main characteristics of the processing routes that are modality-specific, before discussing how these integrate to lead to a more abstract, modality-independent representation. Marslen-Wilson, Tyler, Waksler and Older (1994) point to the importance of distinguishing between the lexical entry for a given word as compared to its access representation. According to Marslen-Wilson et al. (1994), a word's lexical entry contains core information about its semantic and syntactic properties. This representation is modality-independent and therefore of a phonologically more abstract nature. Within the word recognition process, it is possible that this representation is accessed only after a more detailed, modality-specific access representation has been tapped into. The association between the incoming sensory information and the access representation is tighter, thereby making the specific auditory and visual information encapsulated in our access representation more comprehensive. With regard to our aforementioned survey of possible models of lexical representation, this means that it is also possible that the architecture of our access representation differs from the way in which it is implemented at a more modality-independent level. In the following two sections, we will review the experimental findings pertaining to both modalities individually, before considering how a more abstract level of representation may be laid out.

2.4.1 Morphology in auditory word recognition

A number of models of spoken word recognition have been proposed. Two of the most influential models have been the *Cohort Model* (Marslen-Wilson & Welsh, 1978; Marslen-Wilson, 1987; Marslen-Wilson & Tyler, 1980) and the *TRACE Model* (McClelland & Elman, 1986). The two models differ with regard to claims concerning the modularity of the speech recognition process with the latter model showing a stronger emphasis on top-down effects in perception. More precisely, this means that higher-level representations, whether syntactic, semantic or contextual, are said to affect and coincide with the recognition process at lower, more directly perceptual levels. The *Cohort Model* is based on the assumption that the information that can be retrieved from the speech signal is linear and sequential. As the speech signal unfolds, a set of possible lexical candidates that are congruent with the speech signal is activated. Candidates are eliminated as soon as they cease to match the incoming speech signal, regardless of the contextual fit of the lexical candidates. Early empirical investigations into auditory word recognition indeed provided evidence for the activation of a set of cohort-compatible lexical candidates during sentence processing. To give an example, in Zwitserlood (1989), a highly predictive sentence such as *'With dampened spirits the men stood around the grave. They mourned the loss of their cap…'* would activate both the predicted word *captain*, as well the cohort competitor *capital* even though the latter is contextually ill-suited. The role of top-down effects has moreover been challenged in view of evidence that contextual effects in speech perception are primarily attested with perceptually degraded stimuli (cf. Burton, Baum & Blumstein, 1989). On the basis of this, the *Cohort Model* has incorporated more contextual elements in its revised implementation, whilst maintaining a strictly linear recognition process in which possible lexical candidates become activated and eliminated incrementally as more perceptual information becomes available. In more recent versions of the *Cohort Model*, the selection and elimination of lexical candidates is more probabilistic, rather than all-or-none.

Within the context of morphological complexity processing, one might argue that the predictions of the *Cohort Model* have clear implications for the auditory recognition of morphologically related words. Since morphologically related words commonly display at least partial overlap in their acoustic realization, competition effects can be expected until the *uniqueness point* (as the point at which the signal is only compatible with one of the remaining activated lexical candidates) for one of the lexical candidates is reached. Note that differences in when a given word's *uniqueness point* is reached can be expected to yield processing differences between, for instance, prefixed and suffixed words for languages that express morphological complexity through affixation. Crucially, the situation is complicated further by the fact that the size of the *morphological cohort* activated during word recognition will depend on the number of different 'competing' lexical candidates and therefore entries.

Again, this brings us back to the notion of morphological representation and whether co-activated morphologically related candidates share a representation, or are stored under separate entries that partake in a similar phonological cohort competition process as morphologically unrelated words, just like *captain* and *capital* in Zwitserlood (1989). The evidence to be reviewed in this section will mainly focus on the auditory processing of morphologically complex words presented in isolation, rather than in a sentential context. Top-down effects from higher-level representations, while possibly to be expected in real language processing, should therefore not play into the experimental findings presented below. It should thus be possible to work with the assumptions of a *Cohort model* as a means of gaining an understanding as to which representations enter into a lexical competition process during auditory word recognition.

In a series of experiments looking into the neurobiological organization of language processing and auditory word recognition, the processing patterns for inflectional and derivational morphological complexity in languages with concatenative morphology such as English, Polish and Italian were investigated (for an overview: Bozic & Marslen-Wilson, 2010; Bozic, Szlachta, & Marslen-Wilson, 2013; Bozic, Fonteneau, Su, & Marslen-Wilson, 2015; Carota, Bozic, & Marslen-Wilson, 2016). The argument was made that the neurobiological organization of language comprehension could be described as twofold on the basis of prior neuroimaging investigations: general perceptual comprehension processes have been shown to display neural underpinnings in bilateral superior, middle and inferior temporal areas (Hickok & Poeppel, 2007) with little evidence for left-lateralization in these cases. Crucially, the neural correlates of syntactic complexity processing and general grammatical analysis have been related to left frontotemporal processing circuits in both lesion studies (Longworth, Marslen-Wilson, Randall, & Tyler, 2005) and investigations using neuroimaging studies with healthy participants (for syntactic processing: Friederici, Fiebach, Schlesewsky, Bornkessel, & von Cramon, 2006; for morphological processing: Lehtohnen, Vorobyev, Hugdahl, Tuokkola, & Laine, 2006; Szlachta, Bozic, Jelowicka, & Marslen-Wilson, 2012).

In the context of morphological processing in the auditory domain, Marslen-Wilson and colleagues consistently found differences between inflectional and derivational complexity processing across a number of studies. Marslen-Wilson and Tyler (2007) report that inflectional morphological processes engaged the left frontotemporal processing circuits including the *left inferior frontal gyrus* (LIFG) - an area of the brain that has been shown to be sensitive to combinatorial processing. For derivational morphology, on the other hand, no evidence for selective activation in the LIFG was discernible – not even for semantically transparent pairs such as *brave* and *bravely* where adverb formation using the suffix -*ly* is moreover highly productive and regular (Bozic, Tyler, & Marslen-Wilson, 2009). Derivational morphological processes were shown to engage the bihemispheric system as a reflection of increased perceptual competition between derived forms and their stems. For highly productive derivational processes (e.g. derivation of *bravely* from *brave*), the pattern of activation observed for the derived word was in fact more similar to morphologically simplex words such as *giraffe* with no evidence for an increase in bilateral activation in these cases. On the basis of this, the authors concluded that derived words were stored separately and holistically with the possibility that highly productive derived words such as *bravely* were subject to decompositional processes given the absence of any evidence for perceptual competition effects. Note that while these generalizations hold across languages with concatenative morphology such as English and Polish, a strict separation of processing patterns in auditory word recognition for derivational versus inflectional morphology is not tenable cross-linguistically in view of empirical evidence from Arabic (Marslen-Wilson, Bozic, & Tyler, 2014).

In Arabic, derivation patterned with inflection, suggesting that there was more evidence for across-the-board decomposition in the language overall. In order to account for these cross-linguistic differences, it is crucial to consider that form in which morphological information is conveyed in the language (through concatenation of morphemes versus non-linearly through templatic patterns) could affect the time point at which information about morphological complexity must become available. To illustrate this, it is helpful to think about the disambiguation point for suffixed words in concatenative morphology during auditory word recognition as predicted by the *Cohort Model*. In order to differentiate between morphologically complex words such as *teacher* and their corresponding base forms (i.e. in this case *teach*), the entire string of the base word needs to have been processed so as to establish which word form was intended. The amount of time that the two word forms are in direct perceptual competition with one another is therefore substantial and can encompass the entire duration of the base form. In Arabic, every single word is composed of a root and word pattern combination. As the word pattern provides clues concerning the morphological properties of the word before it is processed fully, it is possible to differentiate between morphological derivates at a much earlier stage than in languages that rely on concatenative mechanisms to express morphological complexity. This differentiation can effectively be expected to surface as the morphological decomposition process that engages left frontotemporal processing circuits.

Thus, *-aa-i-* is a word pattern that signals an agentive meaning, corresponding to the function fulfilled by the *-er* suffix in English. When intertwined with a root such as *k-t-b* ('to write'), the incremental nature of the speech signal enables speakers to differentiate between morphologically related forms at a much earlier stage than for most suffixed items in concatenative morphology, namely as soon as the vocalic word pattern is presented. The two pieces of information are thus possibly processed as units on separate tiers that need to be analysed jointly to extract a meaning. Neurobiological evidence for distinct neural correlates for consonantal roots versus vocalic word patterns in Arabic is indeed reported in Boudelaa, Pulvermüller, Hauk, Shtyrov and Marslen-Wilson (2010). If, as we have argued, the linearity of the unfolding information extracted from the speech signal plays a paramount role in auditory speech processing, the processing pattern for prefixed words in concatenative morphology could be expected to be different from that for suffixation. This is because in prefixed items, morphological information about the complex word is delivered at a much earlier point and from the perspective of the *Cohort Model*, there is thus no direct competition between prefixed items and their bases.

Neuroimaging evidence for prefixation is yet to be conducted, but from a behavioural perspective, Schriefers, Zwitserlood and Roeloefs (1991) conducted a comprehensive study into the processing of prefixation in Dutch. Gating and phoneme monitoring tasks were employed in order to investigate whether prefixed words would be processed incrementally and holistically, or whether there would be evidence for decomposition during the recognition process. In a gating task, participants hear words in increments and are asked to indicate when they have identified the word in question. Phoneme monitoring tasks require participants to scan incoming speech for a particular phoneme and to indicate when this particular phoneme is perceived. In the first experiment, the experiments compared the processing of a morphologically simple verb such as *staan* (V, 'to stand') in Dutch with its prefixed variants such as *toestaan* and *opstaan*. Crucially, the two sets of prefixed words differed in the position of their *uniqueness point*. While words like *opstaan* possess the same *uniqueness point* as their base word *staan*, the *uniqueness point* for *toestaan* is situated earlier within the word. This situation raises the question whether or not items like *toestaan* would be identified earlier in a gating task. The results showed, however, that both types of prefixed items - the *opstaan* and the *toestaan* set - were identified prior to their respective base form *staan*. In a subsequent phoneme monitoring task in which participants were asked to scan the incoming auditory signal for the phoneme /n/, prefixed items again patterned together. Phonemes in prefixed words were recognized significantly faster than in their stems. This disconfirms the predictions of the *Cohort Model* that all spoken words are processed continuously in a strictly linear way. Instead, it appears that the morphological status of the item (prefixed versus unprefixed) modulates auditory processing. In a follow-up experiment, the processing of prefixed verbs for which the *uniqueness point* was either early (e.g. *leren*, (V, 'to learn')) or late (e.g. *leveren*, (V., ‘to deliver’) in the stem form was compared. Crucially, in the prefixed variants, the *uniqueness points* for both conditions were matched (see Table 2.3).

Table 2.3 *Overview of experimental conditions in gating and phoneme monitoring experiments (Schriefers et al., 1991) with uniqueness point marked by capitalization*

	STEM	**PREFIXED FORM**
EARLY	leRen (V., 'teach')	af-leRen (V., 'unlearn')
LATE	leveRen (V., 'supply')	af-leVeren (V., 'deliver')

In line with the previous study, a processing advantage of prefixed over unprefixed forms was found with both types of prefixed verbs being identified before their respective stems. The comparison between the two stem forms, on the other hand, demonstrated faster recognition of stems with earlier *uniqueness points*. As the items in the two conditions were not matched for stem frequency, it is difficult to tease apart whether the differential effect between the two stem forms was driven by the *uniqueness point* or by the frequency of the stem, but it does become clear that auditory word recognition cannot proceed strictly left-to-right given that properties of the stem (whether it was indeed the stem frequency or the *uniqueness point* of the stem form) influenced the recognition of the prefixed variant. Items like *afleren* (whose stem has an early *uniqueness point*) were recognized faster than items having stems with later *uniqueness points*. All things considered, it appears that both morphological properties, as well as factors pertaining to a word's *uniqueness point* and thus incremental left-to-right processing play a role in auditory word recognition.

The role of morphological complexity in auditory word recognition was also taken up in a recent MEG study by Ettinger, Linzen and Marantz (2014) in which the authors investigated the relationship between morphological complexity and input prediction. The onsets of both monomorphemic and bimorphemic items were paired with two sets of continuations. These consisted of either high- or low-surprisal continuations of a shared stem (for morphologically complex items) or a shared onset string (for morphologically simple items). The authors found that the presence of morphological complexity stimulated predictive processes, resulting in a stronger surprisal effect in these items than in monomorphemic words. Evidence from this study offers further support to theories that allow access to information about the stem during the processing of complex words. Crucially, this information can only be retrieved through the application of a morphological analysis. Again, this is an argument against the sole involvement of incremental, left-to-right processing strategies for morphologically complex words in auditory word recognition.

Nonetheless, despite some evidence that the auditory word recognition of complex words is not reducible to a linear matching procedure, differences between the auditory and visual processing routes are worth considering. Emmorey (1987), for instance, presents the results of a lexical decision task with different types of nonwords in which the two modalities are contrasted directly. The nonwords consisted of noncomplex controls (e.g. **harvame*), suffixed nonword stems (e.g. **garnly*), word-initial nonwords (e.g. **cagelo*), as well as suffixed existing words (e.g. **crushly*). In line with the predictions of the *Cohort Model*, suffixed nonword stems such as **garnly* only led to interference effects in visual word recognition, but not in the auditory domain. This is argued to be the case since a non-match result with existing lexical entries was already attained before the suffix *-ly* was presented, suggesting that suffixes were not identified independently of the base in auditory word processing. In both modalities, however, nonwords consisting of existing stems (e.g. *crush*) and suffixes (e.g. *-ly*) led to the most extended reaction times, arguably as a reflection of increased processing demands induced by checking the compatibility of the stem-affix combination. Thus, while processing consequences relating to the nature of the relevant modality are to be taken into consideration, the underlying linguistic constraints that shape morphological processing may not be too dissimilar. In the following section, we will outline some major findings related to the visual recognition of morphological complexity before turning to the notion of abstractness in modality-independent representations.

2.4.2 Morphology in visual word recognition

The role of morphological processes in the recognition of visually presented words has generated a large volume of research ever since Taft and Forster's (1975) early proposals of a morphologically structured lexicon that is accessed through an *affix-stripping* procedure. Recall that in a series of experiments looking into the processing of pseudowords, Taft and Forster (1975) found that prefixed pseudowords such as **dejuvenate* took significantly longer to be classified as nonwords in a lexical decision task than noncomplex nonwords such as **depertoire*. The key difference between the two non-existent items was argued to relate to the retrieval of an existing real stem form *juvenate* (from *rejuvenate*). This was achieved through the 'stripping' of the affix *de-* in *dejuvenate.* Much of the research that followed these early findings has corroborated the hypothesis that affixed words are segmented into their constituents in visual word recognition, especially during the early stages of word processing. Longtin, Segui and Hallé (2003) put forward a strong case for an early segmentation process into stems and affixes by showing that any word that could be demarcated into viable morphological constituents through its surface morphology induced significant priming effects in French, unlike purely orthographically related controls. Neither semantic transparency between prime and target (e.g. *gaufrette* (N., 'wafer') and *gaufre* (N., 'waffle')), nor an etymological morphological link (e.g. *fauvette* (N., 'warbler') and *fauve* (N., 'wildcat')) between prime and target were necessary for priming effects to emerge. Instead, words such as *baguette* (N., 'little stick') that - based on surface-level segmentation procedures - can be partitioned into a morphologically unrelated stem *bague* (N., 'ring') and an existing suffix *-ette* primed their embedded target word *bague* in a masked priming experiment. Moreover, the degree of priming was not modulated by semantic transparency or an existing morphological relationship; that is, transparently related pairs (e.g. *gaufrette – gaufre*) did not induce a stronger priming effect.

Similar findings were later reported for English (Rastle, Davis & New, 2004), also using a masked priming paradigm. Again, a synchronically transparent semantic relationship between prime and target did not appear to constrain the application of morphological decomposition at this early stage of visual word recognition, with pairs such as *corner* and *corn* or *brother* and *broth* showing facilitation while this was not the case for orthographically related control pairs such as *brothel* and *broth*. Masked priming arguably taps into the very early processes of word processing by minimizing the possibility for conscious perception of the prime word. This is achieved by reducing the duration of presentation of the prime to less than 70 ms. In another masked priming study, Longtin and Meunier (2005) further addressed the question whether the effects observed were partly driven by orthographic similarity. The authors compared the processing of pseudowords that were composed of an existing stem and its combination with an existing suffix such as **rapidifier* with other non-existent items containing endings that occur at the end of French words, but do not function as existing suffixes in the French language (i.e. *uit*). It was found that simple letter overlap and a high degree of visual similarity to the target, as in **rapiduit*, was not sufficient to lead to a priming effect. This suggests that an *affix-stripping* mechanism was applied to those items that were composed of existing stems and viable suffixes, whether the form in its entirety was in fact morphologically complex or not.

Considering the findings reported in the aforementioned studies, the effects observed during the early stages of visual word recognition appear to ignore lexical information associated with specific entries. Instead, more general knowledge of what constitutes a suffix in the given language is manifested in the stripping of letter strings that constitute affixes in these stages of processing.

Whiting, Shtyrov and Marslen-Wilson (2015) established a timeline for the processes involved in visual word recognition through a simple viewing paradigm in MEG (see Figure 2.5). At around 300-370 ms after the visual stimulus was presented, differential brain activity between sets of morphologically simple and morphologically complex items could be detected. Contrasts in activity between inflected and noncomplex words were discernible in left lateralized inferior frontal and middle temporal regions as early as 300-320 ms after stimulus presentation. Similar contrasts emerged between derived and noncomplex words at around 330-340 ms.

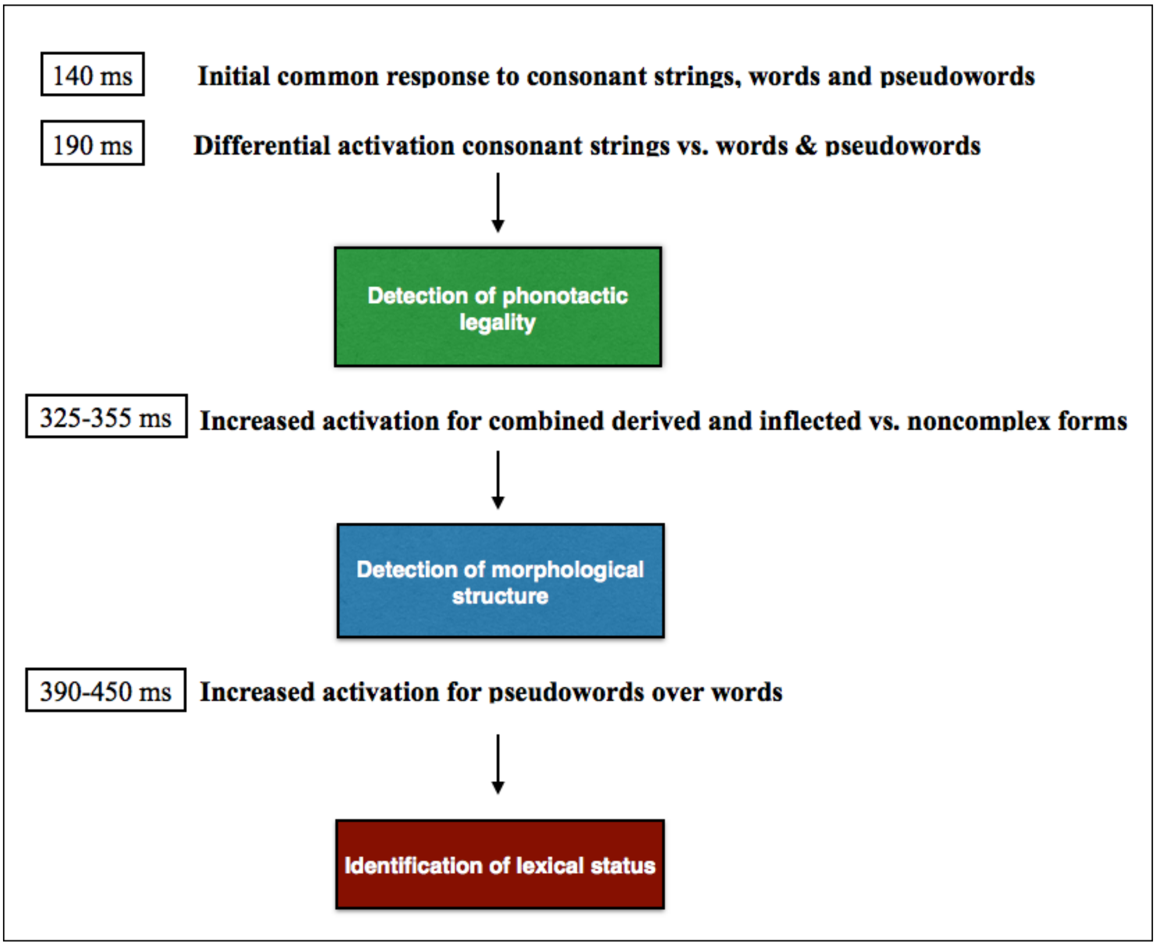

Figure 2.5 *Timeline for visual word recognition based on findings reported by Whiting et al. (2015)*

The 'complex' sets included two subgroups consisting of (1) pseudo-derived monomorphemic (e.g. *corner*) and (2) morphologically complex real derived words such as *farmer*. No differences were found between these two subgroups in the given time window, suggesting that it is likely to coincide with the early stages of visual word recognition into which masked priming provides an insight. The authors underscore that these orthographically-driven segmentation processes observed under masked priming require access to both a potential stem and a potential affix, regardless of whether their combination yields a word that is morphologically complex (e.g. *corner*, *ashed*). This is because monomorphemic words that were composed of a viable suffix such as *-ish,* but a non-existent stem such as *blem-* patterned with other morphologically simple existing words such as *scandal* in the given time window, showing no evidence for segmentation processes based on surface morphology. In a complementary analysis of differences in activation between morphologically simple words and pseudowords, divergences in processing emerged at a later stage (around 390-500 ms following stimulus presentation). Similarly, a comparison between pseudo-complex items such as *corner* or *ashed* with their corresponding semantically transparent conditions (e.g. *farmer*) revealed analogous spatial and temporal distributions in which pseudo-complex items elicited increased processing over complex items within left anterior frontal magnetometers. Within the context of the *affix-stripping* model as proposed by Taft and Forster (1975), this processing stage could correspond to a recombination procedure for stems and affixes that takes place once lexical information becomes accessible and can permeate the word recognition process.

Overall, we see that the kind of morphological knowledge that is utilized during visual word processing shifts over the time course of morphological processing, even though there is some evidence from a number of investigations pointing to earlier effects of meaning compositionality that are already operative at the initial segmentation stage as in Feldman, O'Connor and Moscoso del Prado Martin (2009). Initially, we see a reliance on orthographically driven segmentation processes that subsequently give way to lexically informed checking procedures. The detection of units that function as morphological constituents in a given language such as *-er* in *corner* versus *-el* in *brothel* builds a strong case for the argument that morphological knowledge shapes visual word recognition.

However, the question we will need to address is whether the paradigms employed to study visual word recognition such as masked priming are able to provide an insight into the architecture of our linguistic knowledge and representations or whether we might be tapping into the access routes that are mainly relevant given the respective modality. For instance, fMRI studies of morphological processing using masked priming paradigms (e.g. Gold & Rastle, 2007) have reported increased activation in middle occipital areas, reflecting morpho-orthographic segmentation processes that develop in parallel with reading acquisition. Based on our discussion, it would hence also be plausible to presume that *affix-stripping* functions as a processing strategy that is specific to the visual domain and facilitates the fast recognition of familiar letter strings without necessarily painting an accurate picture of the architectures and mechanisms supporting our language system. In the next section, we therefore turn to a discussion of abstract representations versus modality-specific access routes that may draw on particular access strategies.

2.4.3 Abstractness in modality-independent representations

Marslen-Wilson et al. (1994) motivated the use of a cross-modal priming paradigm in an attempt to further our understanding of the modality-independent, abstract organization of the mental lexicon and the role of morphology therein. The authors argued that a change in modality within the presentation of the prime-target pairs could grant access to a type of representation that is abstract and illustrative of the more general linguistic knowledge that we are endowed with. In a series of six experiments, the relationship between an auditory word and a visually presented target was varied systematically by investigating morphological decomposition in both prefixation and suffixation. These investigations were complemented by a further manipulation, namely the degree to which the relationship between prime and target was semantically transparent. Thus, suffixed derived words such as *government* were paired with their base *govern* and compared with pairings that did not display a semantically transparent relationship such as *department* and *depart*. Throughout the experiment, semantic transparency emerged as a necessary condition that had to be met for priming to occur. Thus, *department* did not show facilitation for *depart*, leading the authors to the conclusion that these two items were not subsumed under the same entry in the mental lexicon. Under such a representation, the lexical entry for *department* would in this case lend itself to the derivation of semantically related morphological derivates such as *departmental*, whereas the lexical entry for *depart* would be the starting point for deriving morphologically related words such as *departure*.

Similarly, for prefixed forms, semantic transparency modulated morphological decomposition as seen in the absence of priming for pairs like *restrain* and *strain*. Converging evidence for this is presented in Longtin et al. (2003). Using the same set of stimuli as for their masked priming experiment discussed in 2.4.2, a pattern akin to the results described by Marslen-Wilson et al. (1994) emerged in a cross-modal priming paradigm. Only semantically transparent prime-target pairs such as *gaufrette* (N., 'wafer') and *gaufre* (N., 'waffle') showed evidence of a priming effect. The other two conditions consisting of morphologically related pairs that shared an etymological link, as well as pairs that displayed an accidental pseudo-morphological form overlap in the absence of a real morphological relationship (e.g. *baguette* - *bague*), did not lead to a priming effect. This suggests that the abstract, modality-independent representation tapped into through cross-modal priming is specified for semantic information. Note, however, that morphologically related words with a semantically opaque relationship have been shown to instantiate priming effects in Hebrew (Frost, Deutsch, Gilboa, Tannenbaum, & Marslen-Wilson, 2000) although the degree of priming was in fact more robust for prime-target pairs that were not only morphologically, but also semantically related. Despite these cross-linguistic differences, the effect of semantics on the more modality-independent processing stages that we probe into through cross-modal priming investigations is evident.

Thus, semantic transparency appears to constrain the links between lexical entries, suggesting a certain degree of specification with regard to their meaning representation. From a phonological perspective, the nature of these representations appears to be more abstract, as reflected in the presence of priming effects in Marslen-Wilson et al. (1994) between morphologically related words that show morpho-phonological alternations. Thus, *sincerity* primed its base word *sincere*, implying a mapping mechanism between different surface realizations onto an abstract underlying representation.

One important caveat in this series of experiments that hampers a clear interpretation of the aforementioned results concerns the presence of purely semantic priming, namely the facilitation between near-synonym pairs like *idea* and *notion.* On the one hand, it is indeed possible that given the substantial perceptual differences between word processing in the auditory versus the visual domain, an available semantic relationship functions as a necessary link to the joint abstract lexical entry. On the other hand, this raises the question whether purely morphological processes can be dissociated from a semantic link between items. On this account, this would imply that *sincerity* could have primed *sincere* based on an existing semantic link, rather than a morpho-phonological mapping procedure. Arguably, given the absence of priming for derived-derived suffixed pairs such as *government* and *governor*, which are also related in meaning, it becomes evident that a semantic relationship between words alone cannot account for the effects observed. Nonetheless, the question remains whether the more abstract, modality-independent representations we are endowed with contain an independent morphological layer of representation and what the nature of this knowledge would be. We have also been tacitly assuming that a cross-modal priming paradigm allows us to access more modality-independent representations, but have not considered the possibility that again, task-related factors may be introducing additional confounds that delimit the scope of enquiry. In the following section, we will therefore review evidence for autonomous morphological processes in word recognition and attempt to tease apart which factors affect the interplay between semantic, formal and morphological relationships in the processing of morphological complexity.

2.5 Autonomous morphology in word recognition: dissociations from semantics and form in different experimental paradigms

As has become apparent in the preceding sections, the role of morphology in word recognition surfaces differently depending on a number of factors such as the modality in which the input is presented. Another important consideration is undoubtedly the experimental paradigm employed given the dissociations we have been seen for visual word recognition. In this section, we will therefore turn to the relevance of the experimental task itself by re-examining the results obtained in the most commonly employed experimental paradigms.

2.5.1 Masked priming

In masked priming, the prime word is presented to participants for a very short duration only (usually less than 70 ms). Thereby, the possibility that participants will become conscious of having been presented with a stimulus other than the target can be minimized. In addition to a short prime duration, this experimental task relies on the presentation of a mask, which usually consists of a series of hash marks (Rastle, Davis, Marslen-Wilson, & Tyler, 2000), unpronounceable letter strings (Diependaele, Morris, Serota, Bertrand, & Grainger, 2013) or even an unrelated word (Forster & Davis, 1984). The presentation of the mask can either precede (*forward-masking*) the prime word; follow its prime (*backward-masking*) or combine both *forward* and *backward-masking*. The combination of these two factors - a short prime duration and the fact that its presentation is obscured by an unrelated string of characters - is conducive to reducing strategic effects that may arise when participants are aware of existing pairings between words, leading to expectations based on previously presented stimuli. Moreover, the interval between prime and target presentation is kept as short as possible in order to ensure that the depth of processing for the prime is minimized. This leads to the assumption that masked priming taps into the very early stages of word processing with the duration of prime presentation affecting the morphological processing in a priming paradigm.

Rastle et al. (2000), for instance, varied the display duration of the prime word and measured priming effects induced for prime durations of 43 ms, 72 ms and finally 230 ms. The patterns observed were found to differ depending on how much processing time was available for the prime. Pairs that were both morphologically and semantically related such as *departure* and *depart* showed priming effects in all three durations, while the absence of a semantic relationship between *apartment* and *apart* only led to a priming effect when the prime was presented for a very short duration (43 ms). Purely semantic effects, on the other hand, emerged for the later durations at 72 ms and 230 ms. While generalizations could be made that with shorter prime durations, the effect of semantic transparency has been shown to diminish, a number of studies (Diependaele, Sandra, &

Grainger, 2005; Diependaele, Sandra, & Grainger, 2009; Feldman et al., 2009) have reported an effect of semantic transparency at prime presentation durations as short as 40 ms. As discussed by Amenta and Crepaldi (2012), however, some of these effects can be attributed to methodological inconsistencies across studies. Amenta and Crepaldi point out that in some studies (Diependaele et al., 2005; Morris, Frank, Grainger, & Holcomb, 2007), a *backward*, rather than a *forward mask* was selected. In Feldman et al. (2009), the prime-target overlap between semantically transparent and semantically opaque pairs was not controlled for, meaning that the opaque set contained pairs in which stem alternations between prime and target pairs were less predictable than in the transparent set (e.g. *relay - RELATION; coin - COYNESS*).

With the exception of a study by Diependaele et al. (2009), in which equivalent facilitation between semantically transparent and opaque prime-target pairs could not be ascribed to differences in methodological procedures, the evidence for a processing stage during early visual word recognition that is not reliant on a transparent semantic relationship between prime and target, especially for very short prime durations, is robust according to Amenta and Crepaldi (2012).

Note moreover that investigations by Crepaldi, Rastle, Coltheart and Nickels (2010) demonstrated that these early priming effects are not restricted to cases in which a morphological segmentation process is straightforward from an orthographic point of view. Already in earlier investigations by McCormick, Rastle and Davis (2008), evidence was advanced that masked priming effects were robust with regard to minimal changes in orthographic structure that could have impeded a straightforward segmentation process into morphemes. In the aforementioned study, common spelling alternations between derived words and their bases such as deletions, additions or duplications of segments in pairs such as *adorable* - *adore*; *lover* - *love* and *dropper* - *drop* all failed to impede the instantiation of masked priming effects.

In Crepaldi et al. (2010), the focus was not on derived, but on inflected complex words. Using a masked priming experiment with a prime duration of 42 ms, irregularly inflected verbs such as *fell* were shown to facilitate the recognition of the morphologically related base word *fall* compared with both orthographically unrelated (e.g. *hope*), as well as orthographically matched but morphologically unrelated control words (e.g. *fill*). Clearly, the results reported by Crepaldi et al. (2010) cannot be explained on the basis of a morpho-orthographic segmentation process. There is no identifiable affix in *fell* that could be 'stripped' in order to lead to the base form *fall.* Could the priming effects observed in Crepaldi et al. (2010) emanate from a stronger semantic relationship, or, in fact, the possibility that inflected words share a lexical entry? The authors argue that even though the semantic overlap between inflectionally related words could be considered more substantial than in derived pairs, this account would still require an explanation as to why semantic effects have - notwithstanding the few exceptions mentioned previously - not produced a processing advantage for derived pairs that are semantically transparent (e.g. *darkness* - *dark*) over pairs that display a semantically opaque relationship such as *corner* and *corn* (Rastle et al., 2004).

On the basis of these overall findings, Crepaldi et al. (2010) put forward a model that could accommodate the priming effects observed between irregularly inflected past tense forms and their base verbs, in addition to the morpho-orthographic segmentation procedures seen in derivation. This model is reliant on previous work by Taft (e.g. Taft, 2003; 2004) in which word recognition requires activation at the level of the lemma. Crepaldi et al. (2010) build on this model to incorporate a number of modifications based on the findings reported in the masked priming literature. At the lemma level, inflectionally related word forms are subsumed under a single entry. This can account for the facilitation observed in classifying *fall* when preceded by its past tense form *fell*. Unlike Taft's model (2003; 2004), the lemma level here is not conceptualized as a layer of representation that relies on a morphemic organization with regard to its constituent units of representation. In Taft et al. (2003), these units include free stems (e.g. *hat*), bound stems (e.g. *navig*- from *navigate*), as well as derivational affixes (e.g. *-er*) and complex derived words (e.g. *cleaner*) that are activated through a joint contribution from their constituent morphemes. Instead, in Crepaldi et al.'s (2010) model, lemmas constitute lexical entries (p.92) as defined by their semantic and lexical-syntactic properties such as word class. No independent representations at the level of the lemma are assumed for inflected words in either model. For derived words, we have seen that Taft (2003) posits links between lemmas for constituent morphemes such as the stem *deal* and a suffix *-er* that propagate to the lemma of a complex derived word such as *dealer*. This situation does not arise in Crepaldi et al. (2010)'s revised model due to the application of a morpho-orthographic segmention procedure that splits segmentable complex words such as *dealer* into *deal* and *-er* before activation spreads to the lemma level. Since lemmas are understood as separate lexical entries based on their semantic and lexical-syntactic properties, derived words such as *deal* and *dealer* are presumed to be stored separately, just like *corn* and *corner*. The amount of activation received from the output of the morpho-orthographic segmentation procedure is thus equivalent for semantically transparent derived pairs such as *dealer* and *deal* and semantically opaque forms such as *corner* that will propagate to representations for both *corn* and *corner* at the lemma level. The model (Figure 2.6) sketched out by Crepaldi et al. (2010) also presents predictions for the processing of regularly inflected words that are subject to both a morpho-orthographic segmentation procedure, as well as direct propagation to a shared lemma entry. In this case, regularly inflected words would be expected to yield stronger priming effects than inflected words that do not lend themselves to morpho-orthographic segmentation.

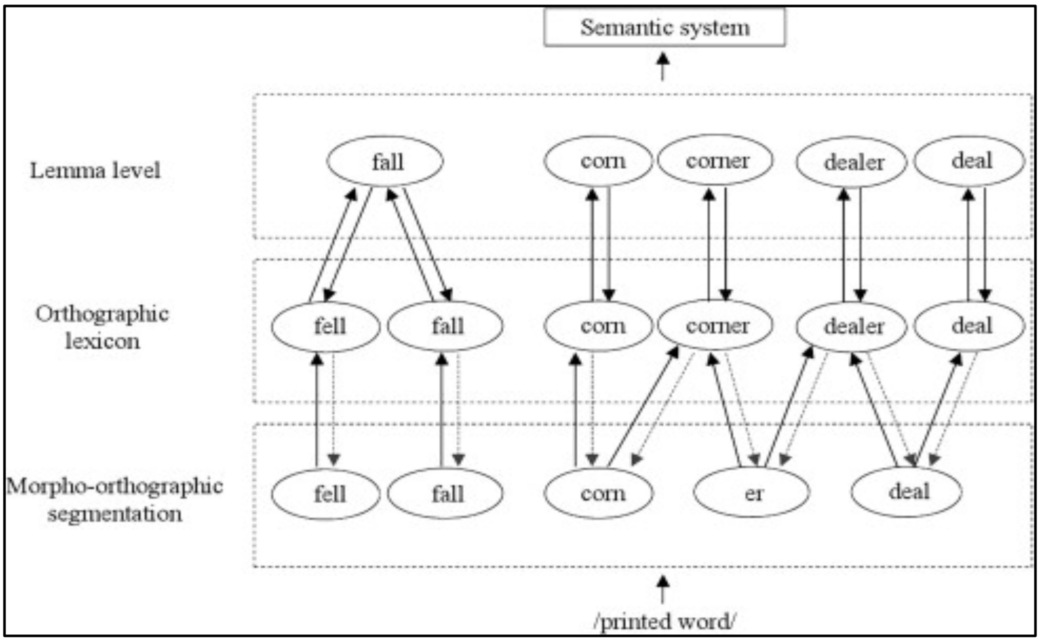

Figure 2.6 *Extended morpho-orthographic model based on Crepaldi et al. (2010)*

There is some evidence that these predictions are borne out in an MEG study with masked priming by Fruchter, Stockall and Marantz (2013). Using the M170 response as a neural index of morphological decomposition in visual word recognition based on previous studies on the component's sensitivity to the transition probability between stem and affix in derivationally complex words, Fruchter et al. (2013) investigated early decomposition effects in four different conditions. In addition to the irregularly inflected verbs and their bases (e.g. *fell* - *fall*), as well as pairs of pseudo-irregulars such as *bell* and *ball* from Crepaldi et al. (2010), an identity condition (e.g. *car* - *car*) and regularly inflected verbs such as *jumped* together with their base words such as *jump* were selected. In the behavioural data, there was significant RT priming for the identity and both morphological conditions. A trend towards facilitation could be also established in the pseudo-irregular condition, but it did not reach significance at $p < .05$. The MEG analysis established an M170 masked priming effect in the left fusiform gyrus. Again, irregularly inflected verbs primed their roots, but priming effects in the identity regular conditions surfaced earlier at a time window of around M100, which, as the authors argue, could be interpreted as abstract letter priming (cf. Pylkkänen & Okano, 2010). In a later time-window of around 350-400 ms, all morphological conditions elicited neural priming, while this effect was not observed in the pseudo-irregular condition.

Overall, these results are in line with Crepaldi et al.'s (2010) model of early visual word recognition as pseudo-irregulars failed to display the patterns observed for morphologically related items and some dissociations between regulars and irregulars could be detected. Morris and Stockall (2012), on the other hand, present evidence from a combined ERP and behavioural lexical decision task on the processing of 120 regular and 120 irregular past tense forms. The stems in both groups were paired with four different types of primes: an identity prime, the past tense form, an orthographic control, as well as an unrelated control. In the RT response data, the predictions advanced by Crepaldi et al. (2010) could be confirmed since the priming effects for regularly inflected verbs did not differ from the Identity Condition, while these effects were reduced for the irregulars. In the critical time windows of 250 ms and 400 ms of the ERP analysis, however, no significant difference in the magnitude of attenuation as an index of priming could be discerned. Sensitivity to differences between the two verb types emerged at a later time window and was reflected in latency effects for the *Late Positivity Component*. Under the model sketched out by Crepaldi et al. (2010), the opposite pattern would have been expected, meaning that an early morpho-orthographic segmentation phase would affect the earliest stages of word recognition, rather than surface as later effects through the *Late Positivity Component* (LPC) in ERP measurements and response latencies in lexical decision tasks.

The results reported by Morris and Stockall (2012) call into question to what extent the lemma level of representation advanced by Crepaldi et al. (2010) is indispensable. On the one hand, it seems that masked priming allows us to access at least two separate levels of processing - one that is sensitive to any morpho-orthographic regularities across the language (both for regularly inflected words, as well as for 'islands of regularity' in irregulars) and another level at which the processing patterns between more common morpho-orthographic segmentations such as regulars deviate from more idiosyncratic regularities. As Morris and Stockall (2012) have shown, these stages are separable using ERP techniques and the early stages of word recognition do not appear to be sensitive to a clear separation.

Under a view in which no lemma representations are accessed in masked priming, the question can be raised which constraints modulate morphological processing under masked priming. So far, we have restricted our discussion to the processing patterns for existing words that were either morphologically complex derived words (e.g. *teacher*), had the appearance of morphological complexity (e.g. *corner*) or were orthographic matched controls (e.g. *brothel*). Parallel investigations were conducted for inflectional morphology.

As we have discussed, not in all cases for which priming effects have been reported did the prime and target pairs display an existing morphological relationship that would have been licensed by a recombination checking procedure. It is, however, precisely the sensitivity to morphological constraints that will be of particular interest in the present study. In a number of studies, the processing patterns for non-interpretable complex items were examined through the analysis of possible decomposition effects for pseudowords. Beyersmann, Duñaibeita, Carreiras, Coltheart and Castles (2012) report the results of a masked priming experiment with nonword primes such as **totalito* that were paired with their embedded stems such as *total*. The nonword primes were conceptualized as 'lexically illegal combinations of stems and affixes' (p. 877), meaning that they do not exist as words in the language. Whether or not they could be words in Spanish is another question and it is not directly addressed in the paper. The suffix -*ito* adds to nouns to form a diminutive, but the stem *total* can be both a noun and an adjective, meaning that depending on how the stem is interpreted, the complex nonword can be more or less viable. In Beyersmann et al. (2012), nonwords with identifiable units such as *total-* and -*ito* elicited priming for an embedded stem *total*. The authors conclude that a semantic relationship between prime and target is not necessary to induce masked priming effects. Considerations regarding the viability of the nonword, as well as whether or not the masked priming paradigm is sensitive to issues arising from morphological viability remain. Masked priming effects as a result of pseudoword decomposition are also reported by Longtin and Meunier (2005) for two sets of French pseudowords such as **rapidifier* and **sportation.* Crucially, while both **rapidifier* and **sportation* do not exist, the argument could be advanced that only items in the former set exemplified by **rapidifier* are possible words since the suffix *-ifier* requires an adjectival base such as *rapide*. In **sportation,* the combination of a nominal base such as *sport-* with a deverbal suffix such as *-ation* should not yield a permissible novel form as Longtin and Meunier (2005) themselves point out. Yet both sets instantiated significant facilitation of their embedded stems under masked priming. Longtin and Meunier's (2005) study is particularly insightful as it is one of the few studies that enables us to assess the salience of morphotactic legality in word recognition, especially with regard to its significance depending on the experimental paradigm employed. In this context, it is particularly instructive that Longtin and Meunier used the same set of stimuli in a follow-up study using cross-modal priming (Meunier & Longtin, 2007), the results of which will be discussed in the next section.

2.5.2 Overt priming paradigms: Cross-modal and within-modality

Overall, semantic constraints on morphological processing have been argued to surface as more robust and tenacious under cross-modal than under masked priming. In Meunier and Longtin's (2007) follow-up study with two sets of French pseudowords using cross-modal priming, only the set that was rated to be semantically interpretable in an off-line task (e.g. **rapidifier*) elicited a priming effect. It is clear that this situation is fostered by the overt auditory presentation of the prime, which is conducive to a deeper processing of the prime than under a masked priming paradigm.[1] Note that while the **rapidifier* set was undoubtedly more interpretable from a semantic point of view, this set only contained morphologically legal combinations of stems and affixes (e.g. **rapidifier*). Morphotactically inadmissible combinations such as *sport*- + *-ation* did not facilitate the recognition of the embedded stem *sport.* Recall that in Marslen-Wilson et al. (1994), an intriguing pattern emerged whereby purely semantic priming was observed in the absence of a morphological relationship between pairs such as *idea* and *notion*, but morphological derivates that received high ratings on semantic relatedness such as *governor* and *government* failed to produce priming effects.

The effects observed between suffixed-suffixed pairs were in fact inhibitory. As discussed in section 2.4.1, auditory word recognition proceeds - at least to a certain extent - incrementally, meaning that there is a possibility that the prolonged time course

[1] Although masked priming using a cross-modal presentation of primes and targets is possible, whereby primes would, for instance, be presented visually and targets auditorily, more commonly primes are presented overtly in cross-modal priming.

during which the acoustic information for derived words (e.g. *government*) overlaps with their stems (here *govern*), as well as other suffixed derivates (e.g. *governor*) induces cohort competition. Based on the results obtained by Marslen-Wilson et al. (1994), this competition appears resolved when either the prime or the target is the stem. Thus, in the aforementioned study, we find that the auditory prime word *friendly* would facilitate the recognition of the visual target *friend*, and vice versa, but suffixed-suffixed combinations such as *government* - *governor* did not facilitate one another. This is argued to be due to an additional layer of competition that arises during morphological complexity processing: the stem form '*govern'* can only be succeeded by one of the two suffixes, but not both. Inhibitory effects were thus attributed to incompatibilities in attachment to the stem, which could be interpreted as rather indirect evidence for sensitivity to morphotactic constraints. While converging evidence for inhibition between suffixed-suffixed derived words is advanced by Feldman and Larabee (2001), Meunier and Segui (2002) did not replicate suffix-suffix inhibition effects in French derived words such as *respectueux* (A., 'respectful') - *respectable* (A., 'respectable'). Purely semantic priming effects for near-synonyms such as *personne* (N., 'person') and *individu* (N., 'individual') parallel the findings reported by Marslen-Wilson et al. (1994), demonstrating that - notwithstanding the numerically larger priming effect for morphologically (32 ms) than semantically related words (23 ms) - the latter cannot entirely be factored out in the interpretation of cross-modal priming experiments of morphological processing. Moreover, while this methodology is essentially intended to permit access to modality-independent, abstract representations, the inconsistencies observed across studies (absence versus presence of facilitation for suffixed-suffixed derived words) are in many cases connected to lower-level, modality-specific processing consequences. Marslen-Wilson et al. (1994) refer to features of cohort-based competition effects and Meunier and Segui (2002) implicate dissimilarities in stress-assignment and rhythm between French and English in their account of how the findings from the two studies can be reconciled. Thus, while there is strong evidence that cross-modal priming taps into more central processing stages than masked priming, the extent to which the representations accessed are abstract is perhaps not as fully resolved as it could be. Nonetheless, it can be claimed that with regard to the issue of semantic transparency, there is overall consensus regarding its role in morphological processing under overt prime word presentation, especially in conjunction with a change in modality between prime and target. This is further supported by a number of studies (e.g. Allen & Badecker, 1999; Laudanna, Badecker, & Caramazza, 1989) reporting inhibitory effects for stem homographs - that is morphologically complex words that accidentally share an orthographically identical stem, but are semantically and morphologically unrelated to one another such as *colp-a* (N., 'fault') and *colp-o* (N., 'stroke') in Italian. Considering that these effects were observed under long-SOA priming paradigms in which participants had the opportunity of processing the prime word in more detail than under masked priming (in which stem homograph pairs exhibit facilitatory links in recognition tasks), this is consistent with the argument of semantic modulation of morphological processing under overt prime presentation.

The situation is further complicated if we move our discussion beyond the cross-modal priming results discussed for English and French so far. For the processing of non-concatenative morphology, it has to be recognised that semantic transparency is not always a precondition for priming between morphologically related items to occur. Recall that Frost et al. (2000) report on the results of a series of experiments in Hebrew in which a cross-modal priming effect only emerged for repeated word patterns in the verbal, but not in the nominal domain. As the authors point out, the number of word patterns in the verbal domain is restricted to seven and these word patterns contribute to the semantic interpretation of a word in a systematic manner. In the nominal domain, however, given the high number of available word patterns (around 100), these contributions are less predictable and consistent, leading to separate underlying (morphemic) representations. In conjunction with the results of a second cross-modal priming experiment in which morphologically related words sharing a root morpheme showed priming effects in the absence of a transparent semantic relationship, these findings further cement the importance of morphological considerations in cross-modal priming, especially in languages with non-concatenative morphology. Even though the degree of root priming increased with semantic relatedness between prime and target, Frost et al.'s (2000) findings underscore that morphological priming effects obtained under cross-modal priming cannot be reduced to a semantic relationship alone.

However, given our particular interest in morphological constraints that operate independently of an existing semantic relationship between words, it is clear that the dissociation between purely morphological effects and semantic similarities between words is not straightforward in a cross-modal priming paradigm and will have to be complemented by evidence from additional experimental paradigms.

2.5.3 Delayed priming

In delayed priming, the lag between prime and target presentation is more extended than in immediate (cross-modal) priming. On the one hand, it could be argued that this contributes to reducing the extent to which the pairing between prime and target is brought to the fore when presented to the participant provided suitable measures with regard to the selection of filler items are taken. On the other hand, the extended temporal separation between prime and target limits the applicability of processing mechanisms such as *spreading activation* that have been regarded as automatic and unaffected by possible processing strategies. Thus, the mechanisms that underlie morphological processing under long-lag conditions and processing consequences possibly emerging through the over-reliance on strategies will need to be considered. The enhanced lag between prime and target can be achieved due to an extended ISI (the interstimulus interval, defined as the duration after the offset of the prime word up until the onset of the target) or through the inclusion of a number of unrelated stimuli between prime and target presentation.

In an early delayed priming study by Stanners et al. (1979), between six and fifteen intervening filler words were inserted between pairs of morphologically related words. When the morphological relatedness was expressed as an inflectional relationship between prime and target, the degree of priming measured was equivalent to the identity priming condition. Derivationally related words also showed priming effects. These were, however, reduced in magnitude relative to the identity condition. In view of these findings, the results of delayed priming were interpreted as the combined effect of semantic relatedness and repeated access to a shared base morpheme. Note, however, that the dissipation of purely semantically related words has commonly been advanced as a key difference between immediate and long-lag priming. To provide an example, a direct comparison between immediate and long-lag priming was established by Bentin and Feldman (1990) by looking at the effect of morphological repetition in Hebrew at lag 0 and at lag 15. At both lags, experimental conditions consisted of three groups: (1) semantically related prime-target words with no morphological relationship, (2) morphological derivates sharing the same root but no semantic association and (3) prime-target words that are morphological derivates through a shared root and are also semantically associated with one another. Semantic priming that was independent of a morphological relationship only surfaced at lag 0. At lag 15, only morphologically related pairs (both semantically associated and semantically unrelated) led to a priming effect, showing that repeated access to a shared root morpheme facilitated responses over a time course that is no longer reliant on semantic associations between two whole word forms. As priming extended to the repetition of nonword roots that had been combined with existing word patterns, repeated access to a common formative did not seem to involve access to an existing lexical entry as such, but rather the extraction and repeated access to an abstract entity that can fulfil morphological functions in the language. Note in this context that the root morpheme has been argued to encode 'core meaning' in Hebrew (Farhy, Veríssimo, & Clahsen, 2017). The observation that delayed priming in Hebrew can operate on non-existent roots lends further support to an independence from semantic factors. Dissociations from semantic (and orthographic) effects in delayed priming were also reported in another early study by Henderson, Wallis and Knight (1984). Similarly, in a more recent study by Scharinger, Reetz and Lahiri (2009), delayed priming was shown to be impervious with regard to purely semantic effects. The absence of semantic priming is therefore a fairly robust observation across multiple studies drawing on the delayed priming paradigm, making it a particularly effective methodology for the study of morphological processing.

While the absence of semantically-motivated effects has been shown to be consistent across a number of delayed priming experiments, the contribution from formal overlap has been shown to vary significantly. As noted by Drews & Zwitserlood (1995), facilitation of orthographic pairs has been reported in delayed priming by Feustel, Shiffrin and Salacoo (1983) and Rueckl (1990) while other studies (e.g. Monsell, 1985; Murrell & Morton, 1974; Napps & Fowler, 1987) found no evidence for facilitation. Using delayed priming with a variable lag between 8 and 12 intervening items, Drews and Zwitserlood (1995) investigated effects emanating from orthographic overlap during morphological complexity processing in a more systematic fashion. While morphological pairs in German such as *BEINE-BEIN* (legs - leg), in which the former is an inflected form of the target, led to facilitatory effects, a numerical tendency towards inhibition was evident in orthographic pairs without an existing morphological relationship (e.g. *SCHALE* (N., 'bowl') – *SCHAL* (N., 'scarf')).

These dissociations - absence of semantic facilitation and a tendency towards inhibition for orthographic overlap - lend additional viability to the delayed priming paradigm as a suitable candidate for investigations into morphological processing, but also raise questions regarding the mechanisms that underlie response facilitation at long-lag intervals between prime and target. As discussed in Drews and Zwitserlood (1995), long-term repetition priming has been conceptualized as an effect arising from 'repeated access to a common lexical entry' (p. 1102). This gives a purely lexical explanation of long-lag repetition priming effects that have not been left unchallenged (e.g. Fowler, Napps, & Feldman, 1985). Objections to delayed priming that have been commonly voiced concern the possibility that participants develop strategies due to episodic memories about previously presented stimuli. In a recent paper by Kouider and Dupoux (2009), however, it has been shown that the minimization of episodic effects through a change from a female to a male speaker in auditory delayed priming, as well the maximization of the distance between prime and target, contributes to the elimination of episodic effects, whilst still inducing morphological priming in French. Crucially, the magnitude of the morphological priming effect did not vary as a function of the lag between prime and target presentation and thus possible episodic influences. This suggests that priming effects observed in the delayed priming paradigm cannot be explained solely on the basis of episodic memory effects. Overall, we find that especially in recent years, masked priming has featured more prominently in research into morphological processing than delayed priming. However, given the dissociability of morphological effects from semantics and orthography in the latter, delayed priming nonetheless presents itself as a viable task for the study of purely morphological complexity processing.

In summary, it has become evident that depending on the experimental paradigm employed, processing patterns through which we aim to identify purely morphological effects during word recognition may differ: co-occurring semantic factors may be more or less stable and the depth of processing may also vary, for instance. It is, however, also important to note that it is not just the type of experimental paradigm (and we have only provided a short overview of a selection of prevalent research methods in the field) that can affect the results obtained. In the following section, we present a tentative overview of the key findings discussed so far, alongside additional factors that we may want to consider as we interpret further evidence from experimental investigations into morphological complexity processing.

2.5.4 Overview of key experimental findings in research into morphological processing

1. The organization of our mental lexicon is shaped by the morphological relatedness between words as evidenced by full (as well as partial) priming effects between morphological relatives.

2. Alongside semantic and orthographic factors, we find accruing evidence for a purely morphological dimension that emerges during the process of word recognition.

3. The nature of this morphological dimension continues to be debated and it is clear that several factors can affect the way in which effects of morphological relatedness surface during word recognition:

    1. **Mode of presentation:** Due to the incremental nature of the incoming speech signal in auditory versus visual word recognition, it is likely that cohort competition between morphological relatives is manifested more strongly during auditory processing of morphological complexity than during visual word recognition.

    2. **Type of morphological process:** In view of the previous point, the implications are that cohort-based competition effects are expected to surface more strongly for suffixation than for prefixation. Note, however, that there has been some variability with regard to purported suffix-suffix inhibition effects (e.g. Marslen-Wilson et al., 1994 versus Meunier & Segui, 2002).

    3. **Time point of word recognition:** Especially with regard to visual word recognition, the different experimental paradigms discussed in the preceding sections (masked versus overt versus delayed

priming) appear to tap into separate stages of word recognition. As a result, constraints such as the semantic transparency between word pairs may be more or less critical depending on depth of processing.

4. **Language-specificity:** If the time course at which morphological information becomes available affects processing, then it can also be assumed that the way in which morphological relationships are expressed in different languages (e.g. concatenative versus template-based morphology) is an important factor shaping word recognition.

5. **Inherited versus loan words**: The degree to which native speakers are sensitive to synchronically opaque morphological relationships continues to be discussed. How do native speakers of English represent a borrowed complex word such as *apartment* with regard to a semantically unrelated embedded word *apart*? How important is semantic transparency between related words at different stages of word recognition?

2.6 Morphological decomposition in action: Representation versus knowledge

So far, our discussions have centred on previous research on the representation of morphologically complex words in our mental lexicon. We have presented a number of different models that have been put forward to account for how morphologically complex words are stored and accessed. The notion of 'representation' denotes a somewhat stable organization of lexical entries, whose relations have been studied using a number of different methodologies as discussed in section 2.4. Distinctions have been made regarding modality-specific versus modality-independent forms of representation, but the overarching aims of research into morphological complexity processing have been particularly motivated by questions regarding the form in which existing complex words are stored in our mental lexicon.

The focus taken in the present thesis is slightly different. In view of the body of research that has examined the representation of morphological complexity in our mental lexicon, as well as finding overall evidence for its role in word recognition, there is an underlying premise that native speakers possess knowledge of the constraints that can yield morphologically complex words. This knowledge is not to be equated with the kind of knowledge that is meta-linguistic in nature and usually available to speakers upon closer reflection about the 'grammar rules' of their language. To give an example, native speakers of English will have a sense that the ending *-er*, when attached to a verb, will denote a person performing that particular action. The implications of this are not necessarily that the mechanisms guiding the recognition of a complex word, such as *writer*, during normal language processing will be isomorphic with our meta-linguistic knowledge. Thus, they need not draw on exactly the same syntactic and semantic information in order to make valid generalizations regarding the function of the suffix -*er*.

But it is precisely these generalizations that enable us to derive new words based on already existing knowledge. Under such a perspective, the representations we have been discussing are arguably not as stable as assumed. Instead, representations can be added to the mental lexicon, but what constraints have to be licensed for this to occur? Are all novel forms equally likely to enter our mental lexicon? Are there any 'word formation rules' that determine which formations we accept as possible? And is a division into possible versus impossible word formations tenable? Before we attempt to address these questions experimentally, we will consider how this topic has been approached in the theoretical linguistics literature.

2.6.1 Actual words versus possible words

Plag (1999) relates the applicability of morphological rules to the notion of productivity. Generally speaking, the observation that some word formation rules yield a larger number of derivates than others is not controversial. To give an example, the aforementioned formation of nouns with an agentive meaning in -*er*, such as *writer*, is more widely attested than nominal formations ending in the suffix -*th*. Yet inconsistencies are common and even for highly predictable and productive word formation rules such as *base verb > agentive noun in -er*, idiosyncrasies are to be expected. Thus, a *cooker* in English is not a person who cooks, but an appliance or stove designed for cooking with. Other complex words such as *government* have become associated with particular lexicalized meanings that are not straightforwardly derived from the meanings of the constituent formatives (here *govern*- and -*ment*) on which the relevant word formation rules could be argued to operate. How are these more marginal, exceptional cases captured in our word formation rules? Especially with regard to lexicalized meanings of complex words, it is clear that word formation rules need to be complemented by additional information that becomes associated with the actually attested words. In these contexts, the status of the complex word as an ‘actual’ word is evidently a prerequisite for the establishment of lexicalized meanings.

Further questions relate to how we account for derivates that are predicted by productive word formation rules and yet not attested. Plag (1999) refers to the combination of the nominalizing suffix *-ity* and the adjectival suffix *-ous* as in *curious* - *curiosity* or *monstrous* - *monstrosity* to illustrate the ‘impossibility’ (p. 6) of deriving analogous nominal forms from *glorious* and *furious.* **Gloriosity* and **furiosity* are indeed not attested, but does this entail that they are impossible formations? Or could the argument be advanced that their non-occurrence is accidental? In that case, we would be concerned with possible (or ‘potential’) words that are not impossible as such, but surface as lexical gaps due to their non-occurrence in language use.

The argument has been advanced that the distinction between actual and potential words is of no theoretical interest if it is found that no morphological process is contingent on “whether or not a word is ‘actual’ or not” (Kiparsky, 1982, p. 26). Under such a view, the difference between actual and possible words could be reduced to a question of degree of frequency. Inevitably, not all complex words will be known and shared by all speakers of a language community - individual differences are always to be expected and in that case, the question can be raised whether conclusions regarding a speaker’s linguistic competence can be drawn at all.

Booij (1987) distinguishes between two different approaches as to how complex words can be conceptualized as a reflection of linguistic competence and the implications that this has on morphological theory. The viewpoint that the notion of ‘actual word’ has no relevance to linguistic theory accords with the 'dynamic approach' (p. 44) of morphological complexity. According to this approach, the set of potential complex words is defined by the so-called 'morphological component' and only simple words and roots need to be listed in the lexicon. The notion of *actual* word bears no importance in this context and is simply a question of performance, not competence. Booij (1987) also introduces the static/dynamic approach in which the lexicon contains both simple, as well as existing complex words. The morphological component is composed of morphological redundancy rules that account for the mapping between existing words, as well as the generation of novel forms. Crucially, only the static/dynamic approach predicts that morphological rules draw on information as to whether a base is an actual word or not.

Recall our previous discussion on idiosyncrasies inherent in the meaning of complex words, yielding forms that are not predicted by their morphological rules of formation, whereby the meaning of *government*, for instance, does not derive compositionally from its constituent parts. These deviations from the expected meaning would have to be captured outside the speaker's competence and thus the morphological component under the assumptions of the dynamic approach, leading to the prediction that these idiosyncrasies would not interact with morphological rules. Booij (1987), however, proceeds to present a number of examples in which the idiosyncrasies of an actually attested complex item are a salient factor for morphological change, as well as further word formation. As an example, Booij (1987) presents the idiosyncratic meaning of the Dutch compound word *klokhuis* and its meaning 'apple core' and not the predicted compositional interpretation of 'clock house'. Idiosyncrasies in meaning are retained in further derivations. Thus, the diminutive form *klokhuisje* derived from *klokhuis* carries over the idiosyncratic meaning of its base to denote a 'little apple core'. The implications of this observation are that successive applications of word formation processes have access to idiosyncratic, marked properties of previous stages of derivation. On the basis of these observations, one would assume that any novel words derived from existing complex words with idiosyncratic properties would inherit the unpredictable facets of meaning exhibited by their bases. Consequently, it appears that the output of the morphological component comprising our word formation rules is produced with great reliability, further cementing the position that our knowledge of morphological composition is an important aspect of linguistic competence.

This leads to a follow-up question, namely the realization of the morphological component. If the notion of a 'possible' word is indeed permitted, then a clear differentiation between how possible and impossible novel forms are realized is of paramount importance. Morphological word formation rules would thus be understood to underlie the morphological knowledge that shapes our sensitivity to constraints determining which word formations occur (actual words), or can occur (possible words) and which formations are simply not possible (impossible words). It has been claimed, however, by Becker (1993, pp. 190-191), for instance, that morphologists cannot make any predictions about possible and impossible complex words anyway since the only way to home in on this issue is through acceptability judgements. These, however, are argued to suffer from well-known flaws with regard to reliability and replicability given that judgements can be inconsistent not only between speakers, but even for a single speaker.

In response to this, we can say, however, that not all phenomena pertaining to syntactic structure yield uniform and unequivocal acceptability judgments across speakers. Nonetheless, the study of the said phenomena and their ramifications with regard to our linguistic competence are not commonly called into question. The study of possible versus impossible formations can thus be justified on this basis. In the following sections, we will therefore turn to an attempt at grouping a number of different types of morphological constraints that could be used to inform our knowledge of what constitutes a possible versus an impossible complex word.

2.6.2 Morphological constraints: Morphological possibility versus impossibility

In section 2.6.1, we have already encountered the claim that any predictions on what constitutes possible versus impossible words will be inherently difficult (Becker, 1993). Nonetheless, we will attempt to offer an overview of a number of distinctive constraints that have been discussed in the literature with regard to rules of word formation.

2.6.2.1 Syntactic category of the base

As pointed out by Fabb (1988), if there were no constraints on suffixation in English, then the 43 suffixes he counts in English would yield the possibility of having 1849 suffix pairs. It is clear that far fewer of these combinations are actually attested. As Fabb (1988) illustrates, the number of possible pairs can be cut down to 663 when accounting for restrictions on the selection of a particular part of speech for the stem to which the suffix attaches. The part of speech of the base word is thus one major restriction on suffixation and has led to the stipulation of a *Unitary Base Hypothesis* (Aronoff, 1976). Following the *Unitary Base Hypothesis*, a given affix only attaches to bases of a particular part of speech. To give an example, the suffix -*ness* attaches to adjectives to form nouns in English while the suffix -*ly* attaches to adjectival bases to derive adverbs. Under the *Unitary Base Hypothesis*, in situations where it appears to be the case that an affix can combine with bases from two different syntactic categories (such as -*ize* from the nominal *emphas*-*ize* or the adjectival base *internal*-*ize*), the constraint still holds and the two affixes are considered to be distinct and merely homonymous, rather than unitary in both form and function.

Note, however, that these restrictions on the syntactic category of the base have not been left unchallenged. Plag (2004), for instance, has argued that apparent restrictions on the syntactic category of the base word are in many instances merely an epiphenomenon of semantic considerations. In a survey of English suffixes and their bases, Plag (2004) identifies a number of suffixes that can take bases of more than one syntactic category. A subset of these examples is given in Table 2.4.

Table 2.4 *Overview of suffixes in English that select bases of different syntactic categories according to Plag (2004)*

SUFFIX	EXAMPLES	MAJORITY BASE CATEGORY	MINORITY BASE CATEGORY	DERIVED CATEGORY	SEMANTIC CATEGORY OF DERIVATIVE
-able	*readable, jeepable*	V	N, root	A	qualitative adjective
-able	*knowledgeable*	N		A	'characterized by X'
-al	*refusal*	V		N	Nomen actionis
-al	*colonial*	N		A	relational adjective
-ed	*wooded*	N, phrases		A	'provided with X'
-ee	*employee*	V	N, root		sentient being
-ize	*normalize, hospitalize*	N, A	root	V	change-of-state verb

Distinctions between homophonous affixes such as *-al* can consequently be made on the basis of their output semantics according to Plag (2004): While -al$_1$ as in *refusal* from *refuse*$_V$ derives a nomen actionis, denominal *-al*$_2$ as in *colonial* yields a relational adjective. It is therefore a viable observation that the output semantics of a derivation are correlated with the syntactic category of the base word. However, particularly in the aforementioned cases, it could be argued that rather than postulating that selectional restrictions surface as a by-product of output semantics, the directionality of cause and effect appears to be reversed: it is the syntactic category of the base that predicts the semantics of the derived word. Now, Plag (2004) points to cases in which a suffix can attach to bases of different syntactic categories and the semantic category of the output derivative will be uniform. As an example that can be gleaned from Table 2.4, we see that the aforementioned suffix *-ize* attaches to both nouns and adjectives. Yet, in both cases, the output category of the derivative is invariant in both semantic and syntactic terms. In the example provided by Plag (2004), both *hospitalize* (from *hospital*$_{\mathrm{N}}$ > *hospital-ize*$_{\mathrm{V}}$) and *normalize* (from *normal*$_{\mathrm{A}}$ > *normal-ize*$_{\mathrm{V}}$) derive a verb denoting a change of state. Here, it can indeed be questioned to what extent the *Unitary Base Hypothesis* is tenable, as it would involve the stipulation of two homonymous suffixes *-ize* that do not exhibit functional differences: both derive complex words with highly congruent syntactic and semantic properties. Even if we were to dispense with the requirement of a single syntactic category per affix, the question remains as to whether the syntactic category (or, as we have seen, the syntactic categories) of the base word are determinant of the combinatorial possibilities between base word and affix.

Thus, while it is true that in a number of cases there is not a one-to-one correspondence between an affix and the required syntactic category of the base word, any adequate and comprehensive theory of word formation will have to account for unattested combinations. To give an example, verbal bases for the suffix *-ary* are not attested. If we were to posit that the selectional restrictions of the base do not account for predicted output forms, then an alternative approach needs to be proposed that can fulfil both the function of generating attested forms as well as blocking the application of word formation rules where forms are not attested. As we pointed out at the beginning of the present section, morphological constraints based on the syntactic category of the base word are particularly important in delimiting the number of possible attested stem + affix combinations. It is therefore undoubtedly the case that these should play a role in an account of morphological possibility. Nonetheless, we shall also consider a number of further restrictions that may govern and restrain the application of word formation rules.

2.6.2.2 Subcategorization and thematic restrictions

In addition to subcategorization restrictions, Aronoff (1983) points to thematic restrictions and their role in word formation. The former concerns the *categorization frame* for any major lexical category, which is argued to comprise the phrasal category that immediately precedes it (thus, *verb phrases* for verbs, *noun phrases* for nouns etc.). As expanded on by Aronoff (1983), the implications of this stipulation are that any word formation rules that operate on verbs will have access to notions such as the NP that will express the direct or indirect object within the verbal phrase in which the verb is contained. No information from outside the phrase structure can permeate into the application of word formation rules. Aronoff (1983) refers to data from Mohawk and English verbal compounds in which these restrictions are indeed maintained (English formations such as *babysitter* or *well-made* indeed incorporate phrasal material, but no material outside of it). It is also suggested that since the lexical entry for a verb comprises information regarding its thematic representation, word formation rules can operate on thematic specifications. Aronoff (1983) illustrates this point on the basis of the suffix *-ee* in English as nominal formations in *-ee* carry the meaning of the patient of an action.

Further restrictions can draw on the valency of the derived word. German verbs that are zero-derived from their base adjectives such as *heilen* (V., 'heal') through *heil* (A., 'intact') > *heilen* (V., 'heal') can acquire both intransitive and transitive meanings. As a case in point, the verb *heilen* can be used intransitively as illustrated in (1):

(1) Die Wunde heil-t von selbst.
the wound heal-PRS.3SG by itself
The wound heals by itself.

The complex verb *heilen* can also be used transitively as in (2):

(2) Diese Crème heil-t die Wunde.
this cream heal-PRS.3SG the wound
This cream heals the wound.

In other cases, the output valency of a derived verb is predictable to the extent that word formation rules only produce specific subcategories. Aronoff (1983) presents the example of English prefixes, the majority of which form transitive derived verbs, even from intransitive bases. Thus, observe the differences between the bases and their derived prefixed forms below:

(3) He thinks.

(4) *He rethinks.

as well as:

(5) She reads.

(6) *She rereads.

Note that the restrictions discussed so far have been concerned with constraints between stems and affixes and the meanings obtained through their combination. Yet in many cases, we will also need to consider restrictions that pertain to possible sequences of affixes. A brief overview of constraints on affix-affix combinability will be presented in the next section.

2.6.2.3 Affix-affix morphotactics

Semantic considerations in particular have been proposed to account for affix co-occurrence restrictions. Affix co-occurrence restrictions refer to the combinatorial possibilities between affixes in multimorphemic words, as well as their relative ordering with regard to the stem. Based on a survey of 50 languages, Bybee (1985) put forward the idea that the semantic influence of an affix with regard to the meaning of the stem would affect its relative position in the construction as a whole. Saarinen and Hay (2014) point to the overall tendency for derivational affixes to precede their inflectional counterparts and thus to be commonly placed closer to the stem. Given that derivational affixes can be expected to have a stronger effect on the semantics of the stem and thus the derived word than inflectional affixes, this pattern is in line with Bybee's (1985) proposal. Further ramifications of the proposition that affix order can be determined through the semantic composition of a complex word relate to the scopal relationships induced by different orderings. As affixes attach to their bases, additional layers of meaning are stacked onto the preceding combinations. In Mithun (1999), this process is illustrated on the basis of Yup'ik to show how variable affix order can give rise to meaning differences in complex derived words:

(7) yug-**pag-cuar**

person-big-little

'little giant'

(8) yug-**cuar-pag**

person-little-big

'big midget'

In these cases, the outermost suffix has scope over the stem and the suffix that follows the stem. In languages with fixed affix ordering, on the other hand, the order in which affixes are combined *can* but need not only reflect semantic factors.

Other factors may also be relevant. In English, for instance, affixes can belong to one of two groups that differ not only in their etymological origin (inherited through Germanic versus borrowed through Romance), but also their semantic and phonological transparency. The first group (termed Class I affixes), exemplified through affixes such as *-ity*, can be semantically as well as phonologically opaque with regard to its relationship to the base. This group also often displays stress-shifting, while the second group (Class II affixes) is predominantly composed of affixes of Germanic origin such as *-ness* which do not induce changes in semantic or phonological transparency and preserve the existing stress structure. In Table 2.5, an overview is provided of how different affixes in English are organised into the two groups.

Table 2.5 *Overview of affix categorization in English based on Siegel (1974)*

CATEGORY	EXAMPLES
Class I suffixes	*-ion, -ity, -y, -al, -ic, -ate, -ous, -ive*
Class I prefixes	*re-, con-, de-, sub-, pre-, in-, en-, be-*
Class II suffixes	*-ness, -less, -hood, -ful, -ly, -y, -like*
Class II prefixes	*re-, sub-, un-, non-, de-, semi-, anti-*

The assumption that affixes can be assigned to different categories implies that the order in which these affixes enter the derivational process is determined by their affiliation with the particular category. The classification of affixes into separate categories offers straightforward predictions with regard to the order of attachment among affixes and has proved adequate in capturing a number of possible and impossible combinations in English derivational morphology. Class II affixes by and large attach outside of Class I affixes, not vice versa, rendering formations such as **beautifulity* impossible. Level-ordering has, however, been argued to lack predictive power (e.g. Fabb, 1988; Plag & Baayen, 2009) on the basis of attested formations that do not follow from the restrictions laid out by the model. This is exemplified by bracketing paradoxes such as *un-grammatical-ity* (Saarinen & Hay, 2014). The paradox here consists in the conflicting predictions made by constraints imposed by selectional restrictions versus level-ordering. The latter would require attachment of *-ity* to precede prefixation with *un-*, which contradicts the expectation for *un-* prefixes to select adjectival (or verbal), but not nominal bases. It is thus clear that a theory of word formation has to incorporate the interplay between constraints and build a framework that can predict which constraints take precedence in a particular situation.

2.6.2.4 Prosodic restrictions

The distribution of some suffixes is governed by factors pertaining to the prosody of the complex word. One particular case in point is the occurrence of the suffixes *-heit* versus *-keit* and *-igkeit* in German. According to Fleischer (1975), *-keit* can be regarded as the "combinatorial variant of -heit" (p. 151). Both *-heit* and *-keit* attach to adjectival bases, but *-keit* is chosen over *-heit* when the adjectival base is a derivate itself. These derivates are mostly suffixed words ending in *-ig*, *-lich*, *-sam* and *-bar* that do not carry stress. Existing complex words in *-keit* such as *Notwendigkeit* (N., 'necessity'), *Ehrlichkeit* (N., 'honesty') or *Seltsamkeit* (N., 'strangeness') show that this prediction is in fact borne out. Morphologically simple bases such as *frech* (A., ‘insolent’) in *Frechheit* (N., ‘insolence’), on the other hand, take the suffix *-heit*. Another criterion for distinction between the two suffixes is the stress assigned to the preceding syllable. Thus, *Sauberkeit* (N., 'cleanliness'), although formed on the basis of a non-complex base, is also suffixed using *-keit*, rather than *-heit*. As a general principle, it can thus be stated that if the immediately preceding syllable carries lexical stress, then *-heit* is selected over *-keit*, yielding the concomitant implication that monosyllabic (and often monomorphemic) adjectival bases combine with the *-heit* variant. Again, it is thus a combination of factors - both the prosodic constraints regarding the stress allocation of the preceding syllable, and the morphological status of the base - that determines the selection of one affix over another.

Overall, we have seen that there are a number of constraints that have been discussed in the linguistic literature and which could be expected to modulate the recognition process. From a psycholinguistic perspective, however, the concern with morphological constraints as abstract knowledge of morphological possibility has been rather limited. The few existing psycholinguistic studies (e.g. Longtin & Meunier, 2005) that have focused on the processing of pseudowords as a means to probing into more general aspects of morphological processing subsumed these complexities under the notion of 'semantic interpretability'. In the present thesis, the aim is not to examine the relevance of all morphological constraints and their interactions with one another, but to study the processing of sets of pseudowords that do **not** disobey the morphological constraints laid out in the preceding section. The idea is thus to investigate the processing of sets of novel formations that are viable as such, as well as matched on critical psycholinguistic variables. Differences between sets will pertain to the lexical status of intermediate stages of derivation and thus the question whether derivations need be built based on *actual* words or whether *possible* words that are lexical gaps can also function as viable bases. This means that the lexical gaps that we shall encounter in the present thesis will be part of sequences of derivations – i.e. derivational chains. These two notions – lexical gaps and derivational chains – will be elucidated in more detail in the next chapter as we build a case for the empirical investigation of the roles they play in word recognition.

3. MORPHOLOGICAL ANALYSIS ACROSS LEXICAL GAPS

3.1 Bridging the gap: Linguistic and psycholinguistic approaches to lexical gaps and derivational chains

In Chapter 2, we have seen that the main questions in psycho- and neurolinguistic research on word recognition have been concerned with whether or not morphological complexity is reflected in the organization of the mental lexicon. This question is intimately linked to the autonomy of morphological processes and whether or not these can be isolated from related properties relating words to one another such as their similarity in meaning and form. In our survey of the experimental literature, the vast majority of studies relied on single-affixed words that were derived from their base words in a single derivational step (e.g. *govern* - *government*; *corn* - *corner*), thus further complicating a strict separation between morphology and epiphenomenal relationships between words that are grounded in their semantic and formal overlap.

We have also homed in on theoretical work that is focused on the constraints underlying the formation of complex words, and have seen that morphological viability is the product of a complex interplay between rules of word formation. At the same time, the understanding has been implicit in our discussion that for derivation, not all forms that are licensed under the rules of word formation are in fact attested. We thus find that formations that 'should' be possible - examples given above include **gloriosity* and **furiosity* - are not attested; they are lexical gaps. The present chapter presents an empirical investigation into the status of lexical gaps in word recognition. This will be combined with an attempt at diminishing the focus on single-affixed words so far shown by experimental research into word recognition. The types of complex words employed in the present study will thus be the result of a series of derivations - a derivational chain. For this purpose, we shall begin by clarifying how the notions of 'lexical gap' and 'derivational chain' will be understood and used in the present study.

3.1.1 Lexical gaps

A lexical gap can be defined as a missing entry in the mental lexicon where a stored representation could have been expected. In the present study, we will not be concerned with cases where these expectations are based on the notion of cross-linguistic comparison and the availability of a given term in one language but not in another. An example would be the German word *Schadenfreude*: the fact that this has no direct equivalent in English does not allow us to identify an English lexical gap in the sense intended here.

Such cases differ from the situation in which the realization of a new word is readily available through derivation, and yet the word as such does not exist. To give an example, the derivate *stealer* from *steal* appears well-formed, that is, it does not violate the morphological constraints laid out by the language. Based on the compositional meaning of its constituents, the overall meaning of the complex word *stealer* can also be readily obtained. Here, the reason for a lexical gap can be ascribed to the influence of so-called *blocking effects*. Rainer (1988) presents two types of blocking effects: type-blocking and token-blocking. Type- blocking describes the competition between two morphological processes that are similar in regularity and productivity, but also have some overlap in their domain of application such as -*ness* and -*ity*, which both attach to adjectives. Plag (1999) exemplifies the implications of type-blocking based on the blocking of affixation with -*ness* by a competing affix such as -*ity* that is more restricted in its domain of application to learned, rather than inherited adjectives (e.g. *sincerity*).

Type-blocking is thus argued to operate not on the basis of individual lexical entries, but is instead propelled by the domain-specificity of competing morphological processes.

In the case of token-blocking, blocking effects hold at the level of individual tokens. Thus, the lexical gap observed for *stealer* is explained on the grounds that a particular lexical entry - here *thief* - already covers the meaning that would be expressed through the formation *stealer*, thereby blocking the new formation (Bauer, 2003). These observations have led to the argument that synonyms are generally disfavoured and avoided when a stored representation for a particular meaning is already existent. Rainer (1988) identifies three conditions for token-blocking:

1. *The Condition of Synonymy*
2. *The Condition of Productivity*
3. *The Condition of Frequency*

The first principle as synonymy avoidance could be viewed as a means to minimizing ambiguity and is also expressed in the **Avoid Synonymy Principle** (Kiparsky, 1982, p. 15): 'The output of a lexical rule may not be synonymous with an existing lexical item'.

The implication of this principle is that when blocked formations such as *stealer* occur, the associated meanings are no longer synonymous, but commonly take on additional layers of meaning such as *ten fingers* for Shakespeare's term '*ten stealers*' (Bauer, 2003). This observation would appear to lend support to the general tendency of avoiding synonymy. However, as Bauer (2003) goes on to demonstrate, we do find semantically highly congruous formations such as *normalcy* and *normality*, thereby disconfirming the pervasiveness of synonymy avoidance. Moreover, as Bauer (2003) argues, it can be seen that in certain cases, formations that date back to later attestations than competing existing tokens (compare *compute* versus *computate*, whereby the former is a newer formation), outperform the earlier forms in occurrence even though their attestation should have been expected to be blocked according to the Condition of Synonymy. This shows that rules of word formation continue to be active despite the availability of existing, sometimes even highly synonymous formations.

As a second condition, the Condition of Productivity stipulates that the blocked formation should follow the rules of word formation. This harks back to the distinction between possible versus impossible formations in Chapter 2 and reinforces the importance of a distinction between the two, since only possible words should be expected to be subject to blocking effects. The third principle (the Condition of Frequency) draws on the observation that blocking constraints are contingent on the frequency of the existing word that is exercising a blocking effect on a potential new entry. On the whole, high-frequency words are less prone to substitution effects from new formations than words that are lower in frequency, suggesting that the degree to which the representation is entrenched in our mental lexicon exerts an influence on the incorporation of new representations (Plag, 1999). Note that these observations do not necessarily only lend support to accounts advocating whole-word storage when the blocking word is morphologically complex. As has been argued previously, *surface frequency* effects can be interpreted as the frequency at which the morphological constituents in a complex word are decomposed and recombined.

Crucially, these considerations reveal potential for psycholinguistic investigation. Plank (1981) also addresses aspects of lexical storage and its effects on blocking of viable formations, suggesting that the storage argument is convincing, but not all-or-nothing, given that speakers do resort to unlisted but well-formed formations whenever memory fails and the stored representation cannot easily be retrieved. Whilst superficially, this may resemble a question more pertinent to *performance* rather than *language competence*, it is nonetheless clear that the formations elicited are not arbitrary compositions, but draw on options that are licensed by our tacit knowledge of word formation rules.

This latter insight sheds light on the possibility that, while lexical storage modulates the lexicalization of competing variants, the viability of their formation is never entirely ruled out. Instead, speakers must have access to a set of rules that generate viable formations, as well as to constraints and restrictions that make other formations impossible. It is precisely this knowledge that we will endeavour to access in the present study. That is to say, if speakers possess knowledge about viability in word formation, then it should be discernible in the processing of novel formations. That is to say, given that these novel formations could constitute the set of solutions to which speakers resort when a stored representation is not available, their processing should trigger the recognition of a viable structure.

So far, our discussion on lexical gaps has focused on possible formations that are a single derivational step away from a listed representation. If we take the generative power of word formation rules a step further, then it should be viable to apply these in succession, thereby looping through a number of so-called lexical gaps. Noteworthy in this respect is Halle's (1973) treatment of the notion of a lexical gap in contrast to the approach offered by Aronoff (1976). In *Prolegomena to a Theory of Word Formation*, Halle (1973) proposed that lexical gaps (examples given include **arrivation* and **deprival*) are marked with a feature {-Lexical Insertion}. This means that while word formation rules can generate these formations, *actual* versus *potential* words are distinguished through the application of a filter that extracts items that are marked for {-Lexical Insertion}. Aronoff (1976), on the other hand, argued that further to the building blocks of word formation having to be words, rather than morphemes as proposed by

Halle, these words had to constitute *existing*, rather than just possible words. This has implications for formations that are lexical gaps themselves, but are also separated from their base words by several derivational steps and thus a number of successive derivational rules - a derivational chain. Before considering the psycholinguistic implications of this, we will delineate our understanding of the notion of derivational chain and its treatment in the literature.

3.1.2 Derivational chains

It is commonly noted that the output of derivational processes is not arranged in neatly organized cells of a paradigm, unlike inflection (Štekauer, 2014). This distinction is partly motivated by the more idiosyncratic nature of word formation processes as succinctly summarized by Plank (1994) through the absence of a delimited system in derivation. Inflectional paradigms, on the other hand, could be understood as a pre-determined pattern containing a finite number of positions that are populated with the output of inflectional rules realizing morphosyntactic feature specifications. As these specifications are pre-determined, and each position within the paradigm system represents the realization of a particular combination of grammatical functions, it can be expected that any newly coined word will project onto the existing pattern provided by the paradigm. Inflectional paradigms thus display a high degree of systematicity. Occasional lexical gaps as expressed through missing entries such as the unavailability of a 1st person singular non-past tense form for the Russian verb победить (V., 'to win') are discussed in Sims (2015) and these can then be considered marginal phenomena in an otherwise highly organized system. But in principle, it may be possible to find systematicity in derivation after all.

The issue may revolve around a change in perspective on the notion of systematicity in view of some of the discussed differences in function between inflection and derivation. Notably, rather than delivering the morphosyntactic specification of an output form, derivation subserves the formation of new lexemes and delivers thus the meaning of a morphologically complex word. One aspect of systematicity in derivation may reside in the directionality of rule application, leading to the construction of sequences of derivation or what we alternatively may call chains of derivation. The observation that the order of application of rules is not entirely arbitrary has been delineated in 2.6.2. In fact, leaving a number of more equivocal cases such as zero-derivation aside, derivational processes can be claimed to be directional in the sense that certain orders of application are observed while others are not and where there is flexibility in their arrangement relative to one another, this has implications for the construction of meaning. As we have discussed in section 2.6.2.3, the order of derivational affixation is in many cases reflective of the semantic scope and thus the order in which semantic operations are applied to the base word. These patterns were illustrated on the basis of Yup'ik (Mithun, 1999) in section 2.6.2.3. This example served as an exemplification of how the successive application of derivational processes is also governed by a degree of systematicity that supports the retrieval of the intended meaning. It can thus be expected that the notion of systematicity becomes more potent the higher the number of derivational processes involved.

Derivational processes can indeed be cumulative to the extent that they apply in succession with the output of one derivational rule serving as the input to the next. Derivation can moreover display elements of recursion (Scalise, 1988). Examples of this include German prefixation in *über-* ('overly') as attested in *über - über - überschwer* (A., 'very very very difficult') and used in this context for emphatic purposes to signal the degree of difficulty. Corresponding English examples can be put forward for the prefix *meta-*, which can also be added recursively to a stem as in *meta-meta*-level (Bauer, 1983). Recursion is thus a particular instantiation of the cumulative nature of derivation, whereby a sequence of derivational processes applies. The possibility for derivational processes to enter recursive loops again offers insight into the limitations presented by an approach to word recognition that is restricted to lexical storage. Hankamer (1989) projects the predictions implicit in a *full-listing* view of word recognition onto agglutinative languages with Turkish serving as a central example. Even if we do not factor in recursiveness, successive applications of derivations in which a derived stem can serve as the base to a subsequent derivation are far from the exception. The example given by Hankamer (1989) – *indirilemiyebilecekler* 'it may be that they will not be able to be lowered' – highlights the process whereby the root *in* ('descend') serves as the base to the causative suffix *-dir*, yielding the meaning 'lower' for the resultant verb *indir*, which in itself is a viable base for the following passive suffix *-il*. This process is repeated until the entire string ending with the plural suffix *-ler* is parsed. The number of *actual* words to be incorporated and possibly listed in the mental lexicon is thus substantial and a clear demarcation between *actual* and *possible* words is exacerbated by the prolificness of recursion as evidenced by suffixes that attach iteratively. After all, the question could be raised: after just how many recursive iterations it is still plausible to assume holistic storage of all intermediate and final complex words? Hankamer (1989) is quick to reject possible objections with regard to the prevalence of such complex words in natural speech by pointing out that words that are made up of at least five morphemes account for nearly 20% of tokens extracted from a speech sample of several thousand words in Turkish. Highly complex words are thus hardly peripheral to the processing mechanisms that must underlie word recognition in Turkish. Especially the iterative potential of some affixes such as the causative suffix *-dir* casts doubt on the absence of morphological parsing in day-to-day language processing. After all, iterations bear the potential of generating output forms that are increasingly likely to present the listener with novel material that has previously not been encountered and stored holistically. For the recognition of highly complex words, Hankamer (1989) advances a computational approach of word recognition in which the root is recognized first through a matching procedure of the lexical form to possible initial substrings. With the attachment of every additional suffix, a new stem form is generated that can only be succeeded by a subset of suffixes available in the language. The availability of the relevant suffixes for further derivation is argued to be determined by the morphotactic constraints of the language. The idea that the recognition of complex words proceeds step-wise as suffixes are added and checked incrementally implies that morphological decomposition could be a mechanism applying 'on-line', that is in real-time as morphological information becomes available. Rather than requiring a look-up mechanism based on stored representations, knowledge of constraints on morpheme combination would be expected to steer the recognition process.

It could, of course, be argued that morphological decomposition as 'on-line' parsing is restricted to agglutinative languages due to the degree of morphological complexity inherent in these languages. However, we have also touched on instances of recursion and iterativity in both German and English as exemplified through prefixation in *über-* and *meta*-respectively. Do these instances represent isolated cases in which speakers of non-agglutinative languages might resort to parsing and composition of morphological complexity? Is the possibility of 'on-line' parsing only conceivable when the interlocutor deviates from more canonical usage? What happens when a speaker decides to attach more affixes to an input form than the listener might have previously encountered and thus stored in their lexicon? Would we presume that recognition fails?

The question whether the parsing of morphological complexity can take place 'on-line' as it draws on the morphotactic possibilities of the language will be central to the empirical investigations laid out in this chapter. Undoubtedly, German does not exhibit the same degree of morphological complexity as inherent in agglutinative languages such as Turkish and Finnish, but differences in degree of morphological complexity are commonplace; that is to say, there are numerous attestations of complex words that possess more complexity than the kinds of single-affixed words discussed in Chapter 2. The derivational chains that are thus typically examined using psycholinguistic methods are composed of one derivational step (although exceptions to this will be considered in more detail in the present chapter). Considering that derivational processes are cumulative, it could be argued that morphological complexity as such cannot just be characterized in terms of its presence or absence in the analysis of a surface form. Instead, degrees of morphological complexity can be captured quantitatively. This means that a complex word formed on the basis of another derived word will exhibit an enhanced degree of morphological complexity compared to a derivation that takes a morphologically simple form as its input.

A central question that will permeate the discussions in this thesis concerns possible processing consequences seen when speakers are presented with differences in derivational depth based on the number of operations expressed through a derivational chain. To illustrate the relevant phenomena at work, let us consider the agentive noun *driver*, which is transparently derived from the verb *drive* in a single derivational step: $drive_{V}$ > $driver_{A}$. The affix *-er* serves as one of the diagnostics in the identification of the directionality that characterizes the relationship between *drive* and *driver*. Through the addition of the affix, *driver* obtains greater semantic specificity and increased morphological complexity compared to its base word *drive*. In a typically cumulative fashion of derivation, it can subsequently serve as the stem to an additional derivational operation that derives *driverless*. It would not be necessary to stop here since *driverless* as a newly derived base lends itself to the derivation of *driverlessness*, thereby mirroring some of the more complex structures previously discussed for agglutinative languages such as Turkish. As we saw above, Hankamer (1989) argued that the degree of morphological complexity had clear implications for human word recognition processes and that these implications would most likely not be restricted to agglutinative languages such as Turkish (p. 404).

Under a view in which morphologically complex words are parsed incrementally, additional layers of morphological complexity might entail enhanced processing demands as a higher number of computations are required for recognition to occur. Put differently, longer derivational chains could be expected to place an increase in processing load onto our parsing mechanism since the number of checking procedures is concomitant with the number of derivations separating the final complex word from its root.

Experimental evidence highlighting a possible uptake in processing demands during the recognition of highly complex words can be gleaned from two neuroimaging studies. In the first study, Meinzer, Lahiri, Flaisch, Hannemann and Eulitz (2009) turned to the investigation of processing patterns for two sets of complex nouns in German such as *Deutung* (N., 'interpretation') and *Ebnung* (N., 'flattening'), which - at least based on a superficial analysis - both appear to be composed of a stem and the nominalization suffix *-ung*. Upon closer inspection, however, the two sets differed in their internal morphological complexity as a function of the length of their derivational chain. *Ebnung*

(N., ‘flattening’) is the result of a 2-step derivation following the derivational chain in *eben* (A., ‘flat’) > *ebnen* (V., ‘flatten’) > *Ebnung* (N., ‘flattening’) while *Deutung* (N., ‘interpretation’) is derived in a single step from its base word as can be gleaned from the derivational chain *deuten* (V., ‘interpret’) > *Deutung* (N., ‘interpretation’). The intermediate derivational step in *Ebnung* via the verb *ebnen* is required given the selectional restriction that *-ung* nouns are derived from verbal, rather than adjectival bases (Eisenberg, 2016; Fleischer & Barz, 1995). Abstracting away from specific examples, the two derivational chains leading to nouns in *-ung* are exemplified by the following two templates:

1. **1-step derivation:** base verb > nominalization through -*ung* suffixation
2. **2-step derivation:** base adjective > verb through zero-derivation > nominalization through *-ung* suffixation

If, as posited by Hankamer (1989), morphological parsing involves the activation of the root morpheme followed by a step-wise checking procedure, then differences in the number of iterations to be performed should be reflected in differences in processing load between the two sets of *-ung* derivations. Although a surface-level composition between the two sets of complex words is comparable, a structural analysis of their derivational chains displays differences in inherent degrees of complexity.

Increased activation in the *left inferior frontal gyrus* was indeed found for the more complex set as an index of processing effort, suggesting that the additional layer of complexity was manifested in brain activation during visual word recognition (Meinzer et al., 2009). Following up on the German study, Pliatsikas, Wheeldon, Lahiri and

Hansen (2014) examined the difference between one- and 2-step derived nouns, this time with *zero-derivation* in English. Words like *bridging* through *bridge*$_{NOUN}$> *bridge*$_{VERB}$ > *bridging* were compared with *soaking* (*soak*$_{VERB}$ > *soaking*), both of which again look very similar in terms of their surface morphological make-up but differ in morphological complexity and therefore the length of their derivational chain. In English word formation, the selectional restriction holds that the suffix *-ing* can only be added to verbs (*staying* and *bridging* are thus possible, but not **graping* from the noun *grape* or **happying* from the adjective *happy*). As in Meinzer et al.'s (2009) study, the derivation of the final noun form thus hinges on the availability of a verbal base word. This base word can either be monomorphemic as is the case in *soak*$_{\mathrm{VERB}}$ or the result of an intermediate derivational step yielding the morphologically complex zero-derived verb *bridge*$_{\mathrm{VERB}}$ from the nominal base word *bridge*$_{\mathrm{NOUN}}$. The two derivational chains underlying the *-ing* derivations in Pliatsikas et al. (2014) are given in 3. and 4., demonstrating again that forms that appear aligned and matched based on their surface realization can differ in their internal morphological composition:

3. **1-step derivation:** base verb > derivation in *-ing*
4. **2-step derivation:** base noun > zero-derived verb > derivation in *-ing*

In addition to the two sets of *-ing* derivations, Pliatsikas et al. (2014) also incorporated a third experimental condition consisting of a set of morphologically simple English verbs ending in *-le* such as *grumble*. These served as a baseline in establishing an effect of morphological complexity on brain activation and thus the processing load observed during visual recognition. Not only was the activation for both sets of complex verbs significantly higher than for the monomorphemic control verbs, activation in 2-step derived *-ing* forms was significantly higher than in the less complex *-ing* forms that were derived from their base words in a single step. That is, the *bridging* set showed higher activation than the *soaking* set within the same narrowly defined region in the *left inferior frontal gyrus*. The gradient nature of the activation patterns observed was interpreted as highly indicative of speakers' sensitivity to levels of morphological complexity.

In both studies, the number of derivational steps performed to access the base word correlated with the degree of activation measured in the *left inferior frontal gyrus*, which was linked to combinatorial and lexical processing. Moreover, despite converging strategies employed in the manipulation of derivational depth, a critical difference between the two studies lies in the morphological realization of degrees of complexity. In the first study, this is achieved through the successive application of affixational processes that inevitably create not only morphologically, but also visually more complex structures through the presence of a greater number of surface morphemes. In Pliatsikas et al. (2014), meanwhile, layers of morphological complexity are instantiated through *zero-derivation* and thus in the absence of any change in surface form that could also be phonologically or orthographically driven. The fact that the imaging results obtained across both studies are parallel suggests that at the level of visual word recognition, it is the length of the derivational chain and thus the number of derivational processes, rather than the type of morphological process involved that affects processing effort. Note that Pliatsikas et al. (2014) had controlled for the directionality of the derivation between the nominal and verbal forms involved in the *conversion* process due to a behavioural pre-study. In this off-line task, participants were required to specify the degree to which a given form displayed more object- or rather more action-specific characteristics. Zero-derived forms for which the off-line ratings were inconclusive were not included in the stimulus material, thereby ensuring that derivational depth and not uncertainty with regard to lexical class was driving the imaging results.

In both studies, the proposed causal link between derivational depth and processing load as evidenced through the degree of activation in the *left inferior frontal gyrus* was motivated on the basis of previous fMRI investigations into morphological processing. In these priming studies, the *left inferior frontal gyrus* was implicated in both the processing of inflectional morphology (Marslen-Wilson & Tyler, 2007), as well as in repetition priming of derived words such as *bravely*-*brave* or *archer*-*arch*, but not during the processing of purely semantically or phonologically related pairs (Bozic, Marslen-Wilson, Stamatakis, Davis, and Tyler, 2007). It should also be noted that across studies, participants were presented with the more complex formation first if the task involved a priming task manipulation. Similarly, in Meinzer et al. (2009) and Pliatsikas et al. (2014), lexical decisions were made to the complex form in a simple, unprimed lexical decision task in which the degree of LIFG activation was correlated with depth of derivation. In view of the directional properties of derivational chains, it can thus be summarized that the discussed neuroimaging studies were focused on a process of decomposition as structural analysis of a complex word into its morphological constituents. Whether or not the decomposition process resembles a parsing system that is akin to the step-wise checking procedure delineated by Hankamer (1989), however, cannot be established on the basis of the aforementioned studies. The complex words employed across those studies are frequent enough overall to be endowed with their own stored representation. It could thus be argued that differences in degree of LIFG activation mirror the increased complexity of the lexical entries associated with 2-step derived words when compared with morphologically simpler entries.

Based on the stimuli employed by Meinzer et al. (2009), this would be reflected in a structurally more complex entry for *Ebnung* compared with *Deutung*:

5. $[[[\text{Eben}_A]_V]\text{-ung}_N]$
6. $[\text{Deut}_V]\text{-ung}_N]$

Even if differences in complexity for the lexical entry were to provide evidence for the independent effect of morphological complexity on the organization of individual lexical entries, the question remains whether morphological decomposition draws on more abstract knowledge of morphological possibility. That is to say, do the results reported by Meinzer et al. (2009) and Pliatsikas et al. (2014) emerge as a consequence of speakers' tacit knowledge of morphological constraints? These constraints would include the requirement for *-ung* nominalizations in German and *-ing* derivations in English to be derived from verbal, rather than adjectival or nominal bases. On the basis of the results reported, however, it is equally possible to surmise that differences in complexity are tied to the specific make-up of the lexical representations investigated. This would not necessarily require a process of 'on-line' morphological parsing based on abstract notions of morphological complexity.

In order to inspect the possibility that the depth of a derivational chain and the morphological rules it captures are accessed during morphological decomposition, we propose to connect the previously discussed properties of lexical gaps and derivational chains. This will involve the investigation of morphological parsing in well-formed pseudowords that constitute lexical gaps in viable derivational chains.

3.2 Pseudowords as lexical gaps in derivational chains

As laid out in Chapter 2, within the field of word recognition of complex words, an on-going discussion has been whether complex derived words are holistic or decomposed and which factors, if any, determine decomposition. This debate centres on the question whether we store every single word form (e.g. *walk*, *walks*, *walker*) holistically (Butterworth, 1983; Joanisse & Seidenberg, 1999) or whether morphologically complex words are represented and in certain cases accessed through their morphological constituents (e.g. Taft & Forster, 1975; Pinker & Ullman, 2002; Clahsen, Sonnenstuhl, & Blevins, 2002). A critical question in morphological processing thus concerns the role of purely morphological effects at different stages of visual word recognition and the interpretability of complex items.

At very early stages of visual word recognition, we have seen that 'automatic' segmentation of morphologically complex words has been well established. Seminal work in masking priming (cf. Rastle, Davis & New, 2004) has shown that suffix-like items (e.g. *-er*) can be stripped off, leading to the activation of a word that is not necessarily morphologically related. For instance, *corn* was activated after seeing *corner,* but *brothel* failed to activate *broth* since *-el* is not an English suffix. This suggests that units that are recognized as suffixes can be 'stripped', even from items where they do not function as an affix, but where a correspondingly simpler word exists, regardless of its meaning. Evidence for this is provided by findings reported in Kazanina, Dukova-Zheleva, Geber, Kharlamov and Tonciulescu (2008). In this study, a masked priming experiment was used to investigate the processing of multi-affixed complex words in Russian. These consisted of a root morpheme to which a diminutive suffix *-k-* was attached and which was followed by a case/number-marking suffix. Transparent forms such as *gor*$_{\text{Root}}$-*k*$_{Dim}$-*a*$_{Nom.SG.}$ (N., 'little mountain') were decomposed as evidenced by a priming effect for the noun *gor*$_{Root}$-*a*$_{Nom.SG.}$ (N., 'mountain'). Pseudo-derived forms such as *lunk*$_{Root}$-*a*$_{Nom.SG}$ (N., 'hole') also primed a morphologically and semantically unrelated target such as *luna*$_{Nom.SG}$ (N., 'moon'). Similarly to the findings reported in Rastle et al. (2004), form controls such as *part*$_{Root}$-*a*$_{Nom.SG.}$ (N., 'desk') failed to instantiate a priming effect for a form-related target *par*$_{Root}$-*a*$_{Nom.SG.}$ (N., 'pair'). These findings demonstrate that early decomposition effects are not limited to single-affixed forms and that word-internal suffixes (here the diminutive -*k*-) can also be stripped. The position of the affixes clearly plays a significant role as shown by Crepaldi, Rastle and Davis (2010), who find that when suffixes such as *-ness* are added to the beginning of a word (i.e. if a suffix becomes a prefix **nesskind*) there is no evidence of stripping.

As mentioned previously, the question then arises to what extent this decomposition extends to pseudowords which are composed of existing stems and suffixes, but are not themselves words of a language. Recall that Longtin and Meunier (2005) pursued this idea in French by comparing two sets of pseudowords consisting of stem and suffix such as **rapidifier* versus **sportation* where both consisted of existing stems and affixes, but only **rapidifier* had the acceptable combination of stem and suffix that follows the morphological rules of French. The suffix *-ifier* is a productive suffix in deriving verbs from adjectives, while *-ation* adds to verbs and does not productively derive nouns from nouns in Modern French. Comparable real words would be *intensifier* 'to intensify' (*intens-*$_{\text{ADJECTIVE}}$ + *ifier*) and *invitation* 'invitation' (*invit-*$_{\text{VERB}}$ + *ation*). An off-line semantic interpretability task showed that words like **rapidifier* were judged to be interpretable, while the **sportation* set elicited significantly lower interpretability ratings. Nevertheless, as both sets of pseudowords elicited priming in a masked priming paradigm, this suggests that semantic interpretability was not taken into account at this early stage of word processing. Form-controls such as **rapiduit* that consisted of an existing word and a non-suffix ending did not prime the embedded word *rapide*. This reinforces the interpretation that masked priming taps into morphological structure and cannot be reduced to a form-related effect. Note, however, that more recent masked priming studies using combined behavioural and event-related potential responses (Morris, Porter, Grainger, & Holcomb, 2011) revealed priming effects for purely form-related pairs such as *cornire* and *corn*. Morris et al. (2011) argue that differences between the two studies can be attributed to divergences in the degree of overlap between prime and target across the two studies. What appears to be consistent across the two studies, however, is that morphological decomposition is independent of the semantic interpretability of the novel form in masked priming, as we have already argued in Chapter 2.

The notion of 'meaningfulness' in pseudowords composed of more than one morpheme was taken up extensively in Marelli and Baroni (2015). They present a computational model of morpheme combination at the meaning level that is based on co-occurrences of morphologically complex novel forms from a distributional semantics perspective. Affixes included suffixes (e.g. *-able, -less*) as well as prefixes (e.g., *re-, un-*). Derivations were varied including verb to adjective (e.g. *sketchable* vs. *dawnable*) and noun to adjective (e.g. *acneless* vs. *hikeless*). Forms like **acneless* and **hikeless* were presented to participants in off-line tasks for acceptability ratings. The results showed that forms that received high ratings for meaningfulness (e.g. **acneless*) had more neighbours than those that were rated low (e.g. **hikeless*). The computational model mirrors the off-line results in that meaningfulness of novel items is closely linked to larger numbers of semantic neighbours.

Both Marelli and Baroni (2015) and Longtin and Meunier (2005) consider the effect of semantic interpretability on morphological processing. A crucial difference between their assumptions is related to the formation of their novel items. Marelli and Baroni (2015) strictly follow legal combinations of stem and affix; i.e. *-less* can attach to nouns and hence **acneless* is a legal novel form. Longtin and Meunier (2005), however, included implausible combinations of stem and affix; thus, **sportation* is not a legal item in the sense that *sport* is a noun, but *-ation* can only add to verbs. Thus, Marelli and Baroni's comparisons of novel items are always legal combinations and their semantic interpretability is not a consequence of the validity of the morphological composition. Although **acneless* is rated as more meaningful than **hikeless*, they are both legal combinations and look very similar on the surface.

Harking back to our considerations in section 3.1 with regard to derivational chains, it is important to consider that there could also be a further cause for this difference, which may be due to hidden depths of morphological complexity. As we have established, English is well known for zero-derivation or conversion where nouns may become verbs and vice versa without any overt affixation: *an eye* vs. *to eye*, *to run* vs. *a run* (Bauer, Lieber & Plag, 2013). Although semantically it may often be obvious which is the basic form (e.g. *eye* is a basic noun), this is not always the case. The word *hike* is equally plausible as a noun or a verb, but *acne* is clearly classified as a noun. For the suffix *-less* to attach to *hike,* it has to be the noun and not the verb. Is it possible that the morphological composition of **hikeless* could be $hike_{VERB}$ > $hike_{NOUN}$ > $*hikeless_{ADJECTIVE}$ as compared to $acne_{NOUN}$ > $acneless_{ADJECTIVE}$? Even if the **hikeless* derivation is directly from the noun *hike,* there is a difference in the morphological neighbourhood of *hike* and *acne.* Consequently, to what extent can the length of the derivational chain or morphological neighbourhood affect semantic interpretability? In fact, if morphological neighbourhood is a factor, then **hikeless* would have more neighbours (both the noun and the verb) than **acneless*. However, Marelli and Baroni's (2015) study was not concerned with derivational depth and morphological neighbourhood and it is not possible to discern to what extent some of the novel items were more complex than others.

Recall, however, that the role of derivational depth has been considered in other studies such as in Meinzer et al. (2009) and Pliatsikas et al. (2014), in which more complex words led to increased processing effort. Combining the notion of semantic interpretability and morphological complexity, we turn to a comparison of novel items in German, which are semantically plausible, but morphologically deviant in different ways. For instance, novel items ending in the same suffix like **Spitzung* (derived from *spitz* A., 'sharp') and **Hübschung* (derived from *hübsch* A., 'pretty') differ because within the same derivational chain, there are differences with regard to where lexical gaps occur. The derivational chain subserving the formation of both sets of nouns can be expressed as follows:

1. base adjective > zero-derived verb > noun in *-ung*

As nouns in *-ung* can only be derived from verbs, the intermediate step via the verb is thus mandatory as per the selectional restrictions underlying the formation of the relevant noun forms. Note that the verb itself can be causative (e.g. the existing verb *kühlen*) or inchoative (e.g. the existing verb *grünen*). Crucially, when we are dealing with pseudowords such as **Spitzung* and **Hübschung* that look matched in surface structure, there can be underlying differences. The verb *spitzen* (V, 'to sharpen') exists, but **hübschen* does not; this means that a possible derivational chain of the novel item **Hübschung* would have been *hübsch* > **hübschen* > **Hübschung* while that of

**Spitzung* is *spitz* > *spitzen* > **Spitzung*. We thus find differences in the lexical composition within the same derivational chain *adjective* > zero-derived *verb* > noun ending in *-ung*. Sequences of multiple derivations – or simply, derivational chains – are also a common occurrence in English, with lexical gaps. To clarify, we provide an example. The word *characterization* has the derivational chain of $character_{NOUN}$ > $character\text{-}ize_{VERB}$ > $characterize\text{-}ation_{NOUN}$. Legal pseudowords can be made with these suffixes such as **criticization* and **nationization*. However, these differ in terms of the intervening lexical gaps: *critic* > *criticize* > **criticization* versus *nation* > **nationize* > **nationization*. These are exactly parallel to the German examples above. Our central question concerns how speakers treat these semantically plausible and morphologically viable pseudowords that constitute lexical gaps in derivational chains.

In the present study, our concern is thus with novel forms differing in intermediate stages of their derivation. We suspect that this might also contribute to how easy it is to integrate a novel form. Our prediction is that even though novel forms containing lexical gaps in their intermediate derivations can be decomposed, pseudowords in intermediate derivations might entail processing costs. This hypothesis is supported by the observation that even though we find complex words in language use that are derived from pseudowords in intermediate positions (*indefatigable* in English is built on the pseudoword **defatigable* through *fatigable* > **defatigable* > *indefatigable;* cf. Booij, 2012, p.57), these formations are not very frequent on the whole.

Before addressing these issues empirically, we need to remind ourselves of the notion of a lexical gap within derivational chains that will be used in the present study. In theoretical linguistics, morpheme- and lexeme-based approaches make conflicting predictions regarding the participation of items in derivational processes that are not actual words. To illustrate this point, in English word formation, we find words like *navig-able* in which the stem *navig-* as such is not an actual word. Under a lexeme-based approach, this issue does not arise because all elements that participate in word formation are actual words, but this comes at the expense of having to add truncation to the list of word-building processes, e.g. *navigate* > *navigate - able* > *navig-able.* Under this analysis, *-ate* is truncated in the derivation of *navigable*. Morpheme-based approaches more straightforwardly derive *navigate* from the nonword stem *navig*-. As adumbrated in Chapter 2, similar issues were addressed experimentally by Taft and Forster (1975) who showed that the morpheme *de-* could be stripped in forms like **dejuvenate* although the stem *juvenate* was not an actual word. It was argued that nonword stems such as *juvenate* were directly listed in the lexicon, providing evidence for morpheme-based decomposition processes that are not reliant on existing lexical representations for the stems.

Our focus in the present chapter is not on the decomposition of complex real words built on non-existent stems as lexical gaps, but rather on processing differences of pseudowords built with real stems. Both research questions are concerned with the internal composition of complex items that can only become available following decomposition. In the present study the two sets of pseudowords differ in the number of missing intermediate steps as discussed above for **criticization* and **nationization*. The novelty of our study thus lies in the empirical investigation of lexical gaps at intermediate stages of morphological composition. Four behavioural experiments were designed to investigate the processing of meaningful pseudowords that include lexical gaps in their derivational chain: three lexical decision tasks with delayed priming and one regular lexical decision task.

3.3 Decomposing across lexical gaps: Experiments 1 and 2

As we have noted previously, empirical investigations of pseudowords within morphological processing have mainly focused on single-suffixed items (e.g. Longtin & Meunier, 2005; Marelli & Baroni, 2015). The study of more complex derived forms has restricted itself to real words in neuroimaging and in the modelling literature (e.g. Meinzer et al., 2009; Plag & Baayen, 2009). In Experiments 1 and 2, we therefore first need to establish whether multi-affixed pseudowords can be decomposed to their base word lying two derivational steps away.

As laid out in Chapter 2, a number of different priming procedures such as masked priming, cross-modal repetition priming and delayed (also commonly termed 'long-lag') priming have been employed to understand whether morphologically complex words activate a morphologically related word. Due to reports of facilitatory effects between structurally impossible combinations such as **sportation* in French and embedded 'stems' such as *sport* (Longtin & Meunier, 2005), masked priming did not lend itself to the study of morphological viability for our set of experiments. In addition to this, in view of our interest in morphological effects that are unaffected by purely semantic relationships, delayed priming presents itself as the most viable paradigm for the present purposes based on the fact that prior studies have used the paradigm and found no evidence for facilitatory effects between purely semantically associated words (Marslen-Wilson & Tyler, 1998; Henderson, Wallis, & Knight, 1984; Drews & Zwitserlood, 1995; Bozic, Marslen-Wilson, Stamakis, Davis, & Tyler, 2007; Scharinger, Reetz, & Lahiri, 2009; Lahiri & Reetz, 2010; Bentin & Feldman, 1990; Napps & Fowler, 1987; Marslen-Wilson, 2007).

Two lexical decision tasks with delayed priming were carried out, comparing the processing of **Spitzung* (Experiment 1) and **Hübschung* (Experiment 2) with existing 2-step derived nouns like *Heilung* (N., 'healing'). In this part of the study, it was decided to keep the two sets separate across the two experiments to avoid the influence of one on the other. As speakers give lexical decisions to both primes and targets in delayed priming, it will also be possible to probe into the processing of the two sets of morphologically viable pseudowords in comparison with non-complex pseudoword fillers through the analysis of responses to the primes. The two delayed priming experiments differed in one test condition. In Experiment 1, we investigated whether complex pseudowords that are one derivation away from a lexical representation (e.g. **Spitzung* through *spitz* > *spitzen* > **Spitzung*) could be decomposed. In this condition (hereafter called 'NonEx1'), items have the features {+ Morphologically complex; - Extant noun; + Extant intermediate derivation}. In Experiment 2, we increased the number of derivations that proceed without the support of a lexical representation by looking into the decomposition of forms like **Hübschung* for which the complex verb **hübschen* filling the intermediate derivational position does not exist, giving this condition ('NonEx2') the features {+ Morphologically complex; - Extant noun; - Extant intermediate derivation}. An example for each type of test item used in Experiment 1 is given in Table 3.1.

Table 3.1 *Overview of test stimuli in Experiment 1*

Condition	Example stimuli	Derivational pattern	Type of violation
Extant: {+ Morph; + Extant noun; + Extant intermediate derivation}	*Heilung* (N, 'healing')	heil - heilen - Heilung	No violation
NonEx1: {+ Morph; - Extant noun; + Extant intermediate derivation}	**Spitzung* (N, 'sharpening')	spitz - spitzen - *Spitzung	Over-application of **one** derivation to a non-existent item

In Experiment 2, we kept the test condition 'Extant' for which all stages of the derivation are filled with lexical representations. Condition 2 was replaced with items like **Hübschung* that display the features {+ Morphologically complex; - Extant noun; - Extant intermediate derivation}. Table 3.2 gives an overview of the test conditions in Experiment 2.

Table 3.2 *Overview of test stimuli in Experiment 2*

Condition	Example stimuli	Derivational pattern	Type of violation
Extant: {+ Morph; + Extant noun; + Extant intermediate derivation}	*Heilung* (N, 'healing')	heil - heilen - Heilung	No violation
NonEx2: {+ Morph; - Extantnoun; - Extant intermediate derivation}	**Hübschung* (N, 'beautifying')	hübsch - *hübschen - *Hübschung	Over-application of **two** derivations to two non-existent items

3.3.1 Experiment 1: Decomposition of two-suffixed pseudowords

3.3.1.1 Method

Materials Experiment 1

There are two conditions in this experiment: condition 'Extant' containing real complex nouns (e.g. *Heilung* (N., 'healing')) and condition 'NonEx1' containing pseudonouns (e.g. **Spitzung* (N., 'sharpening')) derived on the basis of the same derivational chain as 'Extant'. In both conditions, target items comprise 16 extant adjective and 16 extant verb base forms. In the 'Extant' condition, all forms within the derivational chain exist. Items in the 'NonEx1' condition follow the same derivational chain as in 'Extant' (base adjective > zero-derived verb > noun in *-ung* or verb > adjective in *-bar* > noun in *-keit*), but the final noun form does not exist. In an off-line rating task with a student population of German native speakers, only items in condition 'Extant' were judged to be existing words in German. In both conditions, unrelated control primes consist of morphologically complex forms that are built using bases that are matched on critical factors such as lexicality, full form and base frequency, length and syllable structure. The full form is either extant ('Extant') or non-existent ('NonEx1'). For each condition, an example of the derivational chain for both adjectival and verbal bases is given in Table 3.3.

Prime items in all test conditions that are built on adjectives as roots are disyllabic with word-initial stress. Verb-based noun primes are a syllable longer and stress also falls on the first syllable. T-tests between the two conditions showed no significant differences in target word length, target word frequency, target lemma frequency, prime-target overlap, orthographic family size of the target, phonological size of the target and morphological family size between conditions. Within each condition, related and unrelated primes were matched in length, lexical status, frequency, syllable structure and stress.

Table 3.3 *Examples of stimuli for test conditions 'Extant' and 'NonEx1' with related and unrelated primes, intermediate derivational position and target words*

	Extant Condition		**NonEx1 Condition**	
Related Prime	*Heilung* (N., 'healing')	*Teilbarkeit* (N.,'divisibility)	**Spitzung* (N., 'sharpening')	**Denkbarkeit* (N., 'thinkability')
Unrelated Prime	*Faultier* (N., 'sloth'; extant complex word; unrelated to root *heil*)	*Abstreicher* (N., 'doormat'; extant complex word; unrelated to root in *teilen*)	**Dürrung* (N., 'act of becoming thin'; non-existent complex word; unrelated to root in *spitz*)	**Förderkeit* (N., 'sponsorability'; non-existent complex word; unrelated to the root in *denken*)
Intermediate form	*heilen* (V., 'heal')	*teilbar* (A., 'divisible')	*spitzen* (V., 'sharpen')	*denkbar* (A., 'thinkable')
Target	*heil* (A., 'intact')	*teilen* (V.,'divide')	*spitz* (A., 'sharp')	*denken* (V., 'think')

Fillers

In order to obfuscate the relationship of interest between words, 32 semantically related pairs (16 adjective-based; 16 verb-based) such as *Schnelle* (N., 'rapidity') and *fix* (A., 'quick'), as well as two sets of 32 phonologically related pairs were included. In order to provide a balanced design in the number of word and nonword stimuli presented to the participants, 96 further pairs of 'nonword' prime and 'nonword' target pairs, as well as a set of 64 'word' prime and 'nonword' target pairs were included. The total number of items was 640 per list.

3.3.1.2 Participants

Thirty-eight German native speakers participated in Experiment 1, of whom 23 were female. All subjects were students at the Goethe University in Frankfurt and were native speakers of Standard German. The study was approved by the local research ethics committee. Each participant gave their informed consent for participation and was reimbursed appropriately (10 €/hour).

3.3.1.3 Procedure

The experiment took place in a quiet room at the Goethe University in Frankfurt. The experimental environment consisted of the experimental hardware, a MacBook Pro running OS X from which the XMOD data gathering software application (Reetz & Kleinmann, 2003) was operated, push button boxes to give and record responses, and a video projector to present the stimuli on a screen. Each stimulus was presented in upper case[2] and remained on the projector screen for 500 ms. Participants had up to 2500 ms to make a lexical decision. Two experimental lists were employed in which the presentation of stimuli was pseudo-randomized. Participants were assigned to one of the two experimental lists and saw each target only once preceded by either its related or unrelated prime. The presentation of related versus unrelated primes in test conditions

[2] All items were displayed in block capitals: this was considered the most neutral way to present experimental stimuli in German, since German nouns are capitalized in line with orthographic conventions.

was counterbalanced across the two lists. Primes and targets were separated by 5 to 7 intervening items. Before starting the experiment, test subjects participated in a test run consisting of 10 practice items. Participants were instructed to respond to every item on the screen by deciding whether it was an extant word in German or not, using the push button box provided. 'YES' responses were made by the participant's dominant thumb.

3.3.1.4 Results

Target analysis. Two participants with error rates higher than 2 standard deviations from the mean (~ 5.3 % excluded of total data) and the item *wett* (~ 1.5 % excluded) that elicited high error rates across all participants were excluded. Items for which reaction times exceeded the participant's individual cut-off point of +/- 2 SD their mean reaction time to targets were not included in the analysis (~ 1.7 %). Only correctly classified targets in the test conditions were submitted to further data analysis (~ 1.9% excluded). The overall amount of data excluded across conditions did not differ ($p > .54$).

Reaction times were log-transformed in all analyses. Based on these data, a two-factor linear mixed model analysis was performed, using the fixed factors *Prime Type* (Related versus Unrelated) and *Base* (Ex versus NonEx1) and the random factors *Subject* and *Item* for the log-transformed reaction times in the statistical package *R* and its downloadable package *lme4* for mixed effects modelling. Contrasts for our fixed effects were sum-coded using (-1/1) coding and random slopes were included when their inclusion resulted in a significantly better fit of the model to our data as accessed through a likelihood ratio test (Bates, Kliegl, Vasishth, & Baayen, 2015). A model containing random intercepts for *Subject* and *Item* and by-item random slopes for *Prime Type* provided the best fit for our data. Through model comparison with and without the relevant fixed factor, we found a significant main effect of *Prime Type* ($\chi^2(1) = 10.448$, p = .001) with no other main effects or interactions reaching significance. This means that a priming effect in delayed priming could be established for both real words and possible pseudowords like **Spitzung* (see Figure 3.1). Error bars represent the standard error in all figures.

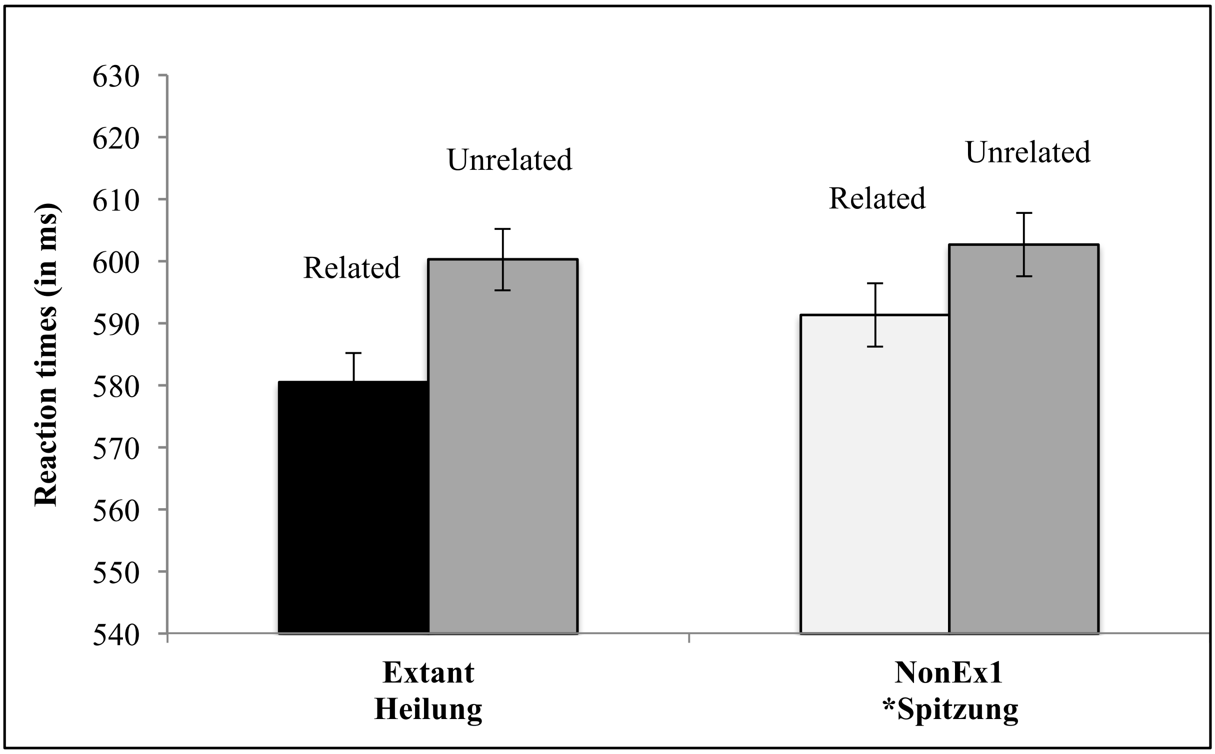

Figure 3.1 *Reaction times to targets in test conditions (Experiment 1)*

Prime analysis. Given that primes are on average a syllable longer than target items in this study, it was deemed worthwhile to calculate mean reaction times to primes only and to exclude all reaction times falling +/- 2 SD from a participant's mean reaction time to primes. Moreover, items that are non-existent, but contain no morphological structure were included in this part of the analysis in a condition termed 'Control NonEx'. Adjective-based controls were built on the basis of matched adjectives to which a pseudosuffix such as *–ang* was attached (e.g. **Plümpang* based on *plump*). Verb-based controls were built on the basis of a matched verb stem that was followed by a sequence of two suffixes the combination of which is not morphological. The combination employed violates morphotactic constraints given that nominalization suffixes such as -*nis* do not attach to adjectives that are already suffixed (Fleischer, 1975). Similarly, pseudo-suffixes such as *-mut* do not follow adjectives that are already suffixed. Noncomplex controls for the 'Non-Ex1' condition are matched in frequency of the 'base word', word-length, syllable-structure and stress pattern with the corresponding complex items in 'Non-Ex1'. In the reaction time analysis to these test primes, only correctly classified items in the three categories 'Extant', 'Control NonEx' and 'NonEx1' were submitted to data analysis. Mean reaction times for the lexical decision task to primes are shown in Figure 3.2.

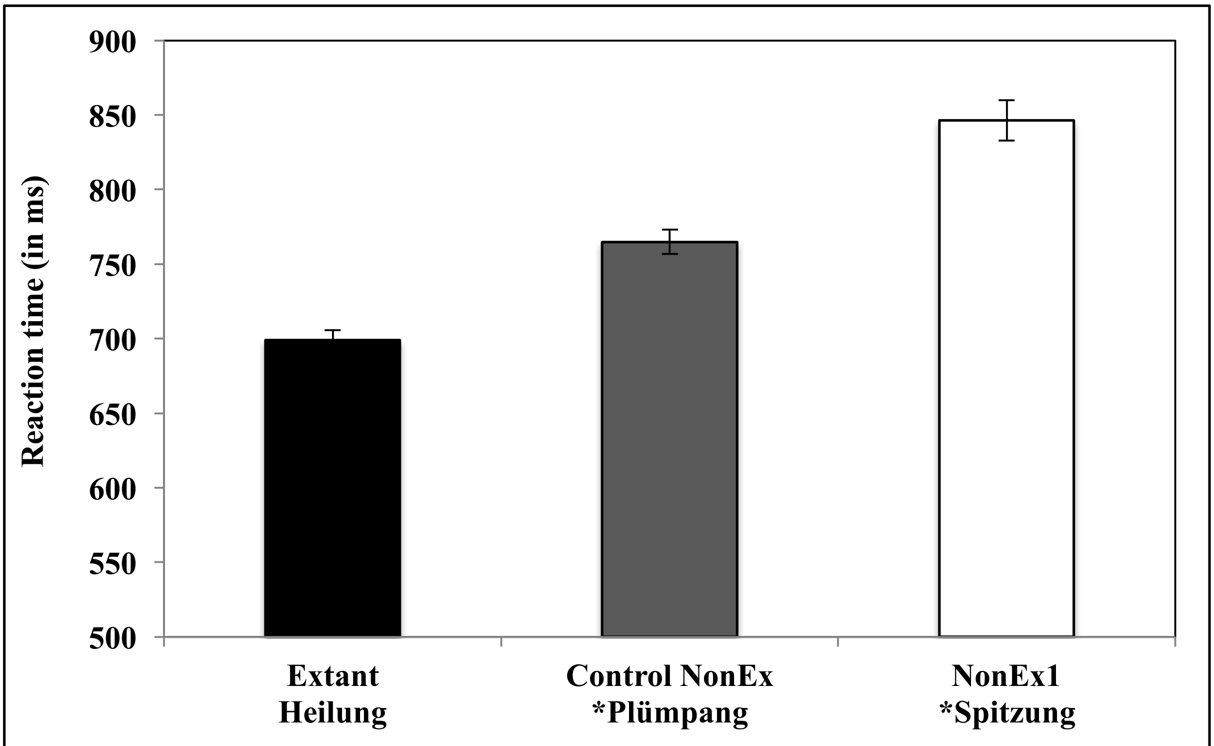

Figure 3.2 *Mean reaction times to primes (Experiment 1)*

To investigate the effect of Base on *Reaction time*, a linear mixed model analysis with the fixed factor *Base* and the random factors *Subject* and *Item* was performed using the statistical analysis software *R* and its downloadable package *lme4.* A linear mixed model with random intercepts for *Subjects* and *Items* and random slopes for *Subjects* provided the best model fit. In this model, the fixed effect *Base* affected *Reaction time* (χ^2 (2) = 36.511, p < .0001). We established pairwise comparisons between all conditions using the R package *lsmeans*. All pairwise comparisons were significant at p < .01 (Control NonEx versus Extant: Est. = 0.03914, SE = 0.01247, t(79) = 3.139, p < .01; Control NonEx versus NonEx1: Est. = -0.04768, SE = 0.01364, t(79) = -3.495, p < .01; Extant versus NonEx1: Est. = -0.08681, SE = 0.01309, t(79) = -6.634, p < .001). Crucially, participants were significantly slower at classifying 'NonEx1' items such as **Spitzung* than their non-complex controls like **Plümpang*, suggesting that the structural validity of constructions such as **Spitzung* was instantiating a delay in lexical decision times. In the error rate analysis the same criteria for exclusion of participants or individual data points were followed with the difference that both correctly and incorrectly classified items were submitted to data analysis. Error rates for the three categories 'Extant', 'Control NonEx' and 'NonEx1' are given in Figure 3.3.

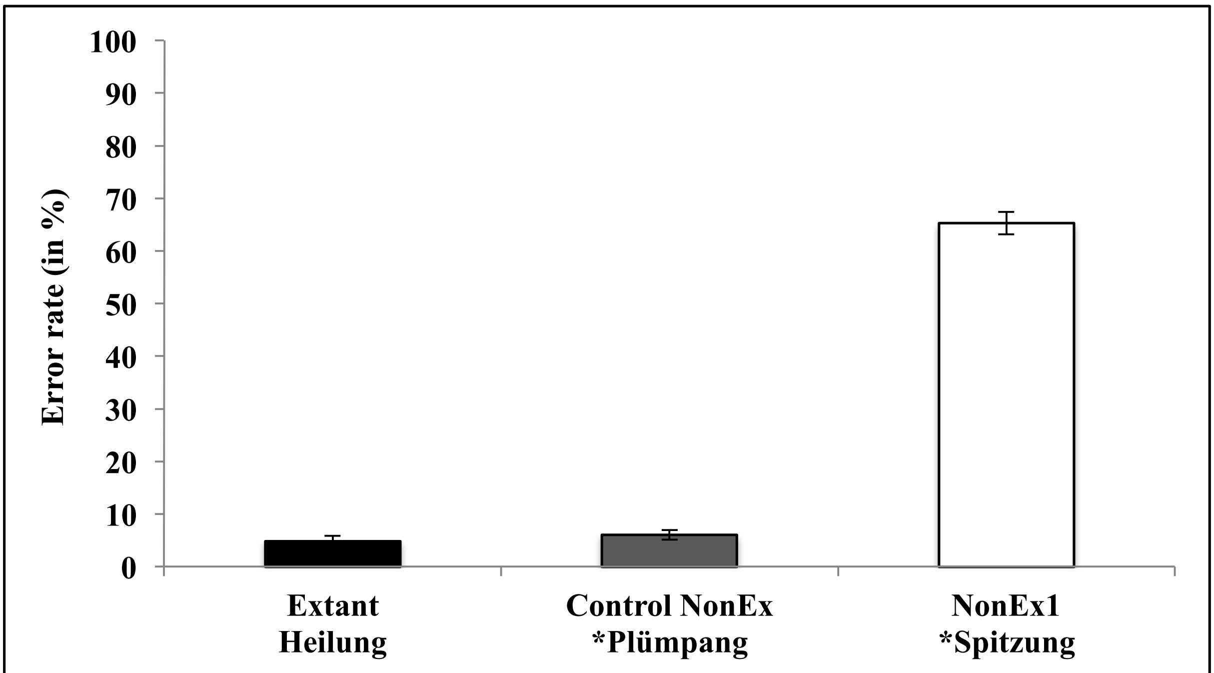

Figure 3.3 *Error rates to primes (Experiment 1)*

The data were analysed using a binomial generalized linear model (GLM) with *Base* as fixed factor and *Error rate* as dependent variable. *Base* significantly improved the fit of the model, χ^2 (2) = 672.72, p < .0001. Planned pairwise comparisons showed that the **Spitzung* set differed from the other two sets at p < .001. (Extant versus Control NonEx: Est. = 0.2334, SE = 0.2668, z = 0.875, p = 0.651; Extant versus NonEx1: Est. = 3.6063, SE = 0.2178, z = 16.559, p < .001; Control NonEx versus NonEx1: Est. = 3.3729, SE = 0.2019, z = 16.706, p < .001). As in the prime reaction time analysis, complex pseudowords such as **Spitzung* were found to produce the most difficulty in classification, eliciting by far the highest error rates.

3.3.1.5 Discussion

In Experiment 1, priming effects were observed between extant morphologically complex words and their base words (e.g. *Heilung* and *heil*), as well as for pairs in which the final noun form is not listed (e.g. **Spitzung* and *spitz*). When considered in conjunction with previous studies on the processing of complex pseudowords, this implies that the application of morphological decomposition is not restricted to single-suffixed pseudowords. Morphologically possible pseudowords such as **Spitzung* also elicited significantly longer lexical decision times and higher error rates than matched non-complex control nonwords. The morphological validity of the internal structure in pseudowords such as **Spitzung* thus has an effect on the processing of novel forms. In order to elucidate the internal composition of the derivational chain further, we conducted Experiment 2 in which the intermediate position is a lexical gap.

3.3.2 Experiment 2: Decomposing through lexical gaps

In Experiment 1, we saw that morphologically possible pseudowords activated their respective base word lying two derivations away. In the next step, we decided to manipulate the internal composition of possible pseudowords such as **Hübschung* in Experiment 2. For this purpose, we investigated the processing of complex pseudowords for which the intermediate derivation contains a lexical gap.

3.3.2.1 Method

Materials Experiment 2

As none of the subjects in Experiment 2 had participated in the previous experiment, the same stimuli for the condition 'Extant' (see Table 3.3) were employed in this part of the study. Condition 'NonEx2' is composed of complex pseudowords for which the nearest extant representation is a 2-step derivation away. Thus, the possible pseudonoun **Hübschung* is built according to the derivational pattern *hübsch* > **hübschen* > **Hübschung*. These nouns appear as primes in the experiment and are paired with their extant base forms as targets. All targets in the present 'NonEx2' condition were matched on word and lemma frequency, word length, prime-target overlap, phonological, orthographic and morphological family size, as well as syllable structure with 'NonEx1' and all other stimuli that appear in this series of experiments.

3.3.2.2 Participants

Thirty-two German native speakers volunteered to participate in Experiment 2, of whom 22 were female. None of the participants from Experiment 1 took part in this follow-up experiment. All participants gave their informed consent for participation and were reimbursed appropriately for their time (10 €/hour).

3.3.2.3 Procedure

The methodology for this experiment was identical to Experiment 1.

3.3.2.4 Results

Target analysis. The same criteria for filtering the data as in Experiment 1 were applied in Experiment 2, resulting in the exclusion of two participants with high error rates (~ 6.25 % excluded). Only responses within two standard deviations of a participant's mean reaction time to targets were included (~2.8 % excluded). Incorrect responses (~ 2.2 %) were not included. The overall amount of data excluded across conditions did not differ (p > .97). Figure 3.4 shows a plot of reaction times for targets in both conditions following related and unrelated primes.

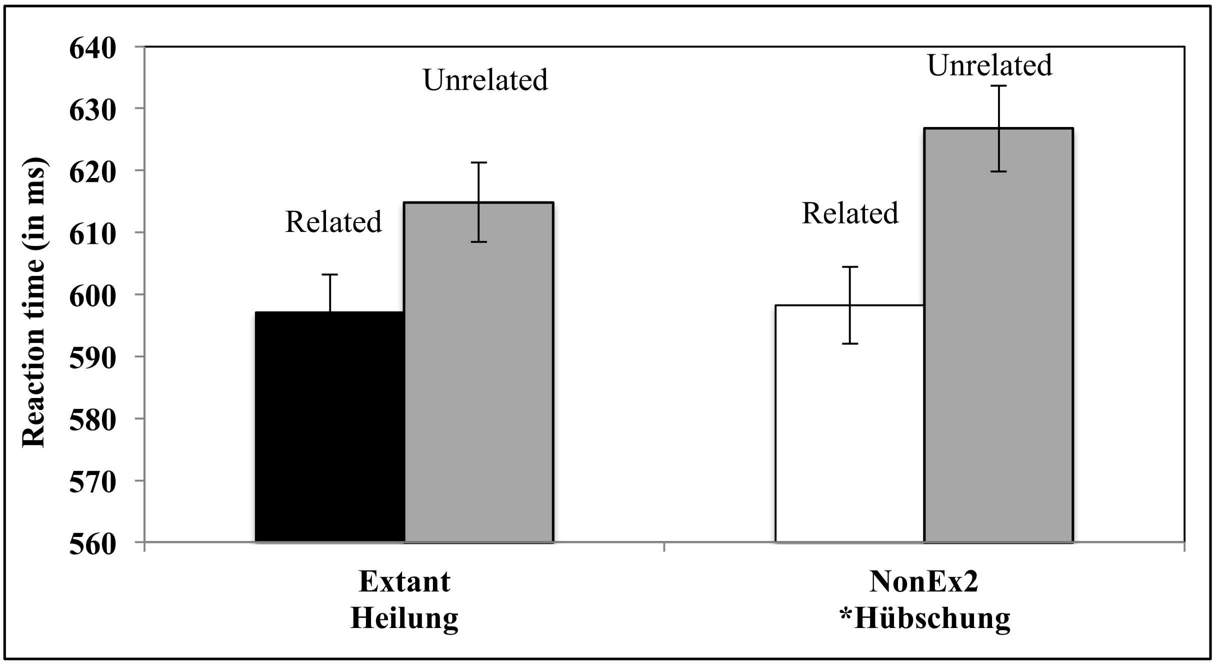

Figure 3.4 *Reaction times to targets in test conditions (Experiment 2)*

Model construction on the log-transformed reaction times followed the same procedure as in Experiment 1. In a model containing the fixed factors *Prime Type* (Related versus Unrelated) and *Base* (Ex versus NonEx2), random intercepts for *Subject* and *Item* and by-item random slopes for *Prime Type*, we found a significant main effect of *Prime Type* (χ^2 (1) = 22.75, $p < .0001$) with no other main effects or interactions reaching significance. The priming effect reported in Experiment 1 for the 'Extant' items could be replicated. Moreover, presentation with morphologically possible pseudowords such as **Hübschung* that are two derivations away from an extant lexical representation also facilitated lexical decisions to their base forms (here *hübsch*). Possible pseudowords could thus be decomposed across lexical gaps for intermediate positions within the derivational chain.

Prime analysis. The same procedures for data filtering as in Experiment 1 were applied. Mean reaction times to all conditions of interest are given in Figure 3.5.

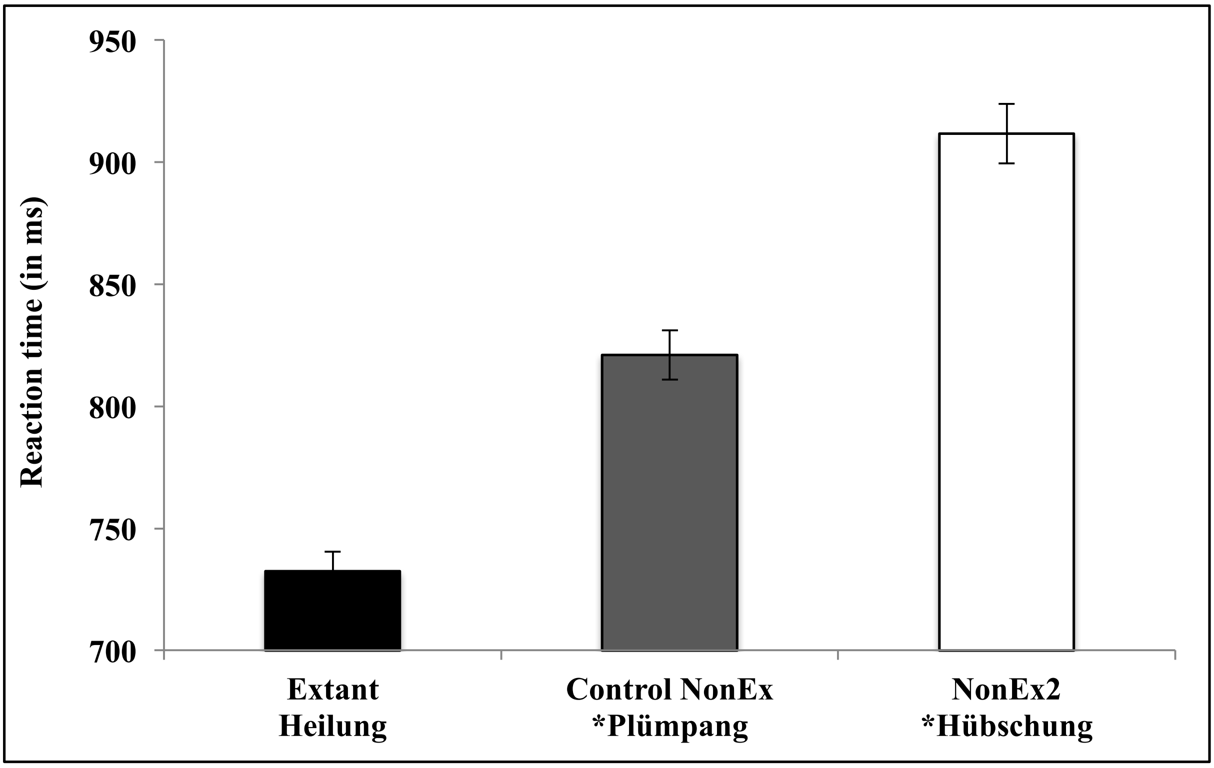

Figure 3.5 *Reaction times to primes (Experiment 2)*

A linear mixed model analysis was performed with the fixed factor *Base* and the random factors *Subject* and *Item*. Through step-wise simplification of the maximal random structure, we found a linear mixed model with random intercepts for *Subjects* and *Items* to provide the best model fit. *Base* affected *Reaction time* (χ^2 (2) = 54.584, p < .0001). Pairwise comparisons were established between all conditions using the R package *lsmeans*. Again, all pairwise comparisons were significant at p < .01 (Control NonEx versus Extant: Est. = 0.05435, SE = 0.01234, t(75) = 4.406, p < .0001; Control NonEx versus NonEx: Est. = -0.04123, SE = 0.01291, t(75) = - 3.194, p < .01; Extant versus NonEx: Est. = - 0.09558, SE = 0.01108, t(75) = - 8.624, p < .0001).

As in Experiment 1, there were significant differences between the two sets of nonwords. Morphologically possible pseudowords such as **Hübschung* elicited significantly longer reaction times than their non-complex controls like **Plümpang*. In the error rate analysis, the data were trimmed on the basis of the same criteria as for the reaction time analysis, but with both correct and incorrectly classified items entering data analysis. Figure 3.6 gives an overview of error rates for the three categories of interest in this part of the study ('Extant' versus 'Control NonEx' versus 'NonEx2').

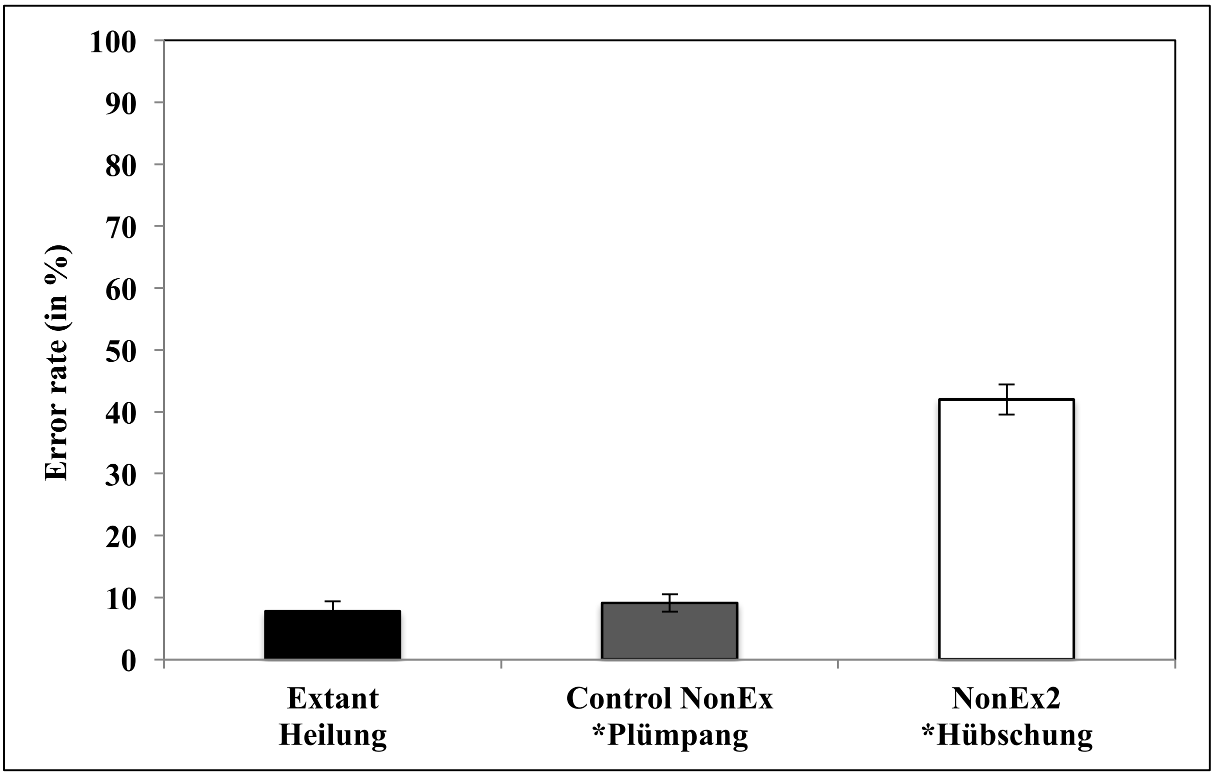

Figure 3.6 *Error rates to primes (Experiment 2)*

In a binomial generalized linear model, the factor *Base* had a significant effect on *Error rate*, χ^2 (2) = 192.8831, p < .0001. Again, speakers made significantly more errors when attempting to classify morphologically possible pseudowords such as **Hübschung* than when presented with morphologically impossible items (e.g. **Plümpang*), Est. = 1.9377, z = 10.110, p < .0001 or with extant (e.g. *Heilung*) words, Est. = 2.1436, z = 10.727, p < .0001.

3.3.3 Interim discussion and follow-up issues

The results obtained in Experiments 1 and 2 suggest that a complex form can contain lexical gaps within its derivational chain and still activate a base word that is multiple derivational steps away. On the one hand, this could mean that processing of morphological complexity can proceed 'on-line' and is not reliant on stored lexical representation within the derivational chain. On the other hand, it is clear that morphologically complex words and pseudowords share a high degree of semantic and formal overlap with their respective base forms. It is thus also possible that the priming effect we have observed in Experiments 1 and 2 was driven by the semantic or formal relationship between prime and target. In order to be able to differentiate between these two options, Experiment 3 was conducted in which we included purely semantically and phonologically related control items. Moreover, given our research focus on the role of lexical gaps in derivational chains, it was decided that a more direct comparison of the priming effects seen for the two types of morphologically viable pseudowords (**Spitzung* and **Hübschung*) should be established. Experiments 1 and 2 provided evidence that decomposition of multi-suffixed pseudowords was possible and that this form of decomposition could span a series of derivations. Experiments 3 and 4 will allow a more direct comparison of the decomposition and processing of multi-suffixed complex items that contain lexical gaps in different parts of their derivational chain (*spitz* > *spitzen* > **Spitzung* versus *hübsch* > **hübschen* > **Hübschung*).

3.4 Experiments 3 and 4: Investigating degrees of morphological violation

If knowledge of morphological viability plays a role in word recognition, then relative degrees of morphological viability should also be discernible. Recall that in morphological theory, there is a long-standing debate regarding the validity of word formation rules that operate on possible, but not actual words. Thus, while both **Spitzung* and **Hübschung* are formed following viable morphological rules of German word formation, **Spitzung* should be felt to be a more probable possible word than **Hübschung* if word formation rules only operate on actual words. To investigate this hypothesis, a more direct comparison between the **Spitzung* and **Hübschung* cases was carried out in Experiments 3 and 4. Experiment 3 is a lexical decision task with delayed priming in which participants are presented with all the morphological conditions examined in Experiments 1 and 2. Moreover, semantically and phonologically related control pairs were included in Experiment 3. If we obtain no priming effects in the non-morphological conditions, we have further substantiation that delayed priming taps into purely morphological processing. An additional simple lexical decision task to primes only was carried out in Experiment 4 comparing the processing of ‘NonEx1’, ‘NonEx2’ and noncomplex items more directly after we found asymmetries in the processing of different types of nonwords in the previous two experiments.

3.4.1 Experiment 3: Dissociation of morphological processing from semantic and form effect

3.4.1.1 Method

Materials Experiment 3

Experiment 3 is made up of six experimental conditions with 24 experimental items each. All three morphological conditions from Experiments 1 and 2 were included in this experiment, as well as semantically and phonologically related controls. These were selected in accordance with the following criteria:

(1) **Form control for 'NonEx'; Base = Adjective:** Form controls for the 'NonEx' condition comprise primes and targets that are matched in word frequency, lemma frequency, word-length, morphological family size, orthographic family size, phonological family size, prime-target overlap, syllable-structure and stress pattern with the corresponding test items in the 'NonEx' categories. 'Non-Ex' control targets are built from an extant base word (e.g. *steil*) that is matched in lemma and word frequency, as well as word length, morphological family size, orthographic family size, phonological family size, prime-target overlap, syllable structure and stress pattern with the bases in the two 'NonEx' categories. Where appropriate, back stem vowels were fronted to ensure a maximum degree of purely visual overlap between 'NonEx' primes and their controls. Endings for control primes consist of suffixes such as -*lein*, -*ler* that require nominal, not adjectival bases and which are therefore not combinable with the relevant base form.

(2) **Form control for 'NonEx'; Base = Verb:** Control nouns for the 'NonEx' conditions were constructed by using a combination of two suffixes that is not morphotactically admissible. Targets are again matched in word and lemma frequency, word length, morphological family size, orthographic family size, phonological family size, syllable structure and stress pattern with the bases in the other experimental conditions. To give an example, the related prime **Schieblosler* is based on the stem of the extant German verb *schieben* to which the two suffixes -*los*, -*ler* are added. The suffix -*los*, however, forms adjectives by attaching to nominal, not verbal bases. Moreover, -*ler* also requires a nominal, not an adjectival base. The item **Schieblosler* should therefore not be decomposable.

(3) **Form control for 'Extant'; Base = Adjective:** Prime and target items display a high degree of visual overlap (including the application of umlauting where appropriate), but are not morphologically related. The prime *Täublein* (N., 'little pigeon'), for instance, is a complex morphological word that is morphologically related to *Taube* (N., 'pigeon'), but not to the adjective *taub* (A., 'deaf') as the corresponding target, which is again matched to the other conditions in this experiment.

(4) **Form control for 'Extant'; Base = Verb:** As in (3), matched form control pairs for 'Extant' that are verb-based display a high degree of visual similarity without being morphologically related to one another. Prime-target pairs in this condition (e.g. the prime *Daunenbett* 'eiderdown' and its target *dauern* 'to last') have a visual overlap of at least three initial letters but even though the prime is an extant complex word, it is not morphologically related to the target with which it is paired.

(5) **Semantic control for 'Extant'; Base = Adjective:** Extant words like *Schnelle* (N., 'rapidity') and *fix* (A., 'quick') are related in meaning, but do not display a morphological relationship. Semantic relatedness was operationalized as follows: for every base word that is matched to the other conditions in this experiment, a synonym was selected. Subsequently, a noun was derived from this synonym that was used as the corresponding related prime. The unrelated prime was a semantically unrelated morphologically complex word. All related and unrelated primes and their targets were submitted in a semantic relatedness questionnaire to 40 native speakers of German who did not participate in any of the experiments. The participants in this questionnaire were asked to rate on a scale from 1 to 7 to what extent the meaning expressed by the paired words was synonymous (1 = entirely unrelated in meaning; 7 = same meaning, synonymous). Related pairs had an average relatedness rating of 4.43, unrelated pairs received an average rating of 1.57.

(6) **Semantic control for 'Extant'; Base = Verb:** As in (5), extant words like *Reinigung* (N, 'cleaning') and *putzen* (V, 'to clean') are meaning-related, but share no form overlap and are not morphologically related to one another. Semantic relatedness was determined as in (5).

Tables 3.4 and 3.5 (in the Appendix A) give examples of the stimuli employed for each condition, as well as statistical support for the matching of stimulus properties. Stimuli were matched on target length, target word frequency, target lemma frequency, orthographic, phonological and morphological family size across conditions (no significant differences for all criteria). All morphological conditions and the non-existent control condition were also matched on prime-target overlap. Related versus unrelated primes were matched on prime length, word and lemma frequency. Frequency information, as well as measures of morphological family size was obtained using the Celex simplex interface (Baayen, Piepenbrock, & Gulikers, 1995). Morphological family size was operationalized as the number of semantically transparent morphologically related words extracted from CELEX for a given base. Orthographic and phonological neighbourhood sizes were retrieved using Clearpond (Marian, Barlotti, Chabal, & Shook, 2012). All experimental stimuli for this set of experiments are given in Appendix B.

3.4.1.2 Participants

Thirty-four German native speakers volunteered to participate in Experiment 3 (age range: 18-28). None of the participants from Experiments 1 and 2 took part in this follow-up experiment. All participants gave their informed consent and were reimbursed appropriately for their time (10 €/hour).

3.4.1.3 Procedure

The methodology for this experiment was identical to Experiments 1 and 2. As in Experiments 1 and 2, a lag of 5-7 intervening stimuli was selected. Each group was presented with 576 items in total.

3.4.1.4 Results

Two items were excluded due to a coding error and three items (*zollen*, *weisen* and *ahnden*) were excluded due to high error rates (> 25 % resulting in exclusion of 3.5% of total data). Only responses that lay within 2 SDs of the participant's mean reaction time to targets (1.3% excluded) and only correct responses were included (2.7 % of total data excluded). There were no statistically significant differences in the amount of data excluded across conditions. Mean reaction times (with standard deviations) and error rates by condition are given in Table 3.6.

Table 3.6 *Mean reaction times in ms (with standard deviations) and error rates to targets (Experiment 3)*

	Extant	***NonEx1***	***NonEx2***	***Form Control Extant***	***Form Control NonEx***	***Semantic control***
Related	598.48 ± 116.54 (0.26)	612 ± 124.84 (0.26)	617.26 ± 130.43 (0.26)	653.41 ± 142.25 (0.29)	659.17 ± 146.9 (0.29)	618.44 ± 126.53 (0.25)
Unrelated	627.35 ± 120.32 (0)	646.92 ± 136.13 (0.54)	633.96 ± 138.4 (0.26)	650.76 ± 130.01 (0)	662.5 ± 137.39 (0)	618.35 ± 116.68 (0.75)

The same procedure for target analysis was applied as in Experiments 1 and 2. Reaction times were log-transformed. In a linear mixed model with *Prime Type* (Related versus Unrelated) and *Base* (Extant, NonEx1, NonEx2, Control NonEx, Form Control Extant, Semantic) as fixed effects, *Subject* and *Item* as random effects (with intercepts only as adding random slopes did not significantly improve model fit), we found that *Prime Type* affected reaction times at (χ^2 (1) = 26.807, p < .0001) and *Base* was significant at (χ^2 (5) = 11.143, p < .05). The interaction between the factors *Prime Type* and *Base* reached significance at (χ^2 (5) = 21.236, p < .001).

In view of the significant interaction between *Prime Type* and *Base*, pairwise comparisons for the priming effect were carried out in all six experimental conditions using *lsmeans*. Results of Tukey-adjusted pairwise comparisons between the Related and Unrelated sets showed significant priming only in the morphological conditions (Form Control Extant: Est. = 0.001505, SE = 0.005120, t(4304)= 0.294, p = .769; Control NonEx: Est. = -0.008132, SE = 0.005284, t(4304) = 0.005284, t(4304) = -1.539, p = .124; Extant: Est. = -0.018217, SE = 0.004873, t(4303) = -3.738, p < .001; NonEx1: Est. = -0.025851, SE = 0.004985, t(4303) = -5.186, p < .0001; NonEx2: Est. = -0.010895, SE = 0.004923, t(4304) = -2.213, p = .0269; Sem: Est. = -0.001363, SE = 0.004822, t(4303) = -0.283, p = .777). P-values were obtained using Satterthwaite approximations for the computation of our degrees of freedom. In Experiment 3, we have priming only in the morphological conditions. The priming effects observed in the present experiment can therefore not be reduced to purely semantic or formal overlap between prime and target. We then conducted a follow-up analysis for the two pseudoword conditions only. In this analysis, we found a significant effect of *Prime Type* (χ^2 (1) = 26.738, p < .0001), as well as a significant interaction between *Prime Type* and *Base* (χ^2 (1) = 4.6029, p < .05). Possible pseudowords that are derived from an actual word within the intermediate position such as **Spitzung* primed their base more strongly than pseudowords derived from a nonexisting word in the intermediate position of the derivational chain such as **Hübschung* (see Figure 3.7).

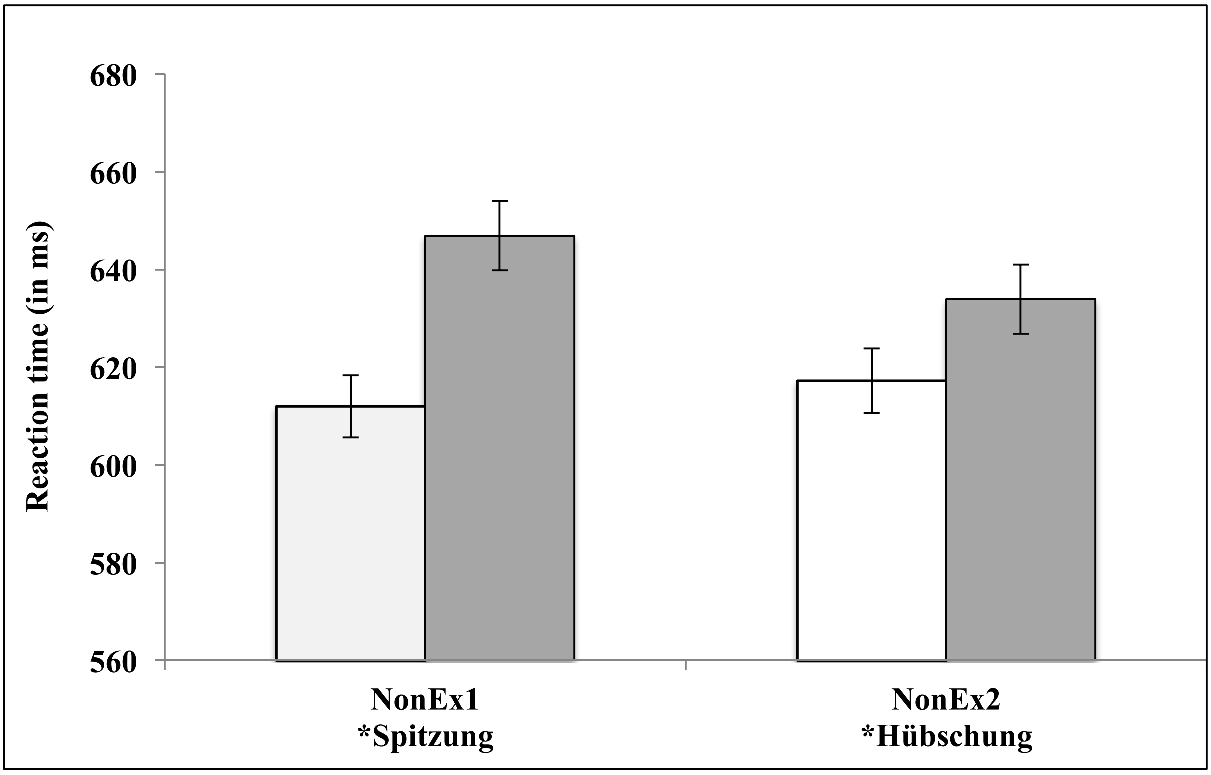

Figure 3.7 *Reaction times to targets in conditions NonEx1 and NonEx2 (Experiment 3)*

Prime analysis. In line with the analyses for Experiments 1 and 2, we also conducted a reaction time and error rate analysis to primes in Experiment 3. We followed the same procedure as in Experiments 1 and 2 for data filtering and model construction. Mean reaction times and error rates to primes can be found in Table 3.7.

Table 3.7 *Mean reaction times (with standard deviations) and error rates to primes (Experiment 3)*

	EXTANT	NONEX1	NONEX2	CONTROL NONEX
REACTION TIME (MS)	743.81 (168.32)	917.35 (199.59)	906.56 (193.67)	911.76 (192.03)
ERROR RATE (%)	3.87	62.7	31.55	14.21

In a linear mixed effects model with *Base* as fixed effect and *Subject* and *Item* as random effects with random intercepts, we found a significant effect of *Base* on *Reaction time* (χ^2 (3) = 70.452, p < .0001). This effect was, however, solely driven by the lexical status of the item. Unlike the results in Experiments 1 and 2, we found no differences in reaction time between the three sets of pseudowords. In the error rate analysis, however, *Base* had a significant effect on *Error rate*, χ^2 (2) = 380.587, p < .0001. In this analysis, we found significant differences between all the pseudoword conditions (Extant versus NonEx1: Est. = 3.7334, z = 13.087, p < .0001; Extant versus NonEx2: Est. = 2.4390, z = 8.499, p < .0001; Control NonEx versus NonEx1: Est. = 2.3183, z = 12.323, p < .0001; Control NonEx versus NonEx2: Est. = 1.0238, z = 5.370, p < .0001; NonEx1 versus NonEx2: Est. = - 1.2944, z = - 8.167, p < .0001). As in the prime analysis for Experiments 1 and 2, pseudowords that are not morphologically viable (e.g. **Steillein*) elicited the lowest error rates and can therefore be classified more accurately than pseudowords that possess internal morphological structure (**Spitzung* and **Hübschung*). Moreover, pseudowords like **Spitzung* for which the intermediate position is an actual word had higher error rates than items from the *Hübschung* set for which the intermediate verb is a pseudoword **hübschen*.

3.4.1.5 Discussion

In sum, when both types of pseudowords **Spitzung* and **Hübschung* are presented to participants in a single delayed priming experiment, differences in priming magnitude emerge. These differences are also discernible in the reactions to the complex items. Possible pseudowords that are derived from an actual word in the intermediate position such as **Spitzung* elicit significantly higher error rates than morphologically possible pseudowords such as **Hübschung* that are two derivations away from the nearest lexical representation within the derivational chain. Differences in reaction times to the complex pseudowords were not discernible. This is in line with the findings reported by Yap, Sibley, Balota, Ratcliff and Rueckl (2015) where the number of affixes in a nonword affected reaction times. Note that the number of affixes in the two pseudoword sets **Spitzung* and **Hübschung* is equal despite differences in lexical composition. However, as we found significant differences between the two sets in the error rate analysis, we considered whether this difference could have been driven by differences in familiarity between **Spitzung* and **Hübschung.* [3] It is worth noting here the processing of morphologically viable Dutch neologisms such as **lobbigheid* (N., 'softness') in a study by de Vaan, Schreuder and Baayen (2007) in a visual lexical decision task with long-lag priming (39 intervening items). The participants were instructed to respond "yes" to neologisms if they seemed like words. It was observed that these pseudoword primes led to identity priming only when they were classified as possible words, showing that novel forms can leave memory traces after a single presentation. In view of this study, we also assessed the influence of the pseudoword prime if it was responded to as a word. That is, would priming occur only if **Spitzung* or **Hübschung* were responded to as words? For this purpose, we included the predictor variable *Prime classification* in our model in addition to the factors *Prime Type* and *Base*. As in the previous model, only the main effect of *Prime Type* ($p < .0001$) and the interaction between *Prime Type* and *Base* ($p < .05$) reached significance. Neither the main effect of *Prime classification*, nor any interactions with the factors *Prime Type* and *Base* showed a significant effect on reaction times. The priming effect was thus independent of the classification of the prime, demonstrating that possible differences in familiarity with the novel form cannot account for priming differences.

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[3] **Spitzung,* for instance, though not in use today, is a technical term attested in the 1930s to designate the pointing of fox fur.

3.4.2 Experiment 4: The role of the lexical representation in derivational chains during processing of morphological complexity

In all experiments so far, complex items and their noncomplex controls were paired with their corresponding targets. In this final experiment, we decided to run a simple lexical decision task to primes only as this might accentuate the difference in processing between the sets of complex items and their controls. Moreover, as the **Plümpang* set has not yet been directly compared with both types of morphologically possible pseudowords (**Spitzung* and **Hübschung*), Experiment 4 was carried out in order to contrast this type of nonmorphological control with the two sets of possible pseudowords.

3.4.2.1 Method

Materials

Only the stimuli that constitute primes in the conditions 'Extant', 'Control NonEx', 'NonEx1' and 'NonEx2' (32 words per condition) in Experiments 1 and 2, i.e. complex extant and non-existent nouns, as well as their control forms (e.g. **Plümpang*) appear in this experiment. Recall that these were controlled for word and lemma frequency, length, stress patterns, morphological, phonological and orthographic family size (see Experiments 1 and 2). One hundred and twenty-eight filler words were included to match the total number of words and nonwords in the experiment and to avoid any possibility of a bias. These filler words also had the appearance of morphologically complex items. Participants saw 256 items in total.

3.4.2.2 Participants

A group of twenty native speakers of German participated in the simple lexical decision task, none of whom had taken part in any of the previous studies. Participants gave their informed consent and were reimbursed appropriately.

3.4.2.3 Procedure

The same procedure was applied as in the previous three experiments. All participants were presented with the same pseudorandomized experimental list.

3.4.2.4 Results

One participant had to be excluded as they had misunderstood the task instructions. As in previous experiments, items for which reaction times exceeded two standard deviations above or below their own mean were considered outliers and not included in the subsequent data analysis. For the first part of the analysis that focused on reaction times, only correctly identified items entered the statistical data analysis. In the error analysis, both correct and incorrect responses entered data analysis.

Reaction time analysis.

Mean reaction times to all primes are given in Table 3.8.

Table 3.8 *Mean reaction times and standard deviations in all conditions (Experiment 4)*

	EXTANT	NONEX1	NONEX2	CONTROL NONEX
REACTION TIME (MS)	785.46 (184.71)	934.62 (177.09)	927.30 (180.00)	878.10 (198.75)

In a linear mixed model analysis with random intercepts for *Subjects* and *Items* and by-subject slopes, the effect of *Base* ('Extant', 'NonEx1', 'NonEx2' and 'Control NonEx') on *Reaction Time* was investigated. The fixed effect *Base* had a significant effect on *Reaction time* (χ^2 (3) = 36.713, p < .0001). All pairwise comparisons between the 'Extant' condition and the different types of pseudowords reached significance at p < .01 with extant words being identified faster (Extant versus Control NonEx: Est. = - 0.050386, SE = 0.013687, t(71) = -3.681, p < .01; Extant versus NonEx1: Est. = - 0.092181, SE = 0.013668, t(71) = -6.744, p < .001; Extant versus NonEx2: Est. = -0.083746, SE = 0.11536, t(71) = - 7.259, p < .001). As already seen in Experiments 1 and 2, 'Control NonEx' items were also rejected significantly faster than both sets of possible pseudowords (Control NonEx versus NonEx1: Est. = - 0.041795, SE = 0.014352, t(71) = - 2.912, p < .05; Control NonEx versus NonEx2: Est. = - 0.03336, SE = 0.012144, t(71) = - 2.747, p < .05). No significant difference emerged in the comparison of reaction times to items in 'NonEx1' versus 'NonEx2'.

Error analysis.

Figure 3.8 gives an overview of error rates for the four categories of interest in this part of the study ('Extant' versus 'Control NonEx' versus 'NonEx1' versus 'NonEx2').

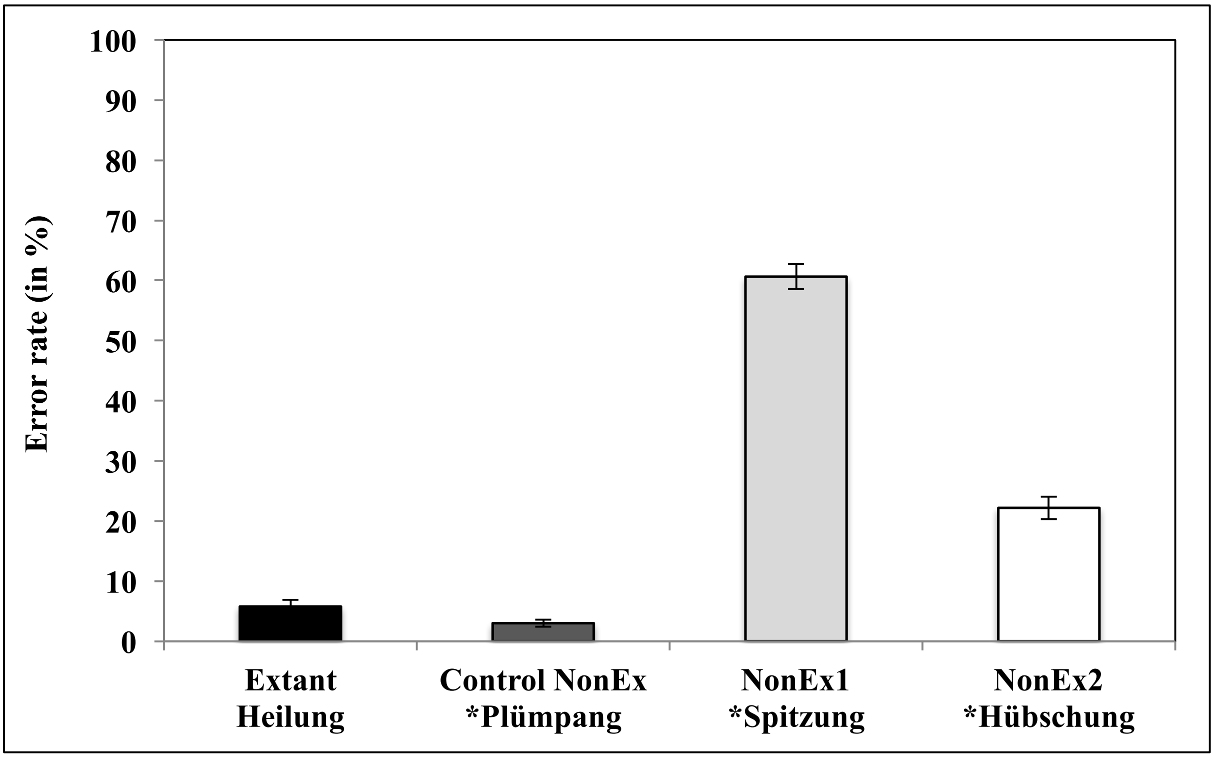

Figure 3.8 *Error rates in test conditions (Experiment 4)*

A generalized linear model (GLM) was performed in order to analyse the effect of *Base* on *Error rate*. The effect was significant at χ^2 (3) = 610.6585, p < .0001. Pairwise comparisons using *lsmeans* were conducted to inspect differences between experimental conditions. All comparisons apart from the comparison between 'Extant' (*Heilung*) and the 'Control NonEx' (**Plümpang*) category showed a significant difference at p < .0001. (Extant versus NonEx1: Est. = 3.2215, z = 16.616, p < .0001; Extant versus NonEx2: Est. = 1.4477, z = 7.148, p < .0001; Control NonEx versus NonEx1: Est. = 3.9659, z = 11.372, p < .0001; Control NonEx versus NonEx2: Est. = 2.1921, z = 6.199, p < .0001; NonEx1 versus NonEx2: Est. = - 1.7738, z = - 13.238, p < .0001). 'NonEx1' (e.g. **Spitzung*) items elicited the highest error rates at 61%. These were significantly higher than in 'NonEx2' (**Hübschung*) items, where the error rate was 21%.

3.4.2.5 Discussion

The general patterns observed in the prime analyses in Experiments 1, 2 and 3 were replicated in Experiment 4. Control non-existent nonwords such as **Plümpang* elicited faster reaction times and significantly lower error rates than the two sets of morphologically possible pseudowords. For the two sets of possible pseudowords, no differences in reaction times were discernible, but items like **Spitzung* showed significantly higher error rates. That is, the 'NonEx1' items were more difficult to reject since the adjective and the intermediate verb exist, which is consistent with the idea that these complex pseudowords are felt to be more 'word-like' and are in fact more likely to become real words given the proximity to an existing lexical representation within the derivational chain. It appears that while any complex pseudoword that obeys morphological constraints can be decomposed to activate its base word, speakers are nonetheless sensitive to the lexical composition within derivational chains.

3.5 General discussion

The research presented in this series of experiments provides evidence for speakers' sensitivity to morphological complexity in both 2-step derived real words and plausible complex novel nouns. We defined plausible novel words as those which conform to the morphological rules of the language, but which are essentially lexical gaps. Thus, *spitz*$_{ADJECTIVE}$ > *spitzen*$_{VERB}$ > **Spitzung*$_{NOUN}$ and *hübsch*$_{ADJECTIVE}$ > **hübschen*$_{VERB}$ > **Hübschung*$_{NOUN}$ follow the morphological rules of deriving nouns with the addition of the suffix *-ung* via verbs formed from adjectives with the suffix *-en*. Consequently, they are plausible derivations. The two forms differ because in the latter the intermediate verb does not exist, while in the former the verb is a real word.

In Experiments 1 and 2, we were able to establish decomposition for multi-suffixed complex words such as *Heilung*, as well as for the two sets of possible pseudowords **Spitzung* and **Hübschung,* since they all successfully primed their adjectival base. In principle then, complex pseudowords containing lexical gaps in their derivational chain can be decomposed. This provides stronger evidence for decompositional rather than 'full-form' storage accounts of morphological access. More specifically, it appears that the decomposition of the pseudoword primes leads to the activation of the base word (*spitz* or *hübsch*), which can successfully prime a later occurrence of the same base word. For existing morphologically related words, it has been shown previously that complex primes are decomposed into their constituent structures (Stanners, Neiser, Hernon, & Hall, 1979). The present findings suggest that this process of decomposition is not restricted to existing words, but can extend to complex pseudowords like **Spitzung* and **Hübschung*. Recall that in Experiments 1 and 2, the **Spitzung* and **Hübschung* sets were kept separate. In the next step, we combined the two sets to examine extra processing costs (if any) for novel forms where the intermediate step was missing; i.e. possible differences between **Spitzung and *Hübschung.* In Experiment 3, as both sets of novel words are morphologically viable, we included a morphologically unviable type of pseudoword as an additional control. These items like **Steillein* (labelled as 'Control NonEx') are not the result of a viable morphological rule of German, similar to the **sportation* items in Longtin and Meunier (2005). Experiment 3 showed that only morphologically viable formations activated their base forms and no priming occurred for the unviable items. Semantic and form-related controls in Experiment 3 did not prime, thus suggesting that the morphological priming effect was not driven by semantic or orthographic similarity alone.

Crucially, however, although both morphologically viable novel words showed priming, they were significantly different from each other. Pseudowords such as **Spitzung,* where the intermediate form is a real word, led to a significantly stronger priming effect than the **Hübschung* set. Further asymmetries in the processing between the two sets of possible pseudowords were also found in the prime error rate analyses in Experiments 3 and 4. The items in the **Spitzung* set elicited consistently higher error rates than items such as **Hübschung,* suggesting that these items were felt to be more 'word-like' by participants even though both sets were classified as nonwords in off-line tasks. These results are compatible with earlier accounts of pseudoword processing that found high error rates for affixed pseudowords in lexical decision tasks (e.g. Taft & Forster, 1975). Complex pseudowords such as **dejuvenate* for which stripping the affix *de-* results in the retrieval of an existing morpheme *juvenate* yielded higher error rates than **depertoire* for which no existing morpheme *pertoire* is available. In our case, although superficially both sets of pseudowords are similar and the stem exists in both cases, decomposition across the first lexical gap in **Spitzung* directly activates an existing lexical representation. The path leading from a complex prime to the base is thus more direct. Although both sets of complex pseudowords prime their base forms, error rates as well as magnitude in priming suggest that the lack of an intermediate point to a pseudoword that is less 'word-like'; i.e. **Hübschung* (without intermediate **hübschen*) causes less interference than **Spitzung* (with intermediate **spitzen*) in a simple lexical decision task, but leads to a processing cost in the activation of the base. This processing cost as evidenced in a reduction of the priming magnitude could arise due to a decrease in the level of lexical activation of the base when the intermediate form is not lexicalized. That is to say, depending on the composition of the novel prime word and whether it is built based on an extant intermediate form or not, the degree of lexical activation received by the base differs. Items like **Spitzung*, for which the intermediate form is lexicalized, could then allow increased activation to be passed on to the base. In combination with the findings reported by Taft and Forster (1975), our results are not compatible with models of morphological access in which the internal composition of complex items plays no role in word recognition.

Alternatively, it could be argued that items like **Spitzung,* where an intermediate derivation exists, are more interpretable and therefore the more plausible novel form. Semantic interpretability is, of course, an important factor. For any nonword to be parsed, it would have to be to some extent interpretable. Marelli and Baroni (2015) have demonstrated the importance of semantic interpretability for novel forms by showing that semantically interpretable novel forms have more semantic neighbours. There can be a number of reasons why a novel word has more semantic neighbours and is felt to be more meaningful. Meunier and Longtin (2007), for instance, showed that morphological legality is a prerequisite for semantic interpretability as only legal combinations of stems and suffixes (**rapidifier*) were judged to be semantically meaningful in off-line tasks. This was indeed the case for our novel words. However, both sets were equally legal in the way they were formed. The question arises then to what extent they differ in their morphological cohort and whether additional meaningfulness could result from the presence of a larger morphological cohort. That is, does one set have a bigger morphological cohort: e.g. more prefixed and suffixed words with the same stem such as *zuspitzen* (V., 'to point')*, aufhübschen* (V., 'to embellish')? Since we had controlled for morphological family size (see discussion of the stimuli set), the differences in priming and errors could not result from the size alone. Thus, the semantic interpretability must arise from within the derivational chain; the presence of *spitzen* in all likelihood increases the meaningfulness of **Spitzung* in comparison to **Hübschung*, which lacks an intermediate verb. Indeed, Marelli and Baroni's stimuli suggest that the low and high interpretability of some of their stimuli could actually be linked to derivational depth (compare *hike*$_{VERB}$ > *hike*$_{NOUN}$ > **hikeless*$_{ADJECTIVE}$ and *acne*$_{NOUN}$ > **acneless*$_{ADJECTIVE}$ where the nominal base in **hikeless* is arguably already complex).

We also considered whether the high number of incorrectly classified primes in the 'NonEx1' condition (e.g. **Spitzung*), suggesting that these pseudowords were processed like real words, led to the difference in the priming effect between the two conditions. That is to say, the fact that **Spitzung* was reacted to incorrectly as a word led to more priming. This was not the case; the reaction to the stem targets, and thus the priming effect, was unrelated to the classification of the novel word primes. Recall that de Vaan et al. (2007) noticed that only when neologisms such as **lobbigheid* were classified as words did they lead to identity priming. Note that in our case, we were not investigating identity priming as a measure of a nascent frequency effect in neologisms. De Vaan et al.'s (2007) study, on the other hand, is not specifically concerned with the morphological analysis of neologisms and their internal composition. Moreover, the target word in de Vaan et al. (2007) for which a priming effect is established is always a nonword, whereas in the present experiment we find the more canonical case of measuring a priming effect for responses to targets that are existing words. These differences in experimental design and the comparisons on which the analyses rest can be advanced as possible explanations as to why the response to the prime word affects the target differently across the two studies. In our study, novel complex forms were decomposed both when the whole form was classified as a word and as a nonword.

In summary, novel words which look similar on the surface may have different derivational paths. **Spitzung* is derived via two well-formed attested words *spitz* > *spitzen*; meanwhile **Hübschung*, although similar in shape, lacks a verb **hübschen,* but the adjective *hübsch* exists. A series of experiments show differences in the two sets of novel nouns. Overall, our results are not compatible with *full-listing* accounts of morphological processing and access (cf. Butterworth, 1983). Instead, morphologically complex novel forms are decomposed to their base as predicted under a decompositional account (e.g. Taft & Forster, 1975). At the same time, the results are not reducible to an automatic affix-stripping procedure as has previously been reported in the masked priming literature. As Orfanidou, Davis and Marslen-Wilson (2011) suggest, during later stages of morphological processing, morpho-orthographic mechanisms are replaced by semantically-informed processes. In our case, this means that the visual recognition of complex words is modulated by subtle properties of the derivational chain, such as the lexicality of intermediate positions within the derivation. Taken together with the results obtained by Meinzer et al. (2009) and Pliatsikas et al. (2014), where despite lack of overt affixation, increased morphological complexity correlated with processing cost, our results indicate that speakers are not only sensitive to the number of derivations required to arrive at an extant complex word, but also to different degrees of morphological violation in derivational paths.

4. TOLERATING THE OVER-APPLICATION OF MORPHOLOGICAL RULES: THE EXTRACTION OF MEANING IN NOVEL FORMS

In the previous chapter, we reported on the results of a series of four behavioural experiments in which we drew on a combination of lexical decision tasks and priming paradigms to assess the degree to which novel morphologically complex formations in German would (1) activate the base words from which they were derived and (2) be processed differently depending on their internal morphological composition. In a behavioural task, our inferences rest on the overt responses given by participants during task execution and it can thus be expected that the button press reflects the cumulative result of a number of possibly different processes that underlie the decision itself.

In order to isolate the processes that are unrelated to the task execution itself, but reflect the processing signatures pertaining to the identification of morphological manipulation, it may be worthwhile to complement the behavioural evidence collected with data from further investigations. Preferably, these methodologies could indicate measures of, for instance, degree of priming without requiring the execution of a motor response. One such possibility is offered by electrophysiological methodologies such as EEG (*Electroencephalography*) as a continuous measure of electrical activity in the brain. The electrical activity is the result of post-synaptic voltage fluctuations as the firing of neurons enables the transmission of information between neurons. On the basis of the EEG signal captured, specific responses to particular sensory or cognitive events can be isolated, so-called ERPs (*Event-Related Potentials*).

In the present chapter, we will therefore begin by charting an outline of previous research into morphological processing using EEG in section 4.1 before we motivate its use for the purposes of the current research in section 4.2. The rest of this chapter will report on and discuss the findings of an EEG study we conducted on the processing of morphological complexity in novel formations.

4.1 Electroencephalography and morphological processing

It is undoubtedly a fair assessment, following a survey of the literature on morphological processing using electroencephalography, that the main focus of research has been on inflectional rather than derivational morphological processes.

On the whole, it appears that decompositional processes are not called into question for the inflectional domain, but it is the question whether or not these apply across the board that has been the focus of most investigations. In an early study using a lexical decision task with delayed priming (an average of 13 intervening items), Weyerts, Münte, Smid and Heinze (1996) investigated the processing of German regularly and irregularly inflected participles. In a paradigm in which German participles such as *getanzt* (V., 'danced') were either preceded by the corresponding infinitival form or embedded in an identity condition in which the participles were presented twice in a row, it was found that regularly inflected participles gave rise to similar priming signatures in the identity and morphological conditions. Irregularly inflected participles, on the other hand, showed reduced priming in the morphological condition, leading the researchers to conclude that regularly versus irregularly inflected forms are represented differently under a *Dual-Route* account with holistic representation for irregularly inflected verbs and a shared representation for morphologically related words displaying regular morphological alternations.

Since this early study, dissociations in the processing of 'regular' versus 'irregular' morphology have been reported in a number of later visual delayed priming studies in English (Münte, Say, Clahsen, Schilz, & Kutas, 1999) and Spanish

(Rodriguez-Fornells, Münte, & Clahsen, 2002). In later studies, the interpretation of dissociations between regulars and irregulars as motivations for a *Dual-Route* account of morphological processing was challenged on the grounds that regularity constituted not a categorical, but a gradual phenomenon (Smolka, Khader, Wiese, Zwitserlood, & Rösler, 2013). These discussions are directly linked to the question whether sensitivity to morphological relatedness in inflection can be subsumed under a single processing system or is distributed over two separate systems. In Smolka et al. (2013), an attempt was made at investigating the effect of degree of regularity by differentiating not between two categories of regularity (regular versus irregular), but between three groups of verb pairs in German. These were argued to display different degrees of regularity depending on their formation of the past participle (regular formation using joint prefixation with *ge*- and suffixation using -*t* vs. irregular formation using joint prefixation with *ge*- and simultaneous suffixation in -*en*) and whether or not stem vowel alternations accompanied the formation of the past participle. Indeed, it was found that the degree to which the participle form activated the morphologically related 1st person singular was affected by the degree of regularity inherent in the participle.

Crucially, all inflectionally related forms showed a priming effect that was reduced in comparison with an identity condition, but significantly stronger than purely semantic priming, indicating that a morphological relationship was detected in all verb form pairs. Differences in degree of activation as a function of regularity are expounded on the grounds of differences in either ‘stem access’ or ‘stem connectivity’ across groups (Smolka et al., 2013: 1301), but critically no categorical distinction was made between regularity and irregularity. The activation of the stem in both regular and irregular forms was shown to extend to the processing of nonwords composed of illegal combinations of stems and affixes (Smolka, Pöhnl, & Eulitz, 2012). In an ERP study, the degree of facilitation obtained for base verbs such as *werfen* did not differ in contexts where it followed its existing participle form (*geworfen*) versus an incorrectly inflected non-existent form **gewurft*. On the basis of these results, Smolka et al. (2012) argued that given the non-existent lexical representation of the incorrectly inflected items, any facilitation must have been driven by access to the stem word itself, again providing strong evidence for decompositional processes even in irregularly inflected formations.

As seen in the short survey of research into inflectional morphological using ERP processing discussed here, the main research questions have been driven by possible dissociations and similarities between processing signatures as a function of regularity. The question whether all inflected forms are accessed via a shared stem entry or not continues to be debated, but evidence for sensitivity to morphological relatedness for at least some pairs of inflectionally related words is assumed.

In the derivational domain, research into morphological processing using event-related potentials by and large mirrors the main questions pursued in behavioural research: the dissociability of morphological from semantic and (morpho)-orthographic effects, but also the relevance of constraints of semantic transparency on morphological processing at different stages of its application. These questions have been of paramount importance for investigations into the processing of derivational morphology given that derivation - unlike inflection - can be assumed to give rise to the creation of new, separate lexemes (and therefore lexical entries). On the basis of this assumption and the aforementioned possibility for derived words to take on additional idiosyncratic layers of meaning that are not directly predictable from the meaning of a base, single-route connectionist models of morphological processing have been proposed. These posit the reliance on joint semantic and formal similarities between derived words without the necessity of including an independent purely morphological level of analysis that links the two representations.

Investigations into the processing of pairs of words that are not morphological derivates of one another (and also not semantically related), but could be analysed as morphologically related in a parsing mechanism that is not semantically driven (*corner-corn*) have thus also featured in a number of ERP studies, in both masked and overt priming paradigms. In an overt visual priming task (prime duration = 226 ms), Lavric, Rastle and Clapp (2011) contrasted the degree of facilitation as indexed by the reduction in N400 response to targets following related versus unrelated primes in three sets of word pairs: (1) morphologically related and semantically transparent (e.g. *magical* - *MAGIC*); (2) morphologically unrelated, but decomposable on the basis of the surface structure and semantically opaque (e.g. *compassion* – *COMPASS*) and (3) morphologically and semantically unrelated, but similar in orthographic form (e.g. *brothel* - *BROTH*). Due to a fine-grained division of the N400 component into separate temporal bins, it was possible to identify two separate stages in the attenuation of the N400 component for the processing of the opaque condition. As reported by Lavric et al. (2011), an early stage (300-380 msec) in which the amplitude and topography of the N400 response was comparable for the transparent and opaque conditions (and clearly distinguishable from the form overlap condition), was followed by a later phase at which the reduction for the opaque condition was attenuated, thereby approximating the patterns seen in the form condition. Based on these results and especially due to the congruent processing patterns between the transparent and opaque conditions in the early time window, the authors argue that the priming effects observed during overt priming paradigms are not merely semantically driven. Instead, the early phase of the N400 component appeared to show similarities to the effects motivated by a morpho-orthographic relationship seen under masked priming.

Indeed, an earlier ERP study by Lavric, Clapp and Rastle (2007) using masked priming confirmed the observations reported for behavioural studies such as Rastle et al. (2004) and discussed in Chapter 2 of the present thesis. Statistically significant effects of an attenuation of the N400 response were evident in the transparent (e.g. *hunter* - *HUNT*) and opaque conditions (e.g. *corner* - *CORN*) with no reliable neural priming (except for a single time window between 380 and 460 msec following target presentation) in the form condition (e.g. *brothel* - *BROTH*).

The presumed early processing stages of morphological complexity processing were subjected to further scrutiny in studies investigating the processing of complex nonwords formed via illegal combinations of stems and affixes (e.g. Morris, Porter, Grainger, & Holcomb, 2011; Morris, Grainger, & Holcomb, 2013). In Morris et al. (2011), it was found that existing derived words (e.g. *flexible*), nonwords composed of illegal combinations of stems and suffixes (e.g. *flexify*), as well as nonwords that were not composed of any identifiable morphological constituents (e.g. *flexint*) led to attenuations in N250 and N400 responses that were equivalent in their magnitude for all conditions relative to an unrelated control. These equivalent priming effects were attributed to the total overlap between target *flex* and the corresponding beginning of the prime words. Critically, as in the behavioural studies by Longtin and Meunier (2005) discussed in Chapter 2, we find again that the masked priming paradigm does not offer the possibility of examining sensitivity to morphological constraints independently of lexicality: priming was discernible in all conditions and regardless of whether the ending that followed the embedded target was an existing suffix or not.

In a later study, Morris et al. (2013) coupled the investigation of processing for complex nonwords with sets of existing words differing in their morphological status (*hunter* versus *corner* versus *scandal*). Complex pseudowords as primes were constructed on the basis the stems of the corresponding existing words to which a suffix -*ity* was attached. Primes thus consisted of nonwords such as *huntity*, *cornity* and *scandity* in the respective conditions. Again, there was evidence for priming effects in all conditions. Only at the very early stages of processing did these data reveal selective activation for transparent complex words such as *hunter*.

Note that while Morris et al. (2013) classify the combinations between stem and suffix as legal, their viability could be called into question. In attested words, the suffix -*ity* is attached to adjectives of Romance origin (e.g. *sincer-ity*, *enorm-ity*), rather than the verbal or possibly nominal bases proposed in Morris et al. (2013). The observation that these morphological constraints do not come into play when primes are presented briefly enough to escape conscious perception in masked priming again attests to the unsuitability of the paradigm for investigations of aspects of morphological processing that go beyond an orthographically-driven analysis, even when embedded in an electrophysiological experiment.

In the context of a level of morphological analysis that is (1) not reducible to the semantic relationship between two morphological relatives and (2) not primarily induced by orthographic factors, Smolka, Gondan and Rösler (2015) turned to the processing of morphological complexity at the lexical level using electrophysiology. In a visual overt priming experiment (SOA of 300 ms), Smolka et al. (2015) put the processing of German prefixed verbs to the test. These differed in their degree of semantic transparency to the base verb. Using a within-target design, priming was established on the basis of the degree of attenuation in the N250 and N400 response to the presentation of a base verb such as *ziehen* (V., ‘to pull’) when preceded by morphologically related prefixed verbs that were either transparent or opaque in their semantic relationship to the base (transparent: *zuziehen* (V., ‘to pull together’) versus opaque: *erziehen* (V., ‘to educate’)) as opposed to verbs that were entirely unrelated to the base (e.g. *tarnen* (V., ‘to mask’)). Semantically and formally related control primes without a morphological relationship to the common base word *ziehen* were also included to account for effects that are extraneous to a morphological relationship. Note moreover for this study that unlike the previous investigations delineated in the present section, the opaque condition here consisted of complex words that are in fact morphologically related to the base. In this sense they differed from pseudocomplex words such as *CORNER* that might be expected to be represented in a monomorphemic fashion at the lexical level.

A comparison between the transparent and opaque conditions revealed no discernible advantage for transparent relative to opaque formations with both conditions yielding equivalent significant neural priming that was not attributable to purely semantic or form-related effects. Verb pairs with orthographic overlap led to inhibitory responses relative to the unrelated control, and semantic controls induced facilitatory priming, which was, however, reduced in magnitude relative to the two morphological conditions.

On the whole, we thus see that while the findings discussed for masked priming appear in part contradictory, the overall results demonstrate the unsuitability of the task for the study of morphological constraints given the early level of word recognition examined. On the basis of the aforementioned overt priming study by Smolka et al. (2015), on the other hand, it is clear that the level of morphological processing tapped into using this paradigm in ERPs can be identified as untainted by purely semantic and form-related effects. While Smolka et al. (2015) were focused on the processing of real words by assessing common lexical access through shared base entries for different types of complex verbs, our interests have been shaped by base activation for non-existent complex words. Despite differences in the make-up of the primes, the proposed reliance on access via the base forms – assuming morphological decomposition is obligatory – offers a viable additional perspective from which the processing of different sets of morphologically complex pseudowords can be examined. In the next section, we shall motivate the present study, which will be embedded in a cross-modal setting.

4.2 Morphological rule over-application as structural violation or mispronunciation

4.2.1 The detection of structural violations in electrophysiology

Variation in the speech signal is ubiquitous. It is, for instance, uncontroversial that no word is ever pronounced in exactly the same way, even by the same speaker (Eulitz & Lahiri, 2004; Friedrich, Lahiri, & Eulitz, 2008; Scharinger & Lahiri, 2010). On the speech sound processing level, it is thus assumed that a system must be in place that is able to map a variety of possible surface realizations of a particular speech sound onto a stored representation, although the precise implementation of the system is subject to debate (cf. Lahiri & Reetz, 2002 for an abstractionist approach; Bybee, 2001 for a full-specification model). In this context, Roberts, Wetterlin and Lahiri (2014) showed that only particular kinds of mispronunciations, for instance when a coronal consonant in the lexical representation of a word such as *sonnet* was realized as a bilabial in **sommet*, could still activate underlying *sonnet* as evidenced through semantic priming of a word such as *song*. Pseudowords such as **inage*, on the other hand, in which an underlying bilabial medial consonant /m/ was realized as [n], did not induce a priming effect for a semantic relative. Certain properties of mispronounced words thus led to their tolerance as possible realizations of an intended form, while others were considered deviant. Other aspects of language processing, however, such as combinatorial or structure-building processes in morphology and syntax, are less tolerant with regard to variation. Deviations from grammatically or well-formedness are therefore expected to be picked up on by detection and possible 'repair' mechanisms that identify these deviations as violations of particular structural constraints of the language. As a technique that offers a high temporal resolution in the processing of complex cognitive processes, electrophysiology has thus not only been used to study priming between morphological relatives, but also in the detection of structural violations on both a syntactic (Osterhout & Mobley, 1995; Friederici, Pfeifer, & Hahne, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991; Gunter, Friederici, & Schriefers, 2000; Allen, Badecker, & Osterhout, 2003) and a morphological level (Leinonen, Brattico, Järvenpää & Krause, 2008; Linares, Rodriguez-Fornells & Clahsen, 2006; Lück, Hahne & Clahsen, 2006; Morris & Holcomb, 2005; Penke, Weyerts, Gross, Zander, Münte & Clahsen, 1997).

As is generally the case in research into morphological processing using electrophysiological measures, the majority of these violation studies have focused on inflectional patterns. More recently, however, a number of studies examined the violation of structural constraints in word formation. Bölte, Jansma, Zilverstand and Zwitserlood (2009), for instance, investigated the processing of different types of violations in the derivation of complex adjectives in German. Participants were presented with sets of sentences containing existing derived adjectives such as *freundlich* (A., 'friendly'), near-synonymous derived pseudowords such as **freundhaft* for which the combination of base and suffix is licensed by the morphological rules of the language and a pseudoword condition in which the combination of base and suffix represents a structural violation (e.g. **freundbar* in which the suffix *-bar* requires a verbal, rather than a nominal base).

Significant differences between the existing condition and the two pseudoword conditions were found in a time window of 450-500 msec after stimulus onset, consisting of a left-lateralized frontal negativity that was interpreted as a LAN effect. The absence of a significant difference between the two pseudoword conditions was traced back to the impossibility of finding a 'structural match' for the combination of the base and suffix that is common to both conditions. Previous research had shown LAN effects to occur in a number of violations of morphosyntactic constraints for inflected forms. Examples include misapplications of regularization processes to irregular forms (e.g. Penke et al., 1997 for German **geladet* instead of *geladen* (past participle for V., 'load') where the regular form of the participle is not expected for the strong verb *laden* (V., 'load')), the selection of the default theme vowel when particular roots require a lexically specified theme vowel (Rodriguez-Fornells, Clahsen, Lleó, Zaake, & Münte, 2001), and in mismatches of gender agreement within a phrase (Gunter, Friederici & Schriefers, 2001).

A second technique that has been employed to examine the effect of structural violations on processing is the mismatch negativity technique (or 'MMN'). The mismatch negativity technique is sensitive to perceptual change in the processing of a deviant (rare) stimulus within the context of a frequently occurring standard stimulus. Two different types of MMN have been reported in response to spoken words that display particular types of violations. A 'lexical MMN' has been found in MMN experiments that contrast the processing of existing words with matched pseudowords (Shtyrov & Pulvermüller, 2002; Pulvermüller et al., 2001). In this case, existing words consistently elicit higher MMNs. In a different set of experiments, it has been found that ungrammatical combinations of words and morphemes give rise to stronger MMNs than licit combinations of morphemes (see Pulvermüller, Shtyrov, Hasting, & Carlyon, 2008). This type of MMN has been termed 'syntactic MMN' and has been interpreted as an index of automatic recognition of ungrammatical structure. Bakker, MacGregor, Pulvermüller and Shtyrov (2013) showed that over-regularized new forms such as **flied* elicited syntactic MMNs, suggesting that the incorrect formation of the past tense for *fly* was not processed like a pseudoword, but as the result of a misapplication of a combinatorial rule. The possibility of dissociating whole-word retrieval ('lexical MMN') from combinatorial violations ('syntactic MMN') also opened up the possibility of studying derivational processing using mismatch negativity.

In a study on the formation of German derived nouns, Hanna and Pulvermüller (2014) put the processing of derived pseudowords in German such as **Sauberheit* and **Sicherkeit* to the test. For both non-existent items, it is the other nominalization suffix that yields an existing word of the language. Thus, *Sauberkeit* (N., 'cleanliness') and *Sicherheit* (N., 'safety') are existing German words. In an MMN design, the stem forms *sicher* (A., 'safe') and *sauber* (A., 'clean') served as the standard stimulus, which was either followed by the correctly derived complex word (*Sicherheit* or *Sauberkeit*) or by a formation in which the respective suffix was not selected appropriately (**Sicherkeit* and **Sauberheit*). Hanna and Pulvermüller (2014) refer to the distribution of the two variants *-keit* and *-heit* as arbitrary and therefore not subject to structural constraints. It was found that the existing complex words *Sicherheit* and *Sauberkeit* gave rise to a stronger MMN effect than the illicit formations **Sicherkeit* and **Sauberheit*, suggesting a lexical rather than a syntactic MMN in this case and therefore whole word storage, rather than combinatorial composition of derived words.

4.2.2 Tolerating degrees of morphological rule over-application: a cross-modal priming investigation

As seen in section 4.2.1, most research into morphological structure violation mechanisms has focused on the distinctive processing signatures observed when deviant forms are encountered. In a similar vein, Janssen, Wiese and Schlesewsky (2006) turned to a comparison of different types of morphological subcategorization violations (morphosyntactic versus prosodic). For the morphosyntactic violation, the property of -*ung* derivations requiring a verbal, and not an adjectival base, was used to investigate the processing of formations such as **Vollung* (N., 'act of making full') that were derived from the adjectival base *voll* (A., 'full'). Prosodic violations were studied on the basis of formations that parallel the set of stimuli used in Hanna and Pulvermüller (2014). Unlike Hanna and Pulvermüller, Janssen et al. (2006), however, refer to the two suffixes *-heit* and *-keit* as occurring in complementary distribution (Fleischer, Barz, & Schröder, 1995). However, as in our discussions in 2.5.2.4, Janssen et al. (2006) argue that the suffix *-keit* *i*s selected over *-heit* when the preceding syllable is unstressed, whereas monosyllabic bases and stressed preceding syllables require the suffix *-heit*. N400-like rather than LAN effects were found for the prosodic violations in **Korrektkeit* and **Einsamheit*, suggesting that these formations were processed like viable pseudowords given the absence of a LAN effect for these items. However, the authors were also surprised to find an N400 rather than a LAN effect for the morphosyntactic violations (e.g. **Vollung*), with an even stronger negativity for these formations.

A possible reason for the observed N400 effect for items such as **Vollung* may lie in their plausibility as derived complex words. A close inspection of the stimuli employed in this condition shows that these items are in fact possible derivations if one allows for zero-derivation of an intermediate verb form. To be more precise, the formation **Vollung* (N., 'process of making full'), for instance, is classified as a morphosyntactic violation by Janssen et al. (2006) given that the deverbal suffix *-ung* is argued to attach to an adjectival base *voll* (A., 'full'). Alternatively, it could be argued that the formation **Vollung* is not impossible if a non-existent, but possible zero-derived verb is factored in. This would yield the following derivational path *voll* (A., 'full') > **vollen* (V., 'become full') > **Vollung* (N., 'act of making full'). The plausibility of the final form **Vollung* as evidenced by a valid derivational path to its formation, could explain why Janssen et al. (2006) found an N400 effect, rather than the anticipated LAN that would be expected for morphosyntactic violations. Instead, the processing of complex pseudowords such as **Vollung* would amount to the processing of possible pseudowords given the priming effects reported for parallel structures such as **Hübschung* in a delayed paradigm (Chapter 3). Note that Janssen et al. (2006) investigated the processing signatures – in this particular case, the presence of a LAN versus an N400 effect – during the visual recognition of the complex formations, not the degree to which the relevant base was activated during processing. Based on these results, there is thus some indication that the kinds of items that we grouped into category 'NonEx2' in Chapter 3 are not interpreted as morphosyntactic violations and thus impossible formations in the language. Instead, their status as pseudowords appears to suggest that their viability as possible words is granted and the meaning of their base words retrieved. The latter point will be the focus of the present study as we turn to the question whether or not the different sets of pseudowords we introduced in Chapter 3 are interpreted as over-applications of particular morphological rules and thus tolerated as possible mispronunciations of intended forms.

Our prediction is that if non-existent items are indeed treated like possible pseudowords that can be derived through morphological rules, then it should be expected that their base words become activated during processing. We expect this activation to be driven by the availability of a morphologically viable derivational chain as we have argued throughout Chapter 3. Conversely, this means any non-existent item that is not the result of a viable morphological rule should not activate an embedded adjective. Controls such as **Wirr-lein* are not formed according to viable morphological rules (the suffix *-lein* would require a nominal, not an adjectival base) and should therefore not activate the embedded existing adjective *wirr* (A., 'confusing').

Moreover, we expect that speakers might be sensitive not only to the distinction between morphological viability and impossibility, but also to degrees of viability. More specifically, recall that following the derivational path presented above for **Hübschung,* the verb from which **Hübschung* is notionally derived (**hübschen*) is already one that does not exist. Only the base adjective *hübsch* is an existing lexical representation. To access the base word, the intervening non-existent verb form would have to be computed due to the requirement of a verbal base for *-ung* nominalizations (Fleischer & Barz, 1995). On the other hand, since we do find examples of non-existent nouns for which the verb does in fact exist, such as *spitzen* (V., 'to sharpen) from *spitz* (A., 'sharp'), the question can be raised as to what extent we will find differences in degree of base activation. While both sets contain noun forms that are non-existent, these items could be argued to differ in the degree to which they are deviant and therefore likely to activate their respective base word. Thus, recall that while **Hübschung* and **Spitzung* end in the same suffix, were judged to be nonwords in off-line tasks and did not yield matches in the CELEX (Baayen et al., 1995) and DWDS (Klein & Geyken, 2010) databases, there are differences in the composition of their derivational path. Both nouns are derived from verbs which are already complex and zero-derived from a base adjective, but differences pertain to the point at which a position within the chain is expressed through a lexical gap, and not an existing lexical representation. Complex nouns like *Heilung* are formed following the same sequence of derivational steps in *base adjective* > *zero-derived verb* > *noun in -ung* (*heil* > *heilen* > *Heilung*), but for these items, all positions within the derivational chain exist. In the present experiment, we included both pseudoword conditions, as well as a condition with existing noun forms in order to compare the degree to which pseudowords activate their respective base words. Impossible formations such as **Wirrlein* served as a control in assessing to what extent any facilitation observed was morphologically driven. Recall that in a cross-modal priming experiment with mispronunciations in monomorphemic words by Roberts et al. (2014), only mispronunciations that could be reconciled with the constraints that govern the mapping of phonological representations were accepted. In the present experiment, we transfer these findings onto the predictions for morphological processing to suggest that there could be differences in how acceptable different sets of morphologically complex pseudowords are found to be.

In a cross-modal priming experiment (prime presented auditorily and target visually), we only expect to see a reduction in the N400 response to base words that follow morphologically viable formations. Thus, impossible formations such as **Wirr-lein* should not activate the embedded existing adjective *wirr* (A., 'confusing'). Moreover, we expected that the lexical gap in intermediate positions for items like **Hübschung* would result in these items being felt to be less interpretable than pseudowords for which the intermediate position exists (e.g. **Spitzung*). Given that cross-modal priming is sensitive to a semantic relationship between prime and target, we expected to find a greater reduction in N400 amplitude for the **Spitzung* than for the **Hübschung* set.

4.3 Methods

4.3.1 Participants

Twenty-one native speakers of German aged 20 to 31 (mean age = 24.6, SD = 2.95) participated in the EEG experiment. All participants were right-handed as assessed through the Edinburgh Handedness Inventory (Oldfield, 1971) and had normal or corrected-to-normal vision. Participants reported no history of psychological or neurological disorders and no hearing or reading impairments. All participants were reimbursed appropriately for their time (£10/hour).

4.3.2 Material

4.3.2.1 Stimuli

The experiment consisted of four experimental conditions containing 40 prime-target pairs per condition. The same number of filler items were included in order to obscure the purpose of the manipulations across the experimental conditions and in order to counterbalance for the number of words and nonwords in prime and target positions. Each target word was associated with two types of primes – a related complex or pseudocomplex prime containing the target item and an unrelated control baseline item. The construction of the related prime was dependent on the characteristics of the relevant experimental condition. Conditions 1-3 consisted of pairings between morphologically complex primes and their stems; condition 4 was constructed as a control condition in which the prime item contained the target word, but was followed by a morphologically impossible suffix or suffix combination. Table 4.1 gives an overview of the stimuli characteristics selected in conditions 1 to 4 (see Appendix C for all stimuli).

Table 4.1 *Summary of characteristics of experimental conditions*

	Derivational path	***Prime-target pairing***	***Priming expected***
Extant	*heil - heilen - Heilung*	*Heilung - heil*	Yes
NonEx1	*spitz - spitzen - *Spitzung*	**Spitzung - spitz*	Yes
NonEx2	*hübsch -*hübschen - *Hübschung*	**Hübschung - hübsch*	Yes
Control NonEx	No existing derivational path	**Wirrlein - wirr*	No

All prime words were German existing (Extant), possible (NonEx1 and NonEx2) or morphologically impossible (Control NonEx) noun forms. The corresponding targets were all existing German adjectives or verbs. These can serve as bases for deriving the nouns in conditions 1-3 through the two morphological rules given in 1. and 2. below:

1. **adjective > zero-derived verb > noun in {-ung}**
2. **verb > adjective in {-bar} > noun in {-keit}**

Unrelated controls in each condition were matched in lexical status, length, syllable structure and stress with their corresponding related controls, but were not semantically, morphologically or phonologically related to their target words. Targets across all four experimental conditions were matched in length, lemma and word frequency and morphological family size.

4.3.2.2 Stimulus recording

All experimental and filler prime words were recorded by a female native speaker of German. Recordings (sampling rate of 44.1 kHz) took place in a sound-attenuated booth using a Roland NT-USB microphone connected to a MacAir laptop running Audacity software (version 2.0.6). The volume of all recordings was subsequently equalized in Audacity software, but no other acoustic manipulations were performed on the naturally spoken stimuli.

4.3.3 Procedure

Participants were seated in a sound-attenuated booth approximately 1m away from a 20-inch screen on which the visual target stimuli were displayed. Participants were first presented with the auditory stimuli via headphones. These were followed by visually presented target words (ISI = 350 ms) with a display time of 750 ms. Participants were asked to decide as quickly and as accurately as possible whether or not the item on the screen was an existing word in German and to press the button on the response box for nonwords only. As only existing words were submitted to subsequent EEG data analysis, this allowed the analysis of electrophysiological data for the target words (which were all existing words), independently of possible artefacts induced by the button press itself. The mapping of response presses was counterbalanced across participants. Half of the participants used their dominant hand to carry out the button press, while the other half used their non-dominant hand to account for response preparation effects (Kutas & Donchin, 1977). Each experimental session was preceded by a practice session consisting of 10 prime-target pairs to familiarize participants with the experimental set-up. The actual experiment consisted of four experimental blocks that were separated by short breaks to minimize the effects of fatigue.

4.3.4 EEG data acquisition

Electrophysiological data were recorded using a BioSemi Active Two amplifier with 64 sintered Ag/AgCl pin-type scalp electrodes. Online referencing was performed to both mastoids and eye movements were recorded using four facial electrodes (IO1, IO2, LO1, LO2), which were placed under and next to the participant's eyes. All participants took part in a short eye-movement task prior to the experiment to enable identification of eye movement artefacts by subsequently applying an EOG correction algorithm (Ille, Berg & Scherg, 2002) to the experimental data. Electrode offsets did not exceed 20 mV. Digitization of the signal was performed at 2048 Hz.

4.4 Data analysis

4.4.1 Behavioural data

Error rate data were collected to ascertain task compliance only. Overall, all participants were attentive to the task as evidenced by high accuracy scores in the nonword identification task (mean = 97.2 %, SD = 0.83).

4.4.2 ERP analysis

During analysis, a 0.01 Hz High-Pass and a 30 Hz Low-Pass filter were applied to the acquired EEG data. Eye movement artefacts were identified using an EOG correction algorithm based on scalp topographies of the respective eye movement artefacts. Visual inspection of the EEG data was performed by an experienced EEG researcher. This was followed by an automatic rejection procedure for trials with an amplitude of over 90 μV or a gradient exceeding 75 μV, using BESA analysis software (version 6.0). Noisy electrode channels were interpolated, avoiding the interpolation of more than three channels within a ROI and more than two adjacent channels within or across ROIs. Only participants for whom at least 75 % of trials per condition were acceptable were included in the subsequent analysis, resulting in the exclusion of data for two participants. Filler and nonword targets were not included in the analysis.

A pre-stimulus-onset baseline of 200 ms was selected for all targets. The averaging epoch was set to -200ms to 1000ms in relation to target onset. The amplitude of the N400 response to targets was calculated within the time window of 350 ms to 550 ms following target onset. Only correctly classified targets were included in the analysis. Based on previous research focusing on the N400 component (Scharinger & Felder, 2011; Roberts et al., 2014; Kutas & Hillyard, 1980), four ROIs were determined: Left Frontotemporal (C5, F5, FC5, FT7, TP7, T7), Right Frontotemporal (C6, F6, FC6, FT8, TP8, T8), Centro-parietal (Pz, P1, P2, CPz, P3, P4) and Fronto-central (Fz, FCz, F1, F2, FC1, FC2).

4.5 Results

Two participants were excluded due to the rejection of more than 30 % of trials in at least one experimental condition. All participants were very accurate in the nonword target classification task with a mean accuracy of 97.2 % (SD = 0.83), demonstrating task compliance for all participants included in the analysis of the ERP data. The visual inspection of the N400 effect revealed an attenuation of the N400 response to related words relative to their respective unrelated control stimuli in all morphologically possible conditions ('Extant', 'NonEx1', 'NonEx2'), but not in the control condition ('Control NonEx'). Difference waveforms were calculated subtracting the related from the unrelated response for each participant in the four experimental conditions. In a linear mixed model with the fixed factors *ROI* (Left Frontotemporal vs. Right Frontotemporal vs. Centro-parietal vs. Fronto-central), *Prime-Type* (Related vs. Unrelated) and *Base*

(Extant vs. NonEx1 vs. NonEx2 vs. Control NonEx) and the random effect *Subject*, the following effects reached significance: the main effect of *ROI* $F(3, 3598) = 496.75$, $p < .001$; the main effect of *Prime-Type* $F(1, 3598) = 48.37$, $p < .001$ and the main effect of *Base* $F(3, 3598) = 68.71$, $p < .001$. The interaction between *Prime-Type* and *Base* was also significant at $F(3, 3598) = 14.24$, $p < .001$ and was followed up by planned comparisons for the unrelated – related N400 responses for each *Base* condition. An overview of the LMM model and the results of the planned comparisons are given in Table 4.2.

Table 4.2 *Overview of LMM effects*

Overview of LMM effects				
Effect	**DF**	**DFDen**	**F Ratio**	**Prob > F**
ROI	3	3598	496.7499	<.0001*
Prime-Type	1	3598	48.3735	<.0001*
ROI *Prime-Type	3	3598	16.3742	<.0001*
Base	3	3598	68.7084	<.0001*
ROI *Base	9	3598	1.7445	0.0738
Prime-Type*Base	3	3598	14.2429	<.0001*
ROI*Prime-Type*Base	9	3598	0.3255	0.9670
Planned comparisons Prime-Type*Base				
Unrelated Extant vs. Related Extant				t = 5.8, p < .0001
Unrelated NonEx1 vs. Related NonEx1				t = 6.6, p < .0001
Unrelated NonEx2 vs. Related NonEx2				t = 3.2, p < .01
Unrelated Control NonEx vs. Related Control NonEx				t = -1.76, p = .08

As can be seen in the planned comparisons, a reduction in the N400 response was elicited for all morphological conditions, irrespective of whether the final noun form exists ('Extant') or not ('NonEx1', 'NonEx2'). Difference waveforms for all conditions are given in Figure 4.1.

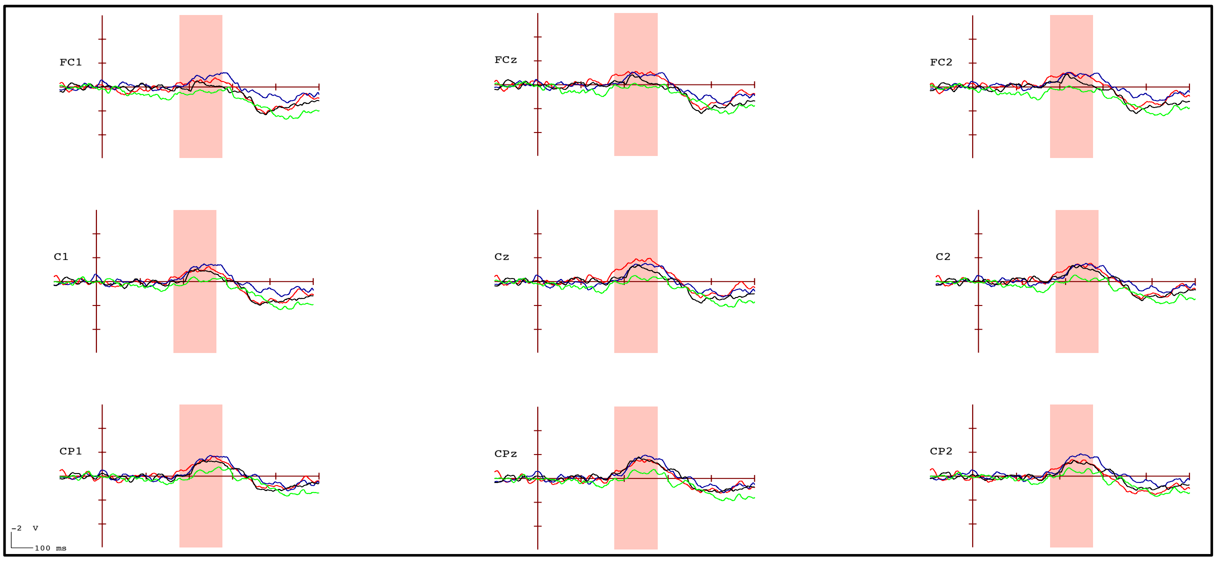

Figure 4.1 *Difference waveforms for all conditions* Extant, NonEx1, NonEx2 *and* Control NonEx

No priming and a trend toward inhibition were observed in the control condition 'Control NonEx' in which the combination between stem and suffix is not morphologically licensed (see Figure 4.2 for an overview of the difference waveforms for all nonword conditions).

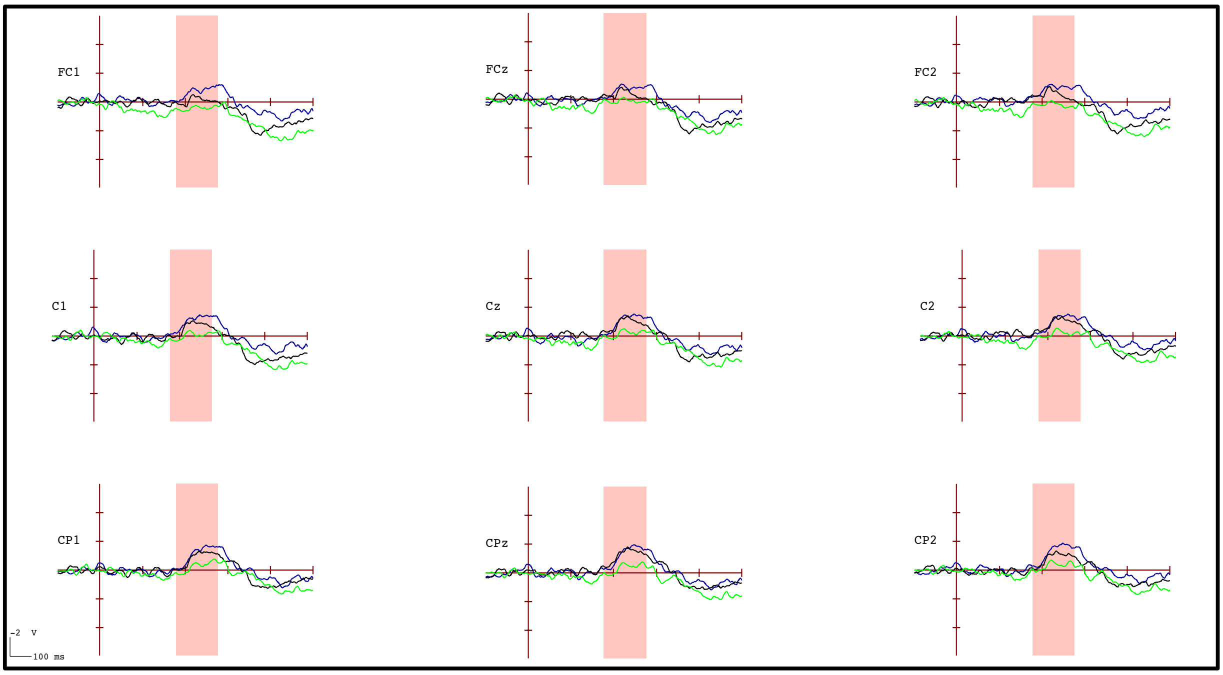

Figure 4.2 *Difference waveforms for all nonword conditions* NonEx1, NonEx2 and Control NonEx

Given our particular interest in the processing of the two types of possible morphologically complex pseudowords, we examined possible differences in the degree of priming between related versus unrelated pairs in the two conditions. We found the priming effect for items in condition 'NonEx1', for which the intermediate position within the derivational chain is an existing word, to be significantly stronger (Est. = -0.25; SE = 0.11; t = -2.39; $p < .05$) than for items in 'NonEx2'. Figure 4.3 shows the difference waveforms between the two pseudoword conditions NonEx1 (blue line) and NonEx2 (black line).

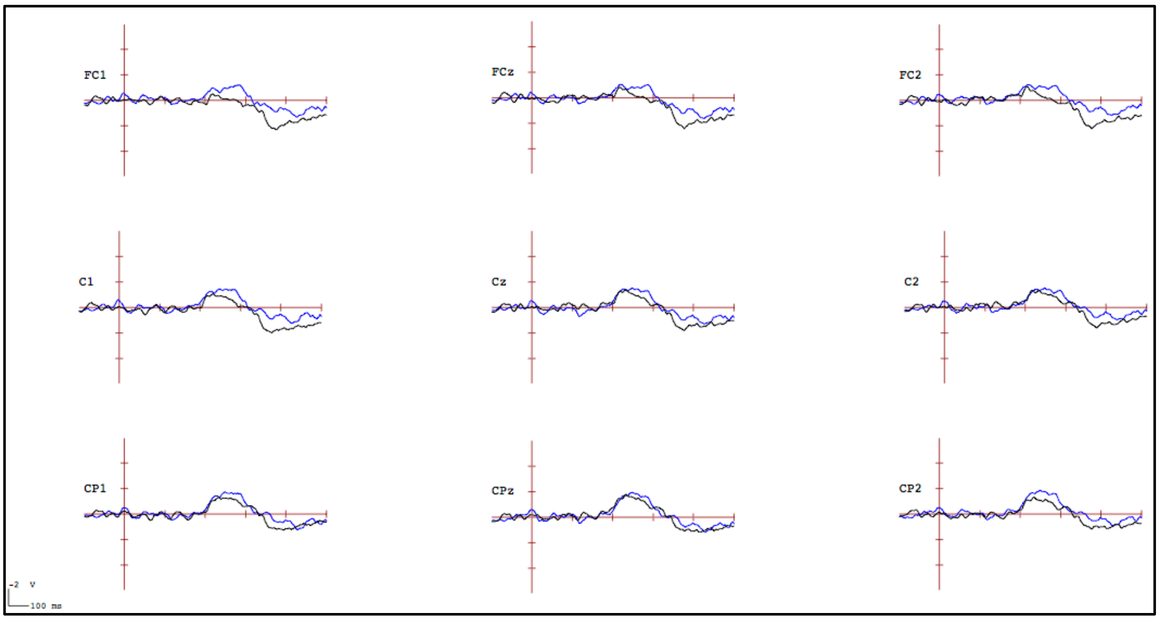

Figure 4.3 *Difference waveforms for NonEx1 (blue) versus NonEx2 (black)*

The difference in priming between existing words and pairs of items in condition 'NonEx1' was not significant (Est. = 0.17; SE = 0.11; t = 1.62; p = .11).

Figure 4.4 gives an overview of the waveforms to targets following unrelated versus related primes for all conditions at electrode CPz, as well as the topographies of the distribution of the negativity component for all conditions at 250 ms versus 450 ms following stimulus onset.

As shown in Figure 4.4., differences in the processing of targets following related versus unrelated primes emerged in all morphological conditions in the N400 time window. No differences between conditions are discernible at 250 ms following stimulus onset. The topographies of the evoked negativity in the N400 time window are comparable in all morphological conditions and are predominantly confined to centro-parietal electrode sites. Any negativity observed in 'Control NonEx' appears to be restricted to extremely parietal electrodes such as Oz that are not typically included in the analysis of an evoked N400 component.

250 ms 450 ms

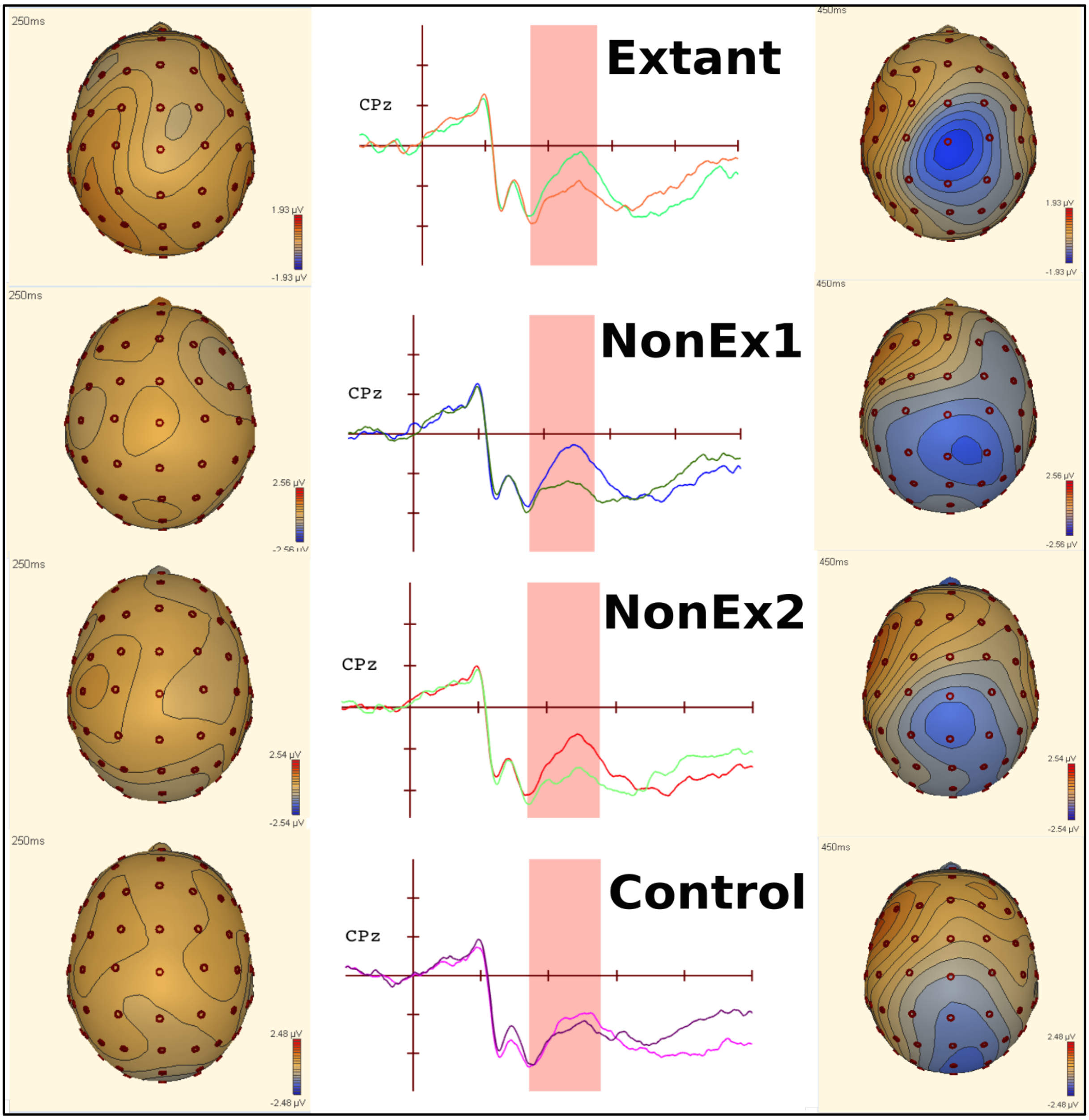

Figure 4.4 *Waveforms to targets following unrelated and related primes in all four conditions at electrode CPz. Topographies of the evoked potentials at 250ms and 450ms following stimulus onset for targets are given.*

4.6 General discussion

Speech communication does not always occur under optimal conditions. Speakers can advertently or inadvertently deviate from conventional or expected output, leaving it to the listener to decode the intended meaning. As demonstrated in Roberts et al. (2013), certain mispronunciations (e.g. **sommet* for *sonnet*) are accepted as possible realizations of the intended form and activate the relevant representation. Other phonological deviations such as the realization of a coronal instead of a bilabial (e.g. **inage* for *image*) do not allow access to the intended form, suggesting that at least in the phonological domain, there is evidence for a mapping mechanism that mediates the retrieval of permissible deviations from an expected form. Yet deviations from well-formedness in the morphological or syntactic domain are not common in the sense that native speakers rarely ignore morphosyntactic agreement constraints in phrases (e.g. **he eat*), apply regularization to irregularly inflected verbs (e.g. **growed*) or ignore morphotactic constraints in their language (e.g. **freundbar* instead of *freundlich* in German). These and similar types of violations have nonetheless been used extensively in a number of electrophysiological studies in order to obtain an understanding of the mechanisms involved in error detection and repair processes in language comprehension. By looking at the brain responses to the violations themselves, the idea has been to identify differences in the components elicited (e.g. LAN versus N400) as a means to determining whether different types of violations lead to specific processing signatures.

The degree to which the intended meaning is still accessible has not yet been the subject of research. In the present study, we therefore approached the question from a slightly different angle. Here, we were concerned with the interpretability of sets of possible novel derived forms (**Spitzung* and **Hübschung*), as well as morphologically impossible constructions (e.g. **Wirrlein*). The 'over-generalized' novel forms consisted of two sets of 2-step derived German complex nouns ending in *-ung* or *-barkeit* that differed in the availability of a lexical representation in the intermediate position.

Firstly, we found no activation of an existing form-related adjective *wirr* after participants were presented with impossible constructions such as **Wirrlein.* In fact, there was a trend towards inhibition for pairs like **Wirrlein* and *wirr* (A., 'confused') relative to control pairs. One interpretation could be that as the speech signal unfolds and participants hear the embedded adjective *wirr* (A., 'confused'), the existing adjective is briefly activated. However, as the adjective *wirr* is followed by the morphologically unviable ending *-lein*, it is discarded for future processing, leading to inhibition effects relative to a baseline comparison. Secondly, we found that novel forms such as **Spitzung* (N., 'sharpening') derived through *spitz* (A., 'sharp') > *spitzen* (V., 'sharpen') > **Spitzung* (N., 'sharpening') led to a stronger priming effect of their respective base than **Hübschung* for which the intermediate verb form **hübschen* does not exist. In fact, the degree of priming for the **Spitzung* set did not differ significantly from the facilitation obtained for existing complex words (*Heilung*) and their base words (*heil*). Note that factors that could have facilitated access to the base word such as morphological family size were matched between conditions. We would therefore argue that factors pertaining to the composition of the derivational path that connect the complex pseudoword and base word could have driven differences in processing. Recall that the two conditions differed in whether or not the intermediate position within the derivational path leading to the complex item was an existing (e.g. *spitzen*) or a possible word (**hübschen*). There are two ways in which this could affect the recognition of the base word.

Firstly, it is possible that, although the overall number of morphological derivates was matched across conditions, the existence of a lexical representation in the intermediate position boosted the extent to which the overall form was semantically interpretable. A second option would be that complex pseudowords for which the previous derivation consists of a real word activate their base words more strongly, because native speakers are sensitive to the morphological rules that lead to the formation of the complex word. To be more precise, the formation of a complex noun in *-ung* is reliant on the availability of a verbal base. The difference between the two conditions can thus also be described as the comparison between noun formation in *-ung* on the basis of an actual (*spitzen*) versus a possible verb (**hübschen*). This would point to speakers' sensitivity to the constraints that govern the formation of morphologically complex words. As discussed in a review paper by Lau, Phillips and Poeppel (2008), the N400 effect obtained in semantic priming can largely be attributed to the facilitation of lexical access triggered by expectation. We would argue that the results obtained suggest that an 'over-generalized' form such as **Spitzung* leads to a higher degree of expectation of its base *spitz* than a matched novel form such as **Hübschung* and its base *hübsch*. Increased expectation is conditional upon the existence of a derivational path that underlies the formation of both complex words as no priming is obtained for morphologically impossible controls. It is moreover driven by the lexical composition of the derivational path as evidenced by a stronger priming effect for items with fewer lexical gaps in their derivational chain such as **Spitzung*, demonstrating that the composition of the derivational chain is inspected during processing. We would therefore argue that the differences in priming between the two sets do indeed point to sensitivity to morphological rules and combinatorial constraints.

Our findings are thus in conflict with the conclusions reached by previous studies on the processing of German derivational morphology. Hanna and Pulvermüller (2014), for instance, found no evidence for combinatorial processing in the derivation of German nouns given that illicit formations such as **Sicherkeit* and **Sauberheit* elicited a lower

MMN effect than the existing formations *Sicherheit* and *Sauberkeit*. A problem that arises in the analysis of MMN data can be ascribed to the limited set of stimuli that can be employed in any condition. In the case of Hanna and Pulvermüller's study, the items **Sicherkeit* and **Sauberheit* are selected as the deviant stimuli that are meant to represent the suffixation processes with an illicit suffix. However, as the authors discuss in later portions of the paper, the complex word *Sicherheit* is significantly more frequent than *Sauberkeit*. Moreover, it could also be argued that **Sicherkeit* displays a violation that is qualitatively different from the one observed in **Sauberheit.* Following the prosodic constraints advanced by Janssen et al. (2006) on the basis of Fleischer and Barz (1995), -*keit* is selected following unstressed syllables. In view of this common distribution, *Sicherheit* could be considered to be more marked than *Sauberkeit*. Hanna and Pulvermüller indeed find a main effect of the root with both formations based on *sicher* eliciting stronger responses than formations based on *sauber.* The higher baseline effect for formations based on *sicher* could suggest that the existing formation *Sicherheit* is already marked and thus leads to a stronger effect than *Sauberkeit.* While it is also possible that these differences in the baseline magnitude for existing items differ between the two conditions due to the higher frequency of the base word *sicher*, both explanations of these baseline differences essentially point to a common problem in the design of MMN experiments: the selection of stimuli is crucial and any idiosyncrasies of form selected for a particular condition may affect the overall result.

Moreover, a clear characterization of the type of violation investigated is crucial. Although Hanna and Pulvermüller (2014) and Janssen et al. (2006) refer to similar sets of morphological violations in derivation, the rules underlying the formation of these forms are interpreted differently between the two studies. In the former study the distribution between -*keit* and -*heit* is claimed to be arbitrary while the latter study provides the phonological constraints that in fact govern this distribution. Thus, it appears to be inherently difficult to investigate the processing of morphological violation and mapping types of morphological violation to distinct processing signatures if we find disagreement over the nature of the violation involved.

In line with the results obtained by Janssen et al. (2006) who found an N400, rather than a LAN effect for pseudowords such as **Vollung*, the present findings indicate that items like **Hübschung* for which the target base word is separated by a non-existent intermediate form, are decomposed or at least processed in a way that activates the existing base word. Janssen et al. (2006) had classified this type of pseudoword as a morphosyntactic violation following the selectional restriction that nouns in *-ung* are derived from verbs and not adjectives. In the present experiment, as well as in Janssen et al. (2006), it appears, however, that a non-existent zero-derived verb is in fact computed and considered morphologically viable during processing. This conclusion is supported by the absence of any priming (and a trend towards inhibition) for pairs such as **Wirrlein* and *wirr* (A., 'confused') in the present study. If pseudowords like **Hübschung* were interpreted as a morphosyntactic violation in which the deverbal suffix *-ung* attaches to an adjectival base, then the processing patterns between 'NonEx2' and 'Control NonEx' would have been expected to be similar. Instead, we have clear evidence that an attenuation of the N400 only occurs following pseudowords that are morphologically well-formed.

Overall, the present results suggest that the 'over-application' of a morphological rule to a possible pseudoword leads to mispronunciations that permit the activation of the respective base word. The degree to which the base becomes accessible differs, however, depending on the lexical status of the derivation immediately preceding the formation of the complex pseudowords. Thus, even though the sets in 'NonEx1' and 'NonEx2' do not appear dissimilar on a surface level, items in 'NonEx1' such as **Spitzung* show stronger activation for the base word *spitz,* arguably because the existence of a lexical representation for the intermediate derivation lends additional plausibility to the pseudoword. Intermediate levels of derivational structure are thus accessed following the auditory presentation with a morphologically viable pseudoword. Morphologically unviable formations such as **Wirrlein,* on the other hand, do not provide a context that allows the integration of an existing word with which it merely shares some formal overlap. Both the structural rules of morphological derivation as well as the mental lexicon are factors that determine the extent to which novel forms can activate a morphologically related existing word. As in the first cross-modal repetition priming study investigating morphological processing with different sets of complex pseudowords, we find that the paradigm is well-suited to an assessment of the extent to which different types of morphological violations lead to the activation of their bases. The paradigm can be used in conjunction with MMNs and unprimed lexical decision tasks as a means of gauging the degree of 'plausibility', rather than the degree of 'violation' of different types of complex and pseudocomplex novel forms. Thereby we hope to provide a window into the mechanisms that enable listeners to deal with novel forms, as well as different levels of deviation in the language input with which they are presented.

5. THE NEURAL CORRELATES OF MORPHOLOGICAL COMPLEXITY PROCESSING

We have so far considered evidence for morphological processing by submitting pairs of morphologically related words and pseudoword-word pairings to two sets of priming paradigms. The first involved a purely behavioural experimental set-up where participants performed a lexical decision task in response to all experimental stimuli (Chapter 3). The second priming paradigm also required participants to perform a lexical decision task to visually presented stimuli, but the responses collected by the experimenter were complemented by electrophysiological measurements (Chapter 4). As ascertained in our delineation of a proposed timeline for visual word recognition in section 2.4.2, the processes implicated in a lexical decision task can be broken up into several distinct stages. The button presses carried out by participants to indicate a lexical decision are situated at the very endpoint of the recognition process when cognitive processes are already manifested in the motor responses elicited. Thus, while 'on-line' tasks such as lexical decisions enable us to study language processing in real-time, especially when contrasted with grammaticality judgment tasks or other types of off-line surveys, it is nonetheless effectively the end product of real-time language processing that is captured using behavioural tasks. Since 'on-line' tasks typically require participants to carry out speeded responses, influences from strategies adopted by the participant can be minimized, though not entirely ruled out.

From a neurocognitive perspective, it is not only the lexical decision made by the participant and the time taken to arrive at a given response that should provide an insight into language processing. In order to understand the role of morphological complexity in language processing, it is necessary to extract possible divergences in the processing signatures which eventually lead to the manifestation of a priming effect or differences in response latencies. If these differences in the response latencies are uncontaminated by extraneous factors and thereby truly reflective of the processing mechanisms subserving the cognitive aspects of the recognition process, then it should be possible to identify the distinct brain processing signatures that are triggered by an experimental manipulation. In Chapter 4, we drew on the properties of event-related potentials to demonstrate that priming as the facilitation for a related word compared to an unrelated baseline could be established not only as a reduction in reaction time, but also through the modulation of brain activity in the absence of an overt motor response.

In some cases, it may even be the case that differences at the neurocognitive level are levelled out in behavioural investigations. Recall for this purpose that Meinzer et al. (2009) found no difference in reaction time to 1-step versus 2-step derived nouns when these were presented to participants in a simple lexical decision task outside the scanner. However, at the neural level, as captured through the BOLD signal measured during the reading of these nouns, clear differences were reported. In this context, it is worthwhile to explicate the neural underpinnings of the signal extracted in functional magnetic resonance imaging. The signal underlying inferences made in neuroimaging using fMRI is the so-called blood-oxygen-level dependent (BOLD) effect. The effect is reliant on differences in magnetization potential between oxygenated versus oxygen-depleted blood. In addition to this, the method draws on the effects of neurovascular coupling through the increase in demand for glucose and oxygen consumption in brain areas that are recruited during a cognitive process (Brühl, 2015). The uptake in glucose and oxygen consumption in active brain areas is accompanied by an increase in blood perfusion to these areas. Consequently, the upshot in blood perfusion is reflected in the changing magnetization signal extracted in the MRI signal, whereby the BOLD signal serves as an index of neuronal activity in particular with regard to the localization of brain areas that are recruited during the execution of an experimental task.

As discussed by Brühl (2015), the time course of the BOLD response is rather slow and follows a pattern in which an initial period of 'undershoot' reflecting increased oxygen consumption in the activated area is succeeded by a signal peak at 5-6 seconds after which the signal returns to baseline at 12 to 15 seconds following stimulus presentation. It should be noted that the change in signal engendered by functional activation and thus neuronal activation is comparably weak in relation to noise, resulting in the necessity for repetition of stimuli or experimental blocks in order to improve the signal-to-noise ratio. With regard to spatial resolution, fMRI offers unparalleled possibilities of identifying the localization of neuronal activation to the accuracy of 1x1x1 mm^3 while providing whole-brain coverage.

Under this perspective, combining the behavioural evidence discussed in Chapter 3 with a neuroimaging angle that gives an insight into the brain areas that require increased resources during processing should provide a more holistic overview of the cognitive processes that underlie the processing of complex pseudowords. In particular, as we have ascertained, differences in reaction time can only give an indication whether differential activity triggered by manipulations of morphological complexity ultimately lead to differences at the end point of the recognition process which influences the lexical decision. By embedding our experimental manipulations into a neuroimaging study, we can identify the brain areas that are recruited during the recognition process and which underlie the differential processing patterns resulting in the effects reported in the previous two chapters. In the present chapter, we report on the results of a neuroimaging study on morphological complexity processing. In a first step, however, we shall provide an overview of the main findings reported in Chapters 3 and 4; that is both the behavioural and the neurophysiological evidence obtained so far that we wish to complement through the present neuroimaging investigation.

5.1 Overview of main behavioural and neurophysiological findings

5.1.1 Behavioural evidence

Evidence from delayed priming

Experiment 1

1. Morphologically complex pseudowords such as **Spitzung* (N., 'sharpening') that require a single decompositional step in order to arrive at an existing word (*spitz* > ***spitzen*** > **Spitzung*) activated the base word *spitz* from which it is separated through two derivational steps.

2. The degree of facilitation obtained for *spitz* when primed by its morphologically related 2-step derived complex noun **Spitzung* was equivalent to the facilitation seen between pairs such as *Heilung* and *heil* where the complex form exists. The degree of facilitation was thus not modulated by the lexical status of the complex formation.

Experiment 2

1. When the derivational distance to an existing lexical representation was extended, morphological decomposition could still be established: **Hübschung* through *hübsch* > **hübschen* > **Hübschung* also primed the base word *hübsch*.

2. Again, there were no statistically significant differences in the degree of activation measured for existing words such as *heil* when paired with a morphologically complex prime versus an unrelated control or in the facilitatory effects seen for *hübsch* following the pseudoword **Hübschung* versus a morphologically unrelated complex pseudoword. As in Experiment 1, the lexicality of the complex word itself had no effect on the activation of the base word.

Possible interpretations of Experiments 1 and 2:

Delayed priming has been proposed to involve repeated access to the lexical entry of a base form (Drews & Zwitserlood, 1995). Based on our findings in Experiments 1 and 2, this would mean that regardless of the lexical status of a morphologically complex formation, its base constituent is extracted and remains activated in delayed priming. Delayed priming has also been linked to being susceptible to effects of episodic memory. Based on our results in Experiments 1 and 2, this could mean that our effects could have been driven by expectation or episodic factors. In a similar vein, these results did not enable us to differentiate purely morphological effects from other parameters in which prime and base share similarities (for instance on a semantic or formal level). If delayed priming is a combination of both repeated access to the base, as well as episodic effects, then incorporating semantic and formal controls should enable us to understand the relative contributions of these factors.

<u>Experiment 3</u>

1. In this experiment, both pseudoword conditions were combined in a single experiment and differences with regard to the degree of activation were discernible: Pseudowords such as **Spitzung* that are a single derivation away from an existing lexical representation primed their base words *spitz* more strongly than **Hübschung* and *hübsch*. Thus, when contrasted directly, differences in the degree of activation observable for the base word became evident.

2. Purely semantically related pairs did not show facilitatory effects. Neither did we obtain priming between complex control nonwords that were not morphologically possible and adjective or verb forms that were embedded in the impossible forms. To be more precise, **Wirrlein*, where the suffix *-lein* does not attach to a base that presents a viable syntactic category, did not prime *wirr*. Recall that *-lein* requires a nominal rather than an adjectival base.

If we build on the assumption that delayed priming is reliant on repeated access to a lexical entry of a base word, then it becomes clear that the degree to which this lexical entry is available is modulated by a number of factors:

3. In order to induce facilitation under a delayed priming paradigm, prime and target need to exhibit a **morphological relationship**. This reinforces the interpretation of repeated access involving a shared unit that is not reducible to a semantic relationship between words. Similarly, partial orthographic or phonological congruency did not appear to facilitate the visual recognition process for items that were not paired with a morphologically related prime word. The availability of a shared base word between prime and target therefore emerged as a prerequisite for priming effects to become discernible.

Only morphologically related pairs such as *Heilung* (Condition 'Extant'), **Spitzung* (Condition 'NonEx1') and **Hübschung* (Condition 'NonEx2') showed evidence for facilitatory access of their relevant base words *heil*, *spitz* and *hübsch*.

4. Moreover, the degree of priming obtained was not tantamount between conditions, but was further modulated by the **directness of the path** leading to successful retrieval of the relevant base word. In a direct comparison between the two pseudoword conditions ('NonEx1' and 'NonEx2'), pseudowords in 'NonEx1' for which only one derivation is required to access the nearest existing lexical representation (*spitzen*), the activation of the monomorphemic base *spitz* was more strongly facilitated than for **Hübschung* in which the base of the preceding derivation was not an actual word (**hübschen*). Note that the degree of facilitation obtained for the monomorphemic base word of the existing complex word *Heilung* (*heil*) did not differ significantly from either pseudoword conditions. This is consistent with the pattern observed in Experiments 1 and 2 in which no differences between either pseudoword condition and the existing complex word condition *Heilung* were discernible. Based on Experiments 1 and 2, we could thus have proposed that priming under delayed priming conditions is consistent with the following accounts: (a) the stripping of a recognisable affix such as *-ung* or a sequence of affixes such as *-barkeit*, regardless of whether the combination of stem and affix yielded a match with an existing lexical representation or not; (2) a process of 'on-line' decomposition that applies to any item that could be interpreted to be well-formed given the morphological constraints available in the language.

Given the results obtained in Experiment 3, we now have stronger evidence against the first hypothesis since differences in priming modulation were observed across the two pseudoword conditions and both sets of words consisted of items composed of exactly the same stem + affix combination. The latter hypothesis encompasses a perhaps implicit assumption that a fully decompositional model of morphological processing is tenable. After all, if the decomposition process for all complex items (whether actual or possible) is reliant on the procedural application of 'on-line' processes of decomposition, then the stipulation of a lexical representation for existing words is no longer required; complex words such as *Heilung* would be processed via the activation of their base morpheme (*heil*). This would explain the absence of an effect of lexicality on priming magnitude. At the same time, the observation that complex pseudowords such as **Spitzung* prime their bases more strongly than matched pseudowords such as **Hübschung* suggests that the process of 'on-line' decomposition is not fully blind to the effects of lexicality at intermediate stages of composition.

5. The accessibility of the base word seems to be measurable in relative terms given that, especially for the pseudoword comparisons, the degree of priming is affected by the structure of the other type of pseudoword presented in the experiment. While the degree of priming observed for existing words is consistent throughout the three experiments and thus appears to be unaffected by the composition of any other experimental manipulations, pseudowords with a lexicalized intermediate position such as **Spitzung* give rise to more efficient time savings in response time to their base words than pseudowords that display a less direct derivational path. We could indeed propose that the response timesavings observed in the decomposition of existing versus non-existent complex items are in fact a reflection of separate processing

mechanisms. For existing words such as *Heilung*, the activation of the base word *heil* does not necessarily require a process of automatic 'on-line' decomposition. It is equally plausible to assume that the lexical representation for *Heilung* into which we tap during the lexical decision task is structured in a way that is linked to its morphological derivates, including the base word on the basis of which it is composed. A possible representation for *Heilung* would thus be $[[[\text{Heil}]_A]_V\text{-ung}]$ and the priming effect obtained would reflect the shared unit of representation for the listed complex word. For neither of the two pseudowords is a listed representation available, meaning that the base cannot be retrieved as a shared representational unit in the complex word, but must be computed. Harking back to the notion of strategic or episodic effects in delayed priming, we may therefore wonder why these episodic effects surface more robustly in one type of pseudoword than in the other. If episodic effects are argued to partly underlie the facilitatory effects seen under delayed priming, then it is clear that pseudowords such as **Spitzung* more easily engage these strategic processes. This leads to the question why pseudowords with a lexicalized intermediate derivate should be more prone to episodic encoding processes. Clearly, episodic encoding appears to be restricted to complex words and their morphological relatives with pseudowords that are closer to existing words appearing most susceptible to memorization. One argument could be that pseudowords that display a higher degree of 'wordness' simply appear more marked to participants, resulting in deeper processing and stronger activation of the base word. The reliance on episodic factors would, in this case, nonetheless involve a mechanism of 'on-line' decomposition for complex formations that cannot be listed as such. After all, the more marked character of one type of pseudoword (**Spitzung*) over another (**Hübschung*) would be the result of the accessibility of an existing word *spitzen* following a checking mechanism of morphological constraints that inevitably leads to a more step-wise application of decompositional processes. Recall that Kouider and Dupoux (2009) argued that morphological priming effects were not subject to episodic effects to the same extent as the repetition of identity pairs, suggesting that episodic factors were unlikely to be the sole component driving our effects.

Evidence from a simple lexical decision task

The lexical decision tasks with delayed priming reported in Experiment 3 included reaction times and error rates to the complex words and pseudowords. The fastest and most accurate responses were recorded for existing words. The two types of possible pseudowords did not display differences in response latency, but error rates were significantly higher for items such as **Spitzung* that are closer to an existing word. In the following, we shall discuss the implications of these results and present questions that remain with regard to the interpretation of the patterns observed. With regard to the existing words, the fast response times, coupled with low error rates, are consistent with two interpretations concerning the lexical storage of morphologically complex words. As a first interpretation, existing words could be listed holistically, thereby enabling efficient and accurate retrieval of the complex word itself in the simple lexical decision task. In combination with the facilitation observed for the base word, however, a structural representation that is informed by morphological considerations appears more likely. Alternatively, a decompositional account of morphological representation for existing words would involve a model of processing that leads to the activation of the base and is succeeded by a recombination procedure. From a processing perspective, the recombination procedure would apply most efficiently for existing words since it can be expected that these particular combinations will have been encountered and therefore analysed before, leading to fast lexical decision times and a high degree of accuracy during the classification process.

Both types of pseudowords elicited significantly longer response latencies and higher error rates than existing words, but only error rates differed between the two types of pseudowords. There are several hypotheses that can be entertained in an attempt to situate these results in a model of morphological decomposition and the representation of morphological complexity. Longer response latencies for pseudowords than for words are commonly accounted for based on a prolonged search period that has to cover the existing mental lexicon for a no-match result to be detected (Forster & Chambers, 1973). As is common in behavioural analyses of word recognition processes, only correctly identified stimuli were entered into the statistical analysis, arguably due to the reduced likelihood for 'correct' responses to represent internal cognitive noise, rather than an index of successful word recognition, although the complete absence of the former in correctly identified trials has recently also been challenged (Diependaele, Brysbaert & Neri, 2012). On the one hand, the comparable response latencies between the two pseudoword conditions could be interpreted as evidence against decompositional accounts of morphological complexity processing since the availability of *spitzen* in *Spitzung* did not appear to modulate the search pattern for *Spitzung* versus *Hübschung*. Thus, it was not the case that pseudowords with a lexicalized intermediate position and thus a higher number of possible matches in the mental lexicon following morphological decomposition instantiated a faster recognition process. On the other hand, the fact that error rates were consistently higher for **Spitzung*-type than for **Hübschung*-type pseudowords not only reduces the statistical power of the reaction time analysis, but could also point to the possibility that decompositional processes lead to the rapid identification of morphological derivates such as *spitzen*, ultimately pre-empting a manifestation in reaction times. A post-hoc analysis of reaction times in Experiment 3 indeed revealed significantly faster incorrect than correct responses in both types of pseudowords ($F(1, 681.1) = 51.05$, $p < .0001$), suggesting that a lexical search process could have been instantiated, but instead of generating a no-match result, erroneous matching could have occurred due to the existence of a lexical representation for the morphological derivates activated during the decomposition process.

The lexical decision task has indeed been argued not to provide sufficient information about the mechanisms that underlie the more dynamic decision-making process (Barca & Pezzulo, 2012). Under such a view, the decision process itself does not need to be considered discrete and uniform from the time point at which the stimulus is first presented until a response is executed. Instead, oscillations between competing response options cannot be ruled out during the classification process. In our example, this would involve an oscillation between a 'WORD' and a 'NONWORD' response for both types of pseudowords. Yet it should not be overlooked that incorrect responses could in principle be triggered for a number of reasons, not all of which can be dissociated from inherent experimental noise. Again, we find confirmation for the necessity of complementing our behavioural findings with more direct measures of neurocognitive activity.

5.1.2 Electrophysiological evidence

It is for this purpose that we conducted a cross-modal priming experiment in Chapter 4, in which the measure of enhanced activation for a morphologically related target word was reflected in the modulation of brain activity independently of an overt response given to a stimulus. The patterns observed were congruent with the results of the delayed priming experiment in Chapter 3 in which all morphological conditions were combined. Given that cross-modal priming has been associated with a concomitant effect of purely semantic priming, stronger facilitatory effects for pseudowords with lexicalized intermediate positions can thus be linked to stronger semantic associations. Yet if the degree of activation that is passed on to the base word in cross-modal priming was solely contingent on the semantic relationship between paired words as a function of spreading activation, then existing complex words could have been expected to trigger the strongest effect of priming. Again, however, we find that differences in degree of facilitation only emerged in the pseudoword comparison. Under a full-listing hypothesis as advocated by Butterworth (1983), these patterns would relate to separate processing mechanisms between words and nonwords. Facilitatory effects between existing words would emanate from spreading activation mechanisms between separate, but not necessarily shared entries as only the processing of pseudowords would entail morphological decomposition. More pronounced effects (although in our case not significantly so) for highly plausible pseudowords such as **Spitzung* and their related base words could be argued to result from accessing the same, rather than a related lexical representation following decomposition. But if all existing complex words are endowed with separate lexical representations under a *full-listing* hypothesis, then it is clear that separate entries would also have to be assumed for *spitzen* and *spitz*. Since participants are only presented with the base words in both pseudoword conditions, full-listing hypotheses would need to account for why a separate lexical representation such as *spitzen* can exert a facilitatory effect on the recognition of *spitz* unless the process of morphological decomposition proceeds step-wise following the morphological constraints of composition. Consequently, if sensitivity to a rule-governed and procedural application of morphological decomposition is initiated each time a novel form is encountered, then it appears that certain links between morphological derivates, namely links between words that are immediate derivates such as *heilen* and *heil*, should be more ingrained than links between morphological relatives that are separated by a larger number of intervening entries (*Heilung* and *heil*).

Ultimately, this raises further questions regarding the processing of lexicality effects at the level of the whole word versus effects of 'wordness' for pseudowords, depending on their composition. Clearly, morphological viability is a prerequisite for semantic activation of existing monomorphemic words when preceded by items that do not possess a lexical representation. Recall in this context that noncomplex pseudowords such as **Wirrlein* failed to show an effect on the recognition process of embedded existing words such as *wirr.* The overlap in auditory and visual input was not sufficient to activate an existing representation, due to the absence of a viable morphological relationship between items. The relationship between morphological viability and lexicality at various stages of composition, however, remains to be investigated. In particular, while we have seen clear evidence for sensitivity to morphological relationships between items, whether listed or not, the question remains how the structural analysis of a complex word is coupled with the retrieval of its meaning, especially at the neurocognitive level. We will begin our attempt at weaving together these two complementary aspects of morphological complexity processing by presenting an overview of neuroimaging research on morphological complexity processing.

5.2 Morphological complexity and the brain

A substantial number of neuroimaging studies in which morphological processing was the focus of investigation have been devoted to the isolation of purely morphological processes in the recognition of complex words, independently of semantic and formal overlap. As we will see, nearly all of these studies examined the processing of existing complex words varying in their semantic properties and the transparency in the relationship to their base word, but a common denominator has been the availability of an existing lexical representation for the complex word. Using a visual masked priming paradigm in which form and meaning relations between words were manipulated in a 2 x 2 design, Devlin, Jamison, Matthews and Gonnermann (2004) found no evidence for processing patterns that depend on purely morphological relationships between words. Experimental conditions consisted of pairs that were purely related in form (e.g. *corner* - *corn*), semantically related items such as *idea* and *notion*, as well as items that were classified as related to one another in both form and meaning (e.g. *boldly* - *bold*) and unrelated pairs such as *ozone* and *hero*. Reductions in BOLD signal following morphological, but also semantic and orthographic primes were observed in the posterior angular gyri bilaterally, as well as in the left posterior occipitotemporal cortex for orthographic pairs and to a lesser extent also in the morphological condition. An overlap between semantic and morphological processing was discernible due to a reduction in BOLD response in a lateral region of the middle temporal gyrus. Overall, due to the absence of a region that was selectively sensitive to morphological processing, the authors concluded that morphological relationships were an epiphenomenon of convergence in form and meaning between words. Note, however, that especially the items composing the orthographic condition in this study - that is *corner* and *corn* - have previously been classified as morphologically linked, semantically opaque pairs in behavioural studies (e.g. Rastle et al., 2004) that induce priming in masked priming paradigms due to early effects of affix-stripping. Devlin et al. (2004) indeed note that future research would need to include pseudo-affixed cases such as *brother* and *broth* in an attempt to dissociate the various competing issues that may be at work during the processing of monomorphemic words that display morphological structure on the basis of their surface-level make-up. This suggestion was taken up in a masked priming experiment coupled with neuroimaging evidence by Gold and Rastle (2007). Pairs that were classified as orthographic controls in Devlin et al. (2004) such as *corner* and *corn* were placed in a pseudomorphological category in Gold and Rastle (2007) while *brothel* and *broth* constituted purely orthographic controls. Semantically related words and unrelated control pairs were also included. Behavioural priming effects and the reduction in BOLD response as an index of neural priming were significantly higher in morphological pairs than in orthographic and semantic pairs.

On a neural level, priming for orthographically related pairs emerged in the middle occipital gyrus and a posterior region in the fusiform gyrus while semantic effects were restricted to the MTG (BA 21). As in Devlin et al. (2004), morphological effects were largely congruent with orthographic priming and did not differ significantly in magnitude of effect size for the two aforementioned regions showing sensitivity to orthographic relationships. A third region was identified for morphological priming in the anterior middle occipital gyrus (BA 19). No orthographic or lexical-semantic effects were reported for this region, thereby identifying a locus for purely morphological effects induced by the masked priming paradigm during early visual word recognition. Gold and Rastle (2007) note that selective morphological activation could be identified in a region that had previously been associated with other high-level cognitive processes such as object processing (Grill-Spector et al., 1999), facial recognition (Gorno-Tempini et al.,

1998) and naming of rapidly presented word stimuli (Dehaene et al., 2001). It is thus clear that, at least from a neurocognitive view, domain-general areas subserve the morphological effects reported as a result of masked priming. A common denominator could be the extraction of cues for pattern matching in the recognition of complex stimuli such as words, but also objects and facial features. During the process of visual recognition of existing words, morphological subunits could serve the purpose of facilitating mapping procedures between visual input and stored representation by identifying regularities (such as the co-occurrence of plausible word strings and existing suffixes such as *-er*). The authors also point to divergences in the activations observed in their study, which are all restricted to more posterior regions for morphological effects in relation to results reported in other neuroimaging studies (e.g. Tyler, Marslen-Wilson, & Stamatakis, 2005; Tyler, Stamatakis, Post, Randall, & Marslen-Wilson, 2005; Miceli et al., 2002) that employed overt priming or/and or decision paradigms and localized purely morphological priming in more anterior regions such as the left inferior prefrontal cortex.

In line with behavioural findings, neuroimaging evidence for morphological processing seems to present a split between early, automatic processes that can be tapped into using masked priming paradigms on the one hand and later, more in-depth analyses of morphological complexity that engage a more frontal network consisting of the left inferior frontal gyrus and posterior temporal regions. Turning to a highly agglutinative language, Lehtonen, Vorobyev, Hugdahl, Tuokkola and Laine (2006) were interested to see which of the two processing patterns would be discernible during a visual lexical decision task involving Finnish inflected words. These have been reported to incur processing costs in behavioural tasks compared to matched monomorphemic controls in a number of studies (Bertram, Laine, & Karvinen, 1999; Hyönä, Vainio, & Laine, 2002; Laine, 1996; Laine & Koivisto, 1998; Laine, Niemi, Koivuselkä-Sallinen, & Hyönä, 1995; Lehtonen & Laine, 2003; Niemi, Laine, & Tuominen, 1994), thereby raising the question whether processing costs arise due to segmentation difficulties at the visual word form level or at a later stage of licensing the stem + affix combination and composition process. The results clearly pointed to effects of morphological complexity in brain areas commonly associated with semantic processing such as the LIFG and left temporal regions.

Based on Hagoort (2005), who identified three main components for language processing, namely memory, unification and control, Lehtonen et al. (2006) interpreted the main function of more ventral parts of the LIFG (BA 47 and 45) to relate to the integration of semantic information. In particular, the LIFG activation observed in this study was argued to reflect the on-line licensing of stem + affix combinations on the basis of a computation of a semantic-syntactic interpretation. With regard to the activation observed in temporal regions, the authors hypothesized that this activation may have reflected checking procedures for the combinability of the stem + affix composition from a structural, rather than a semantic unification point of view. Interestingly from our perspective, the authors raise the question whether or not the latter process is only induced under 'special task demands' (p. 190) such as in an experimental setting that includes violations of stem + affix combinations in pseudowords.

Lehtonen et al. (2006)'s model of morphological complexity contrasts sharply with the conclusions drawn by Tyler et al. (2005). The latter study investigated the processing of regular inflection in auditorily presented words, finding increased activation in the LIFG and STG for regular inflection relative to irregulars, but not monomorphemic items. The LIFG is here argued to subserve a phonological segmentation process of the complex word into stem and affix followed by any syntactic processes triggered by the presence of an affix. In this context, it is worth noting that while both studies refer to activation in the LIFG, the main locus of activation is found to differ, with the auditory task by Tyler et al. (2005) showing increased activation in BA 44 - a subregion of the LIFG that is usually recruited during phonological, rather than semantic tasks (Friederici, 2011). Lehtonen et al. (2006), on the other hand, report activation in the pars triangularis, which may therefore be more sensitive to semantic properties of morphological complexity. While Lehtonen et al. (2006) only investigate inflectional processes in Finnish, some predictions are put forward regarding processing patterns for derived words: based on the absence of processing costs for derivations relative to matched monomorphemic words in Finnish, the authors hypothesize that the neural correlates of morphological complexity processing of derived words may reveal entirely different activations.

Proposed differences in processing between inflected and derived words have indeed both permeated behavioural investigations (e.g. Stanners et al., 1979) and also played a substantial role in the neuroimaging literature. As discussed in Section 2.4.1, a number of investigations into morphological processes using paradigms in the auditory domain have found distinct processing circuits for inflectional versus derivational aspects of morphological complexity in languages such as English, Polish and Italian (Bozic & Marslen-Wilson, 2010; Bozic, Szlachta, & Marslen-Wilson, 2013; Bozic, Fonteneau, Su, & Marslen-Wilson, 2015; Carota, Bozic, & Marslen-Wilson, 2016). Recall that the overall neural framework for language processing has been argued to contain 'two intersecting, but distinguishable neurobiological systems' (Marslen-Wilson, Bozic, & Tyler, 2014) consisting of (1) a left-lateralized frontotemporal system subserving the processing of syntax and (2) a bihemispheric processing circuit shared with our primate ancestors. The former encompasses a network that links regions in the left posterior temporal lobe with key language processing areas such as the left inferior frontal lobe, while the latter recruits a broader network including regions in the right hemisphere. Based on evidence from neuropsychological studies, networks in the RH have not been shown to be able to compensate for lesions in critical areas in the LH during the processing of syntax and inflectional morphology (Tyler et al., 2011). Instead, the bihemispheric system has been reported to be engaged in the perceptual recognition of monomorphemic words (Bozic & Marslen-Wilson, 2010), as well as by derived words due to increased cohort competition induced by the respective stem forms (Bozic et al., 2013; Szlachta et al., 2012) although this activation is modulated by the relevant properties of derived words, with transparent derivations such as *bravely* failing to generate cohort competition.

These results point to different processing signatures for inflectional versus derivational morphology in English and in Slavic languages. Neuroimaging results from Arabic, on the other hand, do not support a strict separation between the two morphological processes with derivational processes eliciting selective activation in the LIFG (Marslen-Wilson et al., 2014). Note that both templatic as well as concatenative elements of Arabic morphology revealed similar processing patterns, leading Marslen-Wilson and colleagues (2014) to the conclusion that a critical factor in morphological processing is whether or not the neural organization of a process is 'actively decompositional' (p. 645) rather a strict classification of a process into inflectional versus derivational. In this context, Marslen-Wilson et al. (2014) note that it remains to be investigated whether the selective activations seen in the LIFG (in the absence of activation in its right-hemisphere homologue) fulfil the purpose of supporting combinatorial processes or more domain-general functions. Overall, our discussions of previous findings in the neuroimaging literature have circled around the notion of combinatorial process, but an analysis of what this is most likely to denote for language processing and especially for the processing of morphological complexity will be attempted in the next section.

5.3 The processing of combinatorial aspects of language and structure detection: an fMRI investigation

Berwick, Friederici, Chomsky and Bolhuis (2013) provide an attempt at addressing the neurocognitive and neurobiological implications that arise due to the combinatorial nature of language. In a first step, Berwick and colleagues note that not all combinatorial possibilities in language can be licensed and lead to the fulfilment of well-formedness conditions. This is exemplified on the basis of difficulties associated with a conceptual interpretation of a syntactic structure such as ‘sleep the apple’ that looks superficially parallel to ‘eat the apple’, but exhibits a departure from well-formedness on a separate interface of linguistic interpretation. As we can see based on the examples given, Berwick et al. (2013) are mainly concerned with combinatorial aspects of syntactic processing, but a number of points raised are equally applicable to the processing of levels of morphological complexity.

The authors present three mechanisms to illustrate combinatorial aspects in structure-building. Two of these come from artificial grammars such as $(AB)^n$ and A^nB^n while the third is an exemplification of the kinds of hierarchical structures that are a common projection of phrase-structure rules in syntactic theory and that the authors argue to be unique to language processing (see Figure 5.1).

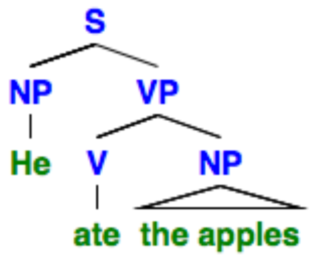

Figure 5.1 *Exemplification of hierarchical structures that are argued to be unique to natural language in Berwick et al. (2013)*

With regard to the neural underpinnings in the processing of these hierarchical structures, the authors point to the pars opercularis (BA44) in the inferior frontal gyrus. In addition to the region in BA44, the processing of hierarchical sentence structure as encountered in human languages, but absent in the aforementioned artificial grammars, is coupled with additional activation in the posterior temporal cortex (STC). The observation that artificial grammars such as $(AB)^n$ and A^nB^n that can also be classified as combinatorial processes engage similar processing patterns in the BA44, but that more posterior regions in the STC are reserved for natural language processing, leads the authors to the conclusion that BA44 is responsible for 'complex structure-building' (p. 94). Areas in the posterior STC, on the other hand, subserve the interpretation and 'integration of syntactic information and semantic information' and might therefore be responsible for the checking of well-formedness conditions at the interface of syntax and semantics for the sentences we have previously been discussing such as *eat the apple* versus *sleep the apple*.

That Broca's area is not only central to the identification of hierarchical structure in familiar combinatorial elements was demonstrated in a study by Musso, Moro, Glauche, Rijntjes, Reichenbach, Büchel and Weiller (2002). The authors investigated the neural underpinnings supporting the acquisition of syntactic structures present in a language other than the participant's native language of which the participants had no command at the time of testing. These were contrasted with the processing signatures for strings of sentences containing the same lexical entries, but for which the syntactic arrangement was not licensed by proposed constraints of Universal Grammar. All participants were German native speakers who were learning three existing grammatical rules in Italian, such as the 'null-subject' parameter that can be expressed through hierarchical structures, as well as three rules drawing on the same lexicon in linear concatenation but which result in structurally unviable sentences not just in Italian, but arguably generally for any language due to the constraints of UG. To give an example, negation was expressed by placing the negation word *non* in fourth position for any phrase irrespective of structural constraints in the language. In a second part of the experiment, similar comparisons were established for the acquisition of a language parametrically rather different from both German and Italian.

Another group of German native speakers was tested during the acquisition of structurally possible and impossible grammars in Japanese. On a behavioural level, both groups showed significant improvement in both accuracy and reaction time for both sets of grammars over time, demonstrating that speakers were able to extract the regularities inherent in structurally possible, as well as unviable grammars. Based on the analysis of the functional imaging data, however, it is argued that different processing signatures were involved in the acquisition of real versus ungrammatical structures. While no specific pattern was discernible for the acquisition of ungrammatical structures in either Italian or Japanese, the acquisition of natural rules as evidenced in the reduction of error rates patterned with activation in two different areas in the left inferior frontal gyrus (Brodmann's area 45). Increased activation in the right inferior frontal gyrus, on the other hand, was correlated with the learning of both real and ungrammatical rules, as well as in the left lingual gyrus. In the Japanese study, common activation patterns for real and ungrammatical rule acquisition extended to the left cingulate, right insula, right supramarginal gyrus and left cerebellum. These results led Musso et al. (2002) to conclude that the acquisition of possible grammatical structures selectively recruits particular areas within the LIFG that are responsible for the detection of viable structures, regardless of the degree to which the grammatical rules of the language are similar to the ones with which a speaker is familiar through their own linguistic background. The regions showing common activation for both real and impossible structures, on the other hand, were argued to underlie episodic memory retrieval and thus the explicit retrieval of information to give an appropriate response during task execution. Although the authors support their argument for a link between neural activation and task performance based on accuracy data, the presence or absence of a correlation between reaction times and LIFG activation is not discussed even though it is noted that only the behavioural responses to 'real' structures displayed progressive reduction in response time as participants became more acquainted with the linguistic material.

Moreover, it is posited by Musso et al. (2002) that the divergence in response time patterns observed between 'real' and 'ungrammatical' structures would be attributable to a possible 'proceduralisation of rule-knowledge' (p. 778) in what are argued to be learnable versus impossible structures. On this basis, the expectation was that further correlations could have become evident between the reduction in response time during the behavioural task and the neural activity as a reflection of the degree to which the acquisition of new rules became 'proceduralized' or consolidated. Note that as this study was concerned with the acquisition of syntactic structure, participants already had been presented with vocabulary lists containing the words to be presented prior to participating in the experimental task. These steps were taken in order to dissociate the acquisition of syntactic structure from the ability to learn and retrieve new words, but for the interpretation of results this raises the question whether the selective activation seen in the LIFG can be traced back to the detection of viable structure regardless of meaning, or whether the integration of meaning was facilitated when the information was conveyed using viable linguistic structures. This point highlights a particular difficulty in the study of combinatorial aspects of language processing given the impossibility of disentangling aspects related to the purely structural viability of a construction and its viability due to the facilitatory effect it has on the integration of meaning. In view of this, a number of fMRI studies have addressed the processing of pseudowords. However, as we shall see, the structural properties of these pseudowords have not yet been the focus of investigation.

Recall that in electrophysiological studies on visual word recognition processing differences between nonwords and readable and thus phonologically viable pseudowords have indeed been reported to occur as early as 155 – 230 ms after stimulus onset, demonstrating that the phonological viability of pronounceable pseudowords is detected at very early stages of processing (Whiting, Shtyrov, & Marslen-Wilson, 2015). Phonologically well-formed pseudowords have also driven research on the neural correlates of reading as a process of grapheme-to-phoneme conversion (Tagamets, Novick, Chalmers, & Friedman, 2000; Xu et al., 2001). Relative to words and fixations, Mechelli, Gorno-Tempini and Price (2003) found increased activation for pseudowords in the left frontal operculum, the left posterior inferior temporal gyrus and the right cerebellum. Fiebach, Friederici, Müller and Cramon (2002) contrasted the reading processes for pseudowords, as well as low and high frequency words in a lexical decision task using fMRI. Pseudowords and low-frequency words showed common activation patterns in the left pars opercularis, anterior insula, thalamus and caudate nucleus as regions supporting grapheme-to-phoneme conversion. Low-frequency words, but not pseudowords, also activated the pars triangularis within the left inferior frontal gyrus as a region supporting lexical-semantic processes.

From a structural perspective, we find that neuroimaging studies investigating the processing of pseudowords have almost focused exclusively on monomorphemic pseudowords, especially in investigations into morphological processing for languages such as English and German. One notable exception to this is a study by Bick, Frost and Goelman (2010) in which a masked priming paradigm was employed to identify the locus of purely morphological priming effects in existing Hebrew words, regardless of orthographic and semantic overlap, as well as complex pseudowords containing valid root and word pattern morphemes. Note that morphological complexity was realized here through template-based rather than affixational morphological processes, allowing the researchers to intersect existing root and word patterns to form novel, complex forms. A fronto-parietal network consisting of the left inferior frontal gyrus, left middle frontal gyrus, left angular gyrus and left intraparietal sulcus was identified to be involved in the recognition of a morphological relationship between existing words and was then used as a ROI for the analysis of pseudoword prime-target pairs. Pseudoword prime-target pairs that shared a root morpheme confirmed the involvement of this network in the processing of morphological complexity, even in pseudowords. However, as the analysis of the nonwords was restricted to the ROIs previously implicated in morphological processing of existing words, an unexplored aspect of pseudoword recognition relates to the neural correlates of structure detection in pseudowords, irrespective of lexicality. This is a serious gap since the relationship between morphological structure and meaning compositionality presents a predominant question in behavioural research on morphological processing. Semantic transparency and interpretability have often been invoked as prerequisites for the decomposition of morphologically complex derived words and pseudowords (Marslen-Wilson, Tyler, Waksler, & Older, 1994; Meunier & Longtin, 2007).

In a number of neuroimaging studies (Friederici, Meyer, & von Cramon, 2000; Humphries, Binder, Medler, & Liebenthal, 2006), the relationship between structural validity and meaning representation was investigated by replacing all content words within a sentence with pseudowords while maintaining a valid syntactic structure through the use of existing function words. Processing differences between well-formed 'meaningless' sentences (e.g. '*The mumphy folofel fonged the apole trecon'*) and pseudoword lists (e.g. '*The norp burch orlont kinker deftey glaunch legery*') were identified (Friederici et al., 2000), suggesting that speakers possess structural knowledge independently of meaning. Crucially, neuroimaging research into the interface of structure and meaning has been restricted to sentence-level phenomena, using structurally valid, but 'meaningless' constructions. Structure detection processes are, however, also common on a single-word level in the analysis of morphological complexity.

Morphological complexity in pseudowords

As we have argued throughout the present thesis, a particular characteristic of morphological complexity is that it can be quantified by looking at the level of structural composition. Morphologically complex words can serve as bases to a morphological rule that yields another complex word that is morphologically even more complex. Two previous studies (Meinzer et al., 2009; Pliatsikas et al., 2014) indeed found that items that possess more morphological complexity (e.g. the German word *Rötung*$_N$ ('reddening') derived through *rot*$_A$ ('red') > *röten*$_V$ ('redden') > *Rötung*$_N$ ('reddening'')) than visually matched, but less complex words (e.g. *Deutung*$_N$ ('interpretation') through *deuten*$_V$ ('interpret') > *Deutung*$_N$ ('interpretation')) elicited more activation in a narrowly defined region within the left inferior frontal gyrus. This was also the case for so called "zero-derived" forms in Pliatsikas et al. (2014). Comparing *bridging* (*bridge*$_N$ > *bridge*$_V$ > *bridging*) with verb-based forms such as *running* (*run*$_V$ > *running*), they found that forms like *bridging* that are the result of two derivations showed stronger activation in the left inferior frontal gyrus. These results have been interpreted as evidence for speakers' sensitivity to the degree of complexity of derived words and therefore the internal structure of morphologically complex items.

In view of these previous results, it is possible that the internal structure of complex items also plays a role in the processing of morphologically complex pseudowords. Psycholinguistic investigations into the processing of pseudowords have considered a number of variables that could affect pseudoword processing such as the number of letters, number of orthographic neighbours and number of affixes (Yap, Sibley, Balota, Ratcliff, & Rueckl, 2015), but the neural correlates of various aspects of pseudoword structure remain largely unclear. In particular, the neural correlates of morphological complexity as a process that involves structural analysis have not yet been considered due to a focus on monomorphemic pseudowords. To fill this gap, the present fMRI study was designed to test differences in internal structure between superficially similar morphologically complex pseudowords. For this purpose, we relied on two sets of morphologically complex pseudowords in German that differed in the degree of plausibility at intermediate stages of their derivation. Our comparison is again based on German complex nouns such as **Spitzung*$_N$ ('sharpening') and **Hübschung*$_N$ ('beautification') that are both derived from the respective base adjectives *spitz*$_A$ ('sharp') and *hübsch*$_A$ ('beautiful') via two derivational steps. In a first step, the adjective is zero-derived to form a verb, which in the case of **Spitzung* is the existing lexical entry *spitzen*, while the corresponding verb for **Hübschung* (**hübschen*) is an accidental lexical gap. These zero-derived verbs can then be turned into the final noun forms **Spitzung* and **Hübschung*, which are non-existent in both cases.

One could imagine that lexicality is only checked at the final surface level on the basis of the existing lexicon. Under this interpretation, there should be no detectable difference in processing between the two pseudowords. Similarly, if the structural analysis of pseudowords merely involved the 'stripping' of affixes, then we would expect identical processing signatures for **Spitzung* and **Hübschung* as the existing adjective *spitz* or *hübsch* is retrieved and combined with the suffix *-ung*. Alternatively, and if decomposition of morphological complexity plays a role in the processing of complex pseudowords, then we might expect that the **Spitzung* set, whose derivational chain contains fewer lexical gaps (*spitz* > *spitzen* > **Spitzung* versus *hübsch* > **hübschen* > **Hübschung*), should be felt to be more plausible. **Hübschung*, on the other hand, is also structurally well-formed, but requires an additional derivational step to proceed 'on-line' – that is, based on structural knowledge of morphological complexity, but without the support from a lexical representation. The structural analysis required for **Hübschung* could thus be argued to be more complex than for **Spitzung*. A comparison between the two pseudowords and with existing noun forms will thus allow us to study the relationship between combinatorial processing through structural analysis versus lexical-meaning representation.

Unlike monomorphemic pseudowords, complex pseudowords can draw on lexical-semantic representations if their morphological structure leads to decomposition and thus the activation of their existing base words. In the comparison between pseudowords and words, we thus expect that pseudowords might lead to increased activation in brain areas associated with lexical search and semantic processing, such as the anterior part of the left inferior frontal gyrus (see Fiebach et al., 2002). Our second focus is on the neural correlates of 'on-line' morphological processing of derived pseudowords. Marangolo et al. (2003) and Marangolo, Piras, Galati and Burani (2006) reported selective right-hemisphere involvement in the processing of derivational, but not inflectional morphology. In these studies, a large fronto-parietal network was found to subserve morphological derivation. In view of a number of both language-specific and domain-general studies that have found a right-lateralized bias in combinatorial processing (Koenigs, Barbey, Postle, & Grafman, 2009; Graves, Binder, Desai, Conant, & Seidenberg, 2010; Mashal, Faust, & Hendler, 2005), we expect that the analysis of morphological structure and viability in pseudowords may be contained within this network.

5.4 Methods

5.4.1 Participants

Thirty right-handed native speakers of German (15 women, mean age = 26.2 years, SD = 4.2) took part in the fMRI experiment. All participants had normal or corrected-to-normal vision with no history of neurological disorders and no reading impairments. Each participant gave their written consent for participation in the study. The study was performed according to the guidelines of the Declaration of Helsinki and approved by the local ethics committee (Medical Faculty at the University of Leipzig).

5.4.2 Experimental Design and Task

A factorial event-related within-subject design using a 2 (Complexity: simpler vs. more complex) by 2 (Lexicality: word vs. pseudoword) design matrix was employed (see Figure 5.2).

		Complexity	
		Simpler	Complex
Lexicality	Word	SW **Deutung**	CW **Heilung**
	Pseudoword	SP ***Spitzung**	CP ***Hübschung**

Figure 5.2 *Design matrix for the fMRI experiment*

The factor *Complexity* for existing words was modelled based on Meinzer et al. (2009) where words with greater derivational depth required more processing effort. For pseudowords, existing lexical representations within the derivational chain were expected to alleviate the degree of structural analysis required. Consequently, there were four groups of test items in the experiment: simpler words ('SW'), simpler pseudowords ('SP'), more complex words ('CW') and more complex pseudowords ('CP'). Each condition contained 50 experimental stimuli. Two filler conditions with equal numbers of words and pseudowords were added to increase the visual variety of stimuli presented to participants. All stimuli were presented twice with the maximal distance possible between identical stimuli across three experimental runs.

Before the start of the experiment, all participants performed a short lexical decision task to familiarize themselves with the task requirements. The same presentation parameters were used in both the practice session and the actual experiment, but none of the stimuli used in the training session were included in the main experiment. Participants were informed that during the experiment, words and pseudowords would be displayed on the computer screen. The task consisted of deciding as quickly and as accurately as possible if the stimulus was a word or a pseudoword in German. A response box with two push buttons was used to give responses and was placed in the participant's left hand to minimize movement-related activity in the left hemisphere. Participants were instructed to use their index and middle fingers for button press. The assignment of button press was counterbalanced across participants with half of participants using their index finger to indicate a real word and the other half using their index finger to indicate a pseudoword. We used variable SOAs, ranging from 2.5 s to 5.5 s. These were randomized per participant and run. Each stimulus was presented in font size 24 for a duration of 1000 ms. Stimulus presentation was controlled using Presentation Software (Version 17.1).

5.4.3 Stimuli

All items in the four experimental conditions are morphologically complex German noun forms. These are constructed on the basis of sequences of morphological rules in German. In 'SW' and in 'CW', all stimuli selected are existing German words that we find in everyday language and in corpora such as CELEX (Baayen et al., 1995) and the DWDS (Klein & Geyken, 2010). In 'SW', the noun is derived from a base adjective or verb in a single derivational step. Nouns in condition 'SW' are therefore morphologically simpler than nouns in 'CW'. With the purpose of providing a greater variety of visually dissimilar items, the stimuli in 'SW' are formed following one of the two morphological rules given below:

a) base verb > noun in {*-ung*} as in *deuten*$_V$ (‘interpret’) > ***Deutung***$_N$ (‘interpretation’)

b) base adjective > noun in {*-igkeit*} as in *müde*$_A$ (‘tired’) > ***Müdigkeit***$_N$ (‘tiredness’)

Nouns in ‘CW’ have greater morphological complexity as one additional derivational step is required to go back to the base word, which can again be either an adjective or a verb. To illustrate this difference, the complex noun *Deutung*$_N$ (‘interpretation’) in condition ‘SW’ is 1-step derived from its verbal base in *deuten*$_V$ (‘interpret’). The verb *heilen*, on the other hand, from which the noun *Heilung*$_N$ (‘healing’) is derived, is already complex. It is zero-derived from the base adjective *heil*. The constraint that the more complex pseudowords are created in a two-level process follows from morphological rules of word formation in German. As discussed in Fleischer and Barz (1995), nouns in *-ung* can be productively derived from a verbal, not an adjectival base. This means that the intermediate step has to be computed ‘on-line’ in order to satisfy the morphological constraints of the language. In a similar vein, derivations in *-keit* require an adjectival, rather than a verbal base. This gives the following two sequences of morphological rules that derive nouns in condition ‘CW’:

c) base adjective > zero-derived verb > noun in {*-ung*} as in *heil*$_A$ (‘whole, intact’) > *heilen*$_V$ (‘heal’) > ***Heilung***$_N$ (‘healing’)

d) base verb > adjective in {*-bar*} > noun in {*-keit*} as in *lesen*$_V$ (‘read’) > *lesbar*$_A$ (‘readable’) > ***Lesbarkeit***$_N$ (‘readability’)

Overall, the nouns presented in the two ‘word’ conditions ‘SW’ and ‘CW’ (such as *Deutung* and *Heilung*) look visually similar, but differ in inherent morphological complexity.

Both pseudonouns in conditions ‘SP’ and ‘CP’ are formed according to the morphological rules given in (c) and (d). However, they differ in the number of derivational steps that proceed without a lexical representation and thus in the degree of morphological complexity that is expressed through lexical gaps. To illustrate this, **Spitzung* in ‘SP’ is formed following the derivational chain in (c) with the final position being filled with a lexical gap as shown in (e):

e) *spitz*$_A$ (‘sharp’) > *spitzen*$_V$ (‘sharpen’) > ****Spitzung***$_N$ (‘sharpening’)

For stimuli in ‘CP’ such as **Hübschung*, already the intermediate position (i.e. the zero-derived verb **hübschen*) is a lexical gap. The structural analysis required for **Hübschung* can thus be expected to be more complex than for **Spitzung*. The derivational chain leading up to **Hübschung* has the format shown in (f):

f) *hübsch*$_A$ (‘beautiful’) > **hübschen*$_V$ (‘beautify’) > ****Hübschung*** (‘beautification’)

To match the types of suffixes presented in the two existing word conditions, half the pseudowords employed in conditions ‘SP’ and ‘CP’ were constructed using the sequence of morphological rules given in (d). For clarity, Table 5.1 gives an overview of the key characteristics of all four experimental conditions.

Table 5.1 *Summary stimulus characteristics*

Condition	Derivational chain	Example stimulus
SW	base verb >	*deuten >*
	noun in {-ung}	***Deutung***
	base adjective >	*müde >*
	noun in {-igkeit}	***Müdigkeit***
CW	base adjective >	*heil >*
	zero-derived verb >	*heilen >*
	noun in {-ung}	***Heilung***
	base verb >	*lesen >*
	adjective in {-bar} >	*lesbar >*
	noun in {-keit}	***Lesbarkeit***
SP	base adjective >	*spitz >*
	zero-derived verb >	*spitzen >*
	noun in {-ung}	****Spitzung***
	base verb >	*denken >*
	adjective in {-bar} >	*denkbar >*
	noun in {-keit}	****Denkbarkeit***
CP	base adjective >	*hübsch >*
	zero-derived verb >	**hübschen >*
	noun in {-ung}	****Hübschung***
	base verb >	*drängen >*
	adjective in {-bar} >	**drängbar >*
	noun in {-keit}	****Drängbarkeit***

SW = simpler word; CW = more complex word; SP = simpler pseudoword; CP = more complex pseudoword

Two filler conditions with 20 items per condition were included to provide a greater variety of visual stimuli. One group consisted of existing real words that are morphologically complex and matched in length and syllable stress with the two groups of existing items in the experimental conditions. Nonwords in the other filler condition consisted of items that are composed of existing stems and suffixes in German, but for which the combination of stem and suffix is not morphologically possible (e.g. **Wirrlein* whose suffix *-lein* would require a nominal, not an adjectival base). Additionally, 20% of trials consisted of fixation crosses for the null-baseline.

Items in all four experimental conditions as well as nonword fillers are matched on lexical factors such as base lemma and whole form frequency, orthographic and morphological family size of the base, length, syllable structure, stress pattern and phonological family size (see Table 5.2).

Table 5.2 *Stimulus matching across word and pseudoword conditions*

	BASE WORD FREQUENCY	BASE LEMMA FREQUENCY	LENGTH	PHON. FAMILY SIZE	ORTHOGRAPH. FAMILY SIZE	MORPH. FAMILY SIZE	NUMBER OF SYLLABLES
SW	94.62	437.26	8.96	0.20	0.16	29.88	2.52
CW	103.52	284.48	9.82	0.20	0.20	36.50	2.58
SP	102.04	369.08	9.80	0.18	0.18	33.56	2.50
CP	96.18	341.46	9.48	0.22	0.22	24.16	2.50
NW	94.34	308.62	9.12	0.16	0.16	29.34	2.50
	p > .99	p > .84	p > .20	p > .98	p > .97	p > .50	p > .93

SW = simpler word; CW = complex word; SP = simpler pseudoword; CP = complex pseudoword; NW = nonword filler

Note: Numbers are rounded to the second decimal place

Morphological family size measures were obtained by extracting the number of semantically transparent morphologically related words for a given base in CELEX (Baayen et al., 1995). Orthographic and phonological neighbourhood sizes were computed using Clearpond (Marian, Bartolotti, Chabal, & Shook, 2012). In addition to this, lemma and whole word frequencies as well as ratings of imageability for the complex word were matched between the two conditions containing existing words (all ps > .25). All stimuli in our experimental conditions and fillers are provided in the Appendix D.

5.4.4 Data acquisition

Functional images were acquired using a Siemens Prisma 3-T scanner (Siemens, Erlangen, Germany). A gradient EPI sequence was employed (TR = 2 sec, 38 axial slices, thickness = 3mm, gap = 1mm, TE = 26ms, flip angle = 90°, field of view = 192 x 192 mm, voxel size = 3 x 3 x 4mm). For each run, scanning was continuous with a total of 404 scans consisting of 38 slices. All T1 images used a standard MPRAGE sequence in sagittal orientation (whole brain coverage, voxel size 1 mm isotropic, matrix size 256 x 240, TR: 1300 ms, TE: 2.98 msec, flip angle 9°).

5.4.5 Statistical Analyses

The analysis of the fMRI data was performed using the software package 'Statistical Parameter Mapping' (SPM 12 Wellcome Trust Centre for Neuroimaging, www.fil.ion.ucl.ac.uk/spm) within Matlab (Version 8.5.0, Mathworks, Nattick, MA, USA, 2015).

Preprocessing involved the application of slice time correction for all functional EPI images to account for differences in acquisition timings across slices. The middle slice served as reference slice in the correction process. Based on the slice-time corrected volumes, a realignment and unwarping procedure was applied in order to minimize movement-induced variance in our data. Field maps were calculated for each run and used for distortion correction.

Coregistration of the respective T1-weighted scan to the mean functional EPI image was carried out for all participants. Subsequent segmentation was reliant on the SPM12 standard tissue probability maps using light bias regularization. In a second segmentation step, a very light regularization procedure was performed on the segmented T1 images. All functional images were normalized to their respective T1 images and then resampled to a voxel size of 3 mm x 3 mm x 3mm^3. In a final step, smoothing (isotropic 8-mm FWHM kernel) was applied to all normalized images (Friston et al., 1995). Through smoothing, effects of anatomical differences were minimized. Statistical inferences have been made on the basis of Gaussian field theory.

The first level analyses were performed separately on all three runs per participant. The runs were equal in duration and contained the same number of stimuli per condition. All four experimental conditions as well as the two filler conditions and the null baseline were specified in the model (design matrix). All trials were included in the analysis. Six movement parameters and an additional vector for the RTs were included in the model specification as regressors of no interest. An explicit mask was applied in the first level analysis that had been calculated from an average of EPI volumes across all participants. The average EPI volume was subsequently binarized with FSL (FMRIB Software Library v5.0, Analysis Group, FMRIB, Oxford, UK). After model estimation, contrasts were specified comparing each experimental condition against the baseline (null-events), resulting in four contrast images per participant for the four experimental conditions ‘SW’, ‘CW’, ‘SP’ and ‘CP’ to be included in the second level analysis.

For the second level analysis, we used a flexible factorial ANOVA design that comprised pooled parameter estimates for each of the above described difference images from the first level across all participants and all three runs in a random-effects analysis, including a correction for non-sphericity. This design crossed the factors complexity (simpler vs. more complex) and lexicality (word vs. pseudoword). For each main effect and interaction, t-contrasts were calculated. Given our main interest in processing differences between the two pseudoword conditions, t-contrasts were also computed showing the additional activation of ‘CP’ over ‘SP’ as an index of complexity within the set of pseudowords. The threshold for p-values was set at $p < .05$. Correction for multiple comparisons was achieved by applying the conservative family-wise error (FWE) method for the main effects and the comparison between the two pseudoword conditions. For the interaction (specified as a t-test), the threshold was set to $p < .001$. However, we combined this threshold with a cluster extent constraint, corresponding to a whole-brain FWE corrected alpha of $p < 0.05$, as determined from a MATLAB-implemented Monte Carlo simulation (Slotnick et al., 2003) with 1000 repetitions. The procedure yielded a cluster extent threshold of 26 resampled voxels that we applied to the analysis of the interaction. The estimation of the threshold assumed an overall smoothing of 16 mm for all comparisons (full width half maximum of the Gaussian smoothing kernel). Overall smoothing was estimated on the basis of the final statistical map within SPM. In addition to this, we also conducted an additional analysis of our data through a one-way ANOVA that included our four main experimental conditions, as well as our nonword filler items in order to establish relevant comparisons between the nonword fillers and morphologically possible pseudowords such as **Spitzung* and **Hübschung*. These additional results are reported in the Supplementary Information. The SPM anatomy toolbox (Version 2.2b; Eickhoff et al., 2005) was used for anatomical localization of activation peaks.

5.5 Results

5.5.1 Behavioural analysis

Reaction times (RT) and error rates for the lexical decision task are given in Table 5.3. In a linear mixed model including the fixed factors lexicality (word versus pseudoword) and complexity (simpler versus complex) and participants and target words as random effects with random intercepts and slopes, we found a significant effect of lexicality on the log-transformed RT, ($\chi 2$ (1) = 48.30, $p < .0001$). Existing words elicited significantly faster reaction times. No other main effects or interactions reached significance (all ps > .5). These results are not surprising given that in the literature pseudowords have been reported to induce longer reaction times than existing words (Forster and Chambers, 1973). In a generalized linear model with the dependent variable Error Rate, we found both lexicality ($\chi 2$ (1) = 1373.1, $p < .0001$) and complexity ($\chi 2$ (1) = 303.8, $p < .0001$) to reach significance, as well as the interaction between the two factors ($\chi 2$ (1) = 73.0, $p < .0001$). We found the interaction to be driven by a statistically more significant difference in error rates between the two types of pseudowords (Est. = 1.12, SE = 0.06, $z = 19.7$, $p < .001$) than between the two types of existing words (Est. = 0.22, SE = 0.09, $z = 2.53$, $p < .05$). On the whole, the distribution of reaction times and error rates is consistent with our behavioural pre-studies in which items like **Spitzung* consistently elicited higher error rates than **Hübschung* (Schuster & Lahiri, in press).

Table 5.3 *Behavioural results*

Experimental condition	RT (SD) in msec	Error Rate (SD) in %
Deutung (SW)	956 (261)	11.4 (0.6)
Heilung (CW)	965 (261)	9.3 (0.5)
****Spitzung (SP)***	1122 (316)	52.7 (0.8)
****Hübschung (CP)***	1144 (336)	26.7 (0.8)

RT= reaction times; SD= standard deviation. SW = simpler word; CW = complex word; SP = simpler pseudoword; CP = complex pseudoword

5.5.2 Imaging Analysis

Pseudowords > Words

Given our particular interest in the recognition of morphologically complex pseudowords, we first identified areas with increased activation for pseudowords compared to words regardless of degree of complexity. We found that complex pseudowords elicited higher activation than real words in the left inferior frontal gyrus (pars triangularis; x = -45, y =26, z =26, t = 6.16, p < .05), in the pre-SMA (x = 0, y = 23, z = 44, t = 6.42, p < .05), and the right insula (x = 33, y = 23, z = -1, t = 5.87, p < .05; all FWE-corrected; see Figure 5.3).

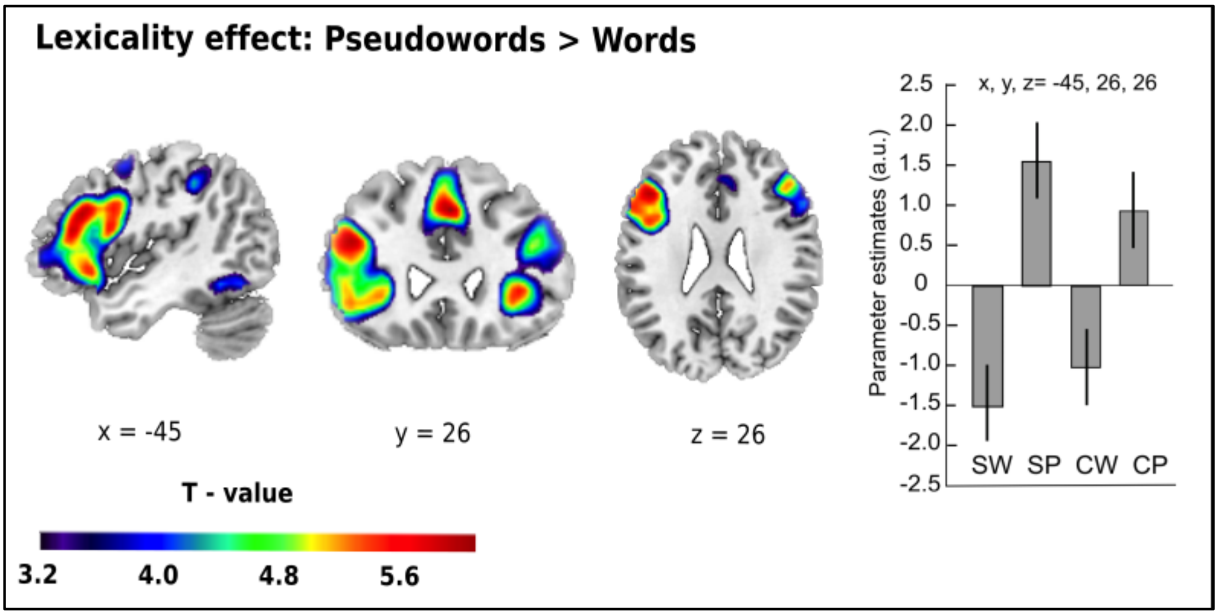

Figure 5.3 *Lexicality effect: Pseudowords > Words*

Complexity

For the main effect of complexity, we found no significant activation at p < .05; FWE-corrected. At a more liberal threshold of p < .001 uncorrected, more complex items showed increased activation in the right middle frontal gyrus (x = 30, y = 62, z = 20, t = 4.36, p < .001), right precuneus (x = 3, y = -64, z = 56, t = 3.93, p < .001) and right superior parietal lobule (x = 42, y = -43, z = 59, t = 3.83, p < .001). Since especially the parietal activations were largely driven by the pseudoword comparions, we turned to a comparison of more complex pseudowords such as **Hübschung* and matched, but less complex pseudowords such as **Spitzung*. We found that processing more complex pseudowords engaged the right superior parietal lobule (x = 39, y = -43, z = 59, t = 5.23, p < .05, FWE-corrected), as well as the left precuneus (x = -6, y = -64, z = 59, t = 4.96, p < .05, FWE-corrected; see Figure 5.4).

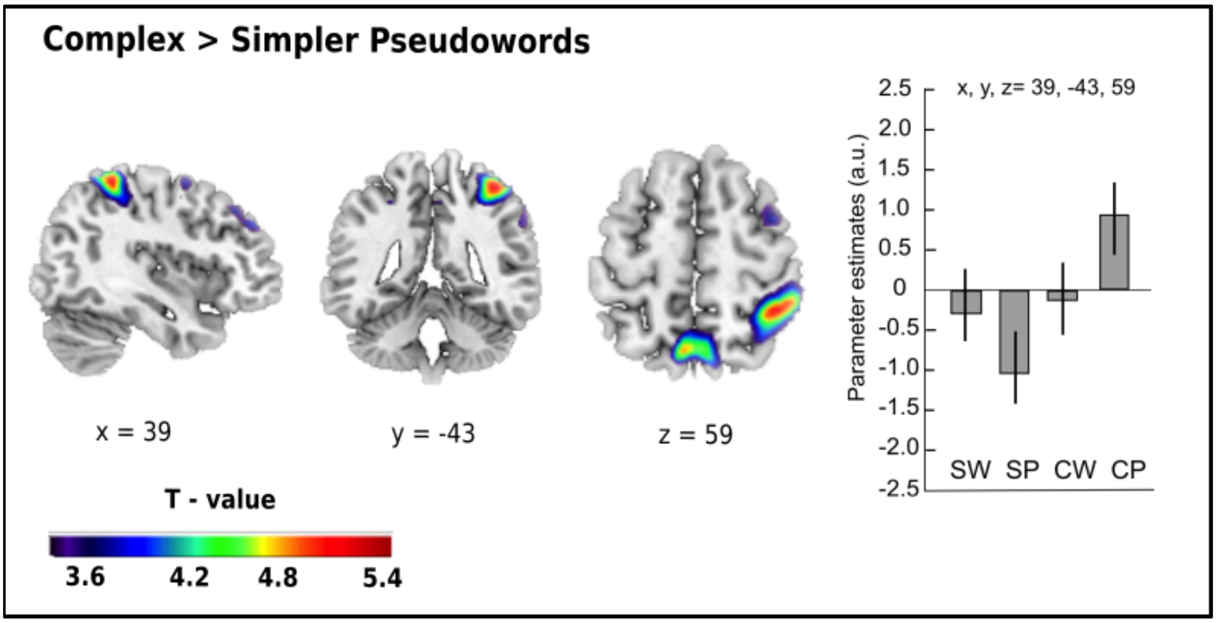

Figure 5.4 *Complexity effect for Pseudowords:* *Hübschung > *Spitzung

Interaction: Lexicality by complexity modulation

We found a significant interaction of lexicality and complexity (p<0.001), (i.e. [SP-SW] - [CP-CW]). This effect showed increased activity in the left middle frontal gyrus (x = -45, y = 50, z = 5, t = 4.21, p < .001, uncorrected). As evident from the parameter estimates for all conditions (see Figure 5.5), the effect was driven by a larger difference in activation in simpler (**Spitzung – Deutung*) than in the more complex (**Hübschung – Heilung*) pseudoword-word comparisons. To test this statistically, effect sizes for all conditions were extracted from the peak in the left middle frontal gyrus using the MarsBaR ROI Toolbox in SPM 12 (version 0.44). A pairwise comparison of the parameter estimates for the different conditions confirmed that the interaction was driven by the highly significant difference between simpler pseudowords and words (SP vs. SW; p < .0001) that was not significant for more complex pairs (CP vs. CW; p > .05). The difference between simpler and more complex stimuli was marginally significant for pseudowords (SP vs. CP; p = .048) but not words (SW vs. CW; p > .05).

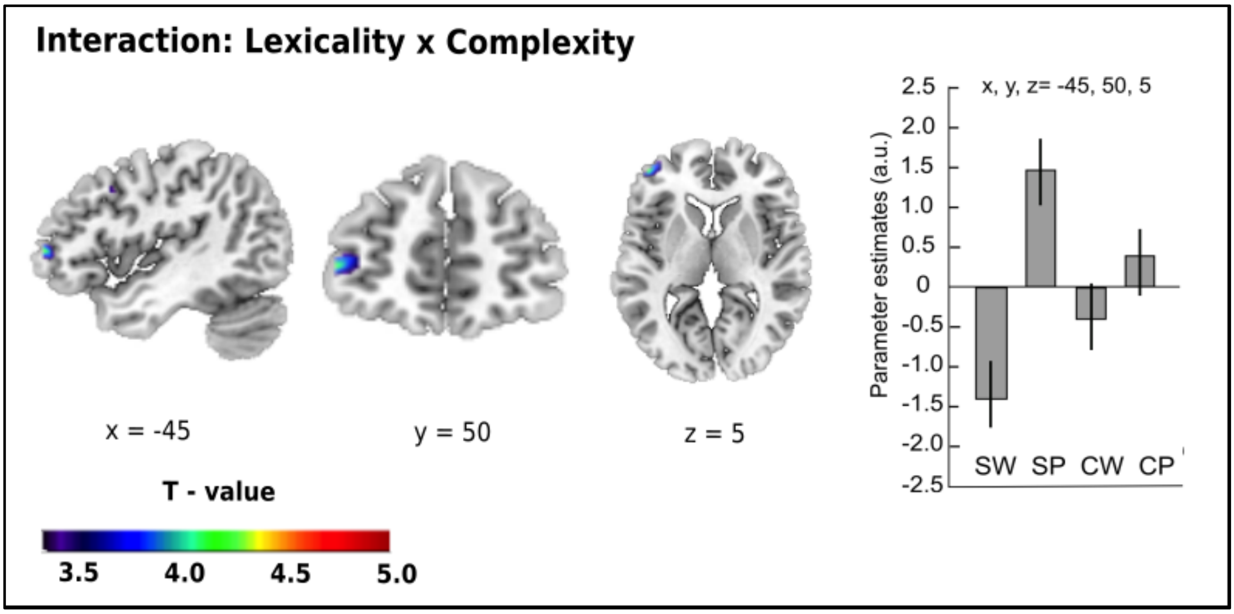

Figure 5.5 *Interaction: Lexicality x Complexity*

Table 5.4 *Regions showing significant activations for contrasts of interest*

Region	*Pseudowords > Words*						
	Coordinates			**Cluster**		**Peak voxel**	
	x	y	z	$p_{FWE\text{-}Corr}$	Size (mm^3)	$p_{FWE\text{-}Corr}$	T-value
L IFG	-45	26	26	< .001	11880	< .001	6.16
R Insula	33	23	-1	< .01	1107	<.01	5.87
pre-SMA	0	23	44	< .001	3726	< .001	6.42
	Complex > Simpler Pseudowords						
	Coordinates			**Cluster**		**Peak voxel**	
	x	y	z	$p_{FWE\text{-}Corr}$	Size (mm^3)	$p_{FWE\text{-}Corr}$	T-value
R SPL	39	-43	59	.001	405	.014	5.23
L Precuneus	-6	-64	59	.026	27	.049	4.96
	Interaction						
	Coordinates			**Cluster**		**Peak voxel**	
	x	y	z	p_{UNCORR}	Size (mm^3)	p_{UNCORR}	T-value
L MFG	-45	50	5	.047	999	< .001	4.21

5.6 General discussion

In the present study, we investigated the neural correlates of morphological complexity processing in sets of words and pseudowords that were matched in critical lexical variables (e.g. cohort size, frequency, length etc.) and surface level complexity. We showed evidence for the brain's sensitivity to morphological structure in superficially matched pseudowords differing in intermediate levels of derivation and thus the complexity of their structural analysis. Recall that unlike nonwords (*dnick*) that do not follow valid structural rules, pseudowords (e.g. *drick*) were defined as sequences of phoneme combinations that are licensed by the phonological constraints of the language. In addition to their phonological viability, the two sets of pseudowords in our study contained morphological structure. Both types of pseudowords were thus morphologically viable, but differed in their internal lexical composition. Our study thus represents the first examination of the neural underpinnings of structural analysis at the single-word level.

Our hypothesis was that if morphological decomposition were to apply to pseudowords, then the lexical meaning representations within intermediate positions could affect processing. We expected to find a fronto-parietal network to subserve the overall task of processing morphological complexity in derivation, but with possible divergences with regard to where we find predominant support for semantic processes versus structural analysis, both of which jointly contribute to the recognition of morphological complexity in pseudowords.

As a first main finding, we observed increased task-related activity in the pars triangularis of the left inferior frontal gyrus for processing of pseudowords relative to existing words. This supports our hypothesis that during the decomposition of pseudowords, the meaning of the existing words from which they are derived should become activated. This conclusion is supported by the finding that unlike the more possible pseudowords such as *Spitzung* and *Hübschung*, structurally impossible combinations such as *Wirrlein* did not show increased activation in the LIFG in our follow-up analysis (even at a more liberal threshold of $p < .001$, uncorrected). The increased activation might also be attributable to longer lexical search for pseudowords than for existing words. However, in this case, since unviable stem-affix combinations such as **Wirrlein* did not engage the LIFG (see Supplementary Information), this means that a lexical search is only triggered when the pseudoword can be decomposed following the morphological rules of the language. For this reason, we would argue that a lexical search in the mental lexicon is instantiated when an existing root such as *spitz* or *hübsch* can be recognized and triggers semantic processing following morphological decomposition. This conclusion is supported by previous studies which have associated the LIFG with both semantic processing (Devlin, Matthews, & Rushworth, 2003; McDermott, Petersen, Watson, & Ojemann, 2003; Roskies, Fiez, Balota, Raichle, & Peterson, 2001) and lexical search (Fiebach et al., 2002). For existing derived words, there is ample evidence for the involvement of the LIFG in morphological processing using priming paradigms (Bick et al., 2010; Bozic, Marslen-Wilson, Stamatakis, Davis, & Tyler, 2007), as well as unprimed lexical decision tasks (Meinzer et al., 2009; Pliatsikas et al., 2014; Vannest, Newport, Newman, & Bavalier, 2010; Vannest, Polk, & Lewis, 2005). Studies that failed to find support for the engagement of the LIFG in the processing of derived words (e.g. Bozic et al., 2013) more commonly employed passive non-linguistic monitoring tasks such as the detection of silences in auditory stimuli. Those studies that did find LIFG activation in morphological processing, however, also report LIFG activation that is not limited to the pars triangularis, but encompasses further subcomponents within the LIFG such as the pars opercularis (Meinzer et al. 2009; Pliatsikas et al. 2014). In this context, it is possible that different subcomponents within the LIFG take on specialized tasks within the processing of morphological complexity. Selective effects for the pars triangularis are reported by Bozic et al. (2007) who found neural priming (i.e. reduction in activation) in the pars triangularis upon second presentation with a complex (*lately*-*lately*), but not with a morphologically simple word (*mist*-*mist*). These results suggest that the priming effect observed was not reducible to a mere repetition effect, but was contingent on the presence of morphological structure.

In the present study, the observed increase in activation for complex pseudowords also extended to the insula and the pre-SMA. Studies investigating the processing of low versus high frequency reading (Carreiras, Mechelli, & Price, 2006; Fiebach et al., 2002) found similar processing signatures with increased activation for low frequency words. Even though our stimuli had been submitted to offline familiarity rating tasks in a behavioural pre-study and did not yield search results in German language corpora, it is indeed possible that the processing routes observed for morphologically viable pseudowords resemble those seen for low frequency existing words. Note that the nonword filler items (e.g. **Wirrlein*) only showed activation in the pre-SMA, but not in the insula relative to existing words. Given that these nonwords are also pronounceable due to their phonotactic legality, we think that the activation in the insula also reflects processes that are related to the activation of the existing root. Just as for the activation seen in the LIFG, an explanation could be that greater processing demands are placed on semantic processes for morphologically complex pseudowords than for nonwords that are not decomposable following the morphological rules of the language such as **Wirrlein*. The latter would rely on grapheme-to-phoneme conversion due to their phonotactic legality, but no influence from lexical representations such as the embedded adjective *wirr* was detectable for these items. The recognition of possible pseudowords, on the other hand, cannot be accomplished without the influence from lexical representations such as the root in complex pseudowords.

Importantly, recognizing complex pseudowords also requires the analysis of morphological structure and our aim in the present study was to investigate the neural correlates that underlie this process. Note that, unlike Meinzer et al. (2009), our effects of complexity as structure analysis were mainly driven by the relevant pseudoword comparisons with no effect of complexity in existing words, which might be due to the increased processing demands placed on the pseudowords in our experiment. In Meinzer et al. (2009), the 1-step versus 2-step derived words showed graded effects of activation in the LIFG, while our frontal activation appeared to be modulated by properties relating to the semantic processes triggered by morphologically viable pseudowords as a result of lexical search. Activation in the LIFG might thus generally be attributable to semantic effects following morphological decomposition. For existing words with increased derivational depth such as *Heilung*, a greater number of existing words within the derivational chain became activated in Meinzer et al. (2009). Yet, in our experiment, these subtle differences may have been overridden by the enhanced semantic processing demands placed on pseudowords. Unlike existing words, these do not possess a lexical representation and hence can only be processed following decomposition into their morphological constituents.

In a next step, we therefore established a direct comparison between the two sets of morphologically viable pseudowords in order to investigate the neural correlates of morphological structure analysis irrespective of lexicality of the final noun form. Even though both sets of pseudowords - **Spitzung* and **Hübschung* - were constructed using the same sequence of morphological rules (base adjective > zero-derived verb > noun ending in *-ung*), the intermediate verb form for **Hübschung* (**hübschen*) was already a pseudoword. This means that the decomposition of **Hübschung* - provided decomposition proceeds step-wise in accordance with the structural rules of the language - is more heavily reliant on processes of on-line decomposition and structure analysis than **Spitzung* for which the intermediate verb form *spitzen* exists. As a second main finding of our study, higher activation for the **Hübschung* set than for the **Spitzung* set was found in parietal regions, including the right superior parietal lobule and left precuneus. Here, the inclusion of nonword fillers such as **Wirrlein* also revealed an interesting pattern (note that these are also composed of existing stems and affixes, but their combination is not structurally viable). As we show in the Appendix E, the filler nonwords also engaged parietal regions, possibly during checking of the legality of the relevant stem-affix combination. But unlike the two viable pseudowords, no frontal activation relative to existing words was observed in the LIFG. Based on these findings, we would like to argue that the parietal activation reflects the degree of processing effort required during the structural analysis of morphological viability in non-existent items, while the activation in the LIFG is indicative of the semantic processes triggered when the structural analysis licenses the relevant combination between stem and affix. Traditionally, the posterior parietal cortex has been associated with visuospatial and attentional processing (Colby & Goldberg, 1999; Vandenberghe & Gillebert, 2009), but more recent neuroimaging studies have provided evidence for an involvement in episodic and working memory tasks (Cabeza, Ciaramelli, Olson, & Moscovitch 2008; Wager & Smith, 2003; Wagner, Shannon, Kahn, & Buckner, 2005).

Specifically, lesions in the SPL were found to affect the manipulation and rearrangement of information in working memory, but not when simple retrieval of information was concerned (Koenigs et al., 2009). In our case, this could translate to the structural analysis that is required as the viability of the stem and affix combinations of non-existent items is checked. For nonword fillers such as **Wirrlein*, this structural analysis involves the detection of the unviability of the relevant combination between stem and suffix. For the morphological decomposition of more complex pseudowords such as **Hübschung*, the structure analysis task requires the retention and manipulation of the intermediate verb form **hübschen* for further decomposition to its base. Note that the two sets of pseudowords **Spitzung* and **Hübschung* were matched in the composition of their surface structure (stem + suffix *-ung*). Our results are thus not reducible to the surface-level segmentation or so-called 'affix-stripping' that has been reported in the behavioural literature (e.g. decomposition of the monomorphemic word *corner* into a pseudostem *corn-* and suffix *-er*). An affix-stripping segmentation procedure would have yielded the existing base words *spitz* and *hübsch* in both our conditions. As these were matched on critical lexical variables such as length, frequency and cohort size (see 5.4 Methods), differences in BOLD signal cannot be ascribed to either the surface level form (both forms were pseudowords) or to properties of the base words themselves. Instead, differences between the two conditions can only become accessible if intermediate levels of derivation are inspected (*spitzen* vs. **hübschen*). Increased activation in the SPL for pseudowords with lexical gaps in intermediate positions (i.e. **hübschen* in **Hübschung*) could thus be driven by additional processing demands placed on decomposition following structural rules without support from existing lexical representations.

With regard to language-specific involvement of the SPL, Marangolo et al. (2006) contrasted the neural correlates of inflection versus derivation in morphological processing and found increased activation in the right superior parietal lobule in a task contrasting noun from verb derivation versus verb repetition in Italian. This converges with behavioural data from two patients with very similar right hemisphere lesions extending to the SPL in a previous study (Marangolo et al., 2003). These patients showed a selective deficit in deriving nouns from verbs, but not in the production of verb infinitives. The involvement of parietal regions in derivational morphological processes is also reported in two studies on morphological processing in Hebrew (Bick et al., 2008, 2010). The first study (Bick et al., 2008) consisted of explicit judgments of morphological, semantic, phonological and orthographic relatedness, as well as an unrelated control task to tease apart which regions would be selectively engaged during the morphological task. Bick et al. (2010) designed a lexical decision task with masked priming using prime-target pairs that were only morphologically related, pairs that were morphologically and semantically related, as well as orthographic, semantic and unrelated controls. Activation in parietal regions for the processing of morphological pairs was observed in both studies, albeit not in overlapping areas. The authors concluded that additional research would be required to assess the role of parietal regions in the processing of morphology, especially with regard to task requirements.

In both previous studies (Bick et al., 2008, 2010) activation in frontal regions (especially within the middle frontal gyrus) was shown to be more consistent across tasks. Consequently, they argued that the MFG is a key area for the processing of morphology during reading (Bick et al., 2010). In our study, significant activation in the left middle frontal gyrus emerged in the analysis of the interaction between lexicality and complexity (i.e. [SP-SW] - [CP-CW]). This effect can be expressed as a stronger difference in activation for the comparison of pseudoword-word pairs that require less structural analysis (i.e. **Spitzung* > *Deutung*) than for their more complex counterparts (i.e. **Hübschung* > *Rötung*). Superficially, both comparisons involve the contrast between a pseudoword and a word and are thus parallel. Yet we find a modulation of the effect by complexity. Again, this points to the effect of intermediate levels of morphological structure on processing. While the lexicality of the complex form undoubtedly plays an important role in the present study, our results are not reducible to a surface-level analysis. Factors pertaining to the internal composition of the derivational chain can thus override surface-level similarities.

As argued by Gabrieli, Poldrack and Desmond (1998), the left MFG is associated with response selection when multiple response options are available and only one option needs to be selected. Note that both comparisons (**Spitzung* vs. *Deutung*) vs. (**Hübschung* vs. *Rötung*) revealed increased activation for pseudowords and deactivation for words. In view of the significantly stronger difference observed in the first pair, our results point to increased processing demands that are placed on simpler pseudowords such as **Spitzung*. Here, we would argue that it is the availability of a lexical representation in the intermediate position for **Spitzung* (meaning that *spitzen* exists while **hübschen* does not) that encumbers a lexical decision. To be more precise, the correct classification of the **Spitzung* cases is exacerbated by competing response options. On the one hand, the complex formation itself is not a word and so participants may want to select the response 'nonword'. On the other hand, decomposition would have led to an existing intermediate verb form *spitzen*, possibly pushing participants towards making a 'word' lexical decision. These patterns are supported by our behavioural data, including the very high error rates in our simpler pseudowords. Simpler pseudowords are perceived to be more word-like given the interference effects from an existing lexical representation in the intermediate position. This is reflected in significantly higher error rates than for **Hübschung* and a tendency towards faster reaction times. Complex pseudowords, on the other hand, require more effortful processing due to a greater reliance on structural analysis without support from a lexical representation. We argue that the degree of structural analysis required is reflected in increased activation in the rSPL. The lexical decision as the end point of processing, on the other hand, is facilitated when the pseudowords appear to be less word-like due to the absence of a lexical representation in the intermediate position of the derivational chain.

Together with the differences in BOLD signal seen in the comparison between the two sets of pseudowords (**Hübschung* > **Spitzung*) and our additional analyses that included the nonword fillers, we would argue that frontal and parietal regions complement one another in the processing of morphological complexity in pseudowords. Frontal regions are engaged when semantic processes activate morphological constituents in the process of morphological decomposition. As we have seen for the left MFG, this activation can lead to competing response options being entertained during task execution. Parietal activation, on the other hand, has been found to relate to the more structural analysis of morphological viability, which we see selectively for pseudowords, but not for words, given that the latter can already be expected to meet the requirements of morphological viability as existing lexical representations.

Conclusion

In the present study, our motivation was to identify the neural correlates of morphological complexity processing, especially with regard to the identification of morphological structure in pseudowords as reported in a number of behavioural studies (e.g. Caramazza et al., 1988; Taft & Forster, 1975). In line with previous investigations (e.g. Marangolo et al., 2006), our results point to an engagement of fronto-parietal regions in the processing of derivational morphology. Given the design of our experiment, we were moreover able to disentangle contributions from structural and semantic components within the network. Semantically driven processes such as lexical search showed a more frontal distribution while combinatorial processes related to structural analysis engaged more parietal parts of the network. The present results add to the existing literature by breaking down the process of morphological decomposition into several components and identifying the neural correlates that underlie their relative contribution to the overall task of morphological processing.

6. MORPHOLOGICAL PROCESSING REVISITED: MORPHOLOGICAL COMPLEXITY PROCESSING THROUGH THE LENS OF PSEUDOWORDS

In the preceding three chapters, an attempt was made at unravelling features pertaining to the processing of morphological complexity by means of subtle experimental manipulation of the properties of complex pseudowords. The processing of two sets of complex words varying in internal structure was examined using a multi-method approach comprising behavioural, electrophysiological and neuroimaging evidence. For now, our discussions have been restricted to the interpretation of our results within the context of the methodology employed in a given study. In the present chapter, we will revisit our main findings and attempt to place their combined significance and limitations into a wider context to address a number of questions relating to the overall task of morphological complexity processing. In section 6.1, our discussions will focus on the detection of structural properties and we will assess to what degree the recognition process of words and pseudowords is reliant on purely structural analysis before considering how effects relating to lexical-semantic interpretation modulate the recognition process in section 6.2. In section 6.3, we shall attempt to situate the present findings in the context of the predominant theories of morphological processing that were introduced in Chapter 2. Not only will these different threads of discussion hopefully lead to a more unified account of possible mechanisms underlying the processing patterns discerned across the different experiments, but they will also open up questions that are yet to be addressed and therefore avenues for further investigation. An outlook on future work will thus be offered in the closing sections 6.4 and 6.5.

6.1 Morphological processing as structure analysis

The premise behind investigating morphological complexity through the processing of pseudowords was rooted in the tacit understanding that despite the absence of a lexical representation in pseudowords, the structural skeleton consisting of viable constituent building blocks would stimulate certain processes involving interpretation and analysis. These processes could in turn be informative with regard to the mechanisms that underlie morphological processing. In order to tap into the more fine-grained elements of structure analysis, an important desideratum throughout the present study has been the selection of stimuli with increased derivational depth and morphological complexity. This has resulted in a move away from the more traditional study of single-affixed or pseudo-affixed forms such as *teacher*, *department* or *corner*. This is not to say that no structural analysis is applied to single-affixed words. As we have indeed seen in Chapter 2, even at the very early stages of visual word recognition, particular language-specific regularities that are discernible on the word-level are detected and have an impact on further processing. This includes the well-established 'stripping' of identifiable affixes such as -*er* (e.g. Rastle et al., 2004), but arguably also the detection of morphological structure in inflected words such as *fell* that have been shown to facilitate recognition of the base word *fall* in the absence of parallel effects for non-morphological pairs such as *bell* and *ball* (Crepaldi et al., 2010).

As briefly touched upon in section 5.2, the neural correlates of selective morphological activation induced by masked priming appear to be subsumed under more domain-general processing areas also implicated in the recognition and identification of visual attributes such as object processing, (Grill-Spector et al., 1999), recognition of facial features (Gorno-Tempini et al., 1998) and the naming of word stimuli (Dehaene et al., 2001). This could also provide an explanation as to why 'islands of regularity' in the formation of the past tense in English appear to modulate early visual word recognition processes as delineated in a study by Fruchter et al. (2013). In this study, only irregularly inflected verbs with a high *AlbrightScore* (e.g. *send* - *sent* in view of a high number of parallel formations such as *lend* - *lent* or *rend* - *rent*), which serves as a measure of the degree to which the formation of a particular past tense form is expected given rules of morphophonological alternation in English, led to a significant priming effect. Although levelled out in the RT data, facilitatory priming for these items was robust at the neural level using the M170 (150-250 ms time window) as an index of facilitatory integration of the verb stem following the presentation with its masked past tense form. Pairs with a low *AlbrightScore* (e.g. *flew* - *fly* as an isolated case in which past tense formation in English involves the morphophonological alternation [uː] - [aɪ]) and therefore a structural relationship that is less supported by other regularities observed across the language did not even instantiate priming effects at the neural level, suggesting that the brain was sensitive to the statistical prominence of particular structural properties. It is therefore entirely possible that the structure detection mechanisms tapped into when using masked priming are susceptible to the identification of any regularities that foster rapid categorization and classification of visual stimuli before more fine-grained processing ensues at subsequent stages of word recognition.

While structure detection undoubtedly takes place in single-affixed items and even at very early stages of processing, the extent to which combinatorial aspects of word composition play a role during recognition is more difficult to tease apart when structural analysis involves a single operation, namely the derivation of a complex word from a base that is monomorphemic. The study of multimorphemic words allowed us to examine a greater number of morphotactic constraints that govern the combination between stems and a number of affixes. Secondly, it increased the overall distinctness of the words under investigation in their morphological properties. Overall, this contributes to a minimization of the reducibility of any observed effects to pure form and semantic overlap. The study of structure detection in multimorphemic words can thus be understood as an attempt at isolating purely morphological elements through the manipulation of the degree to which they are prevalent in a given word.

In this context, it is noteworthy that at least in the syntactic processing literature, manipulations of syntactic complexity have proven to be a viable method for investigations into the underlying structure detection mechanisms that operate at the sentence level, especially when dissociated from semantic contributions (e.g. Friederici et al., 2000; Humphries et al., 2006). For morphological processing, on the other hand, we only find a handful of studies - whether psycho- or neurolinguistic - that have approached the study of morphological processing via the manipulation of the quantifiable degree of morphological complexity involved. Recall that Kazanina et al. (2008) showed using masked priming that multi-affixed words such as the diminutive *gor-k-a* (N., 'little mountain') in Russian could be decomposed, thereby demonstrating that early decompositional effects are not restricted to the identification of two structural units, a stem and an affix. In view of our previous discussions of possible processing mechanisms at work during early word recognition, it is not surprising that the detection of statistical regularities in visual input could extend to encompass a greater number of units although the aforementioned findings reported by Fruchter et al. (2013) indicate a possible modulation by affix co-occurrence in these cases. In the present study, the combination of derivational processes investigated was highly productive and thus a high degree of co-occurrence of our affixes was guaranteed. The use of methodologies that tap into later stages of lexical processing, such as delayed priming (Chapter 3), cross-modal priming (Chapter 4) and unprimed lexical decision (Chapters 3 and 5), was hoped to enable the identification of structure detection effects that do not draw on morphology (or morpho-orthography) as an epiphenomenon of more domain-general pattern recognition strategies during early visual word recognition. In our case, the structure detection processes of interest were rather related to sensitivity to some of the morphological constraints introduced in section 2.5.2 such as selectional restrictions applying to the syntactic category of a base word. Indeed, our results point to the viability of employing the delayed priming paradigm for investigations into combinatorial aspects of stem and affix combinations since pseudowords such as **Wirrlein* did not facilitate the recognition of an embedded pseudo-stem *wirr*, while parallel of sets pseudowords in French such as **sportation* appeared to show decompositional effects in masked priming (Longtin & Meunier, 2005). Both sets of results point to the relevance of morphological structure in pseudowords, but reveal possible differences in the nature of the structure detection mechanisms at work. In line with our hypothesis that early effects of decomposition may be attributable to more domain-general aspects of pattern recognition, it appeared to be the case that any pseudoword composed of recognisable stem + affix sequences affected early visual word recognition in Longtin and Meunier (2005), while our effects were modulated by structural constraints operating on intermediate levels of composition. This is supported both by the absence of facilitatory effects in impossible stem + affix combinations such as **Wirrlein* and *wirr*, as well as by the differential effects in degree of priming between **Spitzung* and **Hübschung*.

In our fMRI study, on the other hand, we argued that attempts at structural analysis were generating the strongest effects in impossible formations such as **Wirrlein* as evidenced by increased activation in the right parietal cortex. Pseudowords without lexicalized intermediate positions such as **Hübschung* also showed increased parietal activation relative to *Spitzung*, with no effects of structural analysis in existing words of varying derivational depth. Even though *Wirrlein* did not facilitate the recognition of its embedded pseudo-stem *wirr,* its recognition as a nonword appeared to be effortful from a processing prospective, suggesting that an attempt at a structural parse may be pursued for these items, but eventually discarded in view of the combinatorial impossibility of stem and affix. This interpretation is supported both by our neuroimaging data and by the unprimed lexical decision times and error rates for these items.

Although tested in two separate behavioural experiments in Chapter 3 and therefore not contrasted directly, tentative conclusions can be drawn based on how nonwords with identifiable, but combinatorially unviable stems and affixes such as *Wirrlein*, versus items like *Plümpang* that have no discernible structural elements, were classified when compared with the two sets of pseudowords *Spitzung* and *Hübschung*. The latter two sets consistently elicited high error rates and long response times in the unprimed component of the lexical decision task. While error rates were significantly reduced for both sets of nonwords *Wirrlein* and *Plümpang*, the reduction was more pronounced for the latter than for the former. One interpretation of these patterns could be that nonwords such as *Plümpang* do not engage processes of structure analysis, whereas the internal composition of the set containing items such as *Wirrlein* is at least considered before a nonword lexical decision is eventually reached at the end point of the recognition process. Nonwords that are devoid of any analysable morphological structure such as *Plümpang* did not enter any of our follow-up analyses in Chapters 4 and 5 and did not form part of the stimulus set for which delayed priming effects were investigated, impeding a clear judgment of the degree to which any evidence for a structural analysis can be advanced for these items. Given the distinct processing signatures we observed for attempts at structural analysis across the different groups of nonwords in our fMRI study, we may therefore consider the incorporation of these items into our stimulus set in a future study. This would enable us to assess whether or not these engage processing patterns that are more akin to the recognition of monomorphemic pseudowords (see Mechelli et al. 2003; Fiebach et al., 2002) or whether we find evidence for parietal activation that we have argued to be indicative of structural analysis.

Notwithstanding the converging evidence we have been proposing for the processing consequences of structural analysis as the main factor propelling differences in our pseudoword/nonword conditions, alternative explanations need to be examined. In particular, the arguments that have dominated our discussions on structure detection so far may leave us with the understanding that the delayed priming paradigm is temporally and functionally distinct from masked priming. However, can we be certain that the effects of delayed priming are exclusively reflective of the structural analysis processes that take combinatorial constraints into consideration? While it is undoubtedly the case that semantic factors have been found to constrain the recognition process under delayed priming in a much more stringent fashion than in masked priming (Orfanidou, Davis, & Marslen-Wilson, 2011), some evidence for processing patterns that are not unlike the 'affix-stripping' segmentations observed during masked priming have indeed been reported for delayed priming, at least for existing words. In Bozic et al. (2007), monomorphemic words such as *archer* led to significant neural priming of the morphologically unrelated word *arch*, not unlike the classical *corner-corn* examples reported for masked priming. Similar results on the behavioural level have been reported by Rueckl and Aicher (2008) for delayed priming. In this context, it is important to note that the locus of the neural priming effect reported by Bozic et al. (2007) is clearly distinct from the masked priming neural priming results seen in studies such as Devlin et al. (2004). While the latter engaged domain-general visual processing areas, Bozic et al. (2007) found neural morphological priming for semantically transparent and opaque pairs in the left inferior frontal gyrus. In view of these differences, it could be argued that although the processing consequences may appear similar, especially for monomorphemic words that could be misinterpreted as being single-affixed, the underlying mechanisms giving rise to these results are likely to differ between the two paradigms. As discussed above, while facilitatory effects in masked priming appear to be related to a tracking procedure of attributes that propel the visual recognition process across different cognitive domains, the structural analysis implicated in delayed priming is likely to be the result of later processing stages due to its engagement of brain areas such as the LIFG. This is supported by our results, given that a superficial linear structure analysis of **Spitzung* versus **Hübschung* should not yield differential effects, as has been argued throughout the present study.

The main stimuli of interest in our study are, however, pseudowords, and the question remains to what extent their properties as non-existent items can be reflective of the structural analysis procedures that apply to existing words. Put differently, can we abstract away from the specific findings we report and claim that, based on the clear separation observed between neatly matched pseudowords in our study, facilitatory effects reported in other studies using the same methodology but with existing words are shaped by similar morphological analysis procedures? In this context, it may be worthwhile to consider that condition 'Extant' throughout Experiments 1 to 3 consistently failed to display the strongest effect of delayed priming compared to our pseudoword conditions. While we argued that the significantly stronger effect of facilitation observed for condition 'NonEx1' (e.g. **Spitzung*) versus 'NonEx2' (e.g. **Hübschung*) was attributable to the existence of a lexical representation at the intermediate stage of derivation in the former, the lexicality of the final noun form in condition ‘Extant’ did not result in a statistically significant modulation of the degree of facilitation seen in the recognition of the corresponding base word. That is to say, the degree of facilitation seen in the recognition of the base word was affected by the lexicality of the intermediate derivation in the pseudoword condition ‘NonEx1’, but the lexicality of the final noun form (the existence of *Heilung* versus the nonword status of **Spitzung* and **Hübschung*) did not render the path to the base word *heil* more direct, thereby boosting its recognition. Similarly, in Experiments 1 and 2, no interaction effects between *Prime Type* and *Base* were observed when the two sets of pseudowords were placed in separate experiments and only contrasted with existing complex words such as **Heilung*. Across the two experiments, we also found that the degree of priming for existing morphologically related pairs (*Heilung* - *heil*) was numerically consistent at around 20ms, demonstrating that the type of pseudoword (**Spitzung* versus **Hübschung*) with which existing complex words co-occurred within an experimental set-up did not modulate the ease of analysis for existing words. Recall that the stimulus set for condition ‘Extant’ was identical across Experiments 1 and 2 as the two experiments were administered to different groups of participants, thereby further confirming the robustness of effects for condition ‘Extant’. In Experiment 3, where all morphological conditions were contrasted in a single experiment using a subset of stimuli from Experiments 1 and 2, priming effects in condition ‘Extant’ were somewhat intermediate in magnitude between **Spitzung* and **Hübschung* with no statistically significant differences in degree of priming between the two word-pseudoword comparisons.

One interpretation could be that the link between the complex item and its base is inevitably more entrenched between pairs of words that can be expected to possess lexical representations. As a consequence, the analysis of existing complex words is less affected by contextual variation. For our fMRI study, however, we argued that the reasons why manipulations of degrees of complexity were transferred onto the pseudoword comparisons and no longer visible for 2-step versus 1-step derived existing nouns were to some extent attributable to contextual factors. Thus, while in Meinzer et al. (2009) processing effort was expressed as the relative degree of difficulty in integrating existing words, the structural proximity of our pseudowords to existing words appeared to diminish the sensitivity to morphological complexity between 2-step and 1-step derived nouns in the present study. Note, in this context, that the types of nonwords employed by Meinzer et al. (2009) were classified as pronounceable nonwords that were 'orthographically and phonologically regular' (p. 1966), but their formation was based on the scrambling of vowels and consonants of existing German words that had been matched to the experimental items for frequency and length. Any structural analysis pertaining to morphological complexity would have only applied to existing words in this experimental set-up. In the present study, the overall degree of morphological complexity manifested across all experimental items could have diverted the processing resources dedicated to structural analysis to non-existent items. After all, the experimental task required a simple lexical decision and thus, task execution for existing items could be accomplished using a lexical look-up strategy in order to devote the required structure analyses processes to the identification of structurally highly similar pseudowords. As complex noun forms were not paired with their base words in Experiment 6, we have no direct measure of base word facilitation in our fMRI study and thus the degree to which the activation of a base word was affected by contextual manipulation or not. Thus, it may be the case that the depth of structure analysis for existing words can be altered depending on the processing resources needed as a function of the experimental design employed, but that the links that exist between complex words and their base words is unaffected by the presence of pseudoword-word pairs that display a similar structural make-up, as seen in Experiments 1 to 3.

Recall in this context the parallel patterns observed in Experiment 5 in which all morphological sets were examined using cross-modal priming with electrophysiological measures of target recognition. Despite the well-established sensitivity to purely semantic effects in cross-modal priming (see Marslen-Wilson et al., 1994), the existence of a lexical representation for condition 'Extant' did not yield significantly stronger processing savings for existing morphologically related pairings in this experiment relative to pseudoword-word pairs. Again, the effects for *Heilung* - *heil* were situated somewhat in between the statistically significant priming differences manifested by **Spitzung* and *spitz* versus **Hübschung* and *hübsch*. Put differently, the lexicality of the complex noun form and thus any associated meaning shared between prime and target did not provide a processing advantage relative to a pair such as **Spitzung* and *spitz*. For the latter, the meaning of the complex noun cannot be retrieved as part of an existing representation. Instead, any lexical-semantic interpretation for the complex pseudoword can only be computed following the activation of an existing morphological base word such as *spitzen* or *spitz*. The effect of lexical-semantic interpretation of morphological derivates on the processing of both existing and non-existent complex items will be discussed in section 6.2.

6.2 Morphological effects as a function of lexical-semantic factors

So far, our discussions have centred on the notion of structural viability and the analysis processes engaged in the detection of this viability. It is, however, also important to take into consideration that a comparison between the two sets of pseudowords revealed through structure analysis results in the identification of differences in lexicality for the intermediate position. This means that the degree of interpretability between the two sets varies as a function of lexical-semantic factors. As already debated in Chapter 3, any dissociation between structural and semantic interpretability is exacerbated by the mutual interdependency between these two factors. These difficulties were already evident in previous studies by Longtin and Meunier (2005) and a follow-up study by the same authors in (2007) in which it was shown that viable combinations of stems and affixes (**rapidifier*) yielded higher ratings of semantic interpretability in off-line rating tasks and led to significant priming in cross-modal paradigms, unlike combinations that did not obey the selectional restrictions of the French language such as **sportation*. Is it possible to disentangle the effect of structural validity (the permissibility of combining a particular stem and affix) from contributions at the lexical-semantic level? By virtue of being existing words, the structural validity of extant items is assured and any clear dissociation between structural and lexical-semantic factors exacerbated. However, the ubiquity of structurally complex words for which the overall meaning is not computed compositionally from the meaning of structurally identifiable constituent units, such as *government* (from *govern-* and *-ment*), suggests that once the idiosyncratic meaning of the complex word is acquired, structural properties no longer interfere with an interpretation. Consider in this case the fact that common usage of the word *government* denotes an authority that carries out the task of governing, rather than the actual act of governing as in parallel formations of verbal bases to which the suffix *-ment* is attached (e.g. *accomplishment*, *amusement*, *movement* etc.). This suggests that structural properties and the semantic interpretation delivered through the step-wise composition of lexical meaning can become overshadowed in the face of a more predominant holistic interpretation. Since word formation is undoubtedly not just a process of structure analysis, but a mechanism that enables the formation of novel, meaningful lexemes, it is not unwarranted to assume that lexical-semantic factors play an important role in morphological processing.

For a comparison between structurally similar sets of pseudowords such as **Spitzung* and **Hübschung*, it could thus be argued that alongside the identification of structural validity in both items, the viability of their interpretability is assessed. Due to the existence of a lexical representation for *spitzen* versus **hübschen*, an interpretation of the novel form **Spitzung* is facilitated. After all, the meaning of nouns derived in *-ung* is contingent on the semantics of the verb, rather than the adjective, if the latter is available at all. As discussed in Chapter 3, nouns in *-ung* can be transitive or intransitive and consequently take on either causative or inchoative meanings. Thus, it could be argued that the existence of a verb *spitzen* is critical since the meaning of the novel form **Spitzung* becomes more readily available as an action/result nominal derived from a verb giving the expected causative meaning. When the intermediate derivation does not possess a lexical representation, possible meanings are yet to be constructed and options include intransitive as well as transitive formations and thus causative as well as inchoative meanings. That is to say, the lexicality of an intermediate position rules out the ambiguity that has to be resolved for novel forms such as **Hübschung*, which could be based on an inchoative or causative meaning of **hübschen*. Again, however, these explanations seem to hold for the comparisons given between the two sets of pseudowords, but raise questions with regard to the absence of a gradient effect of lexicality on base facilitation in both our delayed priming experiments, as well as in the results of the cross-modal task reported in Chapter 4. After all, the meaning of existing complex words such as *Heilung* is not just predictable and thus easily computed based on the semantics of the verb, but it is in fact readily available as part of the lexical information associated with the existing word. By the rationale pursued in the previous section, it could thus have been expected that items that do not require the property of 'interpretability', but are in fact already 'interpreted' from a lexical-semantic point of view should have yielded the most significant time savings during processing.

In this context, an interesting perspective is offered in a study by Taft (2004) on the so-called *Reverse Base Frequency Effect*. Using the same set of existing stimuli across two experiments, it is shown that the morphological composition of nonwords that accompany the presentation of existing test items can shape the recognition process for existing words. More specifically, nonwords generated through suffixation of non-existent stems such as **milphs*, **kossled* and **juxing* arguably permitted the execution of a lexical decision for both words and nonwords based on the lexical status of the embedded stem following obligatory segmentation of both sets of items into stems and affixes. Nonword distractors such as **mirths, *joying* and **kettled*, on the other hand, which were composed of existing stems and affixes, appeared to shift the focus of processing onto the recombination stage of stem and affix, whereby the processing advantage of existing words with high base frequencies was diminished. In the present study, the existing words employed across the experiments reported had reasonably high base frequencies (average of 268.33 words per million in CELEX) with an average surface/base frequency ratio of 3.4 % - a value that is comparable with the stimuli classified as LS/HB (low surface frequency/high base frequency) in Taft (2004). The relevance of the findings in Taft et al. (2004) for the interpretation of our results emanates from the effect nonword distractors were shown to bring about in the recognition of existing words. If, as argued by Taft (2004), the presence of real stem nonword distractors relocates greater processing resources onto the recombination stage, then any processing advantages inherent in the availability of a prominent base word are levelled out as a result of the checking procedures that ensue for stem and affix combinability. Note that the evidence that Taft (2004) advances pertains to the predictions of a fully decompositional model with an obligatory recombination stage of processing for single-affixed LS/HB words. The implementation of a recombination process for multi-affixed words is not delineated, and in particular the question whether the checking mechanism proceeds step-wise following the recognition of the base word is not discussed further. It is precisely this question, however, that would be particularly pertinent for the present study.

Assuming a step-wise application, the viability of deriving a verb form based on the base adjective would be inspected first before the formation of a noun based on the derived verb form could be checked in a subsequent step. Harking back to the notion of ambiguity with regard to the meaning expressed in a novel formation, it is clear that pseudowords in condition 'NonEx2' already present the processor with an element of uncertainty when recombination occurs for the verbal form as the absence of a lexicalized form means that both causative and inchoative meanings are possible. For conditions 'Extant' versus 'NonEx1', on the other hand, the number of checking procedures that involve increased processing difficulty is essentially equivalent in view of the existence of a lexically specified intermediate position in both cases.

Given that all stimuli apart from the pseudoword condition were kept constant across Experiments 1 and 2 in Chapter 3, we decided to conduct a post-hoc analysis on the reaction times to prime words in condition 'Extant' in a combined analysis for both experiments. The purpose of this post-hoc analysis was to shed light on the effect of different types of pseudowords with existing stems (**Spitzung* versus **Hübschung*) on the processing of existing words with high base and low surface frequencies. In this analysis, we found no effect of *Experimental Setting* (Experiment 1 versus Experiment 2) on *RT* when *Participants* were included as random effects ($p > .1$), suggesting that the longer *RT* for condition 'Extant' in Experiment 2 were induced by overall differences in response time across the participants to whom the test was administered across the two experiments. An analysis of the effect of *Experimental Setting* on *Error Rate*, on the other hand, was marginally significant (p = .052) with higher *Error Rates* for existing complex words when these were presented alongside pseudowords without a lexicalized intermediate position such as **Hübschung*. While an interpretation of these results needs to be considered with caution since responses were collected from different groups of participants, the observed patterns appear to be in line with the predictions offered by Taft (2004)'s *Reverse Base Frequency Effect* and the possible applicability of the mechanisms discussed in Taft (2004) in view of our experimental set-up. Pseudowords such as **Hübschung* that could be expected to place greater processing demands on the recombination stage due to increased lexical-semantic ambiguity affected the processing of existing words more strongly.

Recall, on the other hand, that we previously noted the absence of an effect of *Experimental Setting* (Experiment 1 versus Experiment 2) on the degree of priming observed for condition 'Extant', implying that the accessibility of the base word as a possible result of morphological decomposition was not modulated by the characteristics of the nonwords that co-occurred with existing words within an experimental setting: the degree of activation obtained for the base word *heil* was thus consistent across the two experiments. An additional post-hoc analysis investigating the effect of *Experimental Setting* and *Prime Type* on *Reaction Time* to the target word for condition 'Extant' confirmed the absence of a modulation of the priming effect by *Experimental Setting*. The responses given to the prime word itself, however, were affected by the pseudoword context in which these existing words were embedded, with significantly higher error rates when the pseudowords consisted of existing stems, but lacked a lexical representation in the intermediate position (e.g. **Hübschung*). These divergences may reflect separate processing stages expressed in base word activation following priming with the corresponding complex formation, as opposed to the processing signatures observed during the classification process of the complex formation itself.

These observations lend support to our previous reflections on the mechanisms implicated at the recombination stage for existing words. These appear to depend on more subtle properties pertaining to internal levels of composition for co-occurring multimorphemic pseudowords. In view of the present results, it could indeed be the case that the uncertainties faced by the processor when no lexical representation is available (e.g. **hübschen*) impede the formation of the final noun form (e.g. **Hübschung*) since the absence of an unambiguous stem for further word formation places additional processing demands on the recombination stage of morphological decomposition.

In summary, we observed divergences between the combined *RT* and *Error* data obtained in the responses to primes where an effect of the composition of the pseudoword condition was manifest relative to the response time to the base word of an existing complex word. Base word responses were shown to be unaffected by the pseudoword manipulations. If we were to assume that the mechanisms that underlie base activation in word and nonword conditions are not dissimilar in delayed priming, then the present results would suggest that the degree of facilitation measured during the classification process of a target word is shaped by the accessibility of the base during decomposition, rather than by properties relating to the recombination stage. The upshot of such an approach would be that the accessibility of the base word for pseudowords varies in delayed as well as in cross-modal priming tasks as a function of interval levels of morphological decomposition, but independently of a possible recombination stage following Taft (2004). In this context, it is clear that the present findings have relevant consequences for the viability of a range of morphological processing models introduced in Chapter 2. We shall address these consequences in section 6.3.

6.3 The processing of complex pseudowords and models of morphological processing

In previous sections, we already touched on the predictions made by full-decomposition models that had been proposed by Taft & Forster (1975) and revised at a number of later stages. In these models, the analysis of morphological complexity is carried out in separate stages, beginning with an identification process that is initiated for the recognition of the stem, which is followed by an obligatory recombination stage. This recombination stage is critical for the analysis of non-existent items such as **Spitzung* and **Hübschung* and especially for nonwords that we have argued to be composed of structurally unviable combinations of stems and affixes such as **Wirrlein*.

The original motivation for the model advanced by Taft & Forster (1975) was supported by data from a simple lexical decision task in which responses (both *RT* and *Error Rate*) to different sets of pseudowords were driven by the recognisability of an existing stem (recall the processing differences between *rejuvenate* and *repertoire*). In the present study, throughout Experiments 1 to 4 in which behavioural responses to the complex words and pseudowords themselves were collected, the combinatorial viability between stems and affixes was reflected in *Error Rate*, but not in *RT*. Similar effects were observable in the behavioural results obtained during fMRI data acquisition: complexity as the degree of structural analysis we expected (in this case for both words and nonwords) was reflected in higher error rates for more complex than for simpler words, but was levelled out in the response latencies to different sets of pseudowords. Note in this context that - as already discussed previously - overall error rates to pseudowords were excessive and reached an average of about 70 % across all items in one of the pseudoword conditions ('NonEx1'). As the RT analysis is commonly based on correct responses, the small number of trials that entered data analysis may have rendered the overall interpretation of the effect of condition on RT responses difficult due to the inherent variability and unreliability within the data. Substantiated by the differences in BOLD signal observed across pseudoword conditions with more pronounced parietal activation for pseudowords requiring enhanced structural analysis (**Hübschung* > **Spitzung*), our results indeed indicate that morphological decomposition in nonwords encompasses more than just the activation of an embedded, recognisable stem: the combinability of possible morphological constituents is inspected, possibly at a recombination stage as put forward by Taft and Forster (1975). Further support for the availability of a processing stage at which the possible components of a morphologically complex formation are analysed based on their functional combinatorial properties emanates from the applicability of the *Reverse Base Frequency Effect.* In line with the predictions made in Taft (2004) regarding the *Reverse Base Frequency Effect*, processing consequences for the classification of existing words arise, arguably as a result of enhanced processing requirements placed on checking mechanisms of combinatorial viability.

Now, in view of the contextual variation observed with regard to the emphasis placed on different processing stages, proponents of *full-listing* models of morphological processing may be inclined to point out the dispensability of a recombination stage during 'normal' processing. Following such an argument, it would be claimed that the structural analysis of the combinatorial viability between morphological constituents only surfaces as a by-product of having included particular types of nonwords, thereby failing to capture the underlying processing mechanisms at work during the recognition of morphological complexity.

With regard to this point, we need to bear in mind that the inclusion of nonwords is an obligatory feature of any lexical decision task. The very fact that the nature of the nonword composition modulated the recognition process for existing words provides evidence for the effortless identification of possible morphological constituents in items that cannot possess a lexical representation of their own. After all, the predictions of a *full-listing* approach to morphological processing would have permitted the holistic retrieval of lexical entries for real words and instantaneous rejection of nonwords based on their surface-level makeup without any interference from morphological properties. For nonwords to exert an effect on the processing of existing words within an experiment, the nonword properties need to be recognized promptly enough to initiate the interference effects that we have been discussing. A viable follow-up question, however, relates to the authenticity and representativeness of the processing patterns that emerge in a laboratory setting employing lexical decision tasks. When morphologically complex words are encountered in an everyday setting, we can be certain that distractor nonwords do not coincide with the presentation of morphological complexity in existing words. The question whether the processing of morphological complexity is adequately captured through a lexical task is undoubtedly legitimate, but if holistic form retrieval were the default mode of morphological complexity processing, then the automaticity of its application could have been expected to display robustness against interference effects. Instead, the interaction effects between word and pseudoword processing we have been reviewing in relation to the results reported by Taft (2004) and observed in the present study suggest that the retrieval of existing words is not merely the result of a simple look-up strategy.

On the other hand, it also needs to be acknowledged that the reported interaction effects between word and nonword properties have not been restricted to the morphological domain (cf. Stone & Van Orden, 1993; Yap, Balota, Cortese, & Watson, 2006; Lupker & Pexman, 2010). Put differently, we find that the degree of resemblance to real words of the monomorphemic nonwords included in a lexical decision task in turn affects the recognition of monomorphemic real words. To give an example, Lupker and Pexman (2010) delineate an intensification of a word frequency effect between sets of real words in an experiment when co-occurring nonwords consisted of pseudohomophones (AMBUR instead of AMBER) rather than the more common pronounceable pseudowords (e.g. AMTER). Similar effects were observed for nonwords with transposed letters such as JUGDE instead of JUDGE. For an argument against the decompositional nature of morphological processing, the aforementioned effects could be advanced as evidence that if monomorphemic real words, which would by definition be represented holistically in terms of morphological structure (or its absence), can be subject to contextual effects of processing, then there is no reason to postulate a *Reverse Base Frequency Effect*. Instead, the claim could be made that any type of existing word (whether monomorphemic or complex) can undergo changes in lexical processing depending on the difficulty of the word-nonword discrimination task.

These predictions are, however, not borne out by investigations into the effect of nonword difficulty on semantic priming between existing words reported in Lupker and Pexman (2010). Across a number of experiments, it emerged that while word frequency effects were subject to influences from the types of nonwords employed, these effects did not transfer to the degree of semantic priming obtained for real words. Thus, whether the experimental set-up included pseudohomophones or transposed letter nonwords as more 'word-like' distractor stimuli, or the more commonly employed pronounceable nonwords, did not modulate the effect size of semantic priming. A number of different mechanisms have been proposed to underlie semantic priming and we will not delve into the detailed analysis of all accounts at this point, but it is likely that given the effect's dependency on the identification of semantic overlap, processing does involve tapping into the lexical representations of the relevant pairings. In any case, it is clear that while retrospective matching strategies for semantic priming have been proposed (Neely & Keefe, 1989), the locus of semantic priming has to be embedded in a more central, abstract stage of word recognition than properties relating to word frequency. Note in this context that the degree to which the more 'word-like' distractors in Lupker and Pexman (2010) are not just 'word-like' to the extent that they could represent a novel, structurally possible monomorphemic word. Instead, these stimuli bear a strong resemblance to **one particular** existing word the recognition of which is exacerbated by spelling inconsistencies. Put differently, nonword distractors such as 'JUGDE' or 'AMBUR' simply have the appearance of misspellings and it is therefore entirely plausible to assume that the presence of such stimuli within an experiment induces increased processing demands on spell-checking mechanisms. These intuitions are shared by Lupker and Pexman (2010) who consider the possibility that the effect nonword manipulations have on word frequency for existing words could then be accounted for based on the ease with which the orthographic viability of a word can be checked. This checking mechanism would not require full access to the lexical-semantic properties of the relevant lexical entries, but could be entirely driven by the frequency and thus familiarity of a particular visual form. The robustness of semantic priming against these effects would suggest that less peripheral aspects of word recognition are immune to the aforementioned interference effects. For the present results, this suggests that the degree of priming observed in our cross-modal priming experiment, for instance, is likely to be robust against task-induced influences and can serve as a measure of how much semantically-driven activation can be expected between two morphologically related existing words using a paradigm that has previously shown to pick up semantic relationships between words (cf. Marslen-Wilson et al., 1994).

In future work, it may be worthwhile to investigate the degree of priming we obtain for words in condition 'Extant' when these do not occur with the types of nonwords we have been employing in the present study, both for delayed and for cross-modal priming. The purpose of this investigation would be to access the degree to which some predictions advanced by proponents of *full-listing* hypotheses are borne out in our data, namely the expectation that morphological decomposition serves as a 'fall-back' strategy (cf. Butterworth, 1983) when no existing lexical representation is available. This would mean that given the absence of a lexical representation for our nonwords, processing strategies relying more strongly on decompositional aspects could have driven overall effects. However, in view of the number of studies that have demonstrated priming effects between pairs of existing morphologically complex words using overt priming paradigms (e.g. Smolka et al., 2009; Smolka et al., 2015), it is unlikely that priming effects between real words are only invoked when the included nonwords display morphological properties.

Our results also do not appear to be entirely consistent with *full-listing* models that postulate the convergence between semantic and orthographic overlap to be at the core of morphological effects (e.g. Plaut & Gonnermann, 2000). Incompatibilities between the present findings and so-called *Parallel Distributed Models* (PDP) arise on the basis of a number of instances in the present study. Firstly, in Experiments 3 and 5 (the former being a delayed priming experiment that incorporated a direct comparison between the sets of non-existent items and the latter being a cross-modal priming experiment using electrophysiological measures), the phonological and orthographic overlap between the nonword conditions was kept constant – that is, the degree of prime-target overlap did not differ significantly across conditions (see the Methods sections of Chapters 3 and 4). None of the forms (e.g. **Spitzung* versus **Hübschung* versus **Wirrlein*) had existing lexical representations, resulting in a match with regard to semantic meaning between prime and target based on the surface-level makeup of the non-existent items. Recall that differences in priming magnitude were obtained with no facilitation for impossible combinations such as **Wirrlein* and their embedded pseudostems *wirr*, as well as reduced facilitatory effects for pseudowords such as **Hübschung* without a lexicalized intermediate position relative to pseudowords that were derived from existing words such as **Spitzung*. On the basis of a surface-level analysis, both our delayed and cross-modal priming thus produced diverging results in terms of degree of priming for items that appeared comparable in both orthographic and semantic overlap. These patterns would not be expected in a model of word recognition that does not factor in a process of morphological analysis. After all, it is only following the step-wise application of morphological decomposition that a lexical representation for *spitzen* becomes available. It could indeed be argued that *Parallel Distributed Processing* models correctly predict the relevance of increased semantic interpretability as a factor that will modulate word recognition for orthographically matched items. The critical point is, however, that these aspects pertaining to semantic interpretability are dependent on a morphological analysis – a point that is not directly predicted by single-route *full-listing* models.

Secondly, morphological priming that surfaces as a function of joint orthographic and semantic similarity would have predicted a gradient effect of semantic similarity for items that are matched in orthographic overlap. Thus, according to *Parallel Distributed Processing* models, in Experiments 3 and 5, the strongest facilitatory effects should have emerged in condition 'Extant' with no observable differences between the sets of pseudowords. As discussed previously, numerical differences in degree of priming were evident between conditions ‘Extant’ and ‘NonEx1’. The tendency towards stronger facilitation in condition ‘NonEx1’, however, runs against the predictions laid out in *Parallel Distributed* models, which would have anticipated a strong effect of semantic interpretability when orthographic determinants are controlled for.

How well do *Dual-Route* models fare in view of the patterns reported in the present study? Recall that most *Dual-Route* models accommodate morphological processing within a race between two competing modes of processing, with both holistic retrieval and morphological decomposition being available. In the *Augmented Addressed Morphology* model (Caramazza, Laudanna, & Romani, 1988; Laudanna & Burani, 1985), clear predictions are set out with regard to the two processing routes, and thereby word versus nonword processing. Whole word retrieval applies by default to existing words while decomposition is only viable for nonwords following a failure of the application of whole word retrieval for these items. For the *Augmented Addressed Morphology* model to capture the patterns reported in the present study, the main tenets of the model have to be extended to encompass the activation of morphologically related base words in existing complex words. One possibility would be to build on interaction effects between the two routes when the predominance of nonword stimuli within an experiment may generate an over-application of the decompositional route to apply to existing words as well. The numerically reduced effect sizes for existing words would then be expounded based on carry-over effects from the nonword manipulations. Following this argumentation, the point could be advanced that indexes of morphological decomposition would not have surfaced under ‘normal’ processing, but are attested when processing strategies for nonwords produce carry-over effects for existing words. As has become evident in our previous discussion, the aforementioned possibility cannot be ruled out entirely, but it does seem to be incompatible with effects relating to sensitivity to derivational depth found in previous studies (Meinzer et al., 2009; Pliatsikas et al., 2014). Note that the types of nonwords employed across the two studies were different. While Meinzer et al. (2014) drew on scramblings of vowels and consonants in existing words in order to form nonword items, Pliatsikas et al. (2014) included nonword distractors that had the appearance of morphological complexity such as **happity*. Yet the neuroimaging results observed for the existing words did not differ across the two studies, suggesting that the complex appearance of complex fillers was not the source of a complexity effect in existing words. More specifically, the manipulation of derivational depth between existing words was reflected in degree of activation, especially in the LIFG. In our fMRI investigation, selective activation in the LIFG did not emerge as a function of derivational depth, but was instead driven by the degree of viability of our pseudowords with no discernible effect for nonwords that do not follow the morphological constraints of the language and which therefore do not activate an embedded stem. Even though the possibility that our chosen nonwords affected responses to existing words cannot be ruled out entirely, the combined observations across these three fMRI experiments could also be attributed to the degree of difficulty experienced during the integration of semantic information. In our experiment, the relative semantic interpretability of our pseudowords may indeed have obliterated subtle differences between depths of derivation and thus the number of lexical representations available in the derivational chain of a given word. In future investigations, it may be worthwhile to contrast word and nonword properties more directly in the light of previous research. Thus, while a small, but significant effect of derivational depth on *Error Rate* was manifested in the behavioural data collected during scanning in the present study, no responses to existing words are available for the experiments reported by Meinzer et al.

(2009) and Pliatsikas et al. (2014), thereby rendering a more direct comparison impossible at this stage.

Overall, the present results do support the hypothesis that morphological decomposition as both the structural analysis of morphological complexity and the activation of lexical-semantic properties relating to the word's morphological constituents occurs in both words and nonwords. This observation is consistent both with the *Morphological Race Model* as put forward by Frauenfelder and Schreuder (1992), as well as with a single-route full-decomposition model (e.g. Stockall and Marantz, 2006). Note that the *Morphological Race Model* – not unlike the other Dual-Route model we have been discussing in the present section, the *Augmented Addressed Morphology* model – gives priority to the application of a holistic retrieval mechanism over morphological decomposition. Under such an approach, features pertaining to the distributional patterns of existing complex words such as their frequency may on the other hand promote the salience of the morphological parsing route for lower frequency words with a high degree of semantic predictability between base and derived word. For full-decomposition single-route models, the aforementioned properties are not expected to be of relevance to the recognition process. As we only employed one set of existing words that was matched to our nonwords in base frequency, future work will need to address the impact of frequency manipulations on degree of priming for existing words. The two approaches also make conflicting predictions with regard to repeated exposure to novel forms. While the Dual-Route *Morphological Race Model* would expect increasing reliance on holistic retrieval as a function of greater exposure and familiarity, *full-decomposition* would apply to novel forms regardless of the effect of degree of familiarity with novel forms. Clearly, while we have been able to find evidence for a morphological analysis applying to novel formations and sensitivity to subtle differences in composition between broad classes of complex words, further questions remain to be addressed. A number of these will be laid out in the following section.

6.4 An outlook on morphological complexity processing

As the first study to examine the possibility that novel formations may undergo step-wise morphological decomposition into their constituent morphological constituents, the main objectives of the present study were to investigate whether or not native speakers would exhibit sensitivity to subtle differences between matched pseudowords. Due to our reliance on psycho- and neurolinguistic methodologies, the provision of stimuli that are otherwise matched on critical lexical variables such as frequency, number of letters and morphological family size was of foremost importance in the design of the three sets of studies presented in the present thesis. Investigating the processing of these groups of matched words and pseudowords indeed indicated that variations in the number of lexical gaps within derivational chains present an additional factor in psycholinguistic research that is critical in the recognition of morphological complexity.

To obtain a more enhanced understanding of further properties that may play a role in the processing of multi-suffixed pseudowords, follow-up studies will need to build on the present results while incorporating additional experimental manipulations into their design. In the present section, we will review some properties that have not been the focus of the present study, but will enable us to obtain a more in-depth understanding of morphological complexity processing, as well as a clearer differentiation between different models.

6.4.1 Investigating 'inherent' properties in the processing of existing and novel complex words

As already outlined in the previous section, Frauenfelder & Schreuder (1992) put forward a model of morphological processing in which both decomposition and whole word retrieval are available. However, only for complex words that exhibit certain 'inherent' properties will the decompositional route win the morphological processing race between the two processing possibilities. Recall that these inherent properties include the degree of phonological transparency between derived word and its base, as well as the degree of transparency in the semantic compositionality that links base and derived word. In the present study, phonological transparency was in fact not always a given. In the derivation from *base adjective* to *verb*, conversion was in a number of cases accompanied by the process of *umlauting*. The alternation between a back vowel in the base word (e.g. *rot*) and an *umlauted* (that is fronted) vowel in both the intermediate position (*röten*) and the final noun form (*Rötung*) was observed in the real word condition and was subsequently also applied to the pseudoword conditions. If the predictions of the *Morphological Race* model were borne out, then less facilitation would be expected for pairs involving vowel alternations. The expectations for pseudowords with stem vowel alternations are less clear since the application of morphological decomposition is assumed to apply by default to complex items with nonword status. To probe the effects of phonological transparency on the processing of morphological complexity in both words and pseudowords, a number of post-hoc analyses were conducted based on the behavioural data obtained in the present study.

In a first step, we endeavoured to establish the extent to which the syntactic category of the base word and the intermediate position contributed to the processing of morphologically complex pseudowords in possibly different ways. This question is tied to any investigation of phonological transparency between complex item and base word since, as we have already ascertained, it is only for adjective-based roots such as *rot* (for condition 'Extant') or *froh* (for condition 'NonEx2') that discrepancies in phonological overlap arise between the final noun and the base. In a first analysis, we focused on the processing of the two types of pseudowords **Spitzung* versus **Hübschung* in Experiment 3 reported in Chapter 3, which offered a direct comparison between the two sets in terms of processing cost of the novel formation itself (expressed in *RT* and *Error Rate*), as well as the degree of facilitation of the embedded base. The analysis of the effect of *Syntactic Category* and *Base* on *Error Rate* confirmed the main effect of *Base* ('NonEx1' versus 'NonEx2') on *Error Rate* ($\chi2$ (1) = 70.27, $p < .0001$) with items in condition 'NonEx1' yielding significantly higher *Error Rates* than items in 'NonEx2' with no lexicalized intermediate position. The analysis also revealed a main effect of *Syntactic Category* ($\chi2$ (1) = 67.26, $p < .0001$) with significantly higher error rates induced by verbal than by adjectival bases. A summary of results is given in Table 6.1.

Table 6.1 *Summary of Error Rate as a function of Syntactic Category of base word and type of Base (%)*

	ADJECTIVAL BASE	VERBAL BASE
NONEX1	47.2	78.4
NONEX2	17.5	46.5

The interaction between the two factors was far from significant ($p > .90$). Overall, we thus see that the effect of the lexical status of the intermediate position was independent of the effect of the syntactic category of the base and intermediate position. Put differently, pseudowords without lexicalized intermediate position and adjective-based formations were found to be easier to classify as nonwords. Indeed, the reasons for this could be driven by differences in phonological transparency (as predicted by *Morphological Race* models), which render complex pseudowords with stem vowels differing from the related base word less 'word-like'. This, in turn, would facilitate the rejection of these nonwords. Following up on these results, we restricted our analysis to adjective-based pseudowords and the effect of *umlaut* application on *Error Rates.* No significant effect of stem vowel alternation between base and novel word formation was found ($p > .84$), indicating that the observed effect of syntactic category of the base on the responses to the complex item was not solely driven by the higher occurrence of phonological alternations between bases and complex noun formations for adjective-based items. A more parsimonious account would refer to differences in length between adjective- and verb-based complex pseudowords as a possible factor contributing to the modulation of accuracy measures: adjective-based pseudowords are on average a syllable shorter, therefore giving the processor more time to make an accurate lexical decision. These discrepancies in word length were inevitable given the design of the present study. Verb-based formations included two suffixes and therefore resulted in the formation of nouns that were not only significantly longer, but also appeared superficially more complex due to the presence of an additional suffix. In future investigations, it might be worthwhile to further differentiate between effects stemming from the type of morphological operation involved during processing (e.g. to disentangle effects of zero-derivation from those of affixation) and effects that simply relate to the syntactic category of the base word. In order to control for surface-level differences pertaining to word length and syllable number, the sequences of morphological operations employed to create a derivational chain would need to be selected carefully. In this context, it is noteworthy that zero-derived verbs can also take nominal bases. The formation of the verb *faxen* (V., 'to fax') is reliant on the noun *Fax* (N., 'fax') – a short form for *Faxgerät* designating a piece of equipment used for transmission of scanned documents. Further derivation to an action noun **Faxung* would run in parallel with the analysis of internal levels of composition for items such as **Spitzung* (*spitz* - *spitzen* - **Spitzung*). In a similar vein, it should be possible to identify a multitude of nouns that do not commonly undergo a morphological process of *conversion* and subsequent suffixation with -*ung*, thereby providing a noun-based counterpart to our condition 'NonEx2' (*hübsch* - **hübschen* - **Hübschung*). These future manipulations might enable us to disentangle the relative contribution of type of word class and composition of derivational chain to the overall task of morphological structure detection in pseudowords.

The aforementioned follow-up analyses of response accuracies to prime words and pseudowords as a function of phonological transparency and syntactic category of the base word were also complemented by an assessment of the degree to which the influence of these factors was reflected in the activation of the base word. For this purpose, the degree of facilitation in the reaction to a base word in Experiment 3 was inspected depending on the syntactic category of the base and the type of derivational chain ('NonEx1' vs. 'NonEx2'). In a model containing the fixed effects of *Prime Type* (Related vs. Unrelated), *Base* ('NonEx1' vs. 'NonEx2') and *Syntactic Category* (Adj. vs. Verb) and random effects for *Participants* and *Targets*, significant effects on the dependent variable *RT* were evident for the main effects of *Prime Type* ($p < .0001$) and *Syntactic Category* ($p < .001$); as well as the interactions between *Prime Type* and *Base* ($p < .05$) and *Prime Type* and *Syntactic Category* ($p < .05$). The effects of *Prime Type* and *Prime Type x Base* were already examined in Chapter 3, where we provided possible explanations for the stronger degree of priming between morphologically related items that have a lexicalized word in the intermediate position. The main effect of *Syntactic Category* with longer response latencies to verbal than to adjectival bases was likely to be driven by – or at least confounded with – stimulus length. As was already the case for the prime word analysis, these effects are not of direct linguistic interest to us and will need to be controlled for in further investigations. The interaction between *Prime Type* and *Syntactic Category*, on the other hand, provided a more promising insight into the subtle differences in processing depending on the morphological classes under investigation, thereby offering new avenues for future research. Overall, it was found that priming effects for verbs were more substantial than for adjectives, suggesting that morphological complexity that is expressed overtly through affixation possibly offers a more direct route for morphological decomposition to apply. As already manifested in the responses to complex items, the application of *umlaut* did not appear to have an effect on the degree of priming.

Note that the above results need to be interpreted with caution since our original experiments were not designed with these additional considerations in mind. Nonetheless, these initial insights suggest that while phonological transparency (understood as the phonological consistency of the stem vowel between morphological relatives) may not affect recognition, other properties relating to the type of morphological process involved may be salient in furthering our understanding of morphological complexity processing.

Additional manipulations that relate to the 'inherent' properties of morphological alternations could draw on the notion of semantic coherence. In this context, all stimuli employed in the present study were chosen to be semantically compositional with regard to the meaning attached to the derived word based on the meaning of its base. To give an example, the existing zero-derived *spitzen* exhibits coherence in meaning in relation to its base *spitz* – the causative verbal derivation designates a causation of change of state expressed by the adjective *spitz*. There also exist, however, pairs of base adjectives and verbs such as *reich* (A., 'rich') and *reichen* (V., 'to suffice', 'to reach') that display a certain degree of meaning overlap, but do not express the expected causative (or inchoative) meanings that a de-adjectival zero-derived verb usually assumes. The question could be raised to what extent a novel form such as **Reichung*, derived on the basis of the verb *reichen*, would activate a formally and semantically similar word such as *reich*. From a diachronic perspective, the relationship between *reich* (A., 'rich') and *reichen* (V., 'to suffice', 'to reach') is far from transparent, with a possible link via the noun *Reich* (N., 'realm'), but with more accidental overlap in both form and meaning also being a possibility. The degree to which novel formations such as **Reichung* - which, as we have argued throughout this thesis, require the availability of a verbal base form for derivation - would activate embedded adjectives such as *reich* could be informative with regard to the relevance of semantic coherence in the interpretation of morphological complexity in novel forms.

6.4.2 Building on 'distributional' properties in further investigations into morphological complexity processing

Note also that we have restricted our study of processing patterns for novel complex forms to sequences of morphological processes that are of reasonable productivity. Morphological productivity as such is undoubtedly a concept for which an uncontentious definition would warrant an investigation of its own with Mayerthaler (1981, p. 124) referring to it as one of the most elusive concepts in linguistics. Nonetheless, there is a sense in which the most basic approach to morphological productivity incorporates a sense of possibility for generalization of existing patterns onto novel forms. In view of the processing patterns we have been describing, this would involve the recognition of structural elements, as well an attempt at a lexical-semantic interpretation in view of prior knowledge. By submitting formations such as **greenth* to psycho- and neurolinguistic investigation, the possibility will become available of understanding whether or not the recognition of morphological structure in non-existent items is restricted to productive morphological processes or can be abstracted to apply to novel forms on the basis of a small set of existing attestations (e.g. *warmth*, *breadth* etc.).

The results described throughout this thesis have shown that the recognition of morphological structure can be tested empirically. Therefore, the extension of psycholinguistic investigation to further examples of word formation processes will enable us to gain a more in-depth understanding of the kind of pattern recognition processes that underlie morphological complexity processing in novel forms. While we have argued for sensitivity to abstract knowledge of morphological structure throughout the present study, the incorporation of a wider number of structural relationships between morphologically related words will shed light on the nature of this abstract knowledge: is it based on morphological 'rules' or can analogies be established based on a handful of known examples?

When Frauenfelder and Schreuder (1992) referred to distributional properties of complex words, what was at stake was also the frequency of occurrence of the complex word and not just the frequency of rule-application as discussed above. Now, the assumption of the present study has been that our novel formations such as **Spitzung* and **Hübschung* would have been unfamiliar to our participants. However, as soon as participants encounter these formations once, it can be expected that a memory trace is created for a given item. In future investigations, it therefore could be insightful to examine the 'learnability' of a given item. Repeated exposure to previously unencountered formations could be informative with regard to the mechanisms that are recruited during the integration and learning process of a novel form. Especially from the point of view of neuroimaging, the observed parcellation of the fronto-parietal network into separate subregions might enable us to track changes from a focus on structural analysis to lexical-semantic integration as the novel formations transition to being interpreted as low-frequency rather than non-existent items. In the context of this follow-up question, it would be insightful to examine whether or not repeated exposure to our different sets of novel formations (**Spitzung* versus **Hübschung*) would show different effects during the integration phase as familiarity with both sets increases, depending on the lexical status of the intermediate position. Recall that when differences were discernible throughout the current experiments for the first presentation with our novel formations, the argument was made that these differences were partly driven by the fact that the intermediate form was not readily available, but had to be computed 'on-line'. If this is indeed the process that underlies the first analysis that is applied to these novel formations, then one implication could be that the novel formation as well as the intermediate position, increases in familiarity as participants become more accustomed to the pseudonouns. Under such an interpretation, differences between the two sets could level out, meaning that the repeated activation of both forms could obliterate any initially predominant distinctions between the two sets. On the other hand, if processing differences persist, then the argument could be made that lexicalization does not occur at these early stages of novel word integration and memory trace formation. Instead, sensitivity to internal levels of morphological composition would be shown not to be restricted to unencountered formations in its effect on the processing of morphological complexity. Consequently, this would provide even stronger support for the salience of morphological complexity and depth of derivation as factors that continue to shape the word recognition process.

As we gather more and more evidence for the psychological reality of the brain's sensitivity to derivational depth, more questions that continue to be tackled in linguistic research with regard to the derivational paths that underlie certain formations may be addressed using psycho- and neurolinguistic methodologies. One such question has direct relevance to the types of formations studied in the present set of experiments. To give an example, as argued by Plank and Lahiri (2015) in response to Nichols, Peterson and Barnes (2004), the German language displays strongly transivitising patterns overall. These tendencies are apparent in certain pairs of valency-changing verbs such as *lahmen* (V., 'to limp') and *lähmen* (V., 'to paralyse') or *kranken* (V., 'suffer from') and *kränken* (V., 'to hurt') in which the former denotes an intransitive while the umlauted form gives rise to a transitive structure with causative meaning. In a comprehensive survey of nearly all existing basic adjectives and a representative sample of nouns, Plank and Lahiri (2015) demonstrate that the pervasiveness of umlaut in the transitive and the lack thereof in the intransitive dominates in the distribution of existing patterns. When an umlauted stem vowel is present in the intransitive as is the case for *nass* (A., 'wet') > *nässen* (V., 'to be wet'), there is a strong tendency for the corresponding transitive verb to carry the umlaut as well as in *nässen* (V., 'to make wet'). The occurrence of the opposite pattern, whereby the umlauted stem vowel would surface in the intransitive while the transitive would maintain the back vowel present in the base word as is the case for *wahr* (A., 'true') > *währen* (V., 'to last') versus *wahr* (A., 'true') > *wahren* (V., 'to maintain, preserve'), is restricted to a small number of verb pairs. For this latter example, Plank and Lahiri (2015) note that their semantic relationship is of a rather opaque nature, thereby supporting the overall conclusion that *umlaut* application, if observed, is more commonly instantiated in the derivation of the transitive and that if umlaut is already found in the intransitive, the corresponding transitive verb will follow suit. This point is critical given the directionality of derivation that is indexed by the umlaut. More specifically, Plank and Lahiri (2015, p. 39) refer to the absence of 'DE-umlauting as a morphological exponent' and the implication this has for the derivational relationship between two words: umlaut will inevitably signal the derived status of a word in a pair of items in which one carries and the other does not carry umlaut. On the basis of this, the question raised by Plank and Lahiri (2015) relates to the derivational relationship expressed between intransitive and transitive verb pairs. The derived status of transitive verbs as expressed in their umlauted stem vowels could emanate from de-adjectival derivation in one step from the base as we have been assuming throughout the present study (e.g. *krank* (A., 'ill') > *kränken* (V., 'to hurt)). Alternatively, one could postulate the derivation via two steps with intransitive verbs in intermediate position (e.g. *krank* (A., 'ill') > *kranken* (V., 'to suffer from') > *kränken* (V., 'to hurt')). The authors lean towards the former explanation in view of the necessity of positing otherwise the derivation of transitives via derivational gaps for intransitives. To give an example, the transitive verb *zähmen* (V., 'to tame') would then be required to proceed via a non-existent **zahmen* in its formation, yielding the derivational chain *zahm* (A., 'tame') > **zahmen* (V., 'to become tame') > *zähmen* (V., 'to tame'). The number of existing transitive verbs without corresponding intransitive formations is indeed a strong argument against their derivation by means of a 2-step process.

As seen throughout the present study, the number of derivational steps involved in the formation of a derived word can modulate the word recognition process. Similarly, the processing cost associated with decomposition across a lexical gap within the derivational chain has been shown to become evident during processing. A psycho- and neurolinguistic investigation of the relevant patterns using the methodologies on which we have drawn throughout the present study may offer additional support for the intuition expressed in Plank and Lahiri (2015) that both types of verbs are derived in a single step from a shared base adjective.

Overall, we thus find that the interaction between linguistic analysis and psycholinguistic experimentation could benefit from a stronger focus on the consideration of research questions that can only be tackled using both perspectives. The future directions of research into morphological complexity processing will have to be shaped by pertinent questions in which a purely linguistic analysis may incline us one way or another and psycholinguistic investigations may help us decide between two linguistically equally sound explanations. Psycholinguistic research, conversely, will need to build on these questions to provide a truly representative account of the mental representation of language. Before these motivations can be turned into reality, it is necessary to place the questions we have been addressing in a wider theoretical context. This will be attempted in the next section.

6.5 Future directions

In the present study, the main focus of our research has been on the processing of novel forms. As laid out in section 6.4, the next step could involve an investigation into the learnability of these different sets of novel forms to see whether or not the **Spitzung* set is not only accepted more easily as a possible word, but is indeed also integrated more rapidly into our mental lexicon.

Taking a step back, we can already claim that on the basis of the present results, there is strong evidence for predicted differences in learnability. After all, we can expect that items that display processing advantages during first-time presentation such as **Spitzung*, which activated their base more strongly than **Hübschung*, will continue to consolidate the already tighter relationship to the base *spitz* upon subsequent presentations. Moreover, we find additional substantiation for these predictions in the form of an entirely different type of evidence: the absence of existing complex nouns in -*ung* and -*barkeit* that possess an existing base, but no lexical representation for the intermediate derivation.

That is to say, during the selection of stimuli for the present study, we did not encounter any existing suffixed noun forms formed according to the derivational pattern given below:

base word > *intermediate derived form > final noun form

Put differently, we do not find lexical gaps in intermediate positions within a derivational chain while these can and do occur at the edges. Indeed, a search for formations in -*ung* in CELEX (Baayen et al., 1995) only yielded two formations for which a preceding verbal base word was not readily apparent: *Zeitung* (N., 'newspaper') and *Innung* (N., 'guild'). When inspecting the etymology of these two items in the DWDS (Klein & Geyken, 2010), however, we find that both words were originally derived from verbs that are no longer in use. Thus, *Zeitung* (V., 'newspaper') is considered a derivate of the corresponding German cognate of the Middle Dutch verb *tīden*, meaning 'to strive for something' or 'to head somewhere'. Similarly, for *Innung* (N., 'guild'), the corresponding base verb has fallen out of use, but can be traced back to the Old High German *innōn* (V., 'to accept'). What this means is that lexical gaps are attested at the edges of a derivational chain and there are two possible reasons why lexical gaps occur:

(1) the relevant formations are not attested (yet), but constitute possible words or (2) previously attested bases have fallen out of use and are thus no longer attested. The former will occur at the right edge of a derivational chain whereas the latter leave a lexical gap at the leftmost position of an otherwise populated derivational chain.

Now, is it really the case that no lexical gaps in intermediate positions can be identified? After all, the results obtained in the present study pointed to the possibility of decomposing novel forms such as **Hübschung* across a lexical gap in **hübschen*. The situation is dissimilar to the extent that **Hübschung* itself is evidently not an existing word and the derivational chain under examination is therefore not discontinuous. Nonetheless, the presence of a priming effect for novel forms that were formed across lexical gaps may be taken to indicate that lexical gaps in intermediate positions do not present insurmountable processing costs.

Indeed, it is possible to identify formations like the prefixed verb *enthaupten* (V., 'decapitate') that appear to have been formed across lexical gaps. The prefix *ent-* has a reversative meaning and commonly attaches to verbs, as we find to be the case for the examples *entgleiten* (V., 'to get out of control') from *gleiten* (V., 'to glide') or *entleeren* (V., 'to empty') from *leeren* (V., 'to empty, to clear'). In *enthaupten*, on the other hand, no existing verbal base **haupten* is available as only a noun *Haupt* (N., 'head') exists. One possibility for interpretation could be that *enthaupten* is analyzed as [ent-[[haupt$_N$]-en]$_V$]$_V$, whereby a non-existent, but possible zero-derived verb **haupten* is derived first before it is prefixed in a second step. An inspection of the etymology for *enthaupten* in the DWDS (Klein & Geyker, 2010) indeed reveals that a corresponding simplex verb *houbeten* was available in Old High German, but has fallen out of use since, thus yielding a continuous, 'gapless' derivational chain at an earlier stage of the language. Other prefixed verbs in *ent-* such as *entgleisen* (V., 'derail') from *Gleis* (N., 'track, platform') > **gleisen* are not as easily explained. Possible explanations draw on a common root **leis-*, meaning 'groove' or 'a trace left on the ground' from which both *Gleis* (N., 'track, platform') and *leisten* (V., 'to achieve') have been derived, thereby again providing support for the continuity of derivational chains with regard to non-peripheral positions - if not synchronically, then at least at a particular stage of the language.

We thus find substantiation for the claim that derivational chains are not discontinuous at the time when a novel formation enters a language. It appears that intermediate lexical gaps do occur, but they only arise once the subsequent derivational step has already led to the formation and possibly lexicalization of a derived word. At the time at which a novel derived word is coined, however, it does appear to be the case that the preceding base is preferably an actual, rather than just a possible word, demonstrating thereby the step-wise application of processes of word formation. Building on the previously used example of *enthaupten*, this is reflected in the availability of a nominal -*ung* derivation in *Enthauptung* (N., 'decapitation') derived from *enthaupten* while the non-prefixed **Hauptung* from **haupten* is not available. Interestingly, some corresponding English examples for which apparent intermediate lexical gaps exist can also be accounted for on the basis their etymology. To give an example, the reversative prefix *de-* in English can attach to verbs as in *demystify* or *decompose*, but for a number of instances, the syntactic category of the base can be arguably interpreted as either a verb or a noun. These include the verbs *degrade*, for which the base *grade* exists both in a nominal and a verbal form, or similarly, the verb *decode*. In other cases such as *derail*, on the other hand, it seems that only a nominal base is available. A corresponding verbal base **rail*$_V$ does not exist, suggesting that the prefixed verb *derail* must have either been derived from a nominal base *rail*$_N$ or via a non-existent zero-derived verb *rail*$_V$. Again, the etymology of the word can provide valuable insights as to how the lexical gap may have come about: according to the *Oxford English Dictionary*, the verb *derail* was borrowed from modern French *dérailler* (V., ‘to go off the rails’) at around 1850. In this case, it is indeed possible that the prefixed verb was borrowed holistically from Modern French without access to its morphological structure and the constraints that govern the formation of prefixed verbs in English. These explanations do not hold for all existing prefixed verbs in *de-* in English, given the existence of formations such as *defrost* for which it does appear that the prefix *de-* either attaches to the existing nominal form *frost* or a non-existent zero-derived verb. In the latter case, this would point to the formation of morphologically complex words across lexical gaps in derivational chains - contrary to the observations with regard to the absence of lexical gaps in derivations that have informed the present study.

In this context, it is, of course, critical not to ignore the observation that the ‘gapless’ derivational chains that have formed the focus of investigation in the present study have been exclusively reliant on suffixation. The examples we have advanced in which intermediate gaps do appear to surface, on the other hand, have been restricted to prefixation processes. In a number of cases we have been able to provide accounts as to how these gaps may have come about synchronically while cases such as *defrost* in English present a more intricate scenario in which prefixation via a zero-derived and non-existent verb **frost* has to be considered if we are to adhere to the principles of the *Unitary Base Hypothesis.*

The future directions that the research presented in this thesis opens up will be guided by the question whether there might be inherent differences in the viability of lexical gaps between different types of processes, namely prefixation versus suffixation. Is it possible that given the incremental nature in which the speech signal is presented in the auditory domain, prefixation processes must be inherently much more flexible with regard to possible continuations? These intuitions are grounded in the argument that prefixed words - when presented auditorily - create more ambiguity for the listener with regard to the structure of the complex word. At the point at which the listener encounters and identifies the prefix, the complex word in its entirety could still be either just prefixed or both prefixed **and** suffixed. In the latter case, there are a greater number of combinatorial options with regard to the morphological structure of the complex word. For suffixed words, on the other hand, it is important to take into account that once the listener gets to the suffix in auditorily presented words with morphological complexity, it is already clear whether or not the complex word is also prefixed or not, thereby limiting the number of structural possibilities that the listener has to entertain in order to parse and understand a morphologically complex word. To provide an example in English, the complex word *unhelpful* is parsed as [un-[[help]$_v$-ful$_A$]$_A$, meaning that upon encountering prefixes such as *un-*, English native speakers need to consider the possibility of an auditorily presented non-existent item **unhelp* before the correct underlying structure can be assigned. The need to entertain two viable underlying structures until the entire word has been processed - depending on whether it will be suffixed or not - demands greater reliance on flexibility on the part of the parser while the acoustic signal and the required morphological parse appear to be more isomorphic in multi-suffixed complex words.

Whether or not these observations bring to bear on any commonly noted asymmetries in the distribution of prefixes and suffixes across languages (e.g. Hyman, 2008) remains to be investigated. Future experimental work on the processing of lexical gaps in derivational chains, however, may be able to draw on the integration of morphological complexities in prefixed words with and without lexical gaps in order to establish whether or not these asymmetries will translate into how existing words and possible pseudowords are interpreted in real time.

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Appendix A: Stimulus matching related versus unrelated primes (Chapter 3)

Table 3.4 Means and standard deviations for matched stimuli characteristics between related and unrelated sets for test and control items (Experiment 3). Note that all numbers are rounded to the second decimal.

	Extant *Heilung*		**NonEx1** **Spitzung*		**NonEx2** **Hübschung*		**Form Control Extant**		**Form Control NonEx**		**Semantic Control**	
Prime word length	Related 9.25 (2.15)	Unrelated 8.88 (1.80)	Related 9.46 (2.15)	Unrelated 9.38 (2.30)	Related 9.5 (2.28)	Unrelated 9.21 (1.91)	Related 9.38 (2.06)	Unrelated 9.33 (2.00)	Related 9.29 (1.55)	Unrelated 9.33 (1.90)	Related 9.29 (2.12)	Unrelated 9.25 (1.54)
	p = 0.27		p = 0.78		p = 0.37		p = 0.92		p = 0.9		p = 0.94	
Prime word frequency	Related 8.13 (13.85)	Unrelated 8.04 (13.10)	Related N/A stem word frequency prime: 98.54 (167.86)	Unrelated N/A stem word frequency prime: 103.71 (162.10)	Related N/A stem frequency prime: 97.38 (74.61)	Unrelated N/A stem frequency prime: 91.71 (67.81)	Related 6.38 (13.93)	Unrelated 6.04 (13.60)	Related N/A stem word frequency: 92.38 (117.39)	Unrelated N/A stem word frequency prime: 90.04 (128.93)	Related 7.79 (15.68)	Unrelated 7.71 (14.80)
	p = 0.82		p = 0.88		p = 0.62		p = 0.39		p = 0.94		p = 0.90	
Prime lemma frequency	Related 9.25 (14.66)	Unrelated 9.67 (15.11)	Related N/A stem lemma frequency prime: 370.08 (587.45)	Unrelated N/A stem lemma frequency prime: 319.38 (560.58)	Related N/A stem lemma frequency prime: 284.71 (211.48)	Unrelated N/A stem lemma frequency prime: 322.63 (292.20)	Related 6.92 (14.93)	Unrelated 7 (15.02)	Related N/A stem lemma frequency: 384.75 (593.52)	Unrelated N/A stem lemma frequency prime: 298.17 (417.49)	Related 9.29 (18.33)	Unrelated 7.71 (14.80)
	p = 0.73		p = 0.7		p = 0.55		p = 0.91		p = 0.54		p = 0.94	

Appendix A: Target stimulus matching across conditions

Table 3.5 Means and standard deviations for matched stimuli characteristics across test and control items (Experiment 3). Numbers are rounded to the second decimal. Note: Extant = {+ Morph, + Extant, + Extant intermediate item}; NonEx1 = {+ Morph, -Extant, + Extant intermediate item}; NonEx2 = {+ Morph, - Extant, - Extant intermediate item};

	Extant ***Heilung***	**NonEx1** ****Spitzung***	**NonEx2** ****Hübschung***	**Form Control Extant**	**Form Control NonEx**	**Semantic Control**	**Results one-way ANOVA**
Target word length	5.25 (1.30)	5.46 (1.32)	5.5 (1.44)	5.21 (1.14)	5.58 (1.35)	5.42 (1.35)	p = 0.92
Target word frequency	95.71 (99.03)	98.54 (167.86)	97.38 (74.61)	98.46 (133.76)	92.38 (117.39)	90.83 (76.48)	p = 0.99
Target lemma frequency	258.04 (255.17)	370.08 (587.45)	284.71 (211.48)	305.21 (498.33)	384.75 (593.52)	319.04 (384.28)	p = 0.92
Orthographic family size	7.71 (3.98)	6.13 (3.15)	6.92 (5.26)	6.38 (5.11)	6.96 (4.89)	5.50 (4.09)	p = 0.62
Phonological family size	13.54 (7.75)	11.33 (9.17)	11.50 (7.73)	11.67 (9.40)	11.63 (8.21)	10.67 (9.91)	p = 0.92
Morphological family size	43.21 (35.17)	27.58 (21.18)	26.04 (23.44)	23.29 (15.28)	32.38 (60.70)	21.67 (17.30)	p = 0.23

Appendix B: Stimulus set behavioural experiments

Stimuli Experiment 1:

<u>Condition</u>

Extant

Unrelated Prime	Related Prime	Target
SENKEL (‘lace’)	KÜHLUNG (‘cooling’)	KÜHL (‘cool’)
DÄUMCHEN (dim. ‘thumb’)	BRÄUNUNG (‘browning’)	BRAUN (‘brown’)
LASTZUG (‘freight train’)	ZÄHMUNG (‘taming’)	ZAHM (‘tame’)
MAHNUNG (‘warning’)	HEILUNG (‘healing’)	HEIL (‘whole, intact’)
ORTSCHAFT (‘village’)	SCHWÄCHUNG (‘weakening’)	SCHWACH (‘weak’)
GLÖCKCHEN (dim. for ‘bell’)	SÄUBERUNG (‘cleaning’)	SAUBER (‘clean’)
ABLUFT (‘exhaust air’)	REIFUNG (‘ripening’)	REIF (‘ripe’)
DECKEL (‘lid’)	RÖTUNG (‘reddening’)	ROT (‘red’)
ABSPRUNG (‘jump’)	KRÄNKUNG (‘hurt’)	KRANK (‘ill’)
FAULTIER (‘sloth’)	GLÄTTUNG (‘smoothening’)	GLATT (‘smooth’)
AUFFAHRT (‘driveway’)	HÄRTUNG (‘hardening’)	HART (‘hard’)
BLENDEN (‘blinding’)	WÄRMUNG (‘warming’)	WARM (‘warm’)
BREMSEN (‘braking’)	TÖTUNG (‘killing’)	TOT (‘dead’)
BIEGUNG (‘bend, lean’)	SCHLICHTUNG (‘arbitration’)	SCHLICHT (‘simple’)
LUTSCHER (‘lollipop’)	KRÜMMUNG (‘bending’)	KRUMM (‘bent’)
FESTTAG (‘festive day’)	LÄHMUNG (‘paralysis’)	LAHM (‘lame’)
ABSTREICHER (‘doormat’)	TEILBARKEIT (‘divisibility’)	TEILEN (‘divide’)
NÖTIGUNGEN (‘coercion’)	WÄHLBARKEIT (‘eligibility’)	WÄHLEN (‘elect’)
GLÄUBIGER (‘creditors’)	SICHTBARKEIT (‘visibility’)	SICHTEN (‘view’)
VOLLTREFFER (‘bull’s eye’)	KOSTBARKEIT (‘value’)	KOSTEN (‘cost’)
HEUSCHNUPFEN (‘hayfever’)	MISCHBARKEIT (‘miscibility’)	MISCHEN (‘mix’)
GIERIGKEIT (‘greediness’)	HEILBARKEIT (‘curability’)	HEILEN (‘cure’)

AUGENARZT(‘ophthalmologist’)	REIZBARKEIT (‘irritability’)	REIZEN (‘irritate’)
ELLBÖGEN (‘elbows’)	MESSBARKEIT (‘measurability’)	MESSEN (‘measure’)
HALSAUSSCHNITT (‘neckline’)	GREIFBARKEIT (‘tangibility’)	GREIFEN (‘grasp’)
ÜBERSTRUMPF (‘stocking’)	TRENNBARKEIT (‘separability’)	TRENNEN (‘separate’)
TROSTWORTE (‘consolation’)	ACHTBARKEIT (‘respectability’)	ACHTEN (‘respect’)
PFLAUMENBAUM (‘plum tree’)	FORMBARKEIT (‘formability’)	FORMEN (‘form’)
AUSSTOPFUNG (‘stuffing’)	BRENNBARKEIT (‘combustibility’)	BRENNEN (‘burn’)
DOPPELHEIT (‘duplexity’)	EHRBARKEIT (‘respectability’)	EHREN (‘respect’)
DIENSTZEITEN (‘office hours’)	LESBARKEIT (‘legibility’)	LESEN (‘read’)
GALLENSTEIN (‘gallstone’)	DANKBARKEIT (‘gratitude’)	DANKEN (‘thank’)

Unrelated Prime	**Related Prime**	**Target**
WILDUNG	LIEBUNG	LIEB (‘lovely’)
BREITTUM	LÄUTUNG	LAUT (‘loud’)
LASSHEIT	GRÜNUNG	GRÜN (‘green’)
STRIKTNIS	BLEICHUNG	BLEICH (‘pale’)
PROMPTTUM	FETTUNG	FETT (‘fat’)
ZÄHNIS	FEUCHTUNG	FEUCHT (‘humid’)
STRENGANZ	LEIDUNG	LEID (‘sorry’)
SCHEUNIS	NÄSSUNG	NASS (‘wet’)
FRISCHTUM	SÜßUNG	SÜß (‘sweet’)
DÜRRUNG	SPITZUNG	SPITZ (‘sharp’)
BLOßHEIT	SCHWÄRZUNG	SCHWARZ (‘black’)
DICHTNIS	ENGUNG	ENG (‘narrow’)
ECHTUNG	STILLUNG	STILL (‘quiet’)
HEITERTAG	WELKUNG	WELK (‘withered’)
BLÄNKUNG	WETTUNG	WETT (‘equal’)
SCHRÄGTUM	WEICHUNG	WEICH (‘soft’)

RÄCHITUR	TASTBARKEIT	TASTEN (‘feel’)
JAGBARKEIT	SCHEINBARKEIT	SCHEINEN (‘seem’)
SICHERSCHAFT	ZAHLBARKEIT	ZAHLEN (‘pay’)
NEIGBARKEIT	BEUGBARKEIT	BEUGEN (‘bend’)
WAHRBARKEIT	SPÜRBARKEIT	SPÜREN (‘sense’)
ATMESCHAFT	FASSBARKEIT	FASSEN (‘fathom’)
ÖFFNEBARKEIT	WASCHBARKEIT	WASCHEN (‘wash’)
ERNTITION	FURCHTBARKEIT	FÜRCHTEN (‘fear’)
TANZITION	DRUCKBARKEIT	DRUCKEN (‘print’)
HEIßEREI	STREICHBARKEIT	STREICHEN (‘paint’)
EINFÖRDERN	DENKBARKEIT	DENKEN (‘think’)
PASSATION	BIEGBARKEIT	BIEGEN (‘bend’)
ANKERSCHAFT	TRINKBARKEIT	TRINKEN (‘drink’)
GRÜßATION	FÜHLBARKEIT	FÜHLEN (‘feel’)
GRINSITEUR	HEIZBARKEIT	HEIZEN (‘heat’)
BITTBARKEIT	WUNDERBARKEIT	WUNDERN (‘wonder’)

Filler items

BÜNDEL (‘bundle’)	BUNT (‘colourful’)
TÄUBLEIN (diminutive ‘pigeon’)	TAUB (‘deaf’)
FÜHLER (‘sensor’)	FRÜH (‘early’)
KALBSBLUT (‘calf blood’)	KALT (‘cold’)
REIFEN (‘wheel’)	REICH (‘rich’)
SCHAFKOPF (type of card game)	SCHARF (‘spicy’)
FLÄSCHCHEN (dim. for ‘bottle’)	FLACH (‘flat’)
ROHRBRUCH (‘pipe bursting’)	ROH (‘raw’)
FILTRATION (‘filtration’)	FILMEN (‘film’)
FAHRGENUSS (‘pleasure of driving’)	FRAGEN (‘ask’)
AHNENBILD (‘ancestral portrait’)	AHNDEN (‘punish’)

KLEEBLÄTTER (‘shamrock’; pl.)	KLEBEN (‘glue together’)
DEUTSCHLÄNDER (‘type of sausage’)	DEUTEN (‘interpret’)
FUGENSCHNITT (‘cut of the tiles’)	FÜGEN (‘join, connect’)
FROSCHKÖNIG (‘Frog Prince’)	FORSCHEN (‘research’)
DAUNENBETT (‘down duvet’)	DAUERN (‘last’)
VORBAU (‘porch’)	PRÜDE (‘prude’)
ZUFAHRT (‘driveway’)	SCHEU (‘shy’)
MEHRWERT (‘surplus’)	ENG (‘tight’)
GÄRUNG (‘fermentation’)	HELL (‘light’)
EINSCHLUPF (‘slip’)	MATT (‘mat’)
FÄDLEIN (dim. for ‘thread’)	NETT (‘nice’)
LAUHEIT (‘tepidity’)	HEIß (‘hot’)
DECKUNG (‘backing’)	ARG (‘bad’)
BUCHUMSCHLAG (‘book cover’)	FANGEN (‘catch’)
EINSTÜRZEN (‘collapse’)	BETEN (‘pray’)
ABLASSBRIEF (‘letter of indulgence’)	LERNEN (‘learn’)
SCHUSSWEITE (‘range of fire’)	KLINGEN (‘sound’)
PATENSCHAFT (‘sponsorship’)	GRABEN (‘dig’)
KANONIST (‘canonist’)	PLATZEN (‘burst’)
HERGÄNGE (‘course of events’)	ROLLEN (‘roll’)
GEQUATSCHE (‘chat’)	SPAREN (‘save’)
STEILANG	STEIL (‘steep’)
RÄUING	RAUH (‘raw’)
PLÜMPANG	PLUMP (‘plump’)
WERTINZ	WERT (‘worth’)
KLEINING	KLEIN (‘small’)
TÖLLONZ	TOLL (‘great’)
FLÖTTINZ	FLOTT (‘speedy’)
BÄRONZ	BAR (‘in cash’)
SCHÄTZIGMUT	SCHÄTZEN (‘gauge’)
KEHRISCHMUT	KEHREN (‘sweep’)
SPANNLICHMUT	SPANNEN (‘strain’)

HASSISCHMUT	HASSEN (‘hate’)
RAUCHIGSCHAFT	RAUCHEN (‘smoke’)
TUMMIGMUT	TUMMELN (‘scrimmage’)
WAGIGMUT	WAGEN (‘dare’)
SCHLAFIGNIS	SCHLAFEN (‘sleep’)
HELLANG	TREU (‘faithful’)
DÜNNANG	BLASS (‘pale’)
FROMMINZ	SCHIER (‘pure’)
RASCHING	SCHLECHT (‘bad’)
QUERING	GROB (‘rough’)
SANFTONZ	FREMD (‘unfamiliar’)
KNAPPANG	TIEF (‘deep’)
ZÄHING	STRAMM (‘tight’)
LINDERISCHNIS	FLATTERN (‘flutter’)
FÜGICHSCHAFT	TRAUEN (‘trust’)
FLUCHISCHNIS	LEISTEN (‘achieve’)
SPIELLICHSCHAFT	DEHNEN (‘stretch’)
FOLGLICHSCHAFT	LEGEN (‘place’)
STÜRZISCHMUT	WEISEN (‘show’)
PAARLICHSCHAFT	FASTEN (‘fast’)
LEUGNISCHMUT	WARNEN (‘warn’)
FEHLEN (‘lack’)	LEER (‘empty’)
UMKREIS (‘radius’)	NAH (‘close’)
AUSMAß (‘extent’)	HÖCHST (‘highest’)
ALTER (‘age’)	JUNG (‘young’)
SCHNELLE (‘speed’)	FIX (‘quick’)
HITZE (‘heat’)	FRISCH (‘fresh’)
UNLUST (‘reluctance’)	FAUL (‘lazy’)
VÖLLE (‘fullness’)	SATT (‘full’)
SCHMUTZIGKEIT (‘dirt’)	PUTZEN (‘clean’)
TREPPENHAUS (‘staircase’)	STEIGEN (‘step’)

GLÜCKSPIEL (‘gambling’)	RATEN (‘guess’)
CHORPROBE (‘choir rehearsal’)	SINGEN (‘sing’)
HANDWERKER (‘engineer’)	BOHREN (‘drill’)
EINDRINGLING (‘intruder’)	STÖREN (‘disturb’)
NACHRICHTEN (‘messages’)	MELDEN (‘notify’)
HALSSCHMERZEN (‘sore throat’)	HUSTEN (‘cough’)
WAHNSINN (‘madness’)	DERB (‘rough’)
BEFUND (‘indication’)	DICK (‘thick’)
NACHBAR (‘neighbour’)	GELB (‘yellow’)
GENUSS (‘consumption’)	LÄNGST (‘long ago’)
LAUBFÄLLE (‘fall of leaves’)	BILLIG (‘cheap’)
RECHTECK (‘rectangle’)	SANFT (‘soft’)
WANDLUNG (‘change’)	SCHLANK (‘thin’)
PRÜFUNG (‘examination’)	SPÄT (‘late’)
LAGERRAUM (‘storage room’)	HÜPFEN (‘jump’)
WEIGERUNG (‘refusal’)	NUTZEN (‘use’)
AUSSTATTUNG (‘equipment’)	LEIDEN (‘suffer’)
TAGUNGEN (‘conferences’)	ESSEN (‘eat’)
REINIGUNG (‘cleaning’)	SCHENKEN (‘give gift’)
SELIGER (‘blessed person’)	SCHIESSEN (‘shoot’)
ANSTRENGUNG (‘effort’)	SCHLIESSEN (‘lock’)
FÖRDERER (‘sponsor’)	MELKEN (‘milk’)

Nonword filler items

GRÄßUNG	GRÄß
GEULUNG	GEUL
PIRZUNG	PIRZ
ZEINUNG	ZEIN
KNUGUNG	KNUG

FULSCHGUT	FULSCH
SCHNAUUNG	SCHNAU
MALTUNG	MALT
WELTSUNG	KLAFT
FUNKTUNG	TRESS
KNEIDUNG	STRELL
LÄSUNG	SUFT
HÄHLUNG	BREUCH
ZÄULNIS	GLICK
SCHMEILER	FARSCH
MEICHTUM	SCHÜN
GADDBARKEIT	GADDELN
KÜMMBARKEIT	KÜMMEN
SCHREIDBARKEIT	SCHREIDEN
FULSCHBARKEIT	FULSCHEN
PEGERBARKEIT	PEGEN
RORRBARKEIT	RORREN
WECHSSAMKEIT	WECHSEN
PACHSAMKEIT	PACHEN
VERRATUNG	LEIGEN
ABENDFAHL	LEUBEN
TALEREI	KÄCHEN
VERSIEBTHEIT	SCHWEIMEN
VERMÄGISMUS	BITZEN
MUNDETUCH	SPECHEN
DEMANTIS	GRAUBEN
MÜTSAMKEIT	TIMMEN
STÄRGTUM	STARG
WÜLDLING	WULD
SPÖTNIS	SPÖT
FRÄHNIS	FRÄH

BLÄVLING	BLAV
SEßHEIT	SEß
DINNLING	DINN
FEUNKEIT	FEUN
ZUGFUHRT	LUNG
ZISCHLING	SCHWIRR
VERKUHR	GUR
DEHRUNG	LÜNG
DOHNZAUS	LEUB
VORTRISS	DÄNN
FÜRTNIS	KÄHL
VERDRIEB	WOLD
KNIEGISTIK	KNIEGEN
FÄGATION	FAGEN
SANNELSCHAFT	SANNELN
TANFATION	TANFEN
STRÜMEREI	STRÜMEN
TRINFITEUR	TRINFEN
DRUFFEREI	DRUFFEN
KONITION	KONEN
URGERNIS	ZEGEN
AUSMEHRUNG	REIDEN
GRIESAMKEIT	SCHNEIFEN
ERMISSLER	SUNNEN
AUFGABUNG	KELTERN
ZWEFERKEIT	FAUERN
ÜBERWENDUNG	SAUBEN
GENEISUNG	STRECHEN
KÜSTANG	KUST
MIRTING	MIRT
FREUMUNZ	FREUM

GRESONZ	GRES
KÜNFINZ	KUNFT
STÄßANG	STAß
NÄUANG	NAU
SCHLEUONZ	SCHLEU
KAGONZ	BLUCK
VAHLANG	LURT
SCHAUSING	STEICH
AUSWING	GLAU
EKNONZ	SAHM
BESORZ	HEIB
VORDANG	BLANN
STÄUONZ	MOSA
SPENSLICHSCHAFT	SPENSEN
KICHLICHSCHAFT	KICHELN
ZEIDIGSCHAFT	ZEIDEN
LAMMISCHNIS	LAMMEN
FOLBLICHSCHAFT	FOLBEN
MECHISCHNIS	MECHERN
STIRPIGNIS	STIRPEN
STINNISCHMUT	STINNEN
FOHLIGNIS	SCHMECHEN
GEUGISCHMUT	WÖHLEN
BITZIGSCHAFT	WECHEN
TERTIGMUT	MERTEN
SICHTIGSCHAFT	HUSEN
TRUTTISCHMUT	SCHLEUCHEN
BEIMLICHNIS	SPRONGEN
MÜTTISCHMUT	DRÜNGEN
NÄRRIN (‘fool’)	NÄRR
KALTBLUT (‘cold-blooded animal’)	KÄLT

RINGELCHEN (type of dish)	RINGELN
HÄLMCHEN (‘little spire’)	HÄLM
RÜCKLICHTE (‘back light’)	RÜCKLEN
SORGSAMKEIT (‘diligence’)	SORGSEN
HUFTIER (‘hoofed animal’)	HUFT
DOCKHAFEN (‘wet dock’)	DOKHEN
DURCHFAHRTEN (‘passage’)	DURCHFEN
DRÜCKER (‘knob’)	DRACK
ÖLFARBEN (‘oil paint’)	ÖRGEN
ENTCHEN (‘little duck’)	ENTZ
FLUGFUNK (‘aircraft radio’)	FLÜG
ÖLFILME (‘oil slick’)	ÖLFEN
KEUSCHHEIT (‘chastity’)	KESCH
IMPFUNGEN (‘vaccinations’)	IMPREN
TÄUFER (‘baptist’)	TAUF
ÖLBERGE (‘mount of olives’)	ÖLBEN
FLÖTIST (‘flautist’)	FLÖT
LANDHEIM (‘country house’)	LÄNDSCH
GUTSCHRIFTEN (‘crediting’’)	GUTSCHEN
KÖNIGTUM (‘kingdom’)	KÖNGTEN
ABSCHAUM (‘scum’)	ÄBSCH
HALBTON (‘semi tone’)	HÄLBEN
SCHALTHEBEL (‘gear lever’)	SCHABELN
FÜLLUNGEN (‘fillings’)	FAUEN
ZEITSINN (‘sense for time’)	ZEITSEN
HOCHSCHÜLER (‘university student’)	HÖCHSCHEN
WETTKÄMPFER (‘competitor’)	WETTKEN
LATTENZAUN (‘picket fence’)	LATTZEN
ZUCHTBULLE (‘breeding bull’)	ZUCHTBEN
SCHAFMILCH (‘sheep milk’)	SCHAFMEN
GRUNDSCHULEN (‘primary schools’)	VENDEN

VORKEHRUNG (‘precaution’)	MINKEN
NEHMER (‘taker’)	MELB
VORHALTUNG (‘remonstrance’)	VEIGEN
ABENDKURS (‘evening class’)	ARDEN
ÄTZUNG (‘cauterization’, ‘etching’)	ZACH
AUSBEUTUNG (‘exploitation’)	MARTEN
NÄSLEIN (dim. ‘nose’)	SLECHT
BACKZAHN (‘molar’)	NELCH
ABBAURECHT (‘mining concession’)	GERREN
JAGDWURST (type of sausage)	RANN
LICHTLEIN (dim. ‘light’)	GRALL
KREMPEL (‘junk’)	IRSCH
MUTWILLE (‘mischief’)	VEULEN
PELZTIERE (‘furry animal’)	BELKEN
VORMÄRSCHE (‘advance’; pl.)	DESEN
LÄMMLEIN (dim. ‘lamb’)	MUGELN
DICHTHEIT (‘density’)	RAHN
ABLAUT (‘ablaut’)	JANG
LACHKRAMPF (‘fit of laughter’)	KNEUN
GIFTGASE (‘poison gas’)	VEINEN
AUSLEIHE (‘loan’)	MATZIG
DURCHMÄRSCHE (‘landslide of a political party’)	KNEPELN
KNÖPFCHEN (dim. ‘button’)	SCHNAUL
LÖCHLEIN (dim. ‘hole’)	STERR
KUNDSCHAFTER (‘scout’)	AUEN
DINGLEIN (dim. ‘thing’)	BLÜNT
VORRUNDEN (‘preliminary rounds’)	BOLLEN
WICHTEL (‘gnome’)	BRAMMEN
SCHÄLUNG (‘walling timber’)	DERN
ZUNAHME (‘increase’)	DERGEN

Note: All items were displayed in block capitals as this was considered the most neutral way to present experimental stimuli in German since German nouns are commonly capitalized in line with orthographic conventions.

Stimuli Experiment 2:

All stimuli employed in Experiment 1, but condition NonEx1 replaced with Condition NonEx2

Condition NonEx2 (Experiment 2)

PROMPTTUM	ÄRMUNG	ARM (‘poor’)
ZÄHNIS	BLÖNDUNG	BLOND (‘blond’)
BLOßHEIT	FRÖHUNG	FROH (‘glad’)
SÖLCHNIS	REINUNG	REIN (‘pure’)
WILDUNG	FERNUNG	FERN (‘far’)
STRENGANZ	HÜBSCHUNG	HÜBSCH (‘pretty’)
BREITTUM	STÖLZUNG	STOLZ (‘proud’)
HEITERTAG	DÜNKELUNG	DUNKEL (‘dark’)
SCHIEFTUM	NÄCKTUNG	NACKT (‘naked’)
QUERTIER	STÜMMUNG	STUMM (‘dumb’)
KLÜGNIS	MILDUNG	MILD (‘mild’)
LASSKEIT	SCHLIMMUNG	SCHLIMM (‘awful’)
ECHTUNG	BRÄVUNG	BRAV (‘tame’)
BLEICHNIS	ZÄRTUNG	ZART (‘tender’)
BLÄNKUNG	KÜHNUNG	KÜHN (‘bold’)
SCHRÄGTUM	BLÄUUNG	BLAU (‘blue’)
RÄCHITUR	WEICHBARKEIT	WEICHEN (‘yield’)

JAGBARKEIT	HERRSCHBARKEIT	HERRSCHEN (‘reign’)
BITTBARKEIT	KÄMPFBARKEIT	KÄMPFEN (‘fight’)
SICHERSCHAFT	HOFFBARKEIT	HOFFEN (‘hope’)
NEIGBARKEIT	SIEGBARKEIT	SIEGEN (‘win’)
HINTERFASS	STERBBARKEIT	STERBEN (‘die’)
ATMESCHAFT	ORDNEBARKEIT	ORDNEN (‘arrange’)
ÖFFNEBARKEIT	KRIEGBARKEIT	KRIEGEN (‘get’)
ERNTITION	BÜßBARKEIT	BÜßEN (‘make amends’)
TANZITION	WEINBARKEIT	WEINEN (‘cry’)
HEIßEREI	REISBARKEIT	REISEN (‘travel’)
EINFÖRDERN	EIGNEBARKEIT	EIGNEN (‘be suited for’)
PASSATION	WERBBARKEIT	WERBEN (‘woo’)
ANKERSCHAFT	ERBBARKEIT	ERBEN (‘inherit’)
GRÜßATION	BADBARKEIT	BADEN (‘bathe’)
GRINSITEUR	BLUTBARKEIT	BLUTEN (‘bleed’)

Stimuli Experiment 3 (see Experiments 1 and 2 for translations)

Extant:

(+ Morph, + Extant, - Related)	(+ Morph, + Extant, + Related)	Target
Senkel	Kühlung	kühl
Däumchen	Bräunung	braun
Lastzug	Zähmung	zahm
Mahnung	Heilung	heil
Trümmer	Schwächung	schwach
Warnruf	Krümmung	krumm
Schuldienst	Lähmung	lahm
Deckel	Rötung	rot
Absprung	Kränkung	krank
Spielplan	Tötung	tot
Tönnchen	Reifung	reif
Blenden	Wärmung	warm
Volltreffer	Kostbarkeit	kosten
Bügelbrett	Strafbarkeit	strafen
Ellbögen	Messbarkeit	messen
Ziegelstein	Wählbarkeit	wählen
Androhung	Sichtbarkeit	sichten
Trostworte	Achtbarkeit	achten
Pflaumenbaum	Mischbarkeit	mischen
Ausstopfung	Brennbarkeit	brennen
Patenkind	Lesbarkeit	lesen
Gallenstein	Dankbarkeit	danken
Trostpreis	Reizbarkeit	reizen
Doppelheit	Ehrbarkeit	ehren

NonEx1:

(+ Morph; - Extant - Related)	(+ Morph; - Extant; + Intermediate position; + Related)	Target
Schrägnis	Liebung	lieb
Schlacknis	Schrillung	schrill
Jähnis	Grünung	grün
Sträffe	Bleichung	bleich
Flautum	Fettung	fett
Schrofftum	Feuchtung	feucht
Gröbnis	Nässung	nass
Purtum	Spitzung	spitz
Jungtum	Weichung	weich
Knäppnis	Engung	eng
Sättnis	Süßung	süß
Dichtnis	Faulung	faul
Lockitur	Tastbarkeit	tasten
Schliessition	Scheinbarkeit	scheinen
Brüllbarkeit	Rauchbarkeit	rauchen
Henkbarkeit	Zollbarkeit	zollen
Endbarkeit	Beugbarkeit	beugen
Hängbarkeit	Spürbarkeit	spüren
Druckbarkeit	Fassbarkeit	fassen
Bahnition	Biegbarkeit	biegen
Schafferei	Trinkbarkeit	trinken
Zahlbarkeit	Denkbarkeit	denken
Streichbarkeit	Heizbarkeit	heizen
Platzbarkeit	Knetbarkeit	kneten

NonEx2:

(+ Morph, - Extant; - Related)	(+ Morph; - Extant; - Intermediate position; + Related)	Target
Prompttum	Armung	arm
Bloßheit	Nettung	nett
Läutnis	Reinung	rein
Wildung	Fernung	fern
Strenganz	Hübschung	hübsch
Schieftum	Nacktung	nackt
Quertier	Stümmung	stumm
Klügnis	Mildung	mild
Kühnnis	Schlimmung	schlimm
Echtung	Bravung	brav
Launis	Zärtung	zart
Breittum	Bläuung	blau
Rächitur	Weichbarkeit	weichen
Jagbarkeit	Herrschbarkeit	herrschen
Greifeschaft	Kämpfbarkeit	kämpfen
Sicherschaft	Hoffbarkeit	hoffen
Neigbarkeit	Siegbarkeit	siegen
Wahrbarkeit	Sterbbarkeit	sterben
Öffneschaft	Kriegbarkeit	kriegen
Erntition	Büßbarkeit	büßen
Tanzbarkeit	Weinbarkeit	weinen
Heißbarkeit	Reisbarkeit	reisen
Passbarkeit	Werbbarkeit	werben
Grinsbarkeit	Blutbarkeit	bluten

Control Form NonEx:

(- Morph, - Extant, - Form overlap, - Related)	(- Morph, - Extant, + Form overlap, + Related)	Target
Kahllein	Steillein	steil
Blödlein	Plümplein	plump
Dürrlein	Wirrler	wirr
Derblein	Strammlein	stramm
Fädlein	Frühler	früh
Treuler	Länglein	lang
Schierlein	Tölllein	toll
Keckler	Flinkler	flink
Blindlein	Helllein	hell
Döfler	Dreistler	dreist
Stärrler	Heißler	heiß
Fairlein	Wächlein	wach
Sitzlossal	Weislossal	weisen
Fanglosler	Schätzlosler	schätzen
Drehschung	Trauschung	trauen
Bremsloslein	Kehrloslein	kehren
Pfeiflossal	Hasslossal	hassen
Fliehlosler	Schieblosler	schieben
Hauloslein	Tummloslein	tummeln
Kennloslein	Waglosler	wagen
Schreiloslein	Warnenlein	warnen
Lachlosler	Schlaflossal	schlafen
Dienensel	Fördensel	fördern
Schiffloslein	Eignenung	eignen

Control Form Ex:

(- Form related, - Morphologically related)	(+ Form related, - Morphologically related)	Target
Mäuschen	Rohrbruch	roh
Bäuchlein	Täublein	taub
Blutdruck	Reifen	reich
Tüchlein	Kalbfleisch	kalt
Räuber	Bündel	bunt
Dampfbad	Schafkopf	scharf
Bahnsteig	Fläschchen	flach
Ringtausch	Heiserkeit	heiß
Dienstzeit	Raucher	rau
Vorkost	Gelstift	gelb
Prahler	Matrix	matt
Zerrbild	Flötist	flott
Schuldiger	Filtration	filmen
Abstumpfung	Fahrgenuss	fragen
Täterin	Ahnenbild	ahnden
Zarentum	Daunenbett	dauern
Winterfrucht	Deutschländer	deuten
Hüftgelenk	Kleeblätter	kleben
Balljunge	Fugenschnitt	fügen
Blechdose	Froschkönig	forschen
Hochschätzung	Betttücher	beten
Aufzugsschacht	Lendenschmerz	lernen
Stoppligkeit	Rohlinge	rollen
Taktmesser	Spargelzeit	sparen

Semantic controls:

(- Semantically related, + Extant, - Morphologically related)	(+ Semantically related, + Extant; - Morphologically related)	Target
Packeis	Blödheit	dumm
Schutzblech	Körperfülle	dick
Schachbrett	Schnelle	fix
Räumchen	Farblosigkeit	blass
Plattfisch	Ehrgefühl	stolz
Zählung	Hemmung	scheu
Blaustich	Völle	leer
Mieter	Umkreis	nah
Schmuckstück	Zartheit	sanft
Hufschmied	Hungerhaken	schlank
Nachschub	Einfalt	schlicht
Köpfchen	Pünktlichkeit	spät
Düsterheit	Chorprobe	singen
Lockmittel	Bremsung	stören
Löffelchen	Seilsprung	hüpfen
Nähkasten	Halsschmerzen	Husten
Halteplatz	Ausbeute	nutzen
Machtfrage	Unwohlsein	leiden
Käuferin	Festmahl	essen
Weigerung	Reinigung	putzen
Anspielung	Treppenhaus	steigen
Hinreise	Glücksspiel	raten
Schaurigkeit	Sturmgewehr	schießen
Nachlese	Kundgabe	melden

Fillers:

Nonword prime	Nonword target		Nonword prime	Nonword target
gräßung	gräß		gaddbarkeit	gaddeln
geulung	geul		kümmbarkeit	kümmen
pirzung	pirz		schreidbarkeit	schreiden
zeinung	zein		fulschbarkeit	fulschen
knugung	knug		pegerbarkeit	pegen
maltung	malt		rorrbarkeit	rorren
weltsung	klaft		verratung	leigen
funktung	tress		abendfahl	leuben
kneidung	strell		talerei	kächen
läsung	suft		versiebtheit	schweimen
hählung	breuch		mütsamkeit	timmen
zäulnis	glick		mundetuch	spechen
küstlein	kust		spenslichschaft	spensen
mirting	mirt		kichlichschaft	kicheln
freumunz	freum		zeidigschaft	zeiden
gresonz	gres		lammischnis	lammen
künfinz	kunft		folblichschaft	folben
stäßang	staß		mechischnis	mechern
kagonz	bluck		fohlignis	schmechen
vahlang	lurt		geugischmut	wöhlen
schausing	steich		bitzigschaft	wechen
auswing	glau		tertigmut	merten
besorz	heib		sichtigschaft	husen
vordang	blann		müttischmut	drüngen
klämmlein	trönn		urgernis	zegen

zischling	schwirr		ausmehrung	reiden
verkuhr	gur		griesamkeit	schneifen
dehrung	lüng		ermissler	sunnen
dohnzaus	leub		aufgabung	keltern
vortriss	dänn		buggeluch	daggeln
fürtnis	kähl		siegeling	tiegeln
verdrieb	wold		geneisung	strechen
vorgumm	blund		zweferkeit	fauern
meichtum	schünn		überwendung	sauben
elnonz	sahm		truttischmut	schleuchen
zugfuhrt	lung		sehgerung	biggeln

Word prime	**Nonword target**		**Word prime**	**Nonword target**
Närrin	närr		Ringelchen	ringeln
Kaltblut	kält		Dockhafen	dokhen
Entchen	entz		Durchfahrten	durchfen
Flugfunk	flüg		Lattenzaun	lattzen
Kettlein	kett		Zuchtbulle	zubben
Landheim	ländsch		Schafmilch	schafmen
Dichtheit	rahn		Pelztiere	belken
Ablaut	jang		Vormärsche	desen
Näslein	slecht		Lämmlein	mugeln
Backzahn	nelch		Hochschüler	höchschen
Ätzung	zach		Wettkämpfer	wettken
Nehmer	melb		Ölberge	ölben
Zeitsinn	zeis		Gutschriften	gutschen
Täufer	tauf		Königtum	köngten

Hälmchen	hälm		Ölfarben	örgen
Drücker	drack		Schalthebel	schabeln
Huftier	huft		Impfungen	impren
Abschaum	äbsch		Lachkrampf	kneun
Diskredit	fanft		Abbaurecht	gerren
Schälung	dern		Zunahme	dergen
Knöpfchen	schnaul		Vorrunden	bollen
Löchlein	sterr		Kettenstich	grauben
Narrheit	frund		Mohnblume	glauen
Raubgier	dild		Mittagsbrot	dingeln
Keuschheit	kesch		Mäuseloch	mäuseln
Küchlein	küsch		Niedrigkeit	nieden
Trinklied	trinn		Fraglichkeit	frällen
Schwellung	schwell		Kreidestrich	kreid
Hutband	hutt		Rosenduft	rossen
Luftsprung	luff		Väterlein	vätten
Wichtel	bramm		Süchtigkeit	maugen
Mehrwert	glibb		Kränchen	neißen
Herbszeit	schwenn		Bärendreck	lucken
Weitblick	grohl		Haushälter	ditzen
Feigling	trahn		Nachsendung	schlubben
Knäblein	drünn		Streckenflug	dählen

Note: All items were displayed in block capitals as this was considered the most neutral way to present experimental stimuli in German since German nouns are commonly capitalized in line with orthographic conventions.

Stimuli Experiment 4:

Condition Extant

KÜHLUNG, BRÄUNUNG, ZÄHMUNG, HEILUNG, SCHWÄCHUNG, SÄUBERUNG, REIFUNG, RÖTUNG, KRÄNKUNG, GLÄTTUNG, HÄRTUNG, WÄRMUNG, TÖTUNG, SCHLICHTUNG, KRÜMMUNG, LÄHMUNG, TEILBARKEIT, WÄHLBARKEIT, SICHTBARKEIT, KOSTBARKEIT, MISCHBARKEIT, HEILBARKEIT, REIZBARKEIT, MESSBARKEIT, GREIFBARKEIT, TRENNBARKEIT, ACHTBARKEIT, FORMBARKEIT, BRENNBARKEIT, EHRBARKEIT, LESBARKEIT, DANKBARKEIT

Condition NonEx1

LIEBUNG, LÄUTUNG, GRÜNUNG, BLEICHUNG, FETTUNG, FEUCHTUNG, LEIDUNG, NÄSSUNG, SÜßUNG, SPITZUNG, SCHWÄRZUNG, ENGUNG, STILLUNG, WELKUNG, WETTUNG, WEICHUNG, TASTBARKEIT, SCHEINBARKEIT, WUNDERBARKEIT, ZAHLBARKEIT, BEUGBARKEIT, SPÜRBARKEIT, FASSBARKEIT, WASCHBARKEIT, FURCHTBARKEIT, DRUCKBARKEIT, STREICHBARKEIT, SCHMECKBARKEIT, BIEGBARKEIT, TRINKBARKEIT, FÜHLBARKEIT, HEIZBARKEIT

Condition NonEx2

ÄRMUNG, BLÖNDUNG, FRÖHUNG, REINUNG, FERNUNG, HÜBSCHUNG, STÖLZUNG, DÜNKELUNG, NÄCKTUNG, STÜMMUNG, MILDUNG, SCHLIMMUNG, BRÄVUNG, ZÄRTUNG, KÜHNUNG, BLÄUUNG, WEICHBARKEIT, HERRSCHBARKEIT, KÄMPFBARKEIT, HOFFBARKEIT, SIEGBARKEIT, STERBBARKEIT, ORDNEBARKEIT, KRIEGBARKEIT, BÜßBARKEIT, WEINBARKEIT, REISBARKEIT, EIGNEBARKEIT, WERBBARKEIT, ERBBARKEIT, BADBARKEIT, BLUTBARKEIT

Control NonEx

STEILANG, RÄUHING, PLÜMPANG, WERTINZ, KLEINING, BÄRONZ, TÖLLONZ, FLÖTTINZ, RASCHING, FROMMINZ, QUERING, SANFTONZ, KNAPPANG, DÜNNANG, HELLANG, ZÄHING, KEHRISCHMUT, SPANNLICHMUT, HASSISCHMUT, RAUCHIGSCHAFT, TUMMIGMUT, WAGIGMUT, SCHLAFIGNIS, SCHÄTZIGMUT, LINDERISCHNIS, SPIELLICHSCHAFT, PAARLICHSCHAFT, FOLGLICHSCHAFT, STÜRZISCHMUT, FLUCHISCHNIS, LEUGNISCHMUT, FÜGICHSCHAFT

Fillers

HITZE, FEHLEN, ERNTUNG, BIEGUNG, EINSCHLUPF, LAUHEIT, LEERTUM, PRÜFUNG, SCHRÄGTUM, EINSTÜRZEN, DOPPELHEIT, GEQUATSCHE, GRÜßUNG, NACHRICHTEN, PATENSCHAFT, FAULTIER, FESTTAG, DIENSTZEITEN, HOLUNG, HERGÄNGE, WANDLUNG, PFLAUMENBAUM, BREMSEN, SELIGER, VORBAU, ÜBERSTRUMPF, ABLASSBRIEF, DICHTNIS, SCHUSSWEITE, AUSSTOPFUNG, KANONIST, BLÄNKNIS, AUFFAHRT, SPRINGUNG, SCHMUTZIGKEIT, ZUFAHRT, HALSAUSSCHNITT, VÖLLE, ANSTRENGUNG, FÄDLEIN, TREPPENHAUS, TANZUNG, HEIßUNG, ECHTSCHAFT, ABSPRUNG, GRINSUNG, UNLUST, TROSTWORTE, DECKUNG, GÄHNUNG, BLENDEN, DÜRRTUM, REINIGUNG, BLOßHEIT, LUTSCHER, BUCHUMSCHLAG, FRISCHTUM, GLÜCKSPIEL, UMKREIS, NACHTEIL, GÄRUNG, RECHTECK, FÖRDERER, GALLENSTEIN, FAHRGENUSS, LASSHEIT, ABLUFT, TAGUNGEN, AHNENBILD, SCHNELLE, BITTUNG, NACHBAR, SPARUNG, FLÄSCHCHEN, EINDRINGLING, HALSSCHMERZEN, VOLLTREFFER, HEUSCHNUPFEN, FLIEGUNG, SCHEUNIS, REIFEN, MALUNG, DECKEL, TÄUBLEIN, DEUTSCHLÄNDER, BÜNDEL, ZÄHNIS, DÄUMCHEN, MAHNUNG, BEFUND, SCHWEIGUNG, AUGENARZT, JAGUNG, GENUSS, GLÄUBIGER, KALBSBLUT, ORTSCHAFT, FRESSUNG, LASTZUG, FILTRATION, SCHAFKOPF, FLUGVERKEHR, WEIGERUNG, LAGERRAUM, WILDSCHAFT, KLEEBLÄTTER, BREITTUM, SCHADUNG, STRENGANZ, LAUBFÄLLE, GLÖCKCHEN, GIERIGKEIT, FUGENSCHNITT, WAHNSINN, AUSSTATTUNG, AUSMAß, CHORPROBE, PROMPTTUM, ROHRBRUCH, ELLBÖGEN, FÜHLER, HANDWERKER, SENKEL, ALTER, DAUNENBETT, ABSTREICHER, FROSCHKÖNIG, STRIKTNIS

Appendix C: Stimulus list EEG-Experiment (Chapter 4)

Condition 'Extant'

Unrelated Prime	Related Prime	Target
	Adjective as Base	
Impfung	Kühlung	**kühl**
Spüler	Bräunung	**braun**
Heimweh	Zähmung	**zahm**
Sorgfalt	Heilung	**heil**
Pfleger	Schwächung	**schwach**
Bäuchlein	Reifung	**reif**
Teelicht	Rötung	**rot**
Schlauheit	Kränkung	**krank**
Laschheit	Glättung	**glatt**
Deckung	Härtung	**hart**
Drücker	Wärmung	**warm**
Mahnung	Tötung	**tot**
Gleichnis	Schlichtung	**schlicht**
Trübsal	Krümmung	**krumm**
Neuheit	Lähmung	**lahm**
Furchung	Höhlung	**hohl**
Bötchen	Querung	**quer**
Gärtner	Wertung	**wert**
Lüfter	Leerung	**leer**
Niesreiz	Schwärzung	**schwarz**

Verb as Base		
Keksdose	Teilbarkeit	**teilen**
Flugverkehr	Wählbarkeit	**wählen**
Ausstrahlung	Sichtbarkeit	**sichten**
Kleidungsstück	Kostbarkeit	**kosten**
Fahndungen	Mischbarkeit	**mischen**
Beiordnung	Heilbarkeit	**heilen**
Sprengpulver	Reizbarkeit	**reizen**
Fertigkeit	Messbarkeit	**messen**
Farbkasten	Greifbarkeit	**greifen**
Überstrumpf	Trennbarkeit	**trennen**
Trostworte	Achtbarkeit	**achten**
Pflaumenbaum	Formbarkeit	**formen**
Standardwert	Brennbarkeit	**brennen**
Kugelform	Ehrbarkeit	**ehren**
Lebensziel	Lesbarkeit	**lesen**
Lohnsteuern	Dankbarkeit	**danken**
Abfahrtszeit	Störbarkeit	**stören**
Dienstzeiten	Schmelzbarkeit	**schmelzen**
Sattelgurt	Planbarkeit	**planen**
Stichwunde	Waschbarkeit	**waschen**

Condition 'NonEx1'

Unrelated Prime	Related Prime	Target
	Adjective as Base	
Schrägnis	Liebung	**lieb**
Kleinnis	Läutung	**laut**
Jähnis	Grünung	**grün**
Sträffe	Bleichung	**bleich**
Flautum	Fettung	**fett**
Schrofftum	Feuchtung	**feucht**
Gröbnis	Nässung	**nass**
Sättnis	Süßung	**süß**
Purtum	Spitzung	**spitz**
Barheit	Frischung	**frisch**
Knäppnis	Engung	**eng**
Dichtnis	Stillung	**still**
Chictum	Welkung	**welk**
Grelle	Faulung	**faul**
Sanfttum	Weichung	**weich**
Schlaunis	Breitung	**breit**
Strikttum	Scheuung	**scheu**
Täube	Reichung	**reich**
Schlacknis	Schrillung	**schrill**
Plättnis	Schrägung	**schräg**
	Verb as Base	
Lockbarkeit	Tastbarkeit	**tasten**
Schliessbarkeit	Scheinbarkeit	**scheinen**
Brüllbarkeit	Rauchbarkeit	**rauchen**

Ahndbarkeit	Schmiedbarkeit	**schmieden**
Endbarkeit	Beugbarkeit	**beugen**
Hängbarkeit	Spürbarkeit	**spüren**
Hörbarkeit	Fassbarkeit	**fassen**
Zahlbarkeit	Denkbarkeit	**denken**
Scheidbarkeit	Druckbarkeit	**drucken**
Klatschbarkeit	Streichbarkeit	**streichen**
Schippbarkeit	Schmeckbarkeit	**schmecken**
Bahnbarkeit	Biegbarkeit	**biegen**
Schaffbarkeit	Trinkbarkeit	**trinken**
Saugbarkeit	Fühlbarkeit	**fühlen**
Forschbarkeit	Heizbarkeit	**heizen**
Platzbarkeit	Knetbarkeit	**kneten**
Klebbarkeit	Schlachtbarkeit	**schlachten**
Filmbarkeit	Zollbarkeit	**zollen**
Henkbarkeit	Brechbarkeit	**brechen**
Juckbarkeit	Rettbarkeit	**retten**

Condition 'NonEx2'

Unrelated Prime	Related Prime	Target
	Adjective as Base	
Prompttum	Armung	**arm**
Zähnis	Blondung	**blond**
Steifung	Nettung	**nett**
Böstum	Fernung	**fern**
Raschung	Hübschung	**hübsch**

Schärfnis	Stolzung	**stolz**
Schiefung	Nacktung	**nackt**
Frechnis	Stummung	**stumm**
Schmalung	Mildung	**mild**
Frohheit	Schlimmung	**schlimm**
Echtung	Brävung	**brav**
Röhnis	Zärtung	**zart**
Blänknis	Kühnung	**kühn**
Tiefung	Bläuung	**blau**
Wehung	Dummung	**dumm**
Lassung	Kältung	**kalt**
Buntung	Treuung	**treu**
Sturung	Strengung	**streng**
Ernstnis	Jüngung	**jung**
Klugtum	Dünnung	**dünn**
Verb as Base		
Rächbarkeit	Weichbarkeit	**weichen**
Jagbarkeit	Herrschbarkeit	**herrschen**
Bittbarkeit	Kämpfbarkeit	**kämpfen**
Sicherschaft	Hoffbarkeit	**hoffen**
Neigbarkeit	Siegbarkeit	**siegen**
Wahrbarkeit	Sterbbarkeit	**sterben**
Atmeschaft	Drängbarkeit	**drängen**
Öffneschaft	Kriegbarkeit	**kriegen**
Erntbarkeit	Büßbarkeit	**büßen**
Tanzbarkeit	Weinbarkeit	**weinen**
Heißbarkeit	Reisbarkeit	**reisen**

Passbarkeit	Werbbarkeit	**werben**
Ankerschaft	Erbbarkeit	**erben**
Fügbarkeit	Badbarkeit	**baden**
Grinsbarkeit	Blutbarkeit	**bluten**
Sprengbarkeit	Grüßbarkeit	**grüßen**
Richtbarkeit	Laufbarkeit	**laufen**
Nervbarkeit	Scheuchbarkeit	**scheuchen**
Klimmbarkeit	Schellbarkeit	**schellen**
Landbarkeit	Schenkbarkeit	**schenken**

Condition 'Control NonEx'

Unrelated Prime	**Related Prime**	**Target**
	Adjective as Base	
Mättlein	Steillein	**steil**
Nähsal	Räuler	**rau**
Blödlein	Plümpsal	**plump**
Wildsal	Gelbsal	**gelb**
Derbsal	Strammlein	**stramm**
Kahllein	Blassler	**blass**
Frömmsal	Flöttlein	**flott**
Fädsal	Fixlein	**fix**
Ärgsal	Flächler	**flach**
Reinlein	Frühler	**früh**
Stärrsal	Stillsal	**bloß**
Währsal	Länglein	**lang**

Schierlein	Töllsal	**toll**
Kecksal	Flinkler	**flink**
Blindsal	Hellsal	**hell**
Döfler	Dreistsal	**dreist**
Leidlein	Fairsal	**fair**
Spätlein	Heißler	**heiß**
Dürrsal	Wirrler	**wirr**
Deutschlein	Wächlein	**wach**
Verb as Base		
Sausloslein	Flatterlossal	**flattern**
Kennloslein	Leistlossel	**leisten**
Klauloslein	Dehnloslein	**dehnen**
Füllossal	Legensel	**legen**
Sitzlossal	Weislossal	**weisen**
Fanglosler	Schätzlosler	**schätzen**
Drehschung	Trauschung	**trauen**
Bremloslein	Kehrloslein	**kehren**
Nählosler	Spannensel	**spannen**
Pfeiflossal	Hasslossal	**hassen**
Fliehlosler	Schieblosler	**schieben**
Hauloslein	Tummloslein	**tummeln**
Sparloslein	Waglosler	**wagen**
Tarnlossal	Fastlossal	**fasten**
Schreiloslein	Warnenlein	**warnen**
Lachlosler	Schlaflossal	**schlafen**
Kränklossal	Blendlossal	**blenden**
Dienensel	Fördensel	**fördern**

Schiffloslein	Eignenung	**eignen**
Spaltenler	Häuflosler	**häufen**

Filler items

Prime	**Target**		**Prime**	**Target**
gräßung	gräß		Nestchen	melb
geulung	geul		Räumchen	dreit
pirzung	pirz		Senkel	klaft
zeinung	zein		Däumchen	tress
knugung	knug		Lastzug	strell
fulschgut	fulsch		Stoßzahn	suft
schnauung	schnau		Ortschaft	breuch
tahmung	tahm		Glöckchen	glick
klammung	klamm		Abluft	farsch
taltung	talt		Deckel	schahn
spärgtum	bluck		Absprung	ling
wüldling	lurt		Klümpchen	schwirg
spötnis	steich		Auffahrt	gur
frähnis	glau		Blenden	lüng
blävling	sahm		Bremsen	leub
seßheit	heib		Biegung	dönn
dinnling	blann		Lutscher	kähl
feunkeit	gohs		Festtag	wold
glummheit	bleun		Altbau	klab
lummheit	graub		Quetschung	tarm

gaddelei	gaddeln		Filtration	kniegen
kümmbarkeit	kümmen		Fahrgenuss	fagen
schreidbarkeit	schreiden		Ahnenbild	sanneln
fulscherei	fulschen		Fanmeile	tanfen
pegerheit	pegen		Barhocker	strümen
rorrität	rorren		Ritterburg	trinfen
wechsamkeit	wechsen		Fugenschnitt	druffen
daufferei	daufen		Anfeindung	konen
miechbarkeit	miechen		Froschkönig	deiden
pachsamkeit	pachen		Kleeblätter	miegen
kniegistik	keltern		Strebsamkeit	mügen
fagelheit	fauern		Grafschaften	sauben
sannelheit	sauen		Daunenbett	naden
tanfetum	strechen		Platzverweis	dangen
strümbarkeit	suchern		Rollenspiel	streiben
trinnbarkeit	leuben		Spartaner	lateln
drufferei	kächen		Sündenbock	wiebeln
kohnbarkeit	bramen		Königtum	pramen
dauberei	krepen		Erdbeben	schniegen
maugbarkeit	drieren		Kämmerchen	tessen

Filler items

Prime	Target		Prime	Target
Zähheit	knass		Stromkreis	drüll
Lüftung	spolz		Nachsicht	drech
Grobheit	kust		Wahnsinn	lechts
Täublein	mirt		Befund	grahn
Hinfahrt	freum		Schnelle	larm
Zufahrt	gress		Nachbar	suht
Bündel	kunft		Ausmaß	klag
Schafkopf	staß		Alter	hülsch
Fläschchen	nau		Genuss	draun
Lauheit	schleu		Laubfälle	deit
Fühler	sparg		Fehlen	sutt
Kalbsbrust	wuld		Umkreis	trann
Nachteil	spöt		Rechteck	mehn
Gärung	fräh		Unlust	schlaug
Einschlupf	blav		Völle	dünf
Fädlein	seß		Wandlung	leug
Rohrbruch	dinn		Hitze	rell
Reifen	feun		Prüfung	dalt
Knödel	boll		Rundfahrt	knav
Mitgift	nahm		Buchung	maub
Chorprobe	schmechen		Pappdeckel	bicheln
Handwerker	träunen		Lobrede	reiden

Eindringling	spensen		Zugewinn	schneifen
Springseile	wöhlen		Heiserkeit	sunnen
Halsschmerzen	kicheln		Vorfreude	mennen
Sinnfrage	wechen		Umschaltung	lahren
Beschwerde	zeiden		Anhäufung	dolgen
Ernährung	terten		Heimlichkeit	spennen
Schmutzigkeit	husen		Rückfrage	nauen
Treppenhaus	stinnen		Austragung	dreben
Glückspiel	schleuchen		Abwechslung	spretten
Mitbringsel	sprongen		Abtragung	stitten
Revolver	stirpen		Herrlichkeit	däußern
Geschäftszeit	drüngen		Anwesen	maten
Kuhweide	schweimen		Tapferkeit	kriefen
Nachrichten	folben		Neuigkeit	saffen
Nettigkeit	bitzen		Sachlichkeit	spafen
Aufhetzung	spechen		Oberhaupt	feben
Übelkeit	grauben		Neugierde	glinzen
Güterzug	mechern		Teilbereich	dichern

Appendix D: Stimulus set fMRI experiment

SW	CW	SP	CP
Müdigkeit	Rötung	Liebung	Kaltung
Heiterkeit	Schwärzung	Läutung	Blondung
Kleinigkeit	Wertung	Grünung	Nettung
Spiessigkeit	Bräunung	Bleichung	Fernung
Frömmigkeit	Wärmung	Fettung	Hübschung
Emsigkeit	Tötung	Feuchtung	Stolzung
Dreistigkeit	Kühlung	Nässung	Nacktung
Leichtigkeit	Lähmung	Süßung	Stummung
Neuigkeit	Zähmung	Spitzung	Ärmung
Freundlichkeit	Kräftigung	Frischung	Schlimmung
Peinlichkeit	Schlichtung	Engung	Bravung
Männlichkeit	Fälschung	Stillung	Zartung
Zärtlichkeit	Krümmung	Welkung	Kühnung
Übelkeit	Querung	Faulung	Blauung
Tapferkeit	Schwächung	Weichung	Dummung
Langsamkeit	Säuberung	Breitung	Mildung
Brüchigkeit	Heilung	Scheuung	Treuung
Fleckigkeit	Leerung	Reichung	Strengung
Lässigkeit	Glättung	Schrillung	Jüngung
Mündigkeit	Reifung	Schrägung	Dünnung
Zehrung	Lesbarkeit	Tastbarkeit	Weichbarkeit

Schulung	Reizbarkeit	Scheinbarkeit	Herrschbarkeit
Pressung	Brennbarkeit	Rauchbarkeit	Kämpfbarkeit
Buchung	Achtbarkeit	Schmiedbarkeit	Hoffbarkeit
Senkung	Wünschbarkeit	Beugbarkeit	Siegbarkeit
Irrung	Formbarkeit	Spürbarkeit	Sterbbarkeit
Packung	Sichtbarkeit	Fassbarkeit	Drängbarkeit
Steigung	Wählbarkeit	Denkbarkeit	Kriegbarkeit
Zerrung	Sparsamkeit	Druckbarkeit	Büßbarkeit
Atmung	Dankbarkeit	Streichbarkeit	Weinbarkeit
Haftung	Kostbarkeit	Schmeckbarkeit	Reisbarkeit
Fügung	Wachsamkeit	Biegbarkeit	Werbbarkeit
Schiebung	Mischbarkeit	Trinkbarkeit	Erbbarkeit
Spülung	Nützlichkeit	Fühlbarkeit	Badbarkeit
Salbung	Ehrbarkeit	Heizbarkeit	Blutbarkeit
Wölbung	Traurigkeit	Knetbarkeit	Grüßbarkeit
Windung	Tauglichkeit	Schlachtbarkeit	Laufbarkeit
Quetschung	Greifbarkeit	Zollbarkeit	Scheuchbarkeit
Zuckung	Waschbarkeit	Brechbarkeit	Schellbarkeit
Deckung	Schmelzbarkeit	Rettbarkeit	Schenkbarkeit
Graumsamkeit	Straffung	Plättung	Schlauung
Niedrigkeit	Härtung	Fremdung	Blindung
Fälligkeit	Schärfung	Bangung	Sturung
Dürftigkeit	Trübung	Langung	Tiefung
Diesigkeit	Öffnung	Rauung	Taubung
Deutung	Schädlichkeit	Schwenkbarkeit	Waltbarkeit

Widmung	Klebrigkeit	Essbarkeit	Wohnbarkeit
Strebung	Schläfrigkeit	Lautbarkeit	Traubarkeit
Kennung	Trennbarkeit	Riechbarkeit	Rasbarkeit
Lösung	Schmiegsamkeit	Schlagbarkeit	Bittbarkeit

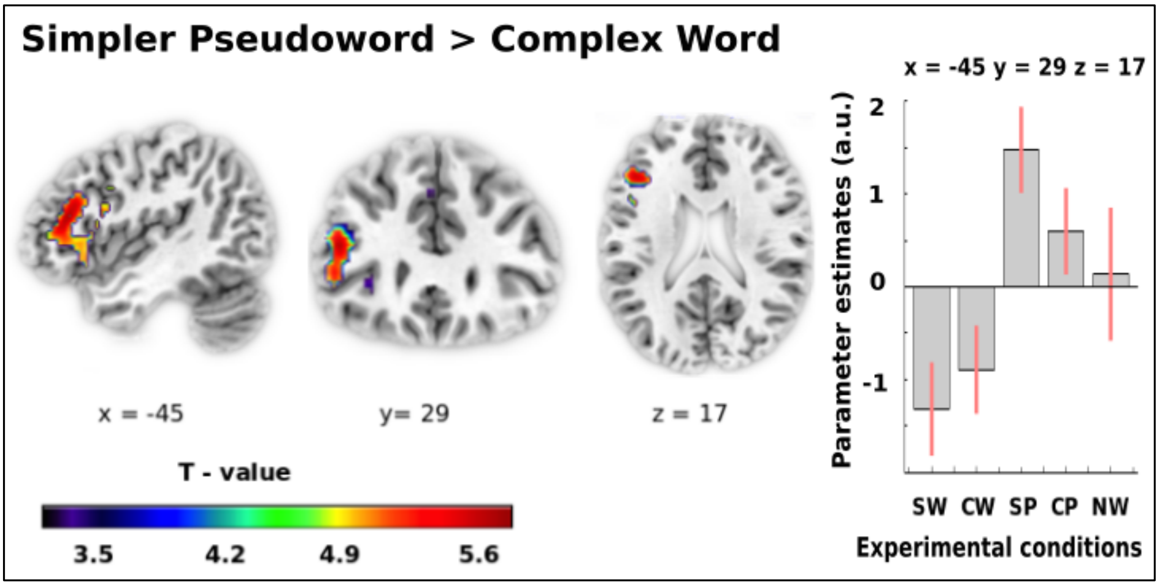
Nonword fillers	**Word fillers**
Steillein	Lichtlein
Nahlein	Häuflein
Plumpler	Spüler
Gelbler	Heimweh
Strammsel	Sorgfalt
Blassler	Pfleger
Flottler	Bäuchlein
Fixlein	Teelicht
Flachler	Laschheit
Frühler	Kochbuch
Dichtsel	Gleichnis
Altlein	Furchung
Tollsal	Gärtner
Flinkler	Lüfter
Hellsal	Niesreiz
Keuschsel	Lastzug

Fairsal	Stoßzahn
Heißler	Ortschaft
Wirrler	Abluft
Wachler	Absprung
Flatterlossal	Auffahrt
Leistlossel	Blenden
Dehnlosler	Lutscher
Legensel	Festtag
Weislossal	Altbau
Schätzlosler	Keksdose
Schleppschung	Flugverkehr
Kehrlosler	Ausstrahlung
Spannensel	Kleidungsstück
Hasslossal	Fahndungen
Fliesslosler	Beiordnung
Tummlosler	Sprengpulver
Waglosler	Fertigkeit
Fastlossal	Farbkasten
Warnenlein	Überstrumpf
Schlaflossal	Trostworte
Blendlossal	Pflaumenbaum
Fördensel	Standardwert
Eignenung	Kugelform
Häuflosler	Lebensziel
Stumpfler	Lohnsteuern

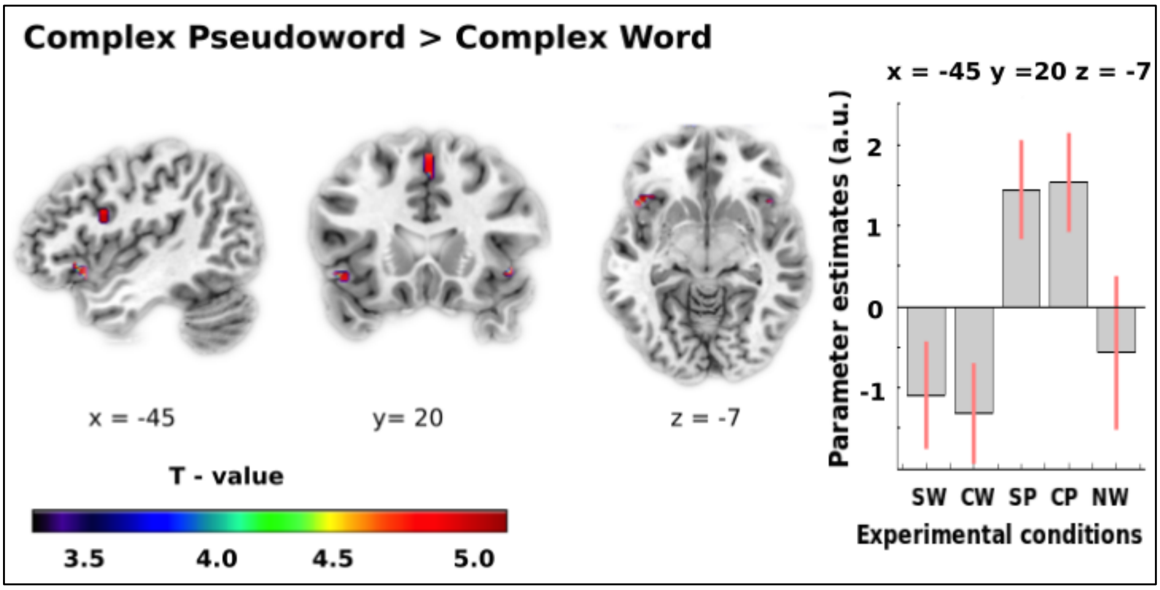
Röhlein	Abfahrtszeit
Höhlsel	Dienstzeiten
Knappler	Sattelgurt
Frechlein	Stichwunde
Züchtlossal	Ausdehnung
Treiblosler	Ausbreitung
Lehrloslein	Erpressung
Schwitzlosler	Pfannkuchen
Wirkensel	Filtration

Appendix E: Supplementary analyses fMRI-study (Chapter 5)

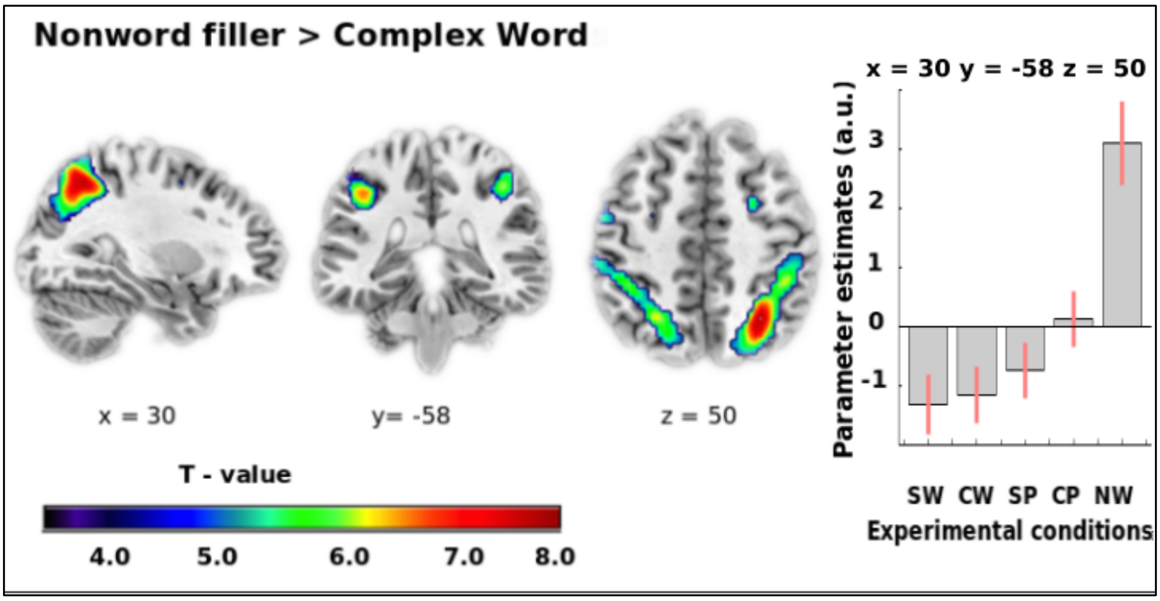
In the follow-up analysis, we performed a within-subjects one-way ANOVA that included the following five conditions: (1) SW (simpler word), (2) CW (complex word), (3) SP (simpler pseudoword), (4) CP (complex pseudoword), (5) NW (nonword fillers). The second-level was based on the difference-images from the first-level across all participants and all three runs. Correction for non-sphericity was applied. T-contrasts were computed for all comparisons of interest. Comparisons of interest included all pairwise comparisons between the nonword fillers and the two types of pseudowords, as well as all nonword and pseudoword comparisons with an existing complex word. The statistical threshold for all analyses was set at $p < .05$, corrected for multiple comparisons using FWE.



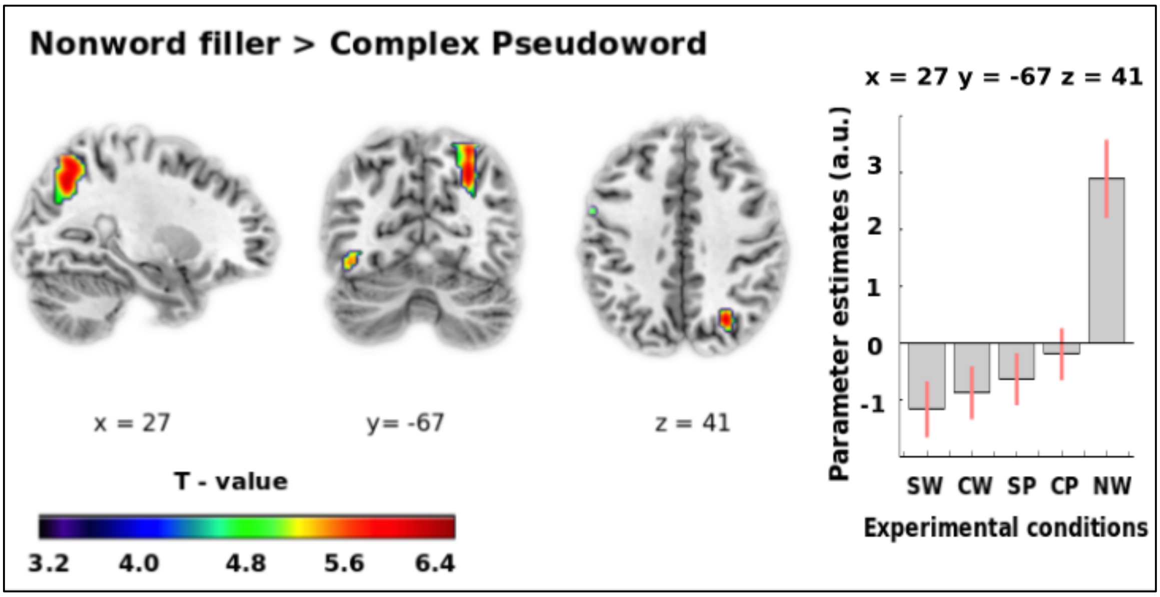
Contrast Simpler Pseudoword > Complex Word. Increased task-related activity for **Spitzung* relative to *Heilung* was mainly found in frontal regions, with the strongest peak at the left inferior frontal gyrus (pars triangularis). Parameter estimates for the main peak (with 95% confidence intervals) are given in arbitrary units (a.u.). Thresholded at p < .05 FWE-corrected. Spatial references are given in MNI space. Simpler Pseudoword = **Spitzung*, Complex Word = *Heilung*.



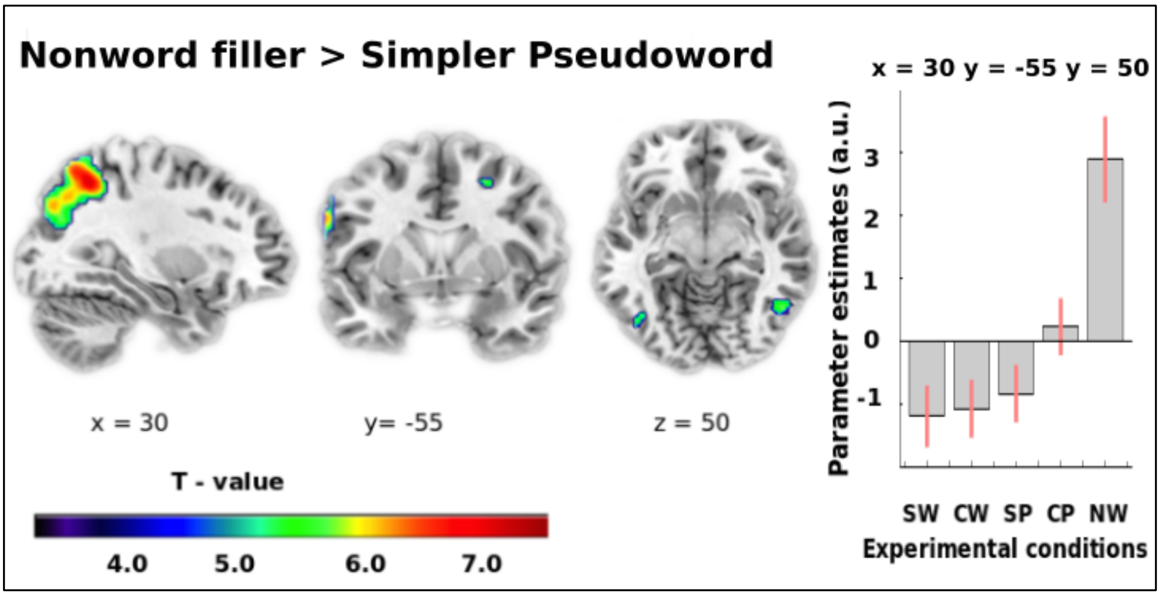
Contrast Complex Pseudoword > Complex Word. Increased task-related activity for **Hübschung* relative to *Heilung* was mainly found in frontal regions, with the strongest peak at the left inferior frontal gyrus (pars orbitalis). Parameter estimates for the main peak (with 95% confidence intervals) are given in arbitrary units (a.u.). Thresholded at p < .05 FWE-corrected. Spatial references are given in MNI space. Complex Pseudoword = **Hübschung*, Complex Word = *Heilung*.



Contrast Nonword Filler > Complex Word. Increased task-related activity for **Wirrlein* relative to *Heilung* was mainly found in parietal regions, with the strongest peak at the right angular gyrus within a cluster extending to the right inferior parietal lobule. Parameter estimates for the main peak (with 95% confidence intervals) are given in arbitrary units (a.u.). Thresholded at p < .05 FWE-corrected. Spatial references are given in MNI space. Nonword Filler = **Wirrlein*, Complex Word = *Heilung*.



Contrast Nonword Filler > Complex Pseudoword. Increased task-related activity for **Wirrlein* relative to **Hübschung* was mainly found in parietal regions, with the strongest peak at the right superior occipital gyrus within a cluster extending to the right superior parietal lobule. Parameter estimates for the main peak (with 95% confidence intervals) are given in arbitrary units (a.u.). Thresholded at p < .05 FWE-corrected. Spatial references are given in MNI space. Nonword Filler = **Wirrlein*, Complex Pseudoword = **Hübschung*.



Contrast Nonword Filler > Simpler Pseudoword. Increased task-related activity for **Wirrlein* relative to **Spitzung* was mainly found in parietal regions, with the strongest peak at the right inferior parietal gyrus within a cluster extending to the right superior parietal lobule. Parameter estimates for the main peak (with 95% confidence intervals) are given in arbitrary units (a.u.). Thresholded at p < .05 FWE-corrected. Spatial references are given in MNI space. Nonword Filler = **Wirrlein*, Simpler Pseudoword = **Spitzung*.