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Learning to read complex words: Morphological processing in reading acquisition

Das Lesen komplexer Wörter:
Morphologische Verarbeitung im Leseerwerb

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Zusammenfassung

Um ein guter Leser zu werden, ist es essenziell morphologisch komplexe Wörter schnell und effizient verarbeiten zu können. Ergebnisse psycholinguistischer Forschung mit Erwachsenen hat wiederholt gezeigt, dass geübte Leser komplexe Wörter in ihre Konstituenten zerlegen. Eine umfassende Beschreibung morphologischer Verarbeitung bei Kindern steht allerdings aus. Daher habe ich in meiner Promotionsarbeit morphologische Verarbeitung aus der Entwicklungsperspektive untersucht. Das zentrale Ziel war, zu beschreiben, ob, wann und wie Kinder Morpheme in der Worterkennung im Deutschen nutzen. Meine Forschung bedient damit zwei übergeordnete Zwecke: erstens, ermöglicht sie ein besseres Verständnis der Leseentwicklung; zweitens erlaubt sie Rückschlüsse über das geübte Lesen zu ziehen.

Vier Studien wurden konstruiert um die Forschungsfragen anzugehen. Die erste Studie umfasste eine groß angelegte Querschnittsstudie mit einem besonderen Schwerpunkt auf der Entwicklungsperspektive. Lexikalische Entscheidung zu unterschiedlichen Arten komplexer Wörter (Komposita, präfigierte und suffigierte Derivationen) wurde mit Zweit- bis Sechstklässlern untersucht. Die Ergebnisse zeigen, dass kindliches Lesen bereits früh in der Entwicklung durch Morphologie beeinflusst wird und dass der spezifische Effekt von morphologischer Struktur auf die lexikalische Verarbeitung abhängig ist von der Art des komplexen Wortes. Im Besonderen sind Leseanfänger im Deutschen zuerst sensibel für Komposita, gefolgt von Suffixen und Präfixen. Dies deutet auf eine Präferenz für Stämme und eine sequenzielle (links-nach-rechts) Verarbeitung hin. Des Weiteren beeinflusst morphologische Struktur Kinder mit größerem Wortschatz früher und starker als Kinder mit kleinerem Wortschatz, was für die besondere Bedeutung von semantischem Wissen für die Erkennung morphologischer Strukturen spricht. Um zwischen den sehr ähnlichen Einheiten Morphemen und Silben zu unterscheiden, verglich die zweite Studie die Nutzung von Morphemen mit der Nutzung von Silben

bei der lexikalischen Verarbeitung in jüngeren und älteren Kindern (Klasse 2 und 4) und Erwachsenen. Die Ergebnisse implizieren, dass zu Beginn der Leseentwicklung Silben präferiert werden und Sensibilität gegenüber Morphemen sich später entwickelt. Dies spezifiziert die Entwicklungstrajektorie von Morphemen weiter. Die dritte Studie wendete sich dem Einfluss von Ganzwort- und Konstituentenfrequenzen bei der lexikalischen Verarbeitung von Komposita zu. Die Ergebnisse zeigen, dass die verschiedenen Frequenzen die Worterkennung gemeinsam beeinflussen, was darauf hindeutet, dass Kinder Information vom Ganzwort und von den Konstituenten kombiniert nutzen. Die vierte Studie befasste sich unter Verwendung einer maskierten morphologischen Primingaufgabe mit der Automatizität der Dekomposition von Derivationen in Stamm und Affix. Die Ergebnisse weisen darauf hin, dass frühe, automatische Primingeffekte in Kindern vorhanden sind und noch nicht von der Präsenz eines Suffixes, sondern eher von der Verfügbarkeit eines Stamms abhängen.

Zusammengenommen zeichnen die vier Studien ein umfassendes Bild des Erwerbs und der Mechanismen morphologischer Verarbeitung bei Leseanfängern. Auf der Grundlage der Ergebnisse wird ein präzisiertes Modell von Morphologie im Leseerwerb vorgeschlagen. Dieses Modell nimmt an, dass orthographische Repräsentationen von Morphemen (Stämme und Affixe) während der Leseentwicklung etabliert werden, basierend auf der Entdeckung von Form-Bedeutung Korrespondenzen. Diese orthographischen Repräsentationen können dann bei der Worterkennung via Stammdetektion genutzt werden. Das verfeinerte Modell erlaubt außerdem Rückschlüsse über die geübte morphologische Verarbeitung bei Erwachsenen. Speziell deutet es darauf hin, dass morphologische Verarbeitung ihren Ursprung in Mechanismen des Leseerwerbs hat und – einmal etabliert – Morphemrepräsentationen und Ganzwortrepräsentationen interaktiv genutzt werden können. Die Dissertation liefert umfassende empirische Evidenz und einen theoretischen Rahmen für das Verständnis der Mechanismen und Strukturen, die beim Leseerwerb komplexer Wörter im Deutschen involviert sind.

Abstract

Many words in German are complex in that they are built by a combination of two or more morphemes. Learning to read efficiently those complex words is a major step in becoming a skilled reader. While psycholinguistic research has provided much evidence suggesting that adults decompose morphologically complex words into their constituents, evidence for morphological processing in children is inconsistent and lacks a comprehensive account. The present dissertation investigates morphological processing from a developmental perspective. The aim of this work is to outline if, when and how children make use of constituent morphemes in complex word recognition in German. This serves a double purpose: first, it allows to better understand reading development; and second, it can inform our knowledge about skilled reading.

Four experiments were designed to tackle these research questions. The first was a large-scale cross-sectional study placing special emphasis on the developmental perspective by examining lexical decision performance for different types of complex words (prefixed derivations, suffixed derivations and compounds) in children from grade 2 through 6 and adults. Results show that morphology affects children's reading at a very young age, and that the specific effect of morphology on lexical processing depends on morphological type. Specifically, readers of German are first sensitive to compound structure, followed by suffixes, and finally prefixes. This indicates a preference for the stem and a left-to-right bias in processing. Furthermore, children with larger vocabulary were affected by morphology earlier and to a greater extent than children with lower vocabulary knowledge, which highlights the importance of semantic knowledge for the detection of morphological structure. In order to dissociate between morphemes and syllables, which are very similar in size, the second study compared the involvement of morphemes to that of syllables in lexical processing in younger and older children (grade 2 and 4) and adults. The results imply that children prefer syllables early in reading development, while sensitivity to morphemes emerges later on. The third study addressed the contribution of whole-word and constituent frequencies to lexical decision performance on compound words. Results show that the frequencies both influence word recognition, indicating that information from the whole-word as well as from the constituents is used together. The fourth study employed masked priming to test the automaticity of decomposition of suffixed words into stem and affix in children. Results suggest that early priming effects are observable in children and are not restricted to the presence of an affix, but rather depend on the presence of a stem.

Taken together, the results from the four studies provide a comprehensive outline of the development and mechanisms of morphological processing in beginning readers. On the grounds of these findings, I suggest a refined model of morphology in reading development. This model assumes that orthographic representations of constituent morphemes (stems and affixes) are established during reading development based on the detection of form-meaning correspondences and can be used in word recognition via stem detection. The refined model also allows drawing inferences on skilled morphological processing. In particular, it indicates that morphological decomposition originates from mechanisms in reading acquisition and – once established – representations of constituent morphemes are used interactively with whole-word representations. The dissertation provides comprehensive empirical evidence and a theoretical framework that advances our understanding of the underlying mechanisms and structures that are involved in learning to read complex words in German.

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Introduction

CHAPTER 1

In her message on the International Literacy Day 2015, Irina Bokova, Director-General of the UN Educational, Scientific and Cultural Organization (UNESCO) described "literacy as a human right, as a force for dignity, and as a foundation for cohesive societies and sustainable development" (Bokova, 2015). The importance of acquiring reading skills is undisputable in a literate society. This is not only true in intellectual contexts, but also to navigate everyday life – from reading street signs to grocery shopping; visual symbols have to be translated into meaning. A fundamental step for becoming a proficient reader is the development of solid word reading skills, which means learning to rapidly translate letter sequences into meaning. However, the mechanisms behind the acquisition of these skills are still not fully understood. My dissertation addresses the question of how children learn to read complex words. In particular, I examine how elementary school children process words that are made up of multiple morphemes (e.g., *readability*) and if, when and how they thereby make use of the single constituent morphemes (*read* + *able* + *ity*). Psycholinguistic research has provided much insight on morphological processing in skilled adult reading. Morphological processing in children, however, is still understudied, despite the ubiquity of morphologically complex words in many languages. Describing the acquisition of morphemes as functional units in children's word recognition is not only important to better understand the course of reading developmental, but also for gaining insights into the underlying cognitive mechanisms and structures that map visual symbols onto meaning.

In this thesis, I investigate the role of morphology in reading acquisition. The present chapter starts out with a short introduction to morphology and specifically morphology in German, the study language. This is followed by a presentation of different current accounts of morphological processing in skilled adult readers. Then I turn to developing readers by first discussing models of reading acquisition and their predictions about the role of morphology in reading development. Subsequently, I present some previous evidence on morphological processing in developing readers. On this ground, I will derive and present my specific research questions and give an overview over the studies addressing those questions. Chapters 2-5 report the conducted studies[1]. The final chapter reviews the study results in the context of models of reading development and accounts of skilled morphological processing, and examines directions for future research.

1.1 Morphology in skilled reading

In linguistic terms, "morphology deals with the systematic correspondence between the form and meaning of words" (Booji, 2014, p. 157). For most words that consist of only one morpheme, the mapping from form to meaning is arbitrary: for instance, the meaning of the word *read* cannot be deduced from its visual or auditory form. Morphological structure, however, introduces some amount of non-arbitrariness: *readable* is related to its parts *read* and *able* in both form and meaning aspects[2]. Mapping visual form onto meaning essentially constitutes the core of reading. Consequently, as morphology presents an interface for this mapping, it seems like a sensible strategy to use this non-arbitrariness in order to read morphologically complex words. Research with skilled adult readers from a variety of languages indeed strongly suggests that morphological structure affects word recognition (for a review see Amenta & Crepaldi, 2012).

Some linguistic features need to be kept in mind for the study of morphology in word recognition, because the specific characteristics of a language have the potential to modulate processing mechanisms (e.g., Ziegler & Goswami, 2005). In the following, I give a short introduction to morphology and also the specific characteristics of German morphology. This is followed by an overview of theoretical models and experimental findings on morphological processing in skilled adult readers, providing

[1] Chapters 2-5 are published in or submitted to peer-reviewed journals. Thus, each of these chapters is written to be read independently from this thesis and, as a consequence, some redundancy between the chapters is unavoidable.

[2] It should be noted that some amount of non-arbitrariness also exists outside the framework of morphology, as in onomatopoeia (e.g., *woof woof* for the sound a dog makes) or phonoaesthemes (e.g., *gl-* in words related to light or vision: *glitter, glimmer, glow, glare*), which can not be considered morphological (see Monaghan, Shillcock, Christiansen, & Kirby, 2014, for a discussion on arbitrariness in language).

the framework against which the research gap concerning morphology in reading development will be identified.

1.1.1 Introduction to (German) morphology

Morphology refers to the system of word formation (Booji, 2014). Morphologically complex words are created by the combination of morphemes, which are defined as the minimal linguistic units that carry grammatical or lexical meaning. In general, three major morphological operations can be distinguished: inflection, derivation and composition. Inflection is used to specify number, tense and gender (e.g., *read* + *s*, *book* + *s*) and can be described as being a more grammatical than lexical device, as it preserves the word class and the main meaning of the stem. Also, inflection is not productive, meaning it is not flexibly used to create novel word meanings. This makes inflection slightly different from the other two morphological operations that are at the core of word formation and will be in the focus of this dissertation: derivation and compounding. Derivation is a device to create words by combining a stem with an affix (e.g., *read* + *er, read* + *able*) in accordance with combinatorial rules. For example, the suffix –*able* is restricted to attach to verb stems. Related words of the same or a different word class as the stem can be created and derivation can cause an idiosyncratic change in meaning. Composition takes two stems to form a new or more specified meaning (e.g., *book* + *worm*, *cook* + *book*). Compounding – unlike derivation – is rarely constrained by combination rules and can thus combine freely, allowing a variety of word formation possibilities.

Overall, German can be classified as a morphologically rich language (Fleischer, Barz, & Schröder, 2012): about 75 – 80% of German words are morphologically complex. Not only is it equipped with a very complex inflectional system, but also is word formation a very prominent linguistic operation. An important characteristic of German compounds is that more morphemes can be added almost without limitation. Novel compounds are regularly produced spontaneously. Moreover, German compounds are always written without interword spacing. Together, this can lead to the formation of remarkably long words, as the often-cited extreme example: *Donaudampfschiffahrtskapitänsmütze*. Morphological complexity and orthographic transparency tend to correlate (Perfetti & Harris, 2013; Seidenberg, 2011) and thus – at the same time as having a rich morphology – German features a rather transparent orthography with almost one-to-one grapheme-phoneme correlations (GPC) (Wimmer & Goswami, 1994; Seymour, Aro, & Erskine, 2003). In German, morphology is also represented in spelling rules through the *morphological principle*, which preserves the written form of morphologically related words even when the spoken form is slightly different and/or allows for an alternative spelling if only based on phonological rules. For example, *Sand* [zant] – *sandig* [zandık] is spelled with a *d,* although it is pronounced [t] in Sand due to devoicing. Moreover, syllables and morphemes, and thus their boundaries, very often coincide in German. In compounds and prefixed words this is the case because the boundary coincides with the first consonant of the stems (e.g., *ver+lesen*). In suffixed words, it is the case because many German suffixes start with a consonant (e.g., *-lich, -sam, -bar, -keit, -lein, -tum*). Also concerning phonology, stress assignment is usually not affected by suffixation as the stress remains on the first syllable. In contrast to other languages, the distinction between syllables and morphemes might therefore be less pronounced in German. One peculiarity of prefixes in German that deserves mentioning is that under the notion of prefixed verbs, two types can be distinguished: *prefix verbs* and *particle verbs*. Prefixes that appear in particle verbs usually also exist as free morphemes. For example, *um* can appear in prefixed verbs like "umfahren", but can also stand alone as a preposition or adverb with a different meaning (e.g., "*um* 5 Uhr" – "*at* 5 o'clock"; "*um* etwas zu sagen" – "*in order to* say something"). Moreover, the same prefix + stem combination can have a different meaning depending on whether it appears in a prefix verb or a particle verb. For example, "(etw.) umfahren" as a prefix verb means "drive around (sth.)", whereas as a particle verb it means "knock over (sth.)". The intonation and position in a sentence is used to discriminate between the different meanings. This is important as it might compromise the form-meaning regularity of some German prefixes. The interrelations between German morphology, orthography and phonology pointed out here deserve consideration in the context of the present dissertation, because such linguistic characteristics might be important for the sensitivity to morphological units in reading.

1.1.2 Morphological processing in adults

As morphemes are reoccurring entities of shared form and meaning, their use as functional units in reading appears natural. Consequently, a vast amount of psycholinguistic research has been devoted to the processing mechanisms behind complex word recognition and the underlying architecture of representations (for a review see Amenta & Crepaldi, 2012). Much debate has revolved on the extent to which morphologically complex words are processed, activated and stored as whole-words or decomposed units that require (re)combination.

The main theoretical division proceeds along the lines of *full-listing* and *full-parsing* hypotheses. Full-listing accounts (Fig. 1.1 a) claim that all known complex words are stored as whole-words in memory and are thus retrieved as such (e.g., Burani & Laudanna, 1992; Butterworth, 1983). Full-parsing accounts (Fig. 1.1 b), in contrast, assume that decomposition is obligatory (e.g., Taft & Forster, 1975, 1976). In between the two opposing hypotheses are several *dual-route* accounts (Fig. 1.1 c) assuming that access is possible both via the whole-word and the constituents (e.g., Baayen & Schreuder, 2000; Libben, 2006; Taft, 1994). In those models, the contribution of the two routes has been suggested to depend on word properties such as familiarity, frequency and transparency. The models vary in their assumptions about whether only one route is chosen or both routes operate in parallel either in a horse-race fashion or interactively. For example, the *Augmented Addressed Morphology* model (AAM) (Caramazza, Laudanna, & Romani, 1988) supposes that whole-word access tends to be the "normal" and faster route for known words and decomposition is only necessary for words that have not been previously encountered. The *Morphological Race Model* (MRM) (Schreuder & Baayen, 1995) states that decomposition and whole-word recognition act in parallel with the faster route "winning". Which route is faster depends on the frequencies of the constituents and the whole-word. In other models, both routes engage in an interactive processing mechanism (Fig. 1.1 d): In Andrews, Miller, and Rayner's (2004) *segmentation-through-recognition* model, the activation of constituents adds activation to the whole-word and vice versa. Similarly, Kuperman, Bertram and Baayen (2008) suggest that morphemes and their combinations are interactively used as probabilistic sources of information (see also Libben, 1994).

Finally, there are amorphous approaches that deny the recourse to abstract representations of morphemes altogether, such as the *Naive Discrimination Learning* (NDL) model by Baayen, Milin, Filipović Đurđević, Hendrix, and Marelli (2011). According to this model, morphological effects emerge solely through the overlap of form and meaning representations. Another type of amorphous models (Fig. 1.1 e), distributed-connectionist theories such as the *parallel-distributed processing* (PDP) triangle model (e.g., Harm & Seidenberg, 2004), presuppose distinct layers of units that encode orthographic, phonological and semantic information and are connected through hidden layers. Morphological effects in distributed-connectionist model are argued to arise as patterns of activation overlap over hidden units in the pathway from orthography to semantics (e.g., Plaut & Gonnermann, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnermann, 2000).

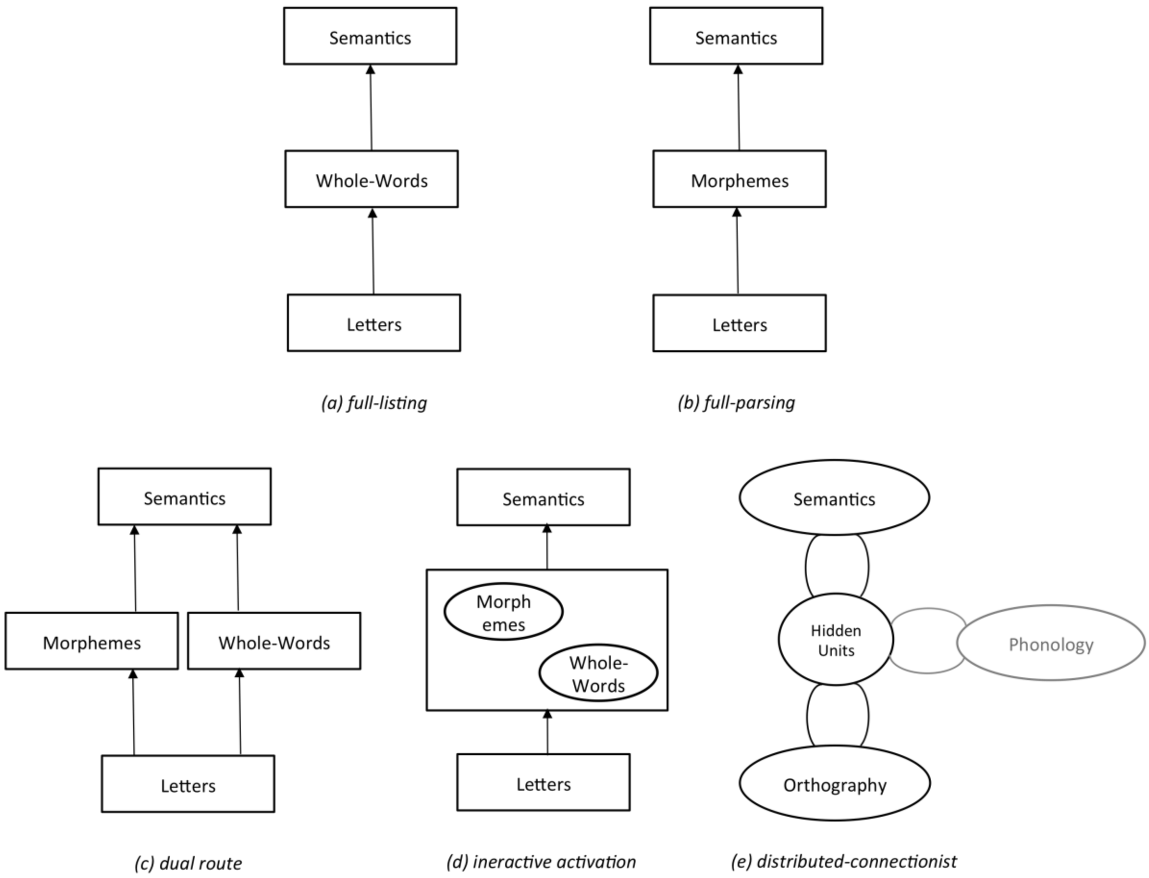

Figure 1.1 Different types of models of morphological processing.

The primary method of experimentally investigating morphological processing mechanisms has been through the lexical decision task (LDT). As a very basic investigation of complex word reading, lexical decision times to multimorphemic words have been compared to those of monomorphemic words. This has yielded mixed evidence: While early studies (e.g., Manelis & Tharp, 1977; Henderson, Wallis, & Knight, 1984) did not find different response times for complex compared to monomorphemic words, supporting full-listing accounts, later studies with better-matched stimulus material generally found processing benefits of complex words, which have been attributed to decomposition into constituents that allows for more efficient activation (e.g., Fiorentino & Poeppel, 2007; Ji, Gagné, & Spalding, 2011; for converging evidence from a naming task see Inhoff, Briihl, & Schwartz, 1996). Seldom, processing costs have also been observed and attributed to effortful recombination and semantic integration after decomposition (e.g., Ji et al., 2011).

In order to further test the influence of morphology on processing, especially for non-lexicalized items, lexical decision to morphologically structured *pseudo*words has been investigated (e.g., Burani, Marcolini, & Stella, 2002; Burani, Dovetto, Thornton, & Laudanna, 1997; Caramazza et al., 1988; Taft & Forster, 1975; see also Bölte, Jansma, Zilverstrand, & Zwitserlood, 2009, for related evidence from German using event-related potentials and sentence reading). Those pseudowords were either composed of non-existent combinations of stem + stem or stem + affix (e.g., *pipemeal, dejuvenate, shootment*), stem + pseudoaffix (e.g., *gasfil, curlip*), or pseudostem + affix (e.g., *vosnal, gopter*). Overall, morphologically structured pseudowords have been found to be more difficult to reject than non-morphological pseudowords (for converging evidence from naming tasks see Burani, et al., 2002; Burani, et al., 1997), suggesting decomposition.

While evidence from lexical decision (and naming) speaks in favor of processing accounts involving decomposition, the simple comparison of morphologically structured and monomorphemic items alone is unable to fully clarify the relationship between decomposition and whole-word processing. To test more explicitly the relative contribution of decompositional and whole-word routes in word recognition, frequency manipulations have been used (e.g., Burani & Carmazza, 1987; Taft, 1979; Taft & Ardasinski, 2006; van Jaarsveld & Rattink, 1988; for German: Bronk, Zwitserlood, & Bölte, 2013). In particular, both whole-word and constituent frequencies have been manipulated to investigate the relative contribution of different constituents (left vs. right, stem vs. affix) and the whole-word. The general tendency is that frequency effects emerge from both whole-word and constituent frequencies, whereas results are mixed with regards to the relative contribution of the different constituents (left vs. right, stem vs. affix).

Based on the accumulating evidence for decomposition (for German see Drews & Zwitserlood, 1995) one question concerns how and when during visual word recognition decomposition might take place. Full-parsing and the various dual-route accounts vary in their assumptions about the mechanisms and time-course involved. Several hypotheses have emerged: While *supra-lexical* accounts suppose that decomposition takes place only after the whole word has been accessed (Giraudo & Grainger, 2001), *sub-lexical* accounts describe decomposition in terms of affix-stripping prior to the access of meaning (Taft & Forster, 1975). *Form-and-meaning* accounts (e.g., Feldman, Milin, Cho, Moscoso del Prado Martín, & O'Connor, 2015) also assume early segmentation, but with the involvement of semantics already at the earliest stages of word recognition. *Form-then-meaning* accounts (e.g., Rastle & Davis, 2008) and *hybrid* models (e.g., Diependale, Sandra, & Grainger, 2009) depict early sublexical (*morpho-orthographic*) segmentation, which is followed by a later meaning-based (*morpho-semantic*) decomposition. Masked priming has become the most prominent paradigm in attempting to disentangle pre- and post-lexical decomposition (for a review see Rastle & Davis, 2008). In those studies, a target word, that is usually a stem, is preceded by the very short (approx. 50 ms) presentation of a morphologically related word (*teacher-TEACH*), a pseudo-morphological prime (either of the type *corner-CORN*, where corner is not the real suffixed derivate of the stem corn, or by a complex pseudoword, such as *sportation-SPORT*) and a non-suffixed control (either a word as *turnip-TURN*, where –ip is not a suffix combining with the stem turn, or a pseudoword, such as *sportip-SPORT*). The general findings from several languages (e.g., Dutch: Diependale, Sandra, & Grainger, 2005; English: Rastle, Davis, & New, 2004; French: Beyersmann, Casalis, Ziegler, & Grainger, 2015; Longtin & Meunier, 2005; Hebrew: Frost, Forster, & Deutsch, 1997; Spanish and Basque: Duñabeitia, Perea, & Carreiras, 2007a) indicate facilitated stem target recognition when the target is preceded by any suffixed prime, regardless of whether this is a truly suffixed, pseudosuffixed or a suffixed pseudoword relative to any non-suffixed prime. This is in favor of pre-lexical decomposition.

The approaches described above have been used to investigate both compounds and derivations (suffixes and prefixes). In addition to the approaches described above, methods have been combined and extended with other paradigms, such as cross-modal priming, and other techniques, such as eye-tracking, electroencephalography (EEG), functional magnetic resonance imaging (fMRI) and magnetoencephalography (MEG). Despite the vast evidence from different paradigms and methods, there is no definite answer so far with regards to which model is theoretically most plausible and accounts best for the observed effects.

While the studies described above have investigated both derivations and compounds in a variety of languages, studies in German to date have primarily focused on inflections (e.g., Drews & Zwitserlood, 1995; Clahsen, 1997; Clahsen, Eisenbeiss, Hadler, & Sonnenstuhl, 2001; Smolka, Zwitserlood, & Rösler, 2007). Those studies illustrate that specific linguistic characteristics of the German morphological system limit the generalizability of findings from morphologically poorer languages, such as English (see also Günther, Smolka, & Marelli, 2016). This observation makes it even more surprising that – despite the prominent role of word formation in German – studies on derivation and compound processing in this language have only emerged in the last years. Importantly, these studies point to a special status of sub-lexical decomposition in German with access via the stem (e.g., Smolka, Gondan, & Rösler, 2015; Smolka, Preller, & Eulitz, 2014). Based on the results from an overt priming study, Smolka, Komlósi, and Rösler (2009) suggest that "the native speaker may be tuned to perceive the constituent morphemes of a new word" as a consequence of the very productive compounding system. This makes German especially interesting as a language to study morphological processing.

Taken together, for skilled adult readers, evidence from psycholinguistic experiments in a range of languages in the past decades has suggested that decomposition is involved in the visual word recognition of complex words. German might even present an extreme case with regard to decomposition. The exact cognitive mechanisms of morphological processing, however, are far from being understood. The question that poses a problem for all accounts that include some kind of decomposition is: why would decomposition take place (see also Baayen et al., 2011)? One could argue that making reading more efficient is not the primary function of morphology. The primary function of morphology is, instead, creating and conveying novel meanings. This makes morphology most relevant to language *production*. Meanings are usually produced to be received, however. Consequently, the ability to also *de*compose complex words in order to extract meaning is inevitable. Once morphological regularities are learned, they might be used in other domains when this is beneficial, such as for reading efficiency. Rastle and Davis (2003, 2008) hypothesize that the origin of morphological decomposition in reading might lie in the process of reading acquisition. The "islands of regularity", as Rastle, Davis, Marslen-Wilson, and Tyler (2000) put it, might help the developing reader to discover and use mappings between orthography and meaning. The morphological rules and regularities that language users know from spoken language might facilitate the decomposition in processing written language. This idea has been expressed by distributed-connectionists models (Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000) that assume morphological regularities as an interface between orthography and semantics, but do not represent morphology explicitly. Also, in localist frameworks, morphological regularities come to be established as explicit representations acting at the interface between form and meaning (e.g., Giraudo & Grainger, 2000; Grainger & Ziegler, 2011). Regardless of the framework that is chosen, a comprehensive model of morphological decomposition in visual word recognition needs to encompass how children acquire these processes in reading development. Thus, all bears on the question: how is morphological decomposition learned?

1.2 Morphology in reading acquisition

Albeit much work has been done on the role of morphology in skilled reading, corresponding research with children has been much more limited. This is surprising considering that the non-arbitrariness of morphology might play an important role in establishing efficient mappings from orthographic form to meaning, as Rastle and Davis (2003, 2008) propose. The major goal of reading development is for children to establish a system that quickly converts orthography into meaning. Morphology might help to efficiently and reliably recognize known words and to decode and understand the many complex words that are encountered for the first time by children. However, research is only just beginning to investigate in detail when and how mappings from orthography to meaning evolve in reading development and what role morphology plays in this mapping (cf. Nation, 2009). The study of this issue is not only relevant to inform models of reading development, but also to move models of (skilled) morphological processing forward.

1.2.1 Models of reading development

Most models of reading acquisition posit that beginning readers learn grapheme-phoneme correspondence (GPC) rules and sound out the words letter by letter at first (e.g., Frith, 1986). As decoding skills develop and children gain more experience with written words, they become able to use larger units, such as syllables, morphemes or whole words to access meaning faster. For example, Ehri (1995) and Perfetti (1992) explain reading development in terms of establishing strong connections between orthography, phonology and meaning. Similarly, in distributed-connectionist frameworks, such as the *triangle model* (Seidenberg, 2005; Seidenberg & McClelland, 1989) (cf. Fig. 1e), reading development is explained as a transition from an orthography-phonology-semantics pathway to a more direct orthography-semantics pathway, on the assumption that children learn to read by linking orthography to phonology, while using the phonology-semantics pathway, which has already been established on the basis of spoken word recognition and production. Later on, through repeated exposure to written language, children can directly map orthography onto meaning. While much research has been dedicated to how children learn to form links from orthography to phonology, surprisingly little attention has been paid to how direct links from orthography to semantics develop (for a review see Nation, 2009). Morphology may play a critical role in investigating this issue.

One explanation of how children establish morphological representations by drawing on the form-meaning correspondence is proposed by Schreuder and Baayen (1995) in their framework of morphological processing, albeit this explanation is not focused on reading acquisition. It holds that children monitor input for consistencies between form and meaning, driven by the detection of overlap at the semantic level and allowing development of a corresponding representation at the (orthographic) access level through feedback activation. Thus, if a child encounters a complex word (e.g. *priceless*), words sharing the same stem (e.g. *pricy, pricetag*) or the same affix (e.g. *nameless, speechless*) are co-activated. Repeated co-activation of morphemes that are consistent in form and meaning allow the establishment of access representations of the single morphemes (*price*, *less*). This account thus provides an explanation for *how* sensitivity to morphology might develop, yet it remains silent about the particular time-course of this development.

Seymour's (2005) *dual-foundation* model acknowledges morphology as an important structure in reading development and makes predictions about the developmental time-course. The model postulates that after a stage of alphabetic decoding using phonemes, children advance to increasingly more complex structures, first centered around rimes, and in the last stage using syllables and morphemes. The model is not very precise, however, about how the different stages are interconnected or how they become acquired.

The *multiple-route model of orthographic processing* (Fig. 1.2) by Grainger and Ziegler (2011) brings together assumptions about acquisition mechanisms and the developmental time-course of morphemes as reading units. This model differentiates between distinct modes of coding of orthographic features for word recognition: it comprises a phonology-based route and an orthographic route, with the latter consisting of two sub-routes: a fine-grained and a coarse-grained route. From a developmental perspective, it predicts that young readers begin with serial letter identification based on phonology and GPC rules (Fig. 1.2 (1a)) or – as Häikiö, Bertram and Hyönä (2016) recently proposed in an extension of the model – via mediation of syllabic assembly (Fig. 1.2 (1b)). As reading develops, children increasingly advance from phonological to orthographic processing (Grainger et al., 2012). This occurs first by means of "chunking" (fig. 1.2 (2)): children start to make use of small letter sequences that feed into phonologically assembled units (Fig. 1.2 (2a)) or directly activate the orthographic representation of the word (Fig. 1.2 (2b)). The letter sequences used in this "chunking" can be frequently re-occurring linguistic units of different sizes, such as multi-letter graphemes (e.g., "ch") or morphemes (e.g., plural –*s*, suffix –*er*, or stem morphemes). In line with the self-teaching hypothesis by Share (1995), repeated exposure to printed words gives children the opportunity to learn direct letter-to-meaning mappings, making the advancement to more holistic coarse-grained processing possible (Fig. 1.2 (3)). Importantly, with the fine-grained and coarse-grained route, the multiple-route model includes the distinction between some kind of a decompositional route based on affix detection and a whole-word route as in dual-route models of skilled morphological processing. As children advance from fine-grained to coarse-grained processing, they establish a decompositional route first, and a whole-word route later on. It should be noted that the mechanism for establishing morphological access units as it is suggested here, is driven by the detection of letter sequences ("chunking") based on frequency of orthographic co-occurrence. This stands in contrast to the establishment of morphological units by the detection of form-meaning regularities suggested above (Rastle & Davis, 2003, 2008; Schreuder & Baayen, 1995), which has a stronger semantic component. Despite this discrepancy, the multiple-route model is most informative for deriving hypotheses about the emergence of morphological processing in reading development.

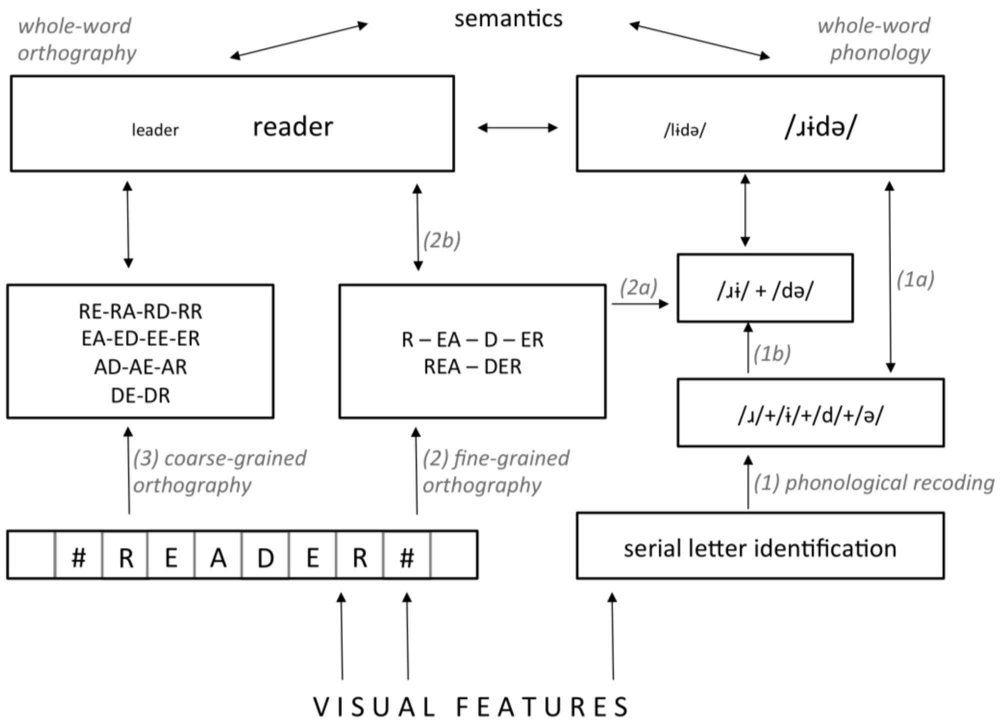

Figure 1.1 Adaption of the multiple-route model by Grainger and Ziegler (2011) and its extension by Häikiö et al. (2016).

As the *psycholinguistic grain size theory* (PGST) (Ziegler & Goswami, 2005) notes, different linguistic units of analysis, called *grain sizes*, can be used in reading and the use of certain grain sizes is determined by the special characteristics of the language. Special linguistic characteristics of a language may pose different demands on learners. As cross-linguistic comparisons show, differences in reading development can be attributed to linguistic characteristics (e.g., Katz & Frost, 1992; Perfetti & Harris, 2013; Seymour et al., 2003). For example, a major challenge in learning to read opaque orthographies, such as English, is the acquisition of the GPC mapping, which are rather inconsistent in opaque orthographies. Therefore, the initial, phonology-based stage of decoding is challenging in learning to read languages like English (Frith, Wimmer & Landerl, 1998) and learners profit considerably more from the use of bigger grain sizes, such as syllables or morphemes, since those tend to have more consistency in spelling and pronunciation (Katz & Frost, 1992). In contrast, German has a more transparent system of grapheme-phoneme mappings, making the acquisition of the initial letter-by-letter decoding relatively easy and fast to accomplish (Frith et al., 1998), such that solid basic reading skills can be achieved quickly by the use of GPC rules only (Wimmer & Goswami, 1994). At the same time, this leads to a decreased pressure of advancing to the use of bigger grain sizes, because phonology-based decoding is so precise and efficient (Ziegler & Goswami, 2005). On the other hand, the richness of German morphology and its omnipresence and productiveness might lead to increased sensitivity to morphemes as grain sizes (see also Günther et al., 2016). Thus, differences in language characteristics potentially impact the units used in reading development, as well as their time-course and order of acquisition. This makes investigation of morphological processing in German particularly interesting.

1.2.2 Morphological processing in children

Research on reading development has strongly focused on the role of phonology in acquisition, because phonological decoding is a major obstacle for children learning to read an opaque orthography, such as English. More recently, it has been suggested that morphemes could also facilitate reading acquisition. Consequently, research about the role of morphology in reading acquisition has been on the rise, not only in opaque, but also in transparent languages, as the latter often come equipped with a rich morphology (Perfetti & Harris, 2013; Seidenberg, 2011). Many studies investigated the role of morphological awareness (the ability to manipulate morphemes) as a precursor skill for reading, thus paralleling the concept of phonological awareness. Such studies have shown that morphological awareness predicts reading comprehension (for a review see Kuo & Anderson, 2006). Such studies also suggest that children are aware of the morphological constituents in a complex word and can use this knowledge to determine meaning (e.g., Krott & Nicoladis, 2005), learn new complex words (Bertram, Laine, & Virkkala, 2000), and spell words correctly (Deacon & Bryant, 2006). Developing readers are often faced with the obstacle of reading long and complex words that they have never encountered in written form before. In fact, the majority of words German children learn in the higher elementary school grades are morphologically complex (Segbers & Schroeder, 2016). Knowledge of morphemes, as the parts of complex words, and the operations by which they can be combined, might not only help in accessing the meaning of a complex word, but also in recognizing a written word fast and efficiently. In word recognition, morphological structure can allow children to identify morphemes they have seen before and then use these morphemes to decode unknown words faster. Some studies have thus started to examine effects of morphological complexity in visual word recognition in children. In a seminal study with English-speaking children, Carlisle and Fleming (2003; see also Carlisle & Stone, 2005) compared reading aloud of monomorphemic and derived words ending in –y (e.g., *silly* vs. *hilly*) and found that children read the derived words faster and more correctly. Naming studies with Italian children have also found increased speed and accuracy for suffixed words in young children (grade 2-3) and poor readers from grade 6 (Burani, Marcolini, De Luca, & Zoccolotti, 2008; Marcolini, Traficante, Zoccolotti, & Burani, 2011). Skilled sixth-graders, however, only showed naming benefits from suffixes in the case of low frequency words. A few studies have also investigated the effect of derived words in LDT. This research has shown that the presence of a root or a suffix in a word speeds up lexical decision in French third-, fourth- and fifth-graders (Casalis, Quémart, & Duncan, 2015; Quémart, Casalis, & Duncan, 2012). While fourth-graders benefit from the co-occurrence of root and suffix, it might cause additional computational costs for third-graders.

As for adults, complex *pseudo*word reading has also been intensively studied with children. The complex pseudowords in those studies are usually built by combining an existing suffix with a pseudostem or with an existing stem to form a non-existent combination (e.g., *puffow, gopter*). The idea behind this is that pseudowords parallel the reading of words that have never been encountered before, which is an especially common scenario for beginning readers. Thus, naming complex pseudowords has been the most popular paradigm for investigating morphology in developing readers in a variety of languages (Italian: Angelelli, Marinelli, & Burani, 2014; Burani et al., 2002; Burani et al., 2008; French: Colé, Bouton, Leuwers, Casalis, & Sprenger-Charolles, 2011). The studies generally show that reading aloud affixed pseudowords (composed of an existing stem and affix in a new combination or a pseudostem and a real affix) is faster and more accurate than reading aloud monomorphemic pseudowords. For LD, Burani et al. (2002) found rejection of affixed pseudowords being more error-prone but faster in Italian grade 3 to 5 children, whereas for French grade 3 and 5 readers (Casalis et al., 2015; Quémart et al, 2012), the presence of an existing affix or stem has been found to slow down rejection.

Another relatively rare paradigm for studying the use of certain units in children's word recognition involves manipulations of the presentation format of words. Colé et al. (2011) visually segmented words congruent with the syllable boundary, (e.g., *ma lade*), morpheme boundary (*mal ade*) and morpheme boundary + 1 grapheme (*mala de*) in a reading aloud task. They found that reading times were equally fast for segmentations at syllable and morpheme boundary for French second- and third-graders, suggesting that both units are helpful in word recognition.

In a similar fashion and as one of the very rare studies on compound processing in children, Häikiö, Bertram and Hyönä (2011) used eye-tracking to compare the reading of concatenated and hyphenated compounds (e.g., *autopeli* vs. *ulko-ovi*). They report advantages from hyphenations only for slow second-grade readers, but not for their faster age-matched peers or grade 4 and 6 readers. This suggests that morphological decomposition is helpful for slow beginning readers, but more advanced child readers prefer to use a whole-word strategy. Development accordingly proceeds towards more holistic processing.

The investigation of differential whole-word and constituent frequency effects that has been intensively studied in adults is almost absent in research with children. Only in one very recent study, de Zeeuw, Schreuder, and Verhoeven (2015) investigated differences between Dutch monolingual and Turkish-Dutch bilingual children's use of whole-word, first, and second constituent frequency in compound reading. The results show a clear role of whole-word frequency, but the effects of the constituent frequencies were not very clear as they were at best marginally significant and not present in all grades. Nevertheless, this points to the involvement of both whole-word and decomposition processes.

In order to disentangle sub-lexical and supra-lexical decomposition, which is a major topic in research on skilled morphological processing, masked morphological priming studies inspired by those with adults have been conducted with children, too. Priming from morphologically related primes (laveur-LAVAGE) has repeatedly been found in both French and English children (Beyersmann, Castles, & Coltheart, 2012; Casalis, Dusautoir, Colé, & Ducrot, 2009; Quémart et al., 2011). Equal priming from pseudosuffixed primes (lavande-LAVAGE) has been observed in French (Quémart, Casalis, & Colé, 2011), but not in English (Beyersmann et al., 2012), questioning whether decomposition in children is morpho-orthographic. Beyersmann, Grainger, Casalis, and Ziegler (2015) found priming from suffixed words and also from suffixed and nonsuffixed nonwords in French selectively for children with high language proficiency, further questioning the morpho-orthographic nature of decomposition in children.

Despite the prominence of morphology in German, there is an astonishing lack of research with German-speaking children in this domain. While some attention has been paid to morphology in German children with regard to spoken language production (e.g., Clahsen, Hadler, & Weyerts, 2004; Jessen, Fleischhauer, & Clahsen, 2106), very little is known about written language comprehension. A recent study by Clahsen and Fleischhauer (2013) presents a first step towards filling this gap. Following the tradition of previous work with adults in German as described before, this study investigated reading of inflections using a cross-modal priming task with two groups of elementary school children (7-9 and 9-10 years old). Results show that the pattern of morphological priming in children resembles that in adults; for the younger group only partially and fully for the older group. The authors argue that

German beginning readers very early in development already employ the same morphologically-structured representations and mechanisms as adults when reading inflected words. It remains open, if this is also true for products of word formation, i.e. derivations and compounds, which have been in the focus of investigation in other languages.

Taken together, previous evidence is in favor of a role for morphology in the elementary school years in both opaque and transparent languages. From the current state of research, we know that children who learn to read English, Italian or French show effects of morphology as early as in second grade. The studies so far have investigated selected age groups and special populations (i.e. poor or dyslexic readers) and have mostly investigated suffixed derivations with reading aloud paradigm. In German, evidence is restricted to inflections. Based on this literature review, I identify the current research in the next chapter.

1.3 Research questions

The Introduction so far has shown that morphology stipulates a systematic relationship between form and meaning and that skilled adult readers appear to use morphological decomposition in complex word processing, although the exact conditions, mechanisms and time-course of this phenomenon are not entirely clear. The origin of morphological decomposition has been proposed to lie in the acquisition of form-meaning mappings in reading development (cf. Rastle & Davis, 2003, 2008). Theories of reading acquisition, however, are underspecified with regard to the emergence and exact nature of morphological processing in children.

Studies so far have investigated only selected age groups or special populations (i.e. poor or dyslexic readers). Due to the fragmented evidence from different languages and groups of children, as described above, we do not know how exactly the effects of morphology *develop* relative to the number of years of reading instruction in one language and relative to the use of other reading units or grain sizes. To address this issue, large cross-sectional or even longitudinal studies are required that cover a broad range of age groups and closely monitor development. Moreover, research has emphasized on suffixed derivations, while prefixed derivations and especially compounds have largely been ignored. Thus, we also do not know, whether the observed facilitation from suffixed words generalizes to prefixed words and compounds. Directly comparing different word formation products is, however, important if we not only want to understand processing of suffixes, but of all morphological types. Such a comparison might also be relevant to investigate positional constraints: prefixes and suffixes differ in their position in a word. As beginning readers are usually more prone to read rather sequentially from left-to-right, this could result in processing differences. In German, evidence from the recognition of all word formation products is absent. From a cross-linguistic perspective, it is uncertain, whether the effects reported in the English, Italian and French languages are likely to be observed in a morphologically rich language such as German. Linguistic characteristics and evidence from skilled processing suggests a special role of morphology in this language, as noted earlier. Stems, in particular, could have a privileged function due to the peculiar compounding system (see Smolka et al. 2009). Also, previous research with children has heavily concentrated on the reading aloud of complex pseudowords and has neglected how this generalizes to silent reading of words, i.e. lexical decision tasks. Silent reading, however, presents a much more common scenario in everyday reading practice, even for young readers (see Nation, 2009) and can be expected to tap more directly into orthographic processes (Nation & Cocksey, 2009). Finally, research on morphology in children is only loosely connected to the research body on skilled morphological processing. Research with children often employs different paradigms and manipulations than research with adults, making comparisons especially problematic. Further, studies with children have not attempted to primarily and explicitly test different models of (skilled) morphological decomposition, albeit this promises novel insights about the underlying mechanisms. Direct comparisons of the nature and mechanisms of decomposition in children and adults are rare. The application of paradigms used regularly in adult studies such as frequency manipulations or masked priming to disentangle whole-word and decompositional processing needs to be tested with children.

Clearly, there is a great deal about morphology in reading development that is not researched much and not yet well understood, but needs to be addressed to advance acquisition theories. As research on the issue is still in the beginning, the most fundamental step right now is to refine models of reading acquisition with regard to their assumptions about morphology. A refined model about morphological processing in children's word recognition is needed as a framework to derive and test more detailed hypotheses in the future. For this purpose, such a refined model needs to be explicit about *when* and *how* morphemes are established and used as reading units. Therefore, this will be one research question of my dissertation. The question of *when* should be answered both relative to years of reading instruction and relative to the use of other functional reading units. The *how* needs to address both the establishment and use of morphemes as reading units. Do children detect form-meaning regularities based on semantics or do they chunk letter sequences based on orthographic co-occurrence? Do children use morphemes as sub-lexical, lexical or supra-lexical units? Moreover, to refine models of morphology in reading development as well as models of skilled morphological processing, it needs to be examined *whether* children's use of morphemes can be tested with the same paradigms that are employed with adults and *whether* and *how* morphological effects in those tasks are different or similar between beginning and skilled readers. This will be another research question in this dissertation. A developmental perspective on morphological processing thus promises to move forward our understanding of reading in both developing and skilled readers.

1.4 Study overview

Above I outlined the most urgent questions that arise from gaps in the research literature at present. In order to tackle those questions in my dissertation, four studies with a slightly varying focus and methodology were undertaken. The first two studies focus more heavily on development: they compare children at different stages in reading development and employ paradigms that are commonly used in the research on morphological processing in children. Those two studies thereby specifically attend to *when* and *how* morphological processing develops. The latter two studies focus more heavily on testing paradigms and effects with developing readers that are typical for the literature on skilled morphological processing. Those two studies thus address *whether* and *how* morphological processing in children can be compared to adults. Each of the four studies in this dissertation provides insights into the above specified questions by uniquely attending to a relevant sub-question. An overview of each study and its specific focus is given below.

Study 1. As discussed above, previous studies have provided evidence for both benefits and costs of morphology and there might be underlying developmental changes that have not been captured so far. Moreover, there might be developmental differences depending on morphological type (compound, prefixed or suffixed derivation). Previous studies with children have almost exclusively focused on the processing of suffixes, albeit structural differences between morphological types might influence the developmental time-course. For example, a more pronounced left-to-right bias in beginning readers (Bijeljac-Babic, Milogo, Farioli, & Grainger, 2004; but see Nation & Cocksey, 2009) could result in developmental differences between prefix and suffix processing. Similarly, the difference in semantic content and the suggested special role for stems in German could result in differences between stem and affix, and thus between prefix, suffix, and compound processing. Study 1 therefore presents a comprehensive description of the trajectory of sensitivity to morphemes in learning to read German. LD data is analyzed that was available from the *Developmental Lexicon Project* for children from grade 2 through 6 children and adults. The data includes reaction times and error rates for a total of 1152 words and 1152 pseudowords, comparing monomorphemic (e.g., *Laterne, Kompire*) to prefixed (e.g., *Abwasser, Unfats*), suffixed (e.g., *Lehrer, Pauner*) and compounded (e.g., *Segelboot, Bettdepse*) items. Vocabulary knowledge is additionally taken into account as an indicator for inter-individual differences. Study 1 thus presents an unprecedentedly comprehensive approach to morphological processing in reading development - on the participant side by including a great number of children across the entire age range of elementary school and on the item side by investigating different morphological types of which two, prefixes and compounds, are severely understudied in child word recognition. Such a large-scale description of the trajectory of reading of all three morphological types will allow refining models of reading acquisition with regard to the developmental time-course and mechanisms of morphological processing.

Study 2. In the framework of the multiple-route model (Grainger & Ziegler, 2011), syllables and morphemes are similarly sized letter sequences and can thus function as units of a fine-grained route. Albeit being formally very similar and often even coinciding, the units differ from each other in important dimensions: syllables are phonologically defined and encode information about pronunciation; morphemes are defined through the convergence of form and meaning, encoding lexical-semantic information. Also, as morpheme and syllable boundaries often coincide in German and stress assignment is usually not affected by morphological operations, the two units might not be very well distinguishable for developing readers. This makes it especially important to disentangle those two units in reading development, giving insights about the chronological order of emergence and relative contribution of mediating units in reading. Study 2 uses a new paradigm to compare the use of morphemes and syllables in visual word recognition in beginning and more advanced child readers and adults. In a LDT, multimorphemic and monomorphemic words and pseudowords were visually disrupted by insertion of a colon either at a syllable-congruent position (e.g., *SPI:NAT, FAH:RER, DOS:TOR, HEL:BER*) or at a syllable-incongruent position (i.e. morpheme-congruent in multimorphemic items; e.g., *SPIN:AT, FAHR:ER, DOST:OR, HELB:ER*). Study 2 provides insights about the development of sensitivity to morphemes in relation to the sensitivity to other units, especially syllables. It also allows further insights into the mechanisms involved in morphological processing in children.

Study 3. Besides examining specific developmental issues about the time-course and mechanisms acquisition of morphological processing, it is important to ask the same questions for children that have been examined in-depth for adult readers. This concerns especially the debate on the relation of whole-word and decomposition that has dominated the research on skilled morphological processing. Particularly beginning readers often encounter long morphologically complex words for the first time in print (cf. Segbers & Schroeder, 2016). Decomposition might be of special importance in order to break down and understand those words. The peculiarity of the German compounding system might further promote decomposition. The relative contribution of the whole-word and decomposition routes in children, however, remains nearly unstudied so far. Additionally, because decoding is still much more sequential from left-to-right in beginning readers, the first constituent might have a privileged role in reading, making the relative contribution of the first and second constituent to compound recognition in children relevant. Study 3 adopts a frequency manipulation, a paradigm which remains completely understudied for children until now. In a LDT, constituent frequencies of German compounds were orthogonally manipulated, while keeping constant one constituent (e.g., *Handschuh, Handtuch, Autobahn, Eisenbahn*) and further taking into account whole-word frequency. Such an approach allows to compare the relative contribution of whole-word frequency and first and second constituent frequency in children's and adults' processing of compound words. Study 3 thus concentrates particularly on answering whether this paradigm – that is typically used to study compound processing in adults – can be employed with children and how whole-word and decompositional processing relate to each other in beginning as compared to skilled readers.

Study 4. Equally, another central debate in skilled morphological processing concerns the automaticity and sub-lexical vs. supra-lexical nature of decomposition. Models of morphological processing in skilled readers differ in their assumptions about the locus of decomposition. As presented above, they differentiate between early automatic segmentation that is based on orthographic form overlap and later strategical segmentation that is based on semantic relationships (e.g., Diependale et al., 2009). Albeit masked morphological priming is the most popular paradigm to investigate sub- vs. supra-lexical segmentation in adults, in has only been conducted with children a few times. First attempts to investigate this issue in English and French children have yielded contradictory results (e.g., Beyersmann et al., 2012; Quémart et al., 2011). It is possible that this is a consequence of cross-linguistic differences or methodological problems. Especially, recent evidence points to a special role of the stem in priming (Beyersmann, Grainger, et al., 2012), as opposed to affix-stripping mechanisms, which is in line with considerations made above. Consequently, the issue deserves further exploration. The distinction between sub- and supra-lexical decomposition processes in children is especially important to disentangle whether the detection of form-meaning correspondences is orthographically or semantically driven in development. Therefore, study 4 looks at masked morphological priming effects in elementary school children by comparing suffixed word primes (*kleidchen-KLEID*), suffixed nonword primes (*kleidtum-KLEID*), nonsuffixed nonword primes (*kleidekt-KLEID*) and unrelated controls (*träumerei-KLEID*). In particular, response time distributions were analyzed in order to examine effects beyond mean response times. The usual practice of collapsing response times into means possibly obscures whether priming effects only occur at very fast RTs (when processing is especially quickly completed) or at very long RTs (when processing has unfolded for a longer time) or across the entire range. Analyzing the response time distributions, however, allows more precise insights into the underlying time-course. Study 4 thus expands a popular paradigm of research on skilled morphological processing to children and combines it with a new statistical method. By doing this, the study specifically addresses differences and similarities in the automaticity and locus of morphological segmentation in children and adults.

Together, the four studies enhance the limited literature on morphological processing in developing readers by providing findings from a new language, German, in which morphological processing has not been studied very extensively, although it features some interesting linguistic characteristics. Moreover, the studies expand the methodological approaches taken in the research with children and bring together the research on morphological processing in children and adults. In conjunction, the studies have the potential to yield valuable insights about reading development as well as skilled reading.

Investigating Developmental Trajectories of Morphemes as Reading Units in German

CHAPTER 2

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2.1 Abstract

The developmental trajectory of the use of morphemes in a transparent language is still unclear. We investigated the emergence of morphological effects on visual word recognition in a large sample across the complete course of reading acquisition in elementary school. To this end, we analyzed lexical decision data on a total of 1152 words and 1152 pseudowords from a large cross-sectional sample of German children from the beginning of grade 2 through 6, and a group of adults. We expand earlier evidence by (1) explicitly investigating processing differences between compounds, prefixes and suffixes, (2) taking into account vocabulary knowledge as an indicator for inter-individual differences. Results imply that readers of German are sensitive to morphology in very early stages of reading acquisition with trajectories depending on morphological type and vocabulary knowledge. Facilitation from compound structure comes early in development, followed by facilitation from suffixes and prefixes later on in development. This indicates that stems and different types of affixes involve distinct processing mechanisms in beginning readers. Furthermore, children with higher vocabulary knowledge benefit earlier in development and to a greater extent from morphology. Our results specify the development and functional role of morphemes as reading units.

2.2 Introduction

Many languages feature a high amount of morphologically complex words (e.g., *readable*) that are built by a combination of two or more constituent morphemes (e.g., *read + able*). In the field of reading acquisition, it has been theoretically suggested and empirically demonstrated that children start using morphemes as functional units in the course of reading development. At present, however, it remains unclear – both from a theoretical and from an empirical perspective – when and how exactly children become sensitive to morphology. To fill this research gap, we adopted a comprehensive approach with participants from the complete range of reading development. Hence, we examined morphological reading in German children from grade 2 through grade 4 and 6, with groups both at the beginning and end of each school year. Lexical decision data for 1152 words and equally many pseudowords from the *Developmental Lexicon Project (DeveL*, Schröter & Schroeder, 2016*)* were analyzed with regard to their morphological status. We explicitly compared compounds, that is words built by the combination of two stems (e.g., *cook+book*), and prefixed and suffixed derivations, that is words consisting of a stem and an affix either preceding or following the stem (e.g., *un+learn*, *read+able*). This allowed differentiating the relative role of stems and different types of affixes in word recognition. Also, vocabulary knowledge was taken into account as an indicator for inter-individual differences, which can be considered at least equally important to age as a factor in development. By taking this extensive approach, we delineate the developmental course of morpheme use in learning to read, giving valuable new insights about the nature of different morphemes as units in word recognition. This is of interest to advance models of reading development with respect to morphological processing.

For skilled adult readers, morphemes have been extensively discussed as functional units of word recognition (for a review see Amenta & Crepaldi, 2012). Accumulated evidence suggests that morphologically complex words are parsed into their constituent morphemes. Some accounts of morphological processing in adult readers assume an obligatory sub-lexical decomposition of all words by means of affix-stripping (e.g., Taft & Forster, 1976). Most support has been put forward in favor of hybrid models, which suggest that lexical access is possible both via a whole-word route and a decompositional route (e.g., Caramazza, Laudanna, & Romani, 1988; Libben, 2006; Schreuder & Baayen, 1995; Taft, 1994), with whole-word access being the default for known words and decomposition helping out in the reading of novel words.

Developing readers often encounter certain words for the first time in print. Those words cannot be retrieved from the orthographic lexicon since they do not have an entry yet: their orthographic form is not stored, because the printed form has simply not been experienced before. Thus, in order to read those words for the first time, smaller units need to be considered, such as graphemes, so that the word can be decoded letter-by-letter using grapheme-phoneme conversion (GPC) rules. Even in languages with straightforward GPC rules, this is rather time and resource consuming. The majority of new words that children encounter during their school years are morphologically complex, as Nagy and Anderson (1984) note, made up of two or more morphemes (see also Anglin, 1993). This is also true for German (Segbers & Schroeder, 2016). Importantly, morphemes are units that reoccur in different combinations and therefore might have been encountered by children in another context before. Breaking down complex words into their morphemes thus may aid the reading of new combinations. Knowledge of morphemes, as parts of complex words, and the operations by which they can be combined, has been found to play an important role with regard to semantics by helping to break down and understand the meaning of unknown words in word definition tasks (i.e., Bertram, Laine, & Virkkala, 2000). Using known morphemes in order to decode unknown words has been proposed as a reading strategy for children to recognize familiar words fast and efficiently.

Complex Word Recognition in Reading Development

Most theories of reading development assume morphology to play a role at some point (e.g., Seymour, 2005), but they do not make more explicit assumptions about how morphology comes about to be used in word recognition. One theory that more explicitly includes the emergence of an access mechanism via morphemes is the multiple-route model by Grainger and Ziegler (2011). This model predicts that beginning readers start out with serial letter identification based on phonology and GPC rules and increasingly advance to more parallel orthographic processing. For orthographic processing, the model comprises two routes that both feed into whole-word orthographic representations: a fine-grained and a coarse-grained route. The fine-grained route uses location-specific coding of letter sequences. These letter sequences are intermediate-sized linguistic units, such as affixes. The fine-grained route thus entails a sub-lexical morphological decomposition mechanism that depends on affix detection and feeds forward activation to whole-word orthographic representations. The coarse-grained mode operates independent of specific letter position information and is more holistic in nature, but also feeds into whole-word orthographic representations. Activation at the orthographic level in turn gains from top-down feedback from semantics. Importantly, with the fine-grained and coarse-grained route, the multiple-route model entails a distinction similar to the decompositional route and whole-word route in hybrid models of skilled morphological processing (e.g., Caramazza et al., 1988; Dipendale, Sandra, & grainger, 2009). From a developmental perspective, the multiple-route model hypothesizes that children start to use affixes as units in reading as they advance from phonological decoding to using letter sequences in the fine-grained route. The authors suggest that this advancement marks an important shift to parallel processing of letters, which is not only important for holistic processing once a coarse-grained route becomes established, but already for the detection of affixes, especially suffixes at word endings, in the fine-grained route. As an empirical consequence, the model predicts that the development of fine-grained processing should manifest in increased sensitivity to morphological structure.

A growing number of studies have investigated the use of morphology in learning to read by comparing reading accuracy and speed of words with or without a morphological structure. This research has shown that the presence of a root or a suffix in a word speeds up lexical decision in French third-, fourth- and fifth-graders (Casalis, Quémart, & Duncan, 2015; Quémart, Casalis, & Duncan, 2012). While fourth-graders benefit from the co-occurrence of root and suffix, it might cause additional computational costs for third-graders. Suffixes have also been reported to increase speed and accuracy of word naming in young Italian readers (grade 2-3) and poor readers from grade 6 (Burani, Marcolini, De Luca, & Zoccolotti, 2008; Marcolini, Traficante, Zoccolotti, & Burani, 2011), while skilled sixth-graders only benefit from suffixes in the case of low frequency words, and adults not at all.

Many studies with children also utilize complex *pseudowords* that are usually built by combining an existing suffix with a pseudostem or with an existing stem to form a non-existent combination. The idea behind this is that pseudowords parallel the reading of words that have never been encountered before and thus cannot be accessed via a whole-word route, making them especially prone to morphological decomposition. The presence of an existing affix or stem makes pseudoword rejection more difficult for French grade 3 and 5 readers (Casalis et al., 2015; Quémart et al, 2012). For Italian grade 3 to 5 children, the case is less clear, as Burani, Marcolini, and Stella (2002) found rejection of affixed pseudowords being more error-prone but faster, which might also be driven by a speed-accuracy trade-off. Naming tasks also show that reading aloud is faster and more accurate for affixed pseudowords (composed of an existing stem and affix in a new combination or a pseudostem and a real affix) than monomorphemic pseudowords (Italian: Angelelli, Marinelli, & Burani, 2014; Burani et al., 2002; Burani et al., 2008; French: Colé, Bouton, Leuwers, Casalis, & Sprenger-Charolles, 2011).

Taken together, the evidence provided so far speaks in favor of a role for morphology to emerge in the elementary school years, in line with the predictions of the multiple-route model. However, the studies addressed above have investigated different groups of children: the participants were of certain selected age or skill groups, or were special populations, such as poor or dyslexic readers. This makes it hard to make coherent assertions about the developmental trajectory. Also, the research has emphasized reading aloud, albeit silent reading is very common even for young readers and even more throughout development (see Nation, 2009). Reading aloud might reinforce a sequential decoding strategy in analogy to the sequential nature of the required oral output. Lexical decision can instead be expected to tap more directly into orthographic processes already in children (Nation & Cocksey, 2009), and this is more relevant to gain a thorough understanding of morphology in reading development since morphological effects are typically considered to arise in orthographic stages of processing (cf. Diependale et al., 2009). Further, previous studies have concentrated on suffixed derivations, neglecting prefixed derivations and compounds. Basically all the above described studies have concentrated on suffixed derivation, while studies examining prefixed derivations and compounds are sparse and use deviating paradigms or methodologies. For example, prefix identification in Dutch third- and sixth-graders was examined by Verhoeven, Schreuder, and Haarman (2006) with a different manipulation and compound reading was studied in Finnish first- and second-graders by Häikiö, Bertam, and Hyönä (2011) using eye-tracking of hyphenated and concatenated compounds in sentence contexts. To our knowledge, no lexical decision or naming experiments as the ones described above have been undertaken with prefixed and compounded words and pseudowords. This is surprising, because those morphological types are also very common in many languages. To gain a thorough understanding of the role of morphology in reading, it is necessary to examine the processing of all morphological types. This would allow to more precisely test the assumptions about affix detection and parallel processing in the fine-grained route of the multiple-route model.

Overall, the developmental evidence remains fragmented both with regard to participants and to items. Yet, in order to truly understand the evolvement of morphology effects in reading development, it is crucial to examine children across the range of reading acquisition and the various morphological types.

Preferences for Morphological Types

As mentioned above, distinct morphological types need to be taken into consideration when examining morpheme use in reading development, specifically the differences between prefixes and suffixes have been neglected. From a linguistic perspective, prefixes and suffixes are rather distinct with regard to their semantic function, their ability to alter phonological or orthographic form and their ability to change the syntactic category of the word. Cross-linguistically, there is a preference for languages to have predominantly suffixes rather than prefixes (Cutler, Hawkins, & Gilligan, 1985). Cutler et al. (1985) argue that this suffix preference reflects principles of lexical processing. Especially, it is attributed to a left-to-right processing bias, which goes hand-in-hand with a preference for the stem as the most informative part favoring the most salient position, i.e. the first (or the left-most) position. Under this assumption, suffixed words can be immediately activated via the stem, whereas identification of the stem in prefixed words needs to be delayed until the rest of the word is recognized. As a consequence, distinct mechanisms could be involved in processing prefixes and suffixes, as corroborated by psycholinguistic studies with skilled adult readers (e.g., Bergman, Hudson, & Eling, 1988; Beyersmann, Ziegler, & Grainger, 2015; Colé, Beauvillain, & Segui, 1989; but see Gonnerman, Seidenberg, & Andersen, 2007). For children, especially in the early phases of reading development, a preference for suffixed words, which have the stem as the more informative part in the beginning, can be predicted, since the left-to-right processing bias is particularly pronounced in beginning readers (Bertram & Hyönä, 2003). However, this stands in contrast to the parallel nature of the affix detection assumed by the multiple-route model (Grainger & Ziegler, 2011). As evidence on prefixes in children's visual word recognition is extremely sparse (but see Verhoeven et al., 2006), it is unclear whether prefixes and suffixes emerge as reading units at the same time or whether they exhibit different developmental trajectories. As a consequence, a systematic and direct comparison of the processing of prefixed and suffixed words in reading development across the elementary school years is urgent. Additionally, it is important to include compounds into the scope of developmental studies on complex words. As compounds are built of two stems, they enable to test morphological effects in the absence of affixes, giving further insight into the mechanisms underlying the emerging ability to extract stems in reading development.

Vocabulary Knowledge in Complex Word Reading

The importance of vocabulary knowledge for reading and reading development has been emphasized by various theoretical accounts (e.g., Perfetti & Hart, 2002; Harm & Seidenberg, 2004). Good vocabulary knowledge is associated with high-quality lexical representations that are important building blocks of reading. Individuals with high levels of vocabulary knowledge usually entertain good representations not only of free stems but also bound morphemes (Reichle & Perfetti, 2003). In their framework of morphological processing, Schreuder and Baayen (1995) hypothesize that experience with morphologically complex forms and with single constituent morphemes supports the detection of form-meaning consistencies, which allows developing morphemic representations at the access level. Thus, if a person encounters a complex word (e.g. *priceless*), access of this word is thought to be supported by previous experience with the whole form itself (*priceless*), as well as the stem (*price*), the affix (*less*) and forms sharing the same stem (e.g. *pricy, pricetag*) or the same affix (e.g. *nameless, speechless*). Thus, knowledge of morphemes or morphological relatives endorses the recognition of complex words (Reichle & Perfetti, 2003). Carlisle and Fleming (2003) provide evidence that knowledge of full forms, stems and affixes influences the development of morphological processing, as does knowledge of morphological relatives (Carlisle & Katz, 2006; Goodwin, Gilbert, Cho, & Kearns, 2014). Also, for skilled adult readers recent work has made a case for vocabulary being associated with differences in the manner and/or extent of morphological decomposition (Andrews & Lo, 2013). Consequently, inter-individual differences in vocabulary knowledge can be expected to have a significant impact over and above grade on the developmental trajectory of morphemes as reading units.

The Present Study

The aim of the present study is to provide a comprehensive examination of the use of morphemes in word recognition across reading development. To this end, we analyze lexical decision data from 9 groups of participants, including grade 2 through grade 4 and grade 6 students, with groups of children both at the beginning or end of each school year, as well as adults, thus covering the whole range of reading development in the elementary school years. This allows comparing the developmental trajectories of the influence of different types of morphemes on word recognition for children at different stages in reading development. In contrast to previous studies, we use the extensive lexical decision data base from the *Developmental Lexicon Project* (Schröter & Schroeder, 2016), comprising many words with a great range of characteristics. Using a large unmatched item set has the advantage that many item characteristics can be statistically accounted for without severely limiting the representativeness of the item set (Baayen, 2010). Such an approach has been repeatedly shown to present a powerful and valuable way of investigating word recognition processes (for a review see Balota, Yap, Hutchison, & Cortese, 2016). Using this approach, we compare responses to compounds, derived and monomorphemic words and pseudowords. Additionally, we investigate two important related issues that are important to move the debate about morphemes as functional units in word recognition forward: (1) differential processing of distinct morphological types and (2) the influence of inter-individual differences in vocabulary knowledge on the developmental trajectory.

Based on previous studies on morphology in reading development and based on the observation that comprehension of derived words substantially increases between grade 3 and 5 (Anglin, 1993; Segbers & Schroeder, 2016), we expect that morphemic structure benefits word recognition in German in grade 3 at the latest, possibly even earlier, after an initial stage of letter-by-letter decoding has been accomplished. In the framework of the multiple-route model, which suggests morphological decomposition by detection of the affix in a parallel fashion, effects from prefixed and suffixed derivations should arise at the same time, and effects of compounds, which do not feature an affix, should arise later in development. Under the assumption of a left-to-right bias and a stem preference, effects from compounds can be suspected to arise earliest in the course of reading development, as they consist of two stems, which are the more informative units for lexical decision. Also, assuming a left-to-right processing bias and a preference for stems, effects from suffixed derivations should arise in an earlier developmental phase than effects from prefixed derivations. Finally, we anticipate that vocabulary knowledge moderates the ability to utilize morphemes in reading development over and above grade, with better vocabulary knowledge being associated with a greater benefit from morphology, as suggested by the framework of Schreuder and Baayen (1995; see also Reichle & Perfetti, 2003).

2.3 Method

Participants

The analyses in this study present archival post-hoc analyses of data that was attained within the framework of the *Developmental Lexicon Project (DeveL)*, a large-scale cross-sectional study on word recognition across the lifespan (Schröter & Schroeder, 2016). Elementary school children attending grade 2 through 4 and grade 6 were recruited and tested during regular school hours at their schools in the Berlin area. For each grade, one group of children was tested at the beginning of the school year and another group of children was tested at the end of the school year. In addition, data was collected from students from the Berlin universities. Participant characteristics are summarized in Table 2.1.

All participants completed a reading fluency test (the SLS 1-4 in grades 2-4 and the SLS 5-8 in grade 6 and in adults; Mayringer & Wimmer, 2003; Auer, Gruber, Mayringer, & Wimmer, 2005), indicating that overall each of the subgroups had reading skills typical for their respective age group (all $t<2$, all $p>.05$; norms for adults were derived from norm data for grade 8). Moreover, individual differences in vocabulary knowledge were assessed with a vocabulary test (the vocabulary subtest of the CFT-20R; Elben & Lohaus, 2000; Weiß, 2006).

Table 2.1

Overview over Participant Characteristics: Number of Participants, Mean Age, Reading Fluency, and Vocabulary Knowledge.

Age group	Grade 2		Grade 3		Grade 4		Grade 6		Adults
	beg	end	beg	end	beg	end	beg	end	
N	43	146	89	62	57	70	56	61	43
Mean Age	7.13	7.85	7.83	8.79	9.17	9.87	11.30	11.73	24.86
Reading Fluency[a]	18.28	28.29	33.88	40.53	41.49	45.74	34.66	37.49	61.09
Vocabulary Knowledge[b]	4.70	7.97	11.23	13.52	14.33	17.77	19.66	21.61	27.79

Note. [a] SLS 1-4 in grades 2 to 4, SLS 5-8 in grade 6 and adults, normalized values (*M*=100, *SD*=15). [b] CFT-20R vocabulary test in grade 2 to adults (0-30 points).

Materials

The material used in the *DeveL* project comprised 1152 German words (768 nouns, 269 verbs, and 115 adjectives) taken from the *childLex* corpus (Schroeder, Würzner, Heister, & Geyken, 2015). Word length ranged from 3 to 12 letters (*M* = 6.0; *SD* = 1.81). Word frequency, as referring to base 10 log-transformed normalized lemma frequency, ranged from -0.99 to 3.81 (*M* = 1.61; *SD* = 0.69). Morphological status was manually determined. Words consisting of only one stem (e.g. *Laterne*, engl. lantern) were marked as monomorphemic (*M*). Words made up by the combination of two stems (e.g. *Segelboot*, engl. sailboat) were categorized as compounds (C). Words with a stem and at least one derivational affix (e.g. *Lehrer*, engl. teacher) were classified as derivations (*D*). Derivations were further subdivided into prefixed (*Pre*) and suffixed (*Suf*) words. In total, there were 959 monomorphemic words, 49 compounds and 144 derivations, of which 75 were prefixed, 62 were suffixed, and 7 contained both a prefix and a suffix.

The lexical decision task additionally comprised 1152 pseudowords that were generated from words using the pseudoword generator Wuggy (Keuleers & Brysbaert, 2010). All resulting pseudowords were pronounceable and matched the words on length and capitalization, since German nouns are always capitalized. For a subset of the pseudowords, morphological structure was preserved. As for the words, morphological status was determined manually for the pseudowords. Pseudowords consisting of a pseudostem only (e.g. *Kompire*) were characterized as being monomorphemic. Pseudowords combining a pseudostem with a real stem (e.g. *Bettdepse*, with *Bett* engl. bed) were classified as compounds. Pseudowords made up of a pseudostem and an existing affix (e.g. *Pauner*, with *-er* being roughly equivalent to the English suffix *-er*) were labeled as derivations and subdivided into prefixed and suffixed derivations. In total, there were 905 monomorphemic, 29 compound and 215 derived pseudowords, the latter of which 80 contained a prefix, 126 contained a suffix, and 9 contained both. Due to a matching error, three pseudowords were duplicated. Item characteristics of words and pseudwowords per morphological type are summarized in Table 2.2. Not all children processed all stimuli, as a multi matrix design was used (see Schröter & Schroeder, 2016 for details), but participant and item effects can be dissociated using linear-mixed-effects models. In total, adults were presented with 1152 items, sixth-graders with 576 items, fourth-graders and third-graders (at the end of the school year) with 384 items, third-graders (at the beginning of the school year) and second-graders were presented with 288 items (see Schröter & Schroeder, 2016 for details).

Table 2.2

Overview over Item Characteristics per Morphological Type: mean Number of Items, Frequency, and Length.

	Compounds	Derivations		Mono-morphemic
		Prefixed	Suffixed	
	Words			
N	49	75	62	959
Frequency[a]	0.88 (0.66)	1.16 (0.76)	1.33 (0.81)	1.70 (0.64)
Length[b]	8.61 (1.29)	8.52 (1.19)	7.37 (1.38)	5.56 (1.55)
	Pseudowords			
N	29	80	126	905
Length[b]	8.50 (1.50)	8.51 (1.19)	6.96 (1.39)	5.52 (1.56)

Note. [a] log10 transformed lemma frequency. [b] number of letters.

Procedure

Each participant was tested individually in a separate room at their schools or university, respectively. As described in more detail by Schröter and Schroeder (2016) stimuli of the experiment were presented on a laptop monitor in the center of a black screen in white lower case letters (28-point Courier New font). Each trial consisted of a 500-ms fixation cross, followed by the stimuli, which remained on screen until a response was made. Participants were instructed to decide as quickly and as accurately as possible whether the presented stimulus was an existing German word or not and indicate their decision by button press. Response time and accuracy was measured.

Results

All data analyses were performed using (generalized) linear mixed-effects models (Baayen, Davidson, & Bates, 2008) as implemented in the lme4 package (Version 1.1-6; Bates, Maechler, Bolker, & Walker, 2014) in the statistical software R. Linear mixed-effects models were chosen, because they are flexible in dealing with unbalanced data sets and variability in participants and items and provide enhanced power (Baayen et al., 2008). Words and pseudowords were analyzed separately. RT data were log-transformed based on inspection of the data with the boxcox function from the MASS package and were then analyzed using a linear model. Accuracy data were logit-transformed and analyzed using a generalized linear model with a binomial link function. The overall effects tests used contrast coding and Type III sum of squares (using the Anova function in the car package). Post-hoc comparisons were carried out using cell means coding and single df contrasts using the glht function of the multcomp package (Hothorn, Bretz & Westfall, 2008) and were evaluated using a normal distribution.

Words. First, we examined the responses to compounds, derived and monomorphemic words in reading development. For analysis of the response time data, all incorrect responses were removed first (7.52%), as were response times below 200ms (0.64%). Further outlier trimming followed Baayen and Milin (2010): a base model was fitted to the data, only including participants and items as random effects. Data points with residuals exceeding 2.5 standard deviations were removed (2.40%). For the remaining response data, we fitted a model with Morphological Type (C vs. Pre vs. Suf vs. M) and Age group (9: grade 2, 3, 4 and 6, each at the beginning and end, vs. adults), both effect coded, and their interaction as fixed effects. Length and

Frequency, as centered continuous variables, were included as control variables in interaction with Age group. Moreover, OLD20, Bigram Frequency, Imageability and Age of Acquisition were included as centered continuous control variables. Participants and Items served as random effects. Descriptive statistics are presented in Table 2.3 and an overview of the overall effects tests is shown in Table 2.4.

Table 2.3

Mean Response Times (ms) and Error Rates (%) to Words (Standard Errors in Parentheses).

	Grade 2 beg	Grade 2 end	Grade 3 beg	Grade 3 end	Grade 4 beg	Grade 4 end	Grade 6 beg	Grade 6 end	Adults
	Response Times (ms)								
Compounds	3096 (165)	1613 (49)	1316 (49)	1107 (48)	1055 (46)	892 (36)	785 (35)	694 (29)	555 (27)
Prefixed	3104 (158)	1687 (48)	1404 (50)	1152 (47)	1140 (49)	925 (35)	801 (34)	713 (29)	555 (26)
Suffixed	3109 (157)	1691 (47)	1377 (48)	1126 (46)	1123 (47)	921 (35)	794 (34)	708 (28)	560 (26)
Mono-morphemic	3060 (139)	1709 (43)	1404 (44)	1168 (44)	1161 (45)	961 (34)	835 (33)	733 (28)	575 (26)
	Error Rates (%)								
Compounds	16.85 (3.50)	4.82 (0.83)	5.02 (1.00)	2.12 (0.52)	2.10 (0.54)	1.19 (0.33)	1.52 (0.37)	1.87 (0.44)	1.01 (0.26)
Prefixed	12.04 (2.30)	7.30 (0.99)	5.95 (0.97)	3.49 (0.67)	3.24 (0.65)	1.96 (0.41)	1.74 (0.35)	2.15 (0.41)	1.04 (0.22)
Suffixed	14.33 (2.67)	7.28 (0.97)	7.95 (1.22)	4.06 (0.77)	3.02 (0.63)	2.54 (0.52)	2.65 (0.51)	2.60 (0.49)	1.34 (0.28)
Mono-morphemic	14.83 (1.66)	8.02 (0.61)	7.86 (0.72)	5.13 (0.56)	4.57 (0.52)	3.56 (0.39)	3.24 (0.37)	4.07 (0.44)	2.52 (0.31)

The model yielded a significant main effect for Age group, indicating overall decreasing response times with increasing age. There was also a main effect of Morphological Type, suggesting that compounds, derivations and monomorphemic words were responded to differently. Importantly, Morphological Type significantly interacted with Age group. To investigate this interaction, the effect of Morphological Type was compared for each age group. For compounds compared to monomorphemic words, there was a significant facilitatory effect starting from the end of second grade, all $t>2.17$, all $p<.03$, while there was no such effect for readers in the beginning of second grade, $t=-0.44$, $p=.66$. For prefixed words, there was a facilitatory effect starting from the end of fourth grade, all $t>2.00$, all $p<.05$, but not before that, all $t<1.10$, all $p>.26$. For suffixed words, there was a facilitatory effect starting from the end of third grade, all $t>2.09$, all $p<.05$, but not before that, all $t<1.23$, all $p>.22$. Exact *t*- and *p*-values for each age group and morphological type comparison are provided in the Appendix (Table A2.1). The effects are also presented in Figure 2.1.

Table 2.4

Results from Mixed-Effect Models for Words with MorphType (C vs. Pre vs. Suff vs. M), Age group (Grade (beg/end) vs. Adults), as well as their Interactions, and Participant and Item as Random Intercepts. Main Effects and Interactions from the Model additionally including Vocabulary Knowledge are indented.

	χ^2	
	RT	Error
Fixed Effects (*df*)		
Intercept (1)	239160*	1685*
Vocabulary Knowledge (1)	207*	76*
Age group (8)	130*	229*
Age group × Vocabulary Knowledge (8)	70*	17*
Morphological Type (3)	18*	37*
Morphological Type × Vocabulary Knowledge (3)	255*	5
Morphological Type × Age group (24)	55*	50*
Morphological Type × Age group × Vocabulary Knowledge (24)	136*	34
Random Effects		
Participants	69759*	59517*
Items	5881*	3310*

Note. Tests are based on Type III sum of squares and χ^2 values with Kenward-Roger *df*. * $p<.05$

The error data was analyzed in a similar fashion. A model was fitted to the error rates as described above. Paralleling the results for the response times, there was a main effect of Age group and a main effect of Morphological Type, which were modulated by the interaction of Morphological Type and Age group. Paralleling the results from the RT analysis, for compounds, there was a facilitatory effect from the end of second grade onwards, all $t>2.28$, all $p<.02$, but not in the beginning of second grade, $t=-0.63$, $p=.53$. For prefixed words, the facilitatory effect emerged from the end of fourth grade onwards, all $t>2.78$, all $p<.004$, and also in the end of third grade,

$t=2.14$, $p=.03$, but not in the beginning of fourth grade, $t=1.70$, all $p=.07$, and not before the beginning of third grade, all $t<1.84$, all $p>.07$. For suffixed words, a facilitatory effect emerged in the beginning of fourth grade, end of grade 6, and in adults, but not for the other age groups. The effects are presented in Figure 2.1. Exact *t*- and *p*-values are provided in the Appendix (Table A2.1).

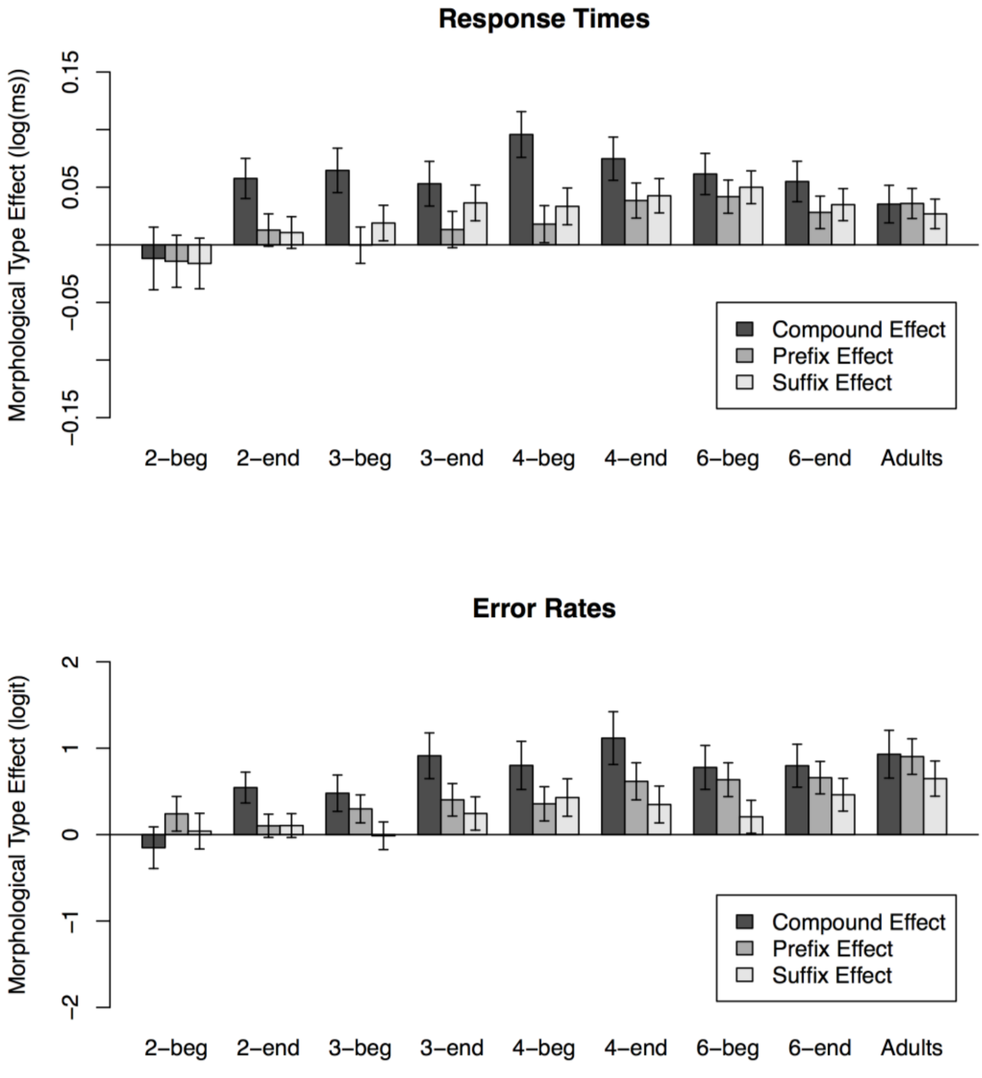

Figure 2.1 Response time differences (log(ms)) and Error rate differences (logit) between compounds and monomorphemic, prefixed and monomorphemic, and suffixed and monomorphemic words by Age group. Error bars show standard errors.

The results point to morphemes as functional units in skilled and beginning reading and a differential developmental trajectory of the processing of compounds, prefixed and suffixed derivations. There is a processing advantage for compounds already in second grade. Effects are slightly different between prefixes and suffixes: facilitation in the response times emerges earlier for suffixed than for prefixed words, while the picture is less stable in the error rates. The direction of the prefix effect is further moderated by vocabulary knowledge. Together, the results indicate that different processing mechanisms are involved in the reading of compounds, prefixed and suffixed words.

Vocabulary Knowledge. In order to assess inter-individual differences in the use of morphemes across reading development, we analyzed how the children's vocabulary knowledge moderates the morphology effect. We fitted a model as described above, but additionally included Vocabulary Knowledge (z-transformed and scaled) as a main effect and in interaction with Age group and Morphological Type. Results of the overall effects tests are shown as indented rows in Table 2.4.

The model yielded a significant effect of Vocabulary Knowledge and an interaction of Vocabulary Knowledge with Age group, an interaction with Morphological Type, as well as a three-way interaction of Vocabulary Knowledge, Age group and Morphological Type. To investigate this interaction, the effect of Morphological Type was compared for readers with higher vocabulary scores (+1SD) in each Age group and for readers with lower vocabulary scores (-1SD) in each Age group. For readers with higher vocabulary scores (+1SD), there was a significant facilitatory effect for compounds from the end of second grade, all $t>2.73$, all $p<.006$, but not in the beginning of second grade, $t=1.10$, $p=.24$. For prefixed words, there was a facilitatory effect from the end of second grade, all $t>2.03$, all $p<.04$, but not in the beginning of second and end of sixth grade, both $t<1.52$, both $p>.13$. For suffixed words, there was a facilitatory effect from the end of second grade onwards, all $t>2.08$, all $p<.04$, but not in the beginning of second grade, $t=-0.15$, $p=.88$. For readers with lower vocabulary scores (-1SD), there were no facilitatory effects for compounds in any age group, all $t<1.92$, all $p>.05$. For prefixed words, there was an inhibitory effect in second grade and in the beginning of third, fourth, and sixth grade, all $t>2.06$, all $p<.04$, and a facilitatory effect in adults, $t=3.21$, $p=.001$, but no effect in the other age groups, all $t<1.28$, all $p>.20$. For suffixed words, there was an inhibitory effect at the end of second and beginning of third grade, both $t>2.09$, both $p<.04$, but no effect in any other age group, all $t<1.74$, all $p>.08$. The effects for higher and lower vocabulary participants in each Age group are presented in Figure 2.2. Exact *t*- and *p*-values are provided in the Appendix (Table A2.1).

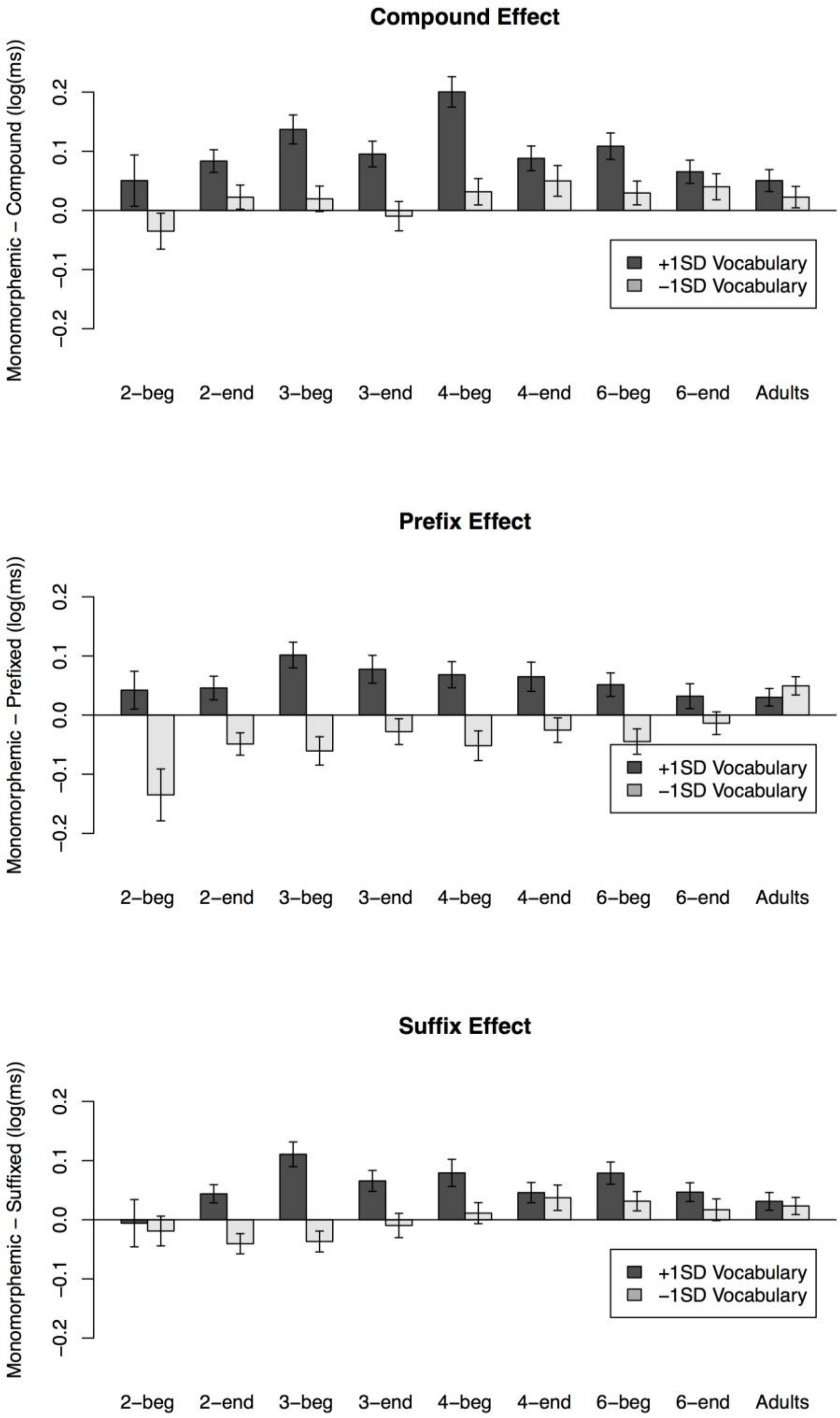

Figure 2.2 Compound, Prefix and Suffix Effects for words in readers with higher (+1SD) and lower (-1SD) vocabulary scores by Age group. Error bars show standard errors.

A similar model was fitted to the error rates. There was a main effect of Vocabulary Knowledge, as well as an interaction of Vocabulary Knowledge and Age group, but no significant interaction with Morphological Type.

Taken together, vocabulary knowledge moderates the benefits of morphology in word recognition across reading development. Readers with better vocabulary knowledge generally show facilitation from morphology earlier in reading development. Readers with weaker vocabulary knowledge have difficulties with derivations, particularly with prefixed words.

Pseudowords. Parallel to the examination of words, we examined the responses to pseudowords that had compound, derived or monomorphemic structure. As for words, all incorrect responses were removed before model fitting (11.80%), as were response times below 200ms (0.05%). Further outlier trimming was executed by fitting a base model and removing data points with residuals exceeding 2.5 standard deviations (2.15%) (Baayen & Milin, 2010). Then, we fitted a model similar to the one for words with Morphological Type and Age group and their interactions as fixed effects. Length in interaction with Age group was included as a control variable, as well as OLD20 and Bigram Frequency. Participants and Items served as random effects. Descriptive statistics are presented in Table 2.5 and an overview of the overall effects tests is shown in Table 2.6.

In the response time model, a significant main effect for Age group and Morphological Type was observed, moderated by their interaction. For pseudocompounds, there was an inhibitory effect for all age groups, all $t>2.06$, all $p<.04$. For prefixed pseudowords, there was an inhibitory effect from the end of third grade onwards, all $t>2.33$, all $p<.03$, but not before that, all $t<1.32$, $p>.19$. For suffixed pseudowords, there was no effect in any age group, all $t<1.84$, all $p>.07$. The effects for each Age group are presented in Figure 2.3. Exact *t*- and *p*-values are provided in the Appendix (Table A2.2).

Table 2.5

Mean Response Times (ms) and Error Rates (%) to Pseudowords (Standard Errors in Parentheses).

	Grade 2 beg	Grade 2 end	Grade 3 beg	Grade 3 end	Grade 4 beg	Grade 4 end	Grade 6 beg	Grade 6 end	Adults
	Response Times (ms)								
Compounds	4549 (303)	2752 (99)	2356 (105)	1746 (90)	1795 (96)	1518 (73)	1200 (63)	1007 (51)	659 (38)
Prefixed	4078 (243)	2599 (84)	2155 (88)	1770 (86)	1736 (88)	1486 (67)	1151 (57)	993 (47)	653 (37)
Suffixed	4098 (234)	2562 (79)	2088 (83)	1649 (77)	1697 (83)	1386 (61)	1086 (53)	942 (44)	627 (35)
Mono-morphemic	4225 (234)	2552 (76)	2110 (80)	1662 (76)	1672 (79)	1368 (59)	1092 (53)	937 (43)	622 (34)
	Error Rates (%)								
Compounds	30.46 (6.41)	21.21 (3.26)	24.92 (4.12)	13.54 (2.91)	16.75 (3.47)	11.26 (2.42)	13.98 (2.76)	15.41 (2.84)	5.28 (1.27)
Prefixed	18.05 (3.31)	11.66 (1.48)	10.75 (1.63)	8.58 (1.50)	7.59 (1.40)	9.42 (1.51)	8.56 (1.41)	10.56 (1.60)	2.97 (0.59)
Suffixed	17.01 (2.64)	11.79 (1.19)	12.25 (1.48)	6.85 (1.03)	8.04 (1.21)	8.86 (1.20)	6.92 (1.00)	8.66 (1.17)	2.93 (0.49)
Mono-morphemic	15.51 (1.98)	10.92 (0.85)	11.13 (1.07)	5.66 (0.68)	6.47 (0.80)	7.77 (0.86)	6.63 (0.80)	8.25 (0.94)	2.50 (0.36)

A similar model was fitted to the error data. Besides a main effect of Age group, there was a main effect for Morphological Status, but no interaction of Morphological Status and Age group. Pseudocompounds yielded significantly more errors than monomorphemic pseudowords (t=-5.70, p<.001) and so did prefixed pseudowords (t=-2.00, p=.04), while there was no effect for suffixed pseudowords (t=1.80, p=.07).

The results suggest that morphological structure is taken into consideration by skilled and beginning readers in judging whether a letter string constitutes a real word or a pseudoword. The presence of a stem in pseudowords with a compound structure makes rejection harder already for beginning readers. The presence of a prefix has this hampering effect later on in reading development, starting in fourth grade, while suffixes do not disturb pseudoword rejection.

Table 2.6

Results from Mixed-Effect Models for Pseudowords with MorphType (C vs. Pre vs. Suff vs. M), Age group (Grade (beg/end) vs. Adults), as well as their Interactions, and Participant and Item as Random Intercepts. Main Effects and Interactions from the Model additionally including Vocabulary Knowledge are indented.

	χ^2	
	RT	Error
Fixed Effects (*df*)		
Intercept (1)	213820*	1059*
Vocabulary Knowledge (1)	167*	37*
Age group (8)	111*	94*
Age group × Vocabulary Knowledge (8)	33*	5
Morphological Type (3)	38*	34*
Morphological Type × Vocabulary Knowledge (3)	29*	6
Morphological Type × Age group (8)	67*	21
Morphological Type × Age group × Vocabulary Knowledge (24)	91 *	32
Random Effects		
Participants	87075*	8767*
Items	3901*	2616*

Note. Tests are based on Type III sum of squares and χ^2 values with Kenward-Roger *df*. * $p<.05$

Vocabulary Knowledge. Parallel to the analyses of the word data, we also investigated inter-individual differences in the pseudoword data. A model as described for the vocabulary knowledge analysis for words was fitted. Descriptive statistics are presented in Figure 2.4 and results of the overall effects tests are shown as indented rows in Table 2.6.

As in the results for the words, in addition to the effects found in the model without inter-individual differences, a significant main effect of Vocabulary Knowledge emerged. The interactions of Vocabulary Knowledge with both Age group and Morphological Type were also significant, as was the three-way interaction of Age group, Morphological Type and Vocabulary Knowledge. For readers with higher vocabulary scores (+1SD), there was an inhibitory effect for pseudocompounds from the beginning of second grade onwards, all $t>2.23$, all $p<.03$, except in the end of third and beginning of fourth and sixth grades, all $t<1.67$, $p>.09$. For prefixed pseudowords, there was an inhibitory effect from the end of second grade, all $t>2.44$, $p<.01$, but not in the beginning of second, fourth, and sixth grade, all $t<1.83$, all $p>.07$. For suffixed pseudowords, there was a facilitatory effect in the end of third and the beginning of fourth and sixth grade, all $t>2.01$, all $p<.04$, but in no other age group, all $t<1.36$, all $p>.17$.

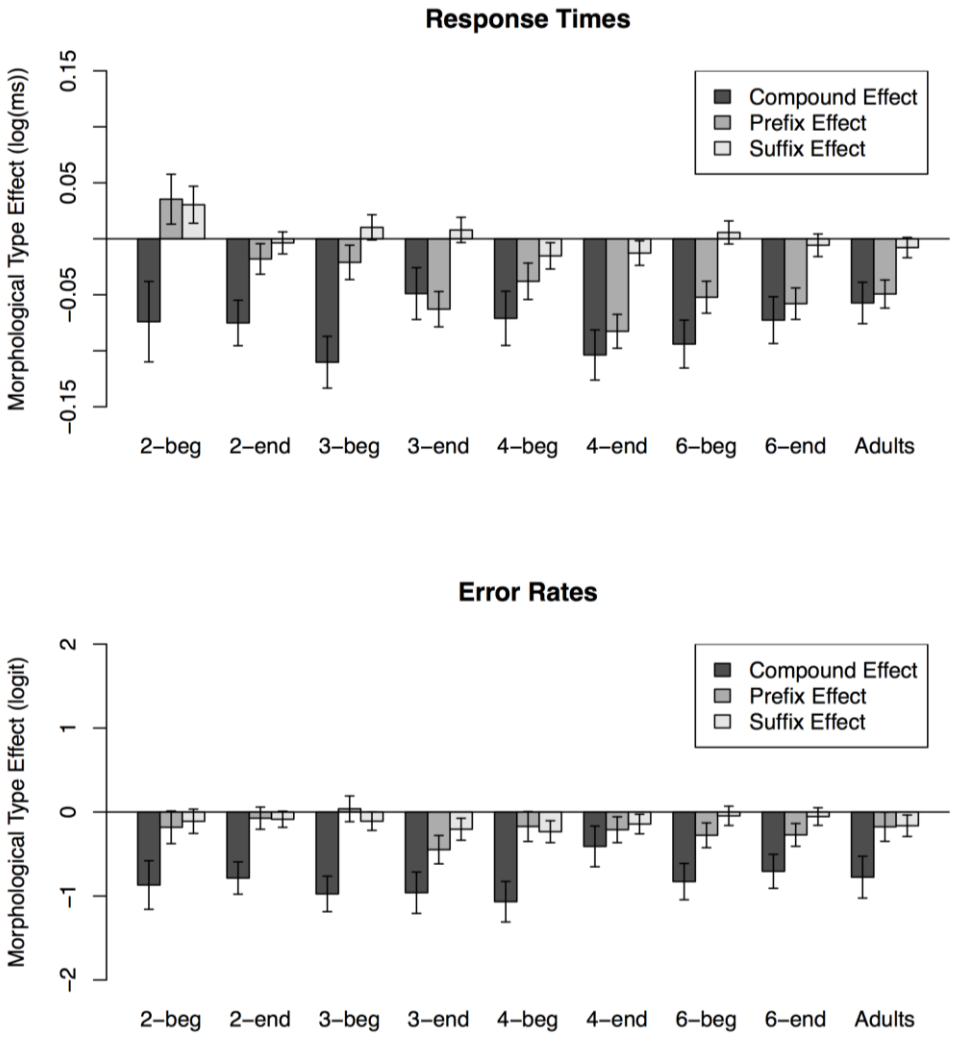

Figure 2.3 Response time differences (log(ms)) and Error rate differences (logit) between compounds and monomorphemic, prefixed and monomorphemic, and suffixed and monomorphemic pseudowords by Age group. Error bars show standard errors.

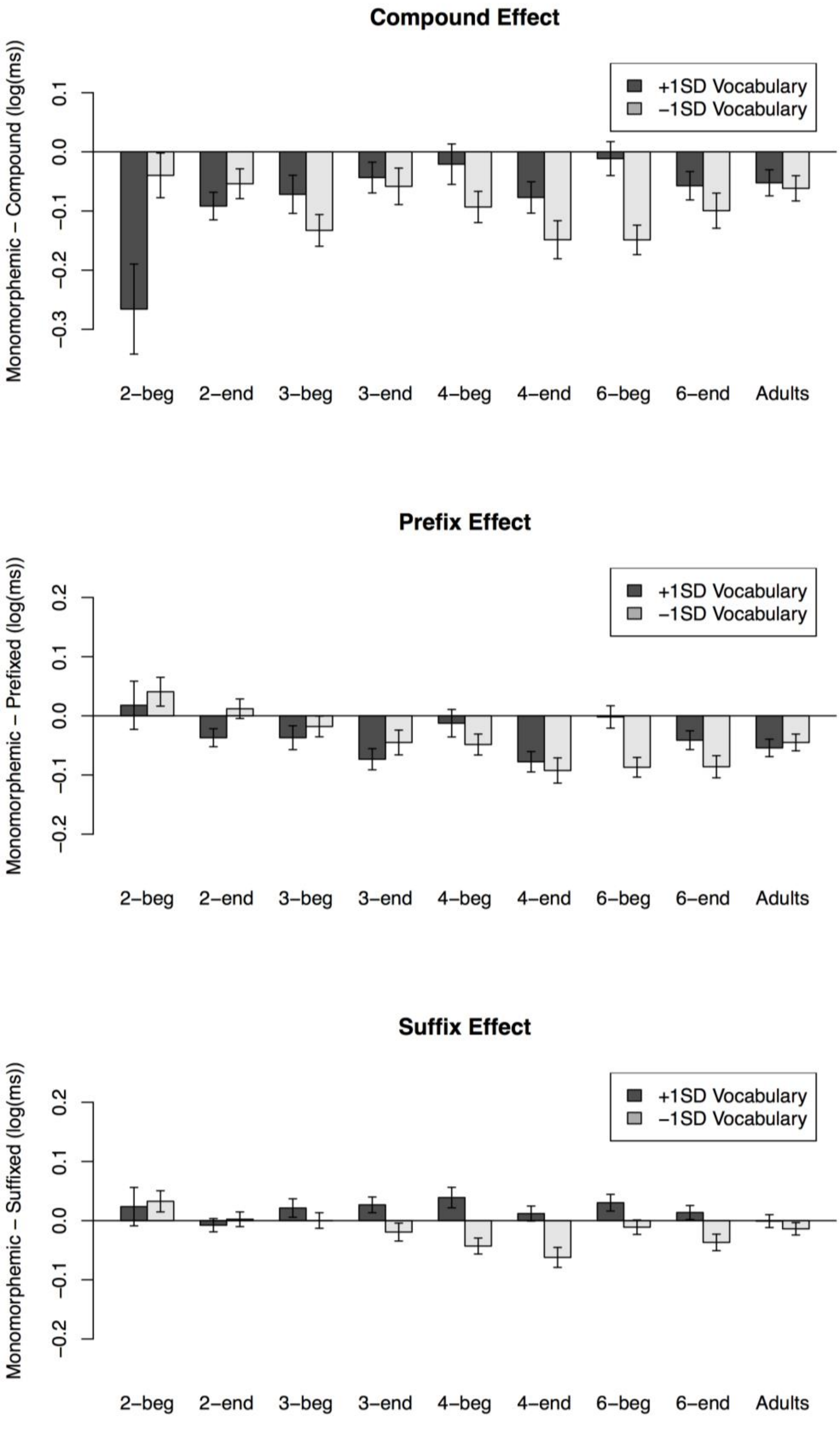

Figure 2.4 Compound, Prefix and Suffix Effects for pseudowords in readers with higher (+1SD) and lower (-1SD) vocabulary scores by Age group. Error bars show standard errors.

For readers with lower vocabulary scores (-1SD), there was an inhibitory effect for pseudocompounds from the end of second grade, all $t>2.14$, all $p<.03$, but not in the beginning of second and end of third grade, both $t<1.89$, both $p>.07$. For prefixed pseudowords, there was an inhibitory effect from the end of third grade, all $t>2.16$, all $p>.03$, but not before this, all $t<1.67$, all $p>.09$. For suffixed pseudowords, there was an inhibitory effect in fourth grade and the end of sixth grade, all $t>2.64$, all $p<.008$, and no effect in the other age groups, all $t<1.83$, all $p>.07$. The effects for higher and lower vocabulary participants in each Age group are presented in Figure 4. Exact *t*- and *p*-values are provided in the Appendix (Table A2).

The corresponding error rate model again only revealed main effects for Age group and Morphological Type, but neither a main effect of Vocabulary Knowledge, nor any interactions involving it.

Taken together, readers with higher vocabulary scores are generally affected by morphological structure in pseudowords in an earlier developmental phase than readers with lower vocabulary scores. Moreover, the direction of the suffix effect in pseudowords is moderated by vocabulary knowledge.

2.4 Discussion

In the present study, we analyzed lexical decision data from a large sample of children from grade 1 through 6, covering the entire range of reading development in the elementary school years, as well as adults, in order to provide a comprehensive examination of the use of morphemes in word recognition across reading development in German. We compared responses to compounds, derived and monomorphemic words and pseduowords. The comprehensive approach of the present study covered the entire developmental trajectory of morphology use and demonstrates that morphemes gradually emerge as units of word recognition in the course of reading development. First effects can be observed as early as in second grade and increase in the elementary school years. Moreover, our study expands earlier evidence by (1) revealing differential processing of different morphological types, and (2) highlighting the influence of vocabulary knowledge on morphological processing.

The sensitivity to morphological structure that starts between grade 2 and 4 is consistent with previous studies from transparent orthographies demonstrating effects of suffixes for words and pseudowords in naming and lexical decision (French: Casalis et al., 2015; Colé et al., 2011; Quémart et al., 2012; Italian: Angelelli et al., 2014; Burani et al., 2002; Burani et al., 2008; Marcolini et al., 2011). Our results demonstrate that the distinction between morphological types is important, because the developmental trajectories for compound, prefix and suffix effects differ. In particular, including compounds shows that sensitivity to morphology emerges slightly earlier in transparent languages than previous studies were able to capture, because they focused on suffixes. Interestingly, for words, facilitation from compounds arises already at the very early stages of reading acquisition around second grade and remains an important unit of analysis throughout development and also for skilled adult readers. Suffix effects in words follow slightly later in the course of reading acquisition and emerge in third grade, in line with findings for French third-graders (Casalis et al., 2015; Quémart et al., 2012). Prefix effects emerge even slightly later.. Thus, there is a sequential order of the emergence of morphological effects in word reading, with compounds being first, followed by suffixes and prefixes. For pseudowords, the pattern of effects is slightly different. For compounds, a detrimental effect in pseudoword rejection emerges as early as the facilitatory effect in word recognition. The trajectories for suffixes and prefixes in pseudowords differ from those in words: Prefixes have no effect on pseudoword rejection early in development, but hamper it later on, while suffixes have no effect.

The differential patterns for compounds, prefixes and suffixes can be best explained by a preference for stems as reading units and a left-to-right bias that favors suffixes over prefixes, as suggested by Cutler et al. (1985). The relatively early emerging and stable compound effect indicates that stems are clearly the most relevant units in word recognition. Considering that stems are the most informative parts of words, focusing on them is a sensible strategy both when extracting meaning in natural reading and for deciding on lexical status in a LDT (see also Bertram & Hyönä, 2003). The observed relevance of the stem converges with evidence from masked priming, indicating that children show sensitivity to stems even in the absence of suffixes at sub-lexical stages of word processing (Beyersmann, Grainer, et al., 2015). The importance of stems can also contribute to explaining the differential processing of prefixes and suffixes. Due to the salient left-most position of the stem in suffixed words, the representation of the stem can be activated relatively quickly, allowing fast verification of its lexicality. Activation of the whole suffixed form itself, as well as co-activation of the affix and forms sharing the same stem and/or the same suffix additionally boosts word recognition (Reichle & Perfetti, 2003; Schreuder & Baayen, 1995). As Cutler et al. (1985) propose, prefixed words carry less information about lexicality and content in the salient left-most position than equivalent suffixed words. The early activation of a prefix in the salient position might therefore not bolster word recognition much and additional activation of the stem in the less salient position or from the whole prefixed word is necessary to decide on the words lexicality. However, in the case of pseudowords, the early activation of a salient prefix leads to a prolonged "search" in attempt to activate a matching whole-word representation. When this remains unsuccessful, it results in the observed disadvantage from prefixes in pseudoword rejection. The salient position of the stem also explains the diminished role of suffixes in pseudoword rejection: the pseudostem in the salient first position allows fast lexical decision based on the stem. When neither a whole suffixed form, nor a stem, nor a related form sharing the stem can be activated, evidence against word status accumulates fast despite the existing suffix, and the suffixed pseudoword can be rejected relatively quickly with high certainty. The explanation presented here for the differential effects for prefixed and suffixed derivations assumes that prefix and suffix processing reflects the same locus. Alternative explanations are possible that locate prefixes and suffixes at different stages in the reading system. Beyersmann et al. (2015) discuss the possibility that suffixes are represented sub-lexically, but prefixes only supra-lexically. Clearly, further research is required to answer this question.

Nevertheless, the observed pattern of effects has important consequences for the multiple-route model (Grainger & Ziegler, 2011), which is currently the only model that makes explicit assumptions about the mechanisms of morphological processing from a developmental perspective. It includes the development of an access mechanism via sub-lexical morphological decomposition in the so-called fine-grained route. This route is thought to involve the establishment and use of orthographic representations of affixes through letter chunking. Consequently, the shift from sequential letter-by-letter decoding to the fine-grained route, which might also allow more parallel processing, is hypothesized to entail an increased sensitivity to morphological structure. This expectation converges with our empirical results. However, the fine-grained route in the multiple-route framework is centered around small, re-occurring letter chunks, that is affixes, and is hypothesized to work in a parallel fashion. Such a decomposition mechanism would hypothesize the emergence of suffix and prefix effects at the same early time in development and compound effects later on. Our study showed an opposite pattern with compound effects developing in the earliest stages, followed by suffix and prefix effects. In the light of our results, a left-to-right parsing mechanism in children, tuned to extract stems, seems more likely than a parallel affix-stripping mechanism. It is possible to attribute the activation of stems to the coarse-grained route, as Beyersmann, Grainger, et al. (2015) suggests, but such an interpretation is problematic in our case as the coarse-grained route is even more parallel in nature, which a) is not compatible with morphological type differences, and b) demands higher expertise in mapping letters to word representations. We therefore suggest that developmental models of visual word recognition not only need to incorporate affixes as important functional units, but also need to account for the early role of stems. Moreover, the parallel nature vs. left-to-right bias of processing in the fine-grained route needs to be reconsidered in order to account for the distinct developmental trajectories of different morphological types.

Furthermore, the second main finding of our study shows that the trajectories of morphological processing are moderated by inter-individual differences in vocabulary knowledge. For words, readers with higher vocabulary show effects from all morphological types already in second grade, and thus earlier than readers with lower vocabulary. This can very well be accounted for by the degree to which children were able to set up morphemes as access units as a function of their experience with morphologically complex forms and with single constituent morphemes, as Schreuder and Baayen (1995) imply. Good representations of the whole-word form itself, as well as the constituent morphemes and their related forms bolsters recognition at the access level (Schreuder & Baayen, 1995). This happens more when more extensive and consistent vocabulary knowledge is available (Goodwin, et al., 2014; Reichle & Perfetti, 2003). Higher vocabulary readers thus show benefits from compounds, prefixed and suffixed words relative to monomorphemic words already early from second grade.

For lower vocabulary readers morphology is more demanding. Compounds showed no effect, suffixes had a detrimental effect early and prefixes throughout development. This means that for lower vocabulary participants, stems are apparently not able to boost activation in word recognition. When less vocabulary is available to detect the form-meaning regularities, the ability to activate the stem might take longer to be learned. As a result, activation takes longer or is weaker due to the limited vocabulary knowledge and does not gain from as many co-activated forms that could boost word recognition. The special difficulty of prefixed words is probably due to the second position of the stem, which is a further disadvantage, as discussed above, that is especially detrimental when scant vocabulary knowledge is available.

Vocabulary knowledge similarly moderates morphological effects in pseudoword rejection. Pseudocompounds and prefixed pseudowords are harder to reject for readers with high vocabulary already in second grade. Interestingly, suffixes do even have a facilitatory effect on pseudoword rejection for high vocabulary readers in grades 3 and 4. Possibly, having many stable representations of words can also support the rejection of pseudostems, when the stem is in the most salient position. The pseudoword can then be rejected on the basis of the nonexistent stem and activation of the existing suffix is less disruptive for high vocabulary readers or might even help them. Burani et al. (2002) also suggested that suffixes in pseudowords might be used solely as decoding chunks, thus saving decoding time, while the lexical decision is still based on the stem. For lower vocabulary readers, pseudocompounds and prefixes also hinder rejection, albeit later than for their higher vocabulary peers, namely from around third grade. Moreover, lower vocabulary readers show a detrimental effect also from suffixes in pseudowords in grade 4 and 6. Due to the smaller vocabulary, it may take longer for them to establish stable access representations of morphemes that produce activation interfering with rejection of complex pseudowords. It is noteworthy that the prefix effects for pseudowords and for words go in the same direction in lower vocabulary readers, which is also the direction of the pseudoword effect in higher vocabulary readers. Moreover, the suffix effect for pseudowords in grade 4 and 6 lower vocabulary readers resembles their suffix effect for words in grades 2 and 3. Thus, lower vocabulary readers seem to process words the same way as pseudowords in the early elementary school years. We suggest that this is the case, because many morphemes are unknown to them and they were not (yet) able to develop access representations for many morphemes due to their smaller vocabulary knowledge.

We have already discussed how our findings on the privileged role of stems and a left-to-right processing bias fit into developmental word recognition models. Besides further supporting the relevance of stems, our findings on the influence of vocabulary knowledge imply that inter-individual differences also need to be considered as relevant factors in the development of morphological decomposition.

Some limitations of the present study need to be resolved in order to meaningfully integrate the above named aspects into models of reading development or even propose specific developmental models of complex word recognition. The first concerns the nature of affixes as functional units in reading: it is unclear whether they are merely cues for lexical status and/or increase word-likeness or are actually functional reading units. The differential effects and developmental trajectories of prefixed and suffixed words and pseudowords in our study suggest that affix activation might be an integral part of lexical access, going beyond signaling lexical status or increasing word-likeness. Investigations targeted especially at the processing differences and commonalities of prefixed and suffixed words can shed more light on this issue. Equally, another issue to be examined in this context is the role of stem activation, for which evidence has accumulated recently, not only through the present study, but also in studies using other methods, such as masked priming (Beyersmann, Grainger, et al., 2015). In order to better understand the dominant role of stems in word recognition, intensive investigation of compound processing in early reading acquisition seems particularly promising. Especially in German, compounding is extremely productive and compounds can be created and interpreted spontaneously. Children encounter many compounds early in reading development and even texts for beginning readers usually encompass compounds (Segbers & Schroeder, 2016). Consequently, the recognition of stems is particularly useful in that language. Thus, cross-linguistic studies on the role of stems are very valuable, particularly comparing compound recognition in languages with less productive compounding. Another issue to be examined bears on the relationship between vocabulary knowledge and morpheme use in reading. In the present study, we focused on the impact of vocabulary knowledge on morpheme use. However, it might not be a causal relationship in one direction, such that higher vocabulary increases the use of morphology. It is also possible that those children, who are more expert in decomposing words into their morphemes, are able to use this competence to grow their vocabulary knowledge. This is also of particular interest for educational practice and reading interventions.

To sum up, the present study extended evidence on the importance of morphemes in reading development to German. It furthermore extended the age range for which the phenomenon is studied, systematically delineating the trajectory of the development of morphological reading and revealing that effects of compound structure already arise at the very beginning of elementary school in grade 2, followed later by suffix and prefix effects. In addition, the intriguing differences in the development and processing of compounds, prefixed and suffixed words and pseudowords highlight the importance of stem and affix recognition rather than affix-stripping. The development and use of stems and affixes as access units in the recognition of complex words depends on experience with whole-word forms and single constituent morphemes. Finally, our results reveal the crucial relationship between vocabulary knowledge and morpheme use. For the decomposition of complex words, children need stable morpheme representations that allow fast activations, especially of stems in order to bolster word recognition. The present study thus provides novel comprehensive insights into morphemes as units in reading development and consequences for the advancement of theories of developmental models of word recognition explicitly accounting for emerging mechanisms of morphological processing.

Syllables and morphemes in German reading development: Evidence from second-graders, fourth-graders and adults

CHAPTER 3

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3.1 Abstract

Children have been found to use units such as syllables and morphemes in fine-grained reading processes, before they transition to a coarse-grained, holistic route. Which units they prefer at different stages in reading development is unresolved. The present study compares the use of syllables and morphemes. Second-graders, fourth-graders and adults performed a lexical decision task on multimorphemic and monomorphemic words and pseudowords that were visually disrupted either syllable-congruent or syllable-incongruent (i.e. morpheme-congruent in multimorphemic items). Syllables turned out to be the preferred unit of fine-grained processing for second-graders, while fourth-graders also used morphemes when morphemes were emphasized by the presentation format. Moreover, the study supports the assumption that children rely more on fine-grained processing, while adults have more coarse-grained processing.

3.2 Introduction

A central assumption of most models of reading acquisition is that children start out by decoding words on a letter-by-letter basis at first (Ehri, 1995; Grainger & Ziegler, 2011, Seymour, 2005; Share, 1995). They learn grapheme-phoneme correspondence (GPC) mappings and sound out words. As their reading skills develop and they gain more experience with written words, it is assumed that they become sensitive to intermediate-sized units until they are finally able to decode whole words directly "on sight". For example, Seymour's (2005) dual-foundation model proposes that reading develops in phases. It is thought to begin with simple alphabetic decoding using phonemes and advances to increasingly more complex structures, first centered around rimes, and in the last stage using syllables and morphemes. Equally, the multiple-route model of orthographic processing (Grainger & Ziegler, 2011) assumes that beginning readers start out by decoding words on a phonology-driven letter-by-letter basis (cf. Share, 1995) that leads them to two routes of orthographic processing: a fine-grained and a coarse-grained route. The main difference between the fine-grained and coarse-grained route is the coding of letter positions: the fine-grained-route is sensitive to ordered letter sequences, whereas letter coding in the coarse-grained route is position-invariant. As a consequence, the coarse-grained route entails direct access from orthography to semantics via whole-words, whereas the fine-grained route is tuned to detect frequently co-occurring letter sequences as functional units for word recognition. Both syllables and morphemes feature frequently co-occurring letter sequences and can thus be suspected to function as sensible intermediate-sized units that are detected in the fine-grained route. Albeit being formally very similar in terms of size and features of letter position coding, syllables and morphemes differ from each other in how they are defined and what type of information they encode. Syllables are phonologically defined and encode information about pronunciation. Morphemes are defined through the convergence of form and meaning, encoding lexical-semantic information. Syllables can thus be seen as being more closely associated with a phonological processing route, while morphemes constitute a more direct link between orthography and semantics. A very recent extension of the multiple-route model by Häikiö, Bertram and Hyönä (2016) captures this relation by proposing a syllabic assembly mechanism as an intermediate stage between a phonological and a fine-grained route, thus predicting the use of syllables to chronologically precede the use of morphemes in reading development.

In a range of languages, empirical evidence has been put forward separately for the use of syllables and for morphemes in reading development. Vast evidence shows that sensitivity to syllables, as a subdomain of phonological awareness, is a strong predictor for later reading ability (e.g., Wagner & Torgesen, 1987), measured for example by syllable counting or syllable segmentation tasks. Also in the process of reading, sensitivity to syllables has been found early in children of different languages. For example, French grade 5 readers show effects of syllable frequency (Chetail & Mathey, 2008) and syllable compatibility effects, that is faster responses when a word was preceded by the corresponding syllable, have been found in syllable detection tasks with grade 1, 3 and 5 children (Colé, Magnan, & Grainger, 1999; Maïonchi-Pino, Magnan, & Écalle, 2010) and in lexical decision tasks with sixth-graders (Chetail & Mathey, 2012). The visual segmentation of a word in a position congruent with a syllable boundary (*pa/per* vs. *p/aper*) results in fewer word recognition errors for poor second-grade readers of English (Katz & Baldasare, 1983) and syllable-congruent coloring similarly speeds up poor second-grade readers of French, while it slows down good age-matched peers (Chetail & Mathey, 2009). Moreover, eye-tracking studies indicate that hyphenation at syllable boundaries is less disruptive than hyphenation within syllables for Finnish readers already by the end of first grade (Häikiö, Hyönä, & Bertram, 2015). This indicates that syllables are helpful units very early in reading acquisition and for dysfluent readers (see also Hautala, Aro, Eklund, Lerkkanen, & Lyytinen, 2012) and that in many languages syllables come into play very early in the course of reading acquisition.

There is also vast evidence that children use morphemes in word recognition. In lexical decision and naming tasks in a variety of languages, elementary school children have been found to respond faster and more accurately to multimorphemic compared to matched monomorphemic words (Italian: Marcolini, Traficante, Zocolotti, & Burani, 2011; French: Colé, Bouton, Leuwers, Casalis & Sprenger-Charolles, 2011; Quémart, Casalis, & Duncan, 2012; English: Carlisle & Stone, 2003, 2005). Reversely, more false alarms and prolonged response times in lexical decision were found in presence of real morphemes in pseudowords, because they were mistaken as real words and thus harder to reject (Quémart et al., 2012). Those effects of morphology were found as early as in grade 2 for French children, and a little later (around grade 3) in Italian children. Moreover, masked morphological priming effects for suffixed words and nonwords have been reported for children in different languages from around grade 3 onwards (English: Beyersmann, Castles, & Coltheart, 2012; French: Beyersmann, Grainger, Casalis, & Ziegler, 2015; Casalis, Dusautoir, Colé, & Ducrot, 2009; Quémart, Casalis, & Colé, 2011). A Finnish eye-tracking study by Häikiö, Bertram and Hyönä (2011) reports advantages from hyphenations in compounds only for slow second-grade readers, but not for their faster age-matched peers or grade 4 and 6 readers. So, as for syllables, there is general consensus that children use morphemes as units at some point in reading development, however findings on when this happens diverge depending on the language studied.

Importantly, only few studies have more directly compared syllables and morphemes in reading (see Prinzmetal, Hoffman, & Vest, 1991, for a study with adults using an illusory conjunction paradigm). However, in order to refine models of reading acquisition it is necessary to disentangle the relative importance of syllables and morphemes in word recognition and determine whether there is an order of their utilization in reading development. One study that has addressed the direct comparison between syllables and morphemes in child reading was undertaken by Colé et al. (2011) with French second- and third-graders. They used multimorphemic words in which the syllable and morpheme boundary do not coincide (e.g. malade). This is the case for multimorphemic words that have a suffix beginning with a vowel. The consonants at the end of the stem in these cases form a syllable unit with the suffix, because syllable division follows the maximal onset principle (Spencer, 1996), which states that the maximally possible number of consonants should be assigned to the onset of a syllable rather than to the end of the preceding syllable. Colé et al. (2011) exploited these cases to more directly compare the impact of syllabic segmentation (e.g., *ma lade*), morphological segmentation (*mal ade*) and morphological + 1 grapheme (mala de) to unsegmented low-frequency derivations (*malade*) in a reading task. Reading times were expected to be shorter if the segmentation is in line with the units that are activated in reading and longer when the segmentation destroys important units. The authors found that both second- and third-graders read words equally fast when they were segmented by a space into syllables or morphemes or were unsegmented. Readers were only slowed down by the morphological + 1 condition. These results point to flexible use of syllables, morphemes and even whole-words at least for French grade 2 and 3 readers in the reading of multimorphemic words.

Importantly, Ziegler and Goswami (2005) emphasize in their psycholinguistic grain size theory that language-specific characteristics determine preferences for the use of certain units as linguistic characteristics of a language and its orthography may pose different demands on learners. Cross-linguistic differences in reading development have been attributed to orthographic transparency (Katz & Frost, 1992), syllable structure (Seymour, Aro, & Erskine, 2003), and morphological richness (Perfetti & Harris, 2013). Learners of opaque orthographies (e.g., English) might need longer to master GPC-based reading, while in transparent orthographies, like German or Finnish, solid reading skills can be achieved quickly by the use of GPC rules only (Wimmer & Goswami, 1994). As a consequence, learners of opaque orthographies can be assumed to profit considerably more from using bigger units, such as syllables or morphemes, since those tend to have more consistency in the way they are spelled and pronounced (Katz & Frost, 1992). However, languages also vary in the complexity of their syllable structure: for example in Finnish and French syllable structure tends to be more simple, while the syllable structure of German and English is rather complex (Seymour et al., 2003). As Seymour et al. (2003) found, complex syllable structures tend to be more challenging for developing readers. Moreover, as the transparency of an orthography tends to be correlated with the morphological complexity of the language (Perfetti & Harris, 2013; Seidenberg, 2011), more transparent languages are often equipped with a richer and more productive morphology. For languages in which morphemes are very prominent, like German or Finnish, then, they suggest themselves as units in word recognition, despite the availability of smaller units. Considering the interplay of syllables and morphemes, languages also differ in the degree of convergence and interactions of the two units. In German, syllables and morphemes very often coincide. Moreover, suffixation usually does not affect stress assignment in the word, whereas in French suffixes often draw the stress. The distinction between syllables and morphemes might therefore be less pronounced in German in comparison to French. Differences between languages in the structure of mappings between phonology, orthography, and meaning can produce differences in the sensitivity to certain sublexical units. Due to the described characteristics, German presents an interesting contrast to the languages in which development of syllables and morphemes as reading units has been studied so far, and different predictions can be made on the basis of its linguistic characteristics. In particular, the orthographic transparency together with complex syllable structure would predict prolonged reliance on graphemes throughout development. However, the morphological richness should act in favor of early advancement to morphemes. Finally, the prevalent convergence of morphemic units with syllabic units can be expected to also enhance reliance on syllables. Consequently, the relative importance of syllables and morphemes in reading development is unclear for this language and needs to be tested empirically.

To address the role of syllable and morphemes as reading units in German reading development, we adopted the methodology from the study by Colé et al. (2011) using a manipulation of the presentation format. Unfortunately, the study by Colé et al. (2011) focuses exclusively on multimorphemic words and does not reveal whether syllables are equally used in reading monomorphemic words. It is possible that a segmentation at the syllable boundary in monomorphemic words leads to even faster responses as it does not simultaneously destroy a morphemic structure. Therefore, we further extended the study design to monomorphemic words and made some slight changes to the paradigm. We included multimorphemic words with a syllabic segmentation (e.g. *FAH:RER*) and a morphological segmentation condition (*FAHR:ER*) in our study, just like Colé et al. (2011). In order to examine the use of syllables in multimorphemic words in comparison to that in monomorphemic words, we also included monomorphemic words that were segmented at the same positions as the multimorphemic words, namely at the syllable boundary (hereafter: syllable-congruent; e.g. *SPI:NAT*) or one letter after the syllable boundary (hereafter: syllable-incongruent; *SPIN:AT*). Note that the latter parallels the morphological segmentation condition of the multimorphemic words, but in the case of the monomorphemic words cannot coincide with a morpheme boundary by definition (-at is not a German suffix). We hypothesized that word recognition would be easiest for readers in the disruption condition which puts emphasis on the functional unit they actually use, while other disruption positions should make reading harder. That is, if a reader uses only syllables as functional units, the syllable-congruent disruption condition should lead to faster word recognition compared to the incongruent disruption in both monomorphemic and multimorphemic words. However, if a reader uses morphemes as functional units, the syllable-incongruent disruption of multimorphemic words (e.g. *FAHR:ER*, thus being morpheme-congruent) should be faster than the syllable-congruent one, while this should not be the case for the monomorphemic words (*SPIN:AT*) since the resulting structure does neither map onto a phonological syllable nor onto a morpheme (but see Taft, 1979, 1986, for another possible structure called BOSS). Our study thus not only allows investigating the findings of Colé et al. (2011) for another language, but also refines them due to the inclusion of monomorphemic words.

Another limitation of the study by Colé et al. (2011) is that no pseudowords were included, although those can also be informative concerning the use of syllables and morphemes in reading new items. Since children, especially those who have just started to read, are often confronted with a given written word for the first time, the use of syllables or morphemes in reading such a newly encountered word is of special interest with regard to the role of different units in reading development. Reading pseudowords most likely parallels the processes involved in reading new words. In the present study, we included pseudowords by employing a lexical decision task. Learners of transparent orthographies achieve basic reading skills with rather high accuracy rates very early in development (Seymour, Aro, & Erskine, 2003; Wimmer & Goswami, 1994) and silent reading – as required in the lexical decision task – is already natural to them. Therefore, a lexical decision is an adequate task to study processing also in beginning readers of German. The pseudowords included in the study matched the real words: they either did or did not feature an existing suffix (multimorphemic and monomorphemic pseudowords) and were also segmented syllable-congruent (e.g., *DOS:TOR*, *HEL:BER*) or syllable-incongruent (*DOST:OR*, *HELB:ER*), the latter again corresponding to a morpheme-congruent disruption for pseudowords featuring a suffix (-er). Considering the hypotheses for pseudowords, one has to keep in mind that – opposite to words – those have to be rejected in a lexical decision task. Syllable-congruent segmentation, encouraging the use of syllables, might help to “read through” the pseudoword faster than a segmentation that destroys this unit when readers rely on a phonological decoding strategy. It might thus allow a faster rejection relative to a syllable-incongruent segmentation, as evidence from English and Serbo-Croatian (Katz & Feldman, 1981; Lima & Pollatsek, 1983) suggests. However, multimorphemic pseudowords have been found to be harder to reject (Burani, Marcolini, & Stella, 2002; Quémart et al., 2012), since morphemes as lexical-semantic units signal word status. Therefore the syllable-incongruent segmentation of multimorphemic pseudowords (e.g. *HELB:ER*), which puts emphasis on the real suffix, might result in prolonged rejection times. Overall, including both mulimorphemic and monomorphemic words and pseudowords in our study provides a more extensive direct comparison of syllables and morphemes as functional units in reading.

To summarize, one of our main aims was to find out how the use of syllables and morphemes changes in the course of reading development in German. In order to investigate developmental differences, children at different stages in reading development were examined. Based on the previously mentioned findings on syllable and morpheme use in children, we decided to conduct the study with second- and fourth-graders. In accordance with the prediction of the multiple route model (Grainger & Ziegler, 2011) that developing readers use a phonological strategy in the beginning, we expected that younger children would be more inclined to make use of syllables in word recognition, since although those are intermediate sized units, they are phonologically defined and thus more approximate to the phonological route (see also Häikiö et al., 2016). Based on the developmental sequence outlined by Häikiö et al. (2016), older children, who had gained more reading experience, were expected to have moved away further from a phonological strategy and more towards an orthographic strategy using fine-grained processing with morphemes as functional units. In order to compare the processing strategies of readers that are still in the course of development to those of skilled readers, we additionally included a group of adults. The adults' processing thus serves as a reference point for the reading skills that the children should be achieving at some point in the future. Skilled readers should have access to both fine-grained and coarse-grained processing. Consequently, their reading strategy should depend on task demands. As coarse-grained processing, that is position-invariant, is more robust to small changes in words that only affect a single sign (i.e., transposed- or substituted-letters: e.g., O´Connor & Forster, 1981; Forster, Davis, Schoknecht, & Carter, 1987), this would be a more beneficial strategy for the present task. It is therefore plausible that adults are able to adjust to this, being considerably less affected by the position of the disruption.

3.3 Method

Participants

Fifty-seven second-grade children were recruited from ten elementary schools in the Berlin area. At the time of testing, the children were at the beginning of second grade, meaning they had received approximately 1 year of formal reading instruction. Permission for participation from the school administration and the children's parents was acquired prior to the experiment. Moreover, 20 fourth-graders were recruited at the after-school care of one Berlin elementary school. Permission from the after-school care and the children's parents was acquired before testing. Every child received a small gift and candy for their participation. Finally, 24 university students from the Berlin area participated for monetary reimbursement.

In order to ensure that participants showed age-appropriate reading behavior, each participant's reading fluency was assessed using the one-minute reading test for words and nonwords from the SLRT-II (Moll & Landerl, 2010). We used reading fluency percentile norm values <3 as an indication that readers belonged to the 3% of the population at the lowest end of the reading fluency scale suffering from dyslexia. This applied to six second-graders. Furthermore, we excluded one adult that reported having a history of dyslexia and two adults that reported having learned German as a second language later in life. As we aimed at investigating unimpaired reading, we excluded those participants. As a consequence, the study included 51 second-graders (24 girls, M_{age} = 6.9 years), 20 fourth-graders (10 girls, Mage = 9.5 years) and 21 university students (10 women, M_{age} = 26.1 years). All remaining participants reported normal or corrected-to-normal vision and had German as their native language or second language acquired before the age of 6. As analyses for monolinguals and early bilinguals showed no differences, all children were included in the analyses.

Materials

Twenty-four multimorphemic words, consisting of a stem and a suffix, were selected from the childLex corpus (Schroeder, Würzner, Heister, Geyken, & Kliegl, 2015). Crucially, suffixes beginning with a vowel were chosen (-er, -in, -ung), because when they are combined with a stem, the syllable boundary does not correspond to the morpheme boundary, thus creating a special morpho-phonological case. The words were disrupted by inserting a colon *:* at the syllable boundary (syllable-congruent condition, e.g. *FAH:RER*) or one letter right of the syllable boundary (syllable-incongruent condition, *FAHR:ER*), which corresponds to the morpheme boundary in the multimorphemic words, thus being morpheme-congruent for those. Moreover, 24 monomorphemic words were selected from the corpus and were also disrupted by a colon at the syllable-congruent (e.g. *SPI:NAT*) or syllable-incongruent (*SPIN:AT*) position. Mono- and multimorphemic words were matched on number of letters, number of syllables, frequency, bigram frequency and neighbours (all $t<1$, $p>.05$, see Table 3.1 for lexical statistics).

Table 3.1

Lexical statistics of the word and pseudoword items.

	M	*SD*	*min*	*max*	*M*	*SD*	*min*	*max*
	Words							
	Monomorphemic				Multimorphemic			
Letters	6.79	1.25	5.00	10.00	6.83	1.09	5.00	10.00
Syllables	2.29	0.55	2.00	4.00	2.25	0.44	2.00	3.00
Frequency[a]	24.13	28.07	0.81	121.92	28.77	50.72	0.31	217.95
Neighbors[b]	2.24	0.59	1.10	3.45	2.11	0.46	1.15	2.85
Bigram frequency[c]	30.11	5.21	22.4	43.17	31.19	4.63	22.96	41.23
	Pseudowords							
	Monomorphemic				Multimorphemic			
Letters	6.54	1.02	5.00	9.00	7.00	1.38	5.00	11.00
Syllables	2.25	0.53	2.00	4.00	2.29	0.46	2.00	3.00
Neighbors[b]	2.42	0.58	1.05	3.65	2.35	0.44	1.75	3.45
Bigram frequency[c]	29.18	4.35	22.20	39.45	32.02	5.95	22.22	48.91

[a] normalized type frequency (per million); [b] OLD20; [c] summed bigram type frequency

Moreover, 24 multimorphemic pseudowords were created by selecting multimorphemic words that were not in the stimulus set but had the same suffixes that were used in the word set (*-er, -in, -ung*).To create pseudowords, one letter in the stem was changed, such that the morphological structure remained due to the presence of the real suffix. Again, the items were disrupted syllable-congruent (e.g. *HEL:BER*) or syllable-incongruent/morpheme-congruent (*HELB:ER*). Also, 24 monomorphemic words were chosen and one letter was changed in order to create monomorphemic pseudowords, which were again segmented at the syllable boundary (e.g. *DOS:TOR*) or one letter to its right (*DOST:OR*). Mono- and multimorphemic pseudowords were matched on number of letters, number of syllables, bigram frequency and neighbors (all $t<1$, $p>.05$, see Table 3.1 for details). Finally, the psedoword set and the word set were matched on these characteristics as well (all $t<1$, $p>.05$, see Table 3.1).

From the final set of 48 words and 48 pseudowords (see Appendix Table A3.1), two lists were created, such that each stimulus appeared both in the syllable-congruent and the syllable-incongruent/morpheme-congruent condition across participants, but each participant only saw each stimulus in one of the conditions.

Procedure

The children were tested individually in a quiet room in their schools or in their after-school care. The adults were tested individually at the test center of the research institution. The experiment was run on a 15″ laptop monitor with a refresh rate of 60 Hz. The stimuli were always presented in the center of the screen in white 20-point Courier New font on black background. Each trial started with a 500-ms fixation cross, followed directly by a disrupted word or pseudoword. The word or pseudoword remained on the screen until a response was made by the participant. Participants were instructed to decide as quickly and as accurately as possible whether the presented stimulus was an existing German word or not while ignoring the colon in the stimulus. They were further instructed to indicate their decision by pressing the D or the K key on a standard keyboard, marked red and green. Eight practice trials with feedback (right or wrong answer) were given prior to the 96 experimental items. After half of the items, the participants had a break that was timed by the experimenter.

Results

Reaction times and error rates from the experiment were collected and analyzed separately for words and pseudowords. For the response time analysis, incorrect responses were removed from the analysis (15.80% for words, 15.80% for pseudowords), as were response times below 200 ms or above 10000 ms (0.91% for words, 3.16% for pseudowords). The remaining response times were then logarithmically transformed. Following Baayen and Milin (2010), model criticism based on a simple model including random effects for subject and item was used for further outlier trimming, excluding all data points with residuals exceeding 2.5 standard deviations for the main analyses (2.32 % for words, 1.95% for pseudowords). It should be noted that adults made very few errors, limiting the meaningfulness of the error rate analysis for adults. For reasons of completeness and because the children made more errors, we report error analyses too. The means and standard errors for words and pseudowords are presented in Table 3.2 and 3.3 and illustrated in Figure 3.1 and 3.2, respectively.

Table 3.2

Mean Response Times (ms) and Error Rates (%) to words. Standard errors are presented in parentheses.

	Monomorphemic		Multimorphemic	
	Syllable-congruent	Syllable-incongruent	Syllable-congruent	Syllable-incongruent/ morpheme-congruent
	Response Times			
Grade 2	3150 (166)	3343 (177)	3411 (181)	3542 (188)
Grade 4	1563 (122)	1683 (131)	1556 (122)	1579 (123)
Adults	682 (52)	688 (52)	701 (53)	680 (52)
	Error Rates			
Grade 2	10.93 (1.97)	19.76 (3.10)	18.58 (2.96)	19.71 (3.10)
Grade 4	12.47 (2.85)	10.83 (2.55)	10.80 (2.55)	7.01 (1.82)
Adults	3.56 (1.06)	3.20 (0.97)	1.97 (0.69)	1.96 (0.69)

Main data analyses were performed using linear mixed-effects models (Baayen, 2008; Baayen, Davidson, & Bates, 2008). A forward-selection procedure was used for model building, starting with a very simple model only including Agegroup as a fixed effect and only adding predictors when they significantly improved model fit as indicated by comparison of the Bayes Information Criterion. The final model included Morphological Status (monomorphemic vs. multimorphemic), Disruption Position (syllable-congruent vs. syllable-incongruent/morpheme-congurent), Agegroup (second graders vs. fourth graders vs. adults) and their interactions as fixed effects, and Participants and items as random factors. Results for the overall effects tests using contrast coding and Type III sum of squares (using the Anova function in the car package) are summarized in Table 4. Post-hoc comparisons were carried out using cell means coding and single df contrasts using the glht function of the multcomp package (Hothorn, Bretz & Westfall, 2008) were evaluated using a normal distribution.

Table 3.2

Mean Response Times (ms) and Error Rates (%) to pseudowords. Standard errors are presented in parentheses.

	Monomorphemic		Multimorphemic	
	Syllable-congruent	Syllable-incongruent	Syllable-congruent	Syllable-incongruent/ morpheme-congruent
	Response Times			
Grade 2	4079 (216)	4274 (226)	4242 (225)	4574 (243)
Grade 4	2208 (175)	2196 (174)	2239 (178)	2539 (202)
Adults	817 (63)	844 (65)	853 (66)	861 (66)
	Error Rates			
Grade 2	15.82 (2.39)	14.12 (2.19)	16.94 (2.51)	20.22 (2.86)
Grade 4	10.24 (2.44)	12.04 (2.76)	13.76 (3.05)	17.65 (3.69)
Adults	1.70 (0.62)	2.62 (0.85)	1.69 (0.61)	0.83 (0.38)

Words. The model fitted to the word data revealed a significant main effect of Agegroup, indicating faster response times with increasing age. Furthermore, Agegroup interacted with Morphological Status as well as with Disruption Position. Decomposing the Agegroup x Morphological Status interaction, post-hoc contrasts showed that albeit second-graders showed a numerical advantage for monomorphemic compared to multimorphemic words, this effect did not reach significance (ΔRT=230ms, t=1.72, p=.08), and neither did the difference between monomorphemic and multimorphemic words in fourth-graders and adults (grade 4: ΔRT=55ms, t<1, p=.42; adults: ΔRT=5ms, t<1, p=.84). The simple main effect of Morphological Status, however, was significantly different in second-graders compared to fourth-graders (t=4.29, p<.01) and compared to adults (t=2.68, p<.01), while fourth-graders and adults did not differ significantly (t=1.57, p>.05).

Decomposing the Agegroup x Disruption Position, it became clear that all children were slowed down significantly by the syllable-incongruent compared to the syllable-congruent condition (grade 2: ΔRT=162ms, t=3.69, p<.01; grade 4: ΔRT=72ms, t=2.21, p=.03), while this was not the case for adults (ΔRT=7ms, t<1, p=.56). The simple main effect of Disruption Position did not differ between second- and fourth graders (t<1, p=.87), but differed significantly between both second-graders and adults (t=2.63, p<.01) and fourth-graders and adults (t=2.02, p=.04).

There was no three-way interaction of Morphological Status, Disruption Position and Agegroup.

A similar model was fitted to the error data. This mirrored the outcome of the response time model with a significant main effect of Agegroup, indicating more accurate responses with increasing age. Agegroup also interacted with Morphological Status and with Disruption Position. Regarding the Agegroup x Morphological Status interaction, post-hoc contrasts showed that the direction of the Morphological Status effect differed significantly between second-graders and fourth-graders (t=2.74, p<.01) and between second-graders and adults (t=2.45, p=.01). All other contrasts were not significant.

Also decomposing the Agegroup x Disruption Position, it became evident that second-graders made fewer errors in the syllable-congruent disruption condition

(t=3.57, p<.01), while this was not the case for fourth-graders (t=1.57, p=.12) and adults (t<1, p=.86).

Taken together, children's word recognition is impeded when syllables are visually disrupted, while adults are not affected differentially by syllable-congruent and syllable-incongruent/morpheme-congruent visual disruptions.

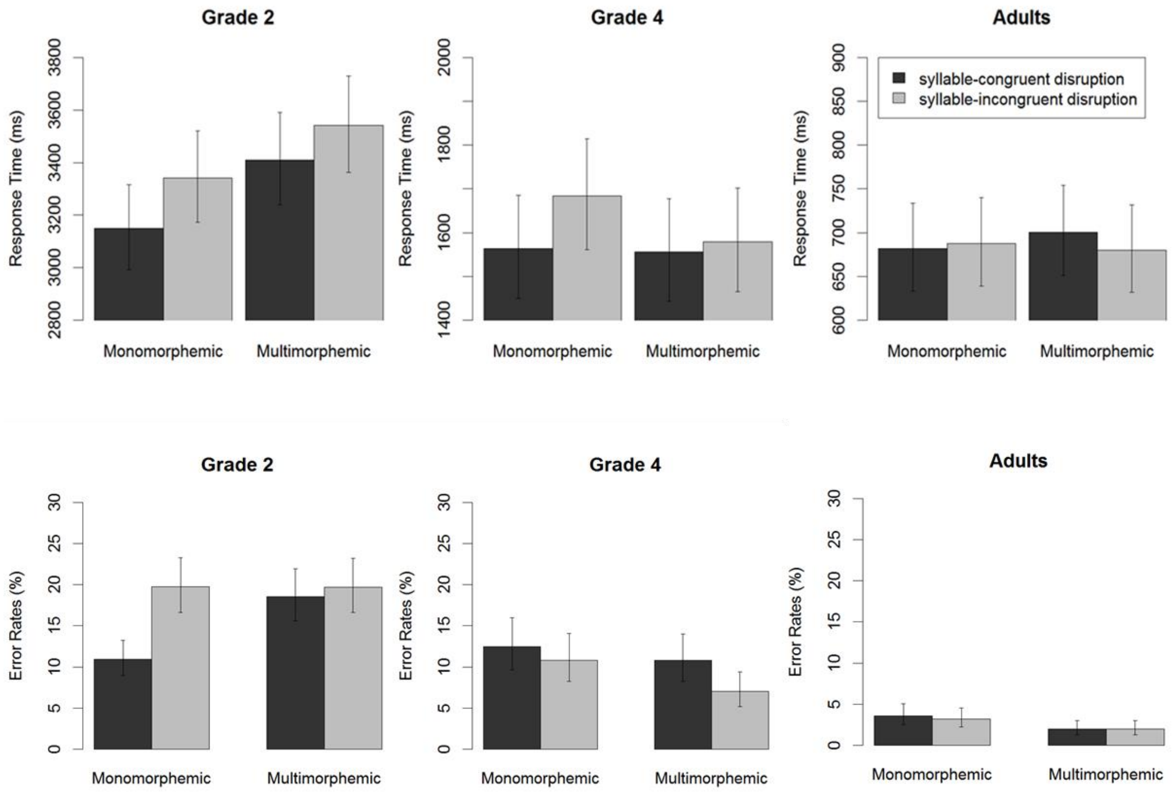

Figure 3.1 Mean response times (ms) and error rates (%) to words in the different conditions by group. Error bars indicate standard erros.

Pseudowords. Response times to pseudowords were analyzed as described above. A main effect of Agegroup was found, indicating that response times to pseudowords became faster with increasing age. This main effect was moderated by a three-way interaction of Morphological Status, Disruption Position and Agegroup.

Post-hoc contrasts showed that for second-grade children there was no interaction of Morphological Status and Disruption Position (t=1.09, p=.28), nor a simple main effect of Morphological Status (t=1.44, p=.15), but the simple main effect of Disruption Position was significant (t=4.62, p<.01). This indicated slower responses to syllable-incongruent compared to syllable-congruent pseudowords (ΔRT=264ms).

For fourth-grade children, there was an interaction effect of Morphological Status and Disruption Position (t=3.23, p<.01). The effect of Disruption Position was only significant for multimorphemic words (t=4.29, p<.01), that is response times to pseudowords disrupted at the syllable-incongruent position were longer when the pseudoword contained an existing morpheme (ΔRT=298ms) and the segmentation was therefore morpheme-congruent. There were no prolonged response times to monomorphemic syllable-incongruent pseudowords (t<1, p=.85).

Adults did not show a significant effect of neither Morphological Status (t<1, p=.42), nor Disruption Position (t=1.17, p=.24), nor the interaction of those (t<1, p=.52).

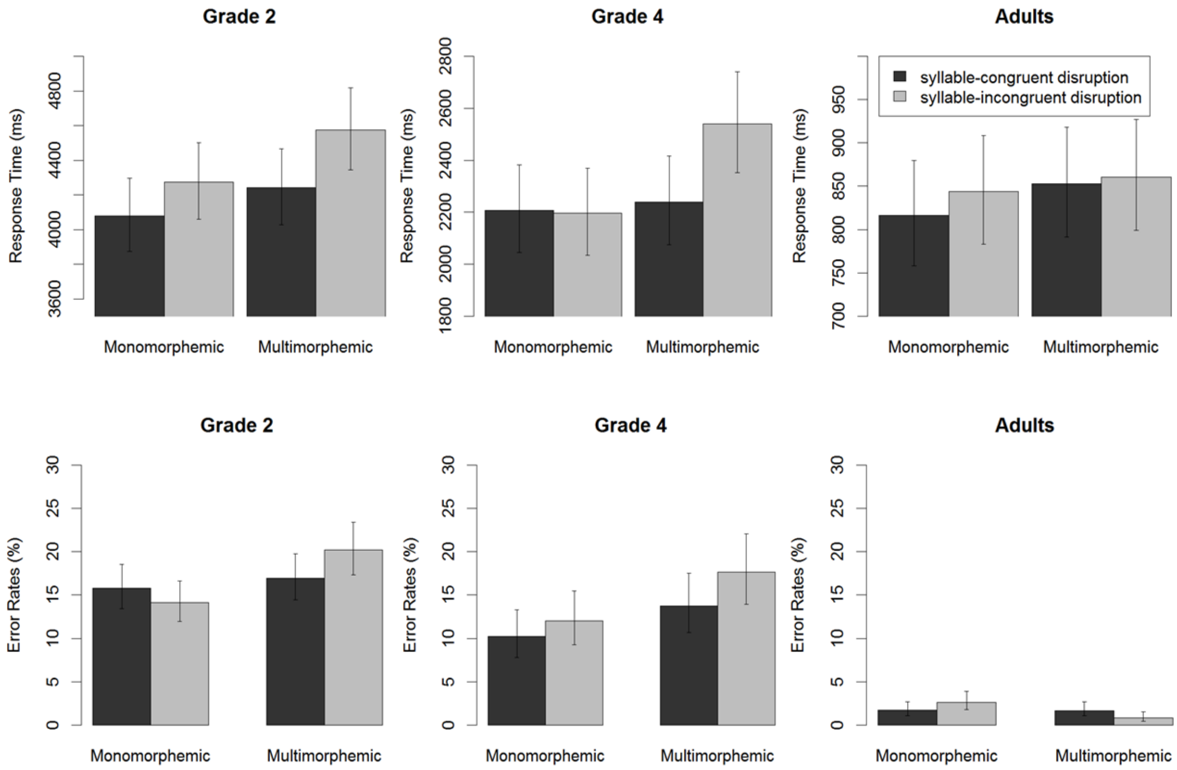

Figure 3.2 Mean response times (ms) and error rates (%) to pseudowords in the different conditions by age group. Error bars indicate standard erros.

Error rates to pseudowords were analyzed parallel to the response times. The model yielded a significant main effect of Agegroup only, indicating that error rates decreased with increasing age.

Summarized, second-graders were slower in rejecting pseudowords when the disruption was syllable-incongruent, while fourth-graders were only slowed down by syllable-incongruent (i.e., morpheme-congurent) disruptions of multimorphemic pseudowords, which were the morpheme-congruent cases. Adults, again, were not influenced by disruptions at all.

Table 3.4

Results from mixed-effect models with Morphological Status, Disruption Position and Agegroup as fixed effects, and Participant and Item as random intercepts.

	χ^2			
	Words		Pseudowords	
	RTs	Errors	RTs	Errors
Fixed Effects (*df*)				
Intercept (1)	8972.15*	192.37*	9157.91*	179.84*
Disruption Position (3)	< 1	< 1	1.37	< 1
Morphological Status (1)	< 1	1.95	< 1	1.69
Agegroup (2)	417.43*	60.76*	405.31*	59.83*
Disruption Position × Morphological Status (1)	1.11	< 1	< 1	1.83
Disruption Position × Agegroup (2)	7.37*	10.03*	3.54	1.11
Morphological Status × Agegroup (2)	20.34*	11.80*	3.15	4.39
Disruption Position × MorphStatus × Agegroup (2)	< 1	1.35	8.23*	3.03
Random Effects				
Participants	6565*	127*	6730*	226*
Items	509*	145*	432*	53*

Note. Tests are based on Type III sum of squares and χ^2 values with Kenward-Roger *df*. Numbers in parentheses indicate degrees of freedom.

3.4 Discussion

The present study examined second-graders', fourth-graders' and adults' use of syllables and morphemes as functional units in word recognition by using a lexical decision task with monomorphemic and multimorphemic words and pseudowords that were visually disrupted either in a syllable-congruent or a syllable-incongruent way (being morpheme-congruent in the case of mulitmorphemic words). Beginning and skilled readers were impacted differently by this disruption, implying that different units are preferred depending on the stage of reading development. Moreover, the effect of disruption position also differed for word recognition and pseudoword rejection in the different age groups. Second-graders were faster when the disruption was syllable-congruent in both word recognition and pseudoword rejection. For fourth-graders, syllable-congruent disruptions were also faster in word recognition, but in pseudoword rejection this was only the case for multimorphemic pseudowords. Together, this indicates that syllables facilitate word recognition for all children, while morphemes selectively impede the rejection of multimorphemic pseudowords in fourth-graders. Adults were not affected differently by syllable-congruent and -incongruent disruptions, neither in word recognition, nor in pseudoword rejection.

Second-grade children in the present study responded faster when disruptions were congruent with the syllables (*SPI:NAT, FAH:RER*) than if they were not (*SPIN:AT, FAHR:ER*), regardless of the morphological status. Moreover, this pattern emerged for both words and pseudowords. Additionally, second-graders made fewer errors to words with syllable-congruent disruptions. Together, this shows that beginning readers of German can use syllables as units in reading. Moreover, the results indicate that word and pseudoword reading in young children is based on the same sublexical mechanism. This can be best interpreted as some kind of phonological restructuring into syllables prior to lexical access (Katz & Feldman, 1981) that helps the flow of reading, making it easier for beginning readers to "get through" the word or pseudoword. Taken together, the response pattern to words and pseudowords militates for the syllable as a salient grain size in German second-graders' reading, while morphemic structure is still tedious.

Children in fourth grade in our study also showed facilitation from syllable-congruent compared to syllable-incongruent disruptions, albeit this effect did only emerge in the response times, but not in the error rates. Interestingly, no facilitation from syllable-congruent disruptions in the monomorphemic pseudowords (*DOS:TOR*) was evident. The disruption position only made a difference in the multimorphemic pseudowords that featured a suffix, which was accentuated in the syllable-incongruent disruption (*HELB:ER*). Since pseudowords have to be rejected, the response times cannot only reflect actual reading processes, but also rejection difficulty. Thus, the longer response times to pseudowords that feature a suffix and are disrupted at the morpheme boundary, such that the suffix is highlighted, might additionally point to a role of morphemes in reading. The prominences of syllables as functional units in word reading, but morphemes in pseudoword reading is very interesting as it suggests that different processing mechanisms can be involved depending on lexicality and/or familiarity. When reading unfamiliar words, such as pseudowords, morphemes might be particularly consulted, as they aid breaking down and understanding unknown words (Bertram, Laine, & Virkkala, 2000). This draws on the different types of information that syllables and morphemes encode. The accentuation of the existing suffix in a pseudoword might thus result in longer attempts at ascribing meaning to the pseudoword, which finally fails (see also Quémart et al., 2012). It can be assumed that fourth-graders have already developed some sensitivity to suffixes as lexical-semantic units, but do not fully capitalize on morphemes as sublexical decoding units in words when they do not coincide with syllables. Together, results from words and pseudowords for fourth-grade readers indicate that in the course of reading development, sensitivity to morphemes emerges, while syllables do not lose their relevance as a grain size in fine-grained reading.

Turning to the results for the skilled adult readers in our study, we failed to find any effects of the disruption, both in the case of words and pseudowords. Certainly, this does not rule out the possibility that adults are sensitive to syllables and morphemes in word recognition, as has been evidenced by many studies with a variety of paradigms (e.g., Carreiras, Álvarez, & De Vega, 1993; Conrad & Jacobs, 2004 for syllable effects ; Amenta & Crepaldi, 2012 for a review of morphological effects). Our results should be interpreted with caution in this regard with several considerations in mind. First, the words were very familiar to adults, since we chose them from a child corpus (childLex, Schroeder et al., 2015) with the developmental focus of the study in mind, and syllable and morpheme effects have been shown to diminish or even disappear with increasing word frequency (Colé et al. 1999; Marcolini et al., 2011). Second, the disruption we used (:) was very subtle for skilled readers, whose reading system is robust to some amount of impreciseness (e.g., O´Connor & Forster, 1981; Forster et al., 1987). Third, as the accentuation of certain units through the disruptions was not always helpful (e.g., *SPIN:AT* leaving no sensible subunits or *HELB:ER* drawing the attention to the misleading existing suffix), adults might have ignored the manipulation altogether. Skilled readers thus showed less sensitivity to syllables and morphemes as sublexical units in the present study, which does not exclude their ability to rely on these grain sizes under task demands. In the present study, however, we suggest that they used a coarse-grained strategy which is more tuned to deal with the insertion of a single character at any position, because it uses position-invariant letter coding. After having arrived at a whole-word orthographic representation via the coarse-grained route, of course, morphological processing is possible. This supralexical morphological processing, however, does not assume the use of morphemes as ordered letter sequences, which we believe our manipulations tap into. The interpretation of the adult data in terms of skilled processing mechanisms is, surely, limited and needs to be investigated separately in future studies. In the present study, the skilled readers nevertheless serve as a control group to illustrate how the same materials should by processed by the end of reading development.

Our developmental results diverge from those of Colé et al. (2011), who reported equal use of syllables and morphemes in multimorphemic words already in second grade, while in our study syllables seemed to be the preferred units in word recognition still in fourth grade. The divergence in findings could possibly be ascribed to differences in the study design: for example, word frequencies might influence the magnitude of syllable and morpheme use (Colé et al. 1999, Marcolini et al., 2011), but are difficult to compare across the two studies. However, cross-linguistic differences affecting reading development (Seymour et al., 2003; Ziegler & Goswami, 2005) seem to present a more crucial factor for children. Particularly, in French, most common suffixes start with a vowel, thus derivations typically have a morpheme-incongruent syllable structure. In German, in contrast, there are many suffixes starting with a vowel and many suffixes starting with a consonant, such that morpheme-congruent syllable structure is not an exception. Moreover, stress assignment in French is typically changed by suffixation, whereas in German, suffixation virtually never changes stress assignment. As a consequence, the distinction between syllables and morphemes might be less pronounced in German as compared to French, such that there is also less pressure to functionally separate them. The establishment of morphemes as separate functional units might only become urgent later for German children and in the beginning particularly for newly encountered words, when the amount of multimorphemic words that are learned through reading drastically increases between grade 3 and 5 (Anglin, 1993; Segbers & Schroeder, 2016). Together with arguably less pronounced, but still effective differences in GPC consistency, syllable complexity, and morphological richness between German and French, this bears the possibility of a deviating developmental trajectory in the two languages.

The present study suggests that, at least for German, functional units of word recognition emerge in a sequential order, with syllables preceding morphemes. This is consistent with Häikiö et al.'s (2016) recent extension of the multiple-route model, which predicts the use of syllables to chronologically precede the use of morphemes in reading development. Nevertheless, comparing our findings to studies in other languages, especially the one by Colé et al. (2001), supports the assumptions of the psycholinguistic grain size theory (Ziegler & Goswami; 2005) that language-specific characteristics pose different demands on learners and determine cross-linguistic differences in the preference for certain reading units across reading development. This strongly suggests that cross-linguistic differences need to be taken into consideration by models of reading development. To base models on findings from a single language severely limits their generalizability across languages. Future studies should therefore aim at comparing the use of different functional units in reading development directly across languages, carefully selecting the languages under investigation with regard to their orthographic transparency, syllable structure and morphological complexity. Also, including younger and older children and reading skills as a moderating factor as well as the influence of other linguistic skills, such as phonological and morphological awareness, is highly desirable in order to investigate individual trajectories in future studies and thus advance models of reading development further.

In summary, by examining the use of syllabic and morphemic units in both mono- and multimorphemic words and also pseudowords in German, our results extend previous findings on children's use of ordered letter sequences in a fine-grained processing route. This allowed us – in an important extension to the findings by Colé et al. (2011) for French – to demonstrate developmental changes in the use of different functional units. We were able to show that the syllable comes first in development and German second-graders have a stronger preference for using syllables in word recognition, while morphemic structure is challenging for them. For the fourth-graders, we did find use of both units in multimorphemic word recognition, indicating that fine-grained reading is still in practice by the end of elementary school and is flexible in regard to syllable vs. morpheme use. While our data suggests that there is an order of acquisition with syllables coming first and morphemes later, this does not need to be the case in all languages, as the comparison to Colé et al. (2011) demonstrates. Therefore, cross-linguistic developmental studies on that topic are highly desirable in order to further disentangle how language-specific characteristics influence the use of certain grain sizes at different stages in reading development.

Comparing effects of constituent frequency and whole-word frequency in children's and adults' compound word reading

CHAPTER 4

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4.1 Abstract

Current models of morphological processing differ in their assumptions about the recognition of compound words. The relative contribution of whole-word frequency and first and second constituent frequency remains unsolved. Particularly for beginning readers, the first constituent might have a privileged role due to more sequential decoding strategies. In the present study, elementary school children and adults performed a lexical decision task in which the constituent frequencies of German compounds were orthogonally manipulated and whole-word frequency was also taken into account. Results show that whole-word frequency strongly affects response times. For children, but not for adults, this was further moderated by first constituent frequency. The results of children and adults together suggest that hybrid models of morphological processing are most suitable and that whole-word and constituent frequencies interactively contribute to compound recognition already in beginning readers.

4.2 Introduction

In the past decades, much research has investigated how morphologically complex words are recognized. In particular, it has been at the center of the debate whether compound words, such as *toothbrush*, are processed as a whole or decomposed into their constituent morphemes, *tooth* and *brush*. Different models of complex word processing have been proposed that vary in their assumptions concerning decomposition. For example, full-listing accounts claim that all known complex words are stored as full forms in the mental lexicon and thus retrieved as such (e.g., Butterworth, 1983). In contrast, full-parsing hypotheses assume obligatory decomposition prior to lexical access and followed by recombination of the constituents (e.g., Taft & Forster, 1976). In addition, there are several hybrid accounts that combine the two former hypotheses, assuming access is possible both via the whole-word and the constituents (e.g., Libben, 2006; Taft, 1994). Hybrid accounts vary in their assumptions about whether one route is chosen, depending on frequency or familiarity (e.g., Caramazza, Laudanna, & Romani, 1988), or whether the routes operate in parallel (e.g., Schreuder & Baayen, 1995; Andrews, Miller, & Rayner, 2004; Kuperman, Schreuder, Bertram, & Baayen, 2009).

One typical way to investigate morphological processing is to examine the reading of compound words in which the frequency of the constituents and the whole-word frequency have been systematically manipulated. Results from such studies are mixed with regard to the contribution of constituent and whole-word frequency. While some studies point solely to a role for whole-word frequency, at least for lexicalized and/or short compounds (e.g., Bertram & Hyönä, 2003; van Jaarsveld & Rattink, 1988), evidence accumulates in favor of interacting effects of whole-word and constituent frequencies (e.g., Bertram & Hyönä, 2003; Kuperman, et al., 2009). For the constituent frequencies, it also remains unclear whether the first and the second constituent have the same relative contribution. Taft and Forster (1976) suggest that recognition occurs via the first constituent and evidence from both lexical decision (van Jaarsveld & Rattink, 1988) and eye-tracking support this view (Hyönä & Pollatsek, 1998). In contrast, several other studies found evidence for the second constituent as the primary processing unit (e.g., Duñabeitia, Perea, & Carreiras, 2007; Juhasz, Starr, Inhoff, & Placke, 2003). Finally, Kuperman et al. (2009) even evidenced a role for both constituents. The relative role of whole-word frequency and first and second constituent frequency in compound processing has thus not been ultimately resolved.

Despite the vast, although inconsistent evidence on frequency effects in compound processing in skilled adult readers, there is very limited research on this issue in children. This is especially surprising considering that in many languages, particularly Germanic languages, compounds are very common and are encountered regularly already by beginning readers. In German, it has recently been shown that many words that are encountered by children for the first time during the elementary school years are, in fact, compounds (Segbers & Schroeder, 2016). Thus, even the youngest readers are faced with the task of decoding those long and complex words, making the investigation of compound processing in children especially relevant.

For children, decomposition can be presumed to play a major role. Not only are the constituents smaller units, which are thus less demanding with regard to visual processes, but also can be used to determine a compound's meaning. For example, compound word explanation tasks have shown that even pre-school children are aware of the constituents in a compound and can use this knowledge (e.g., Krott & Nicoladis, 2005). In written texts, children encounter many compounds for the first time, but might have experience with the constituents in isolation or from a different context. Thus, the decomposition into constituents presents a sensible operation to read compounds. In particular, a privileged role for the first constituent can be hypothesized, as reading proceeds from left to right and is usually still rather sequential in beginning readers (see also the visual acuity hypothesis of Bertram & Hyöna, 2003).

As one of the few studies investigating compound reading in elementary school children, Häikiö, Bertram, and Hyönä (2011) show that both decomposition and whole-word processing are active in Finnish beginning readers. They used eye-tracking of sentences in which the constituents of compounds were either concatenated or hyphenated. Slow beginning readers' fixation durations were shorter for hyphenated than concatenated compounds; fast and advanced reader read concatenated compounds faster than hyphenated ones. The authors interpret the results as implying that slow beginning readers rely on a decomposition strategy and more advanced child readers prefer to use a whole-word strategy, suggesting development towards more holistic processing. Due to the study design, the results did not allow conclusions about the relative contribution of whole-word, first and second constituent frequencies. Moreover, it is difficult to compare eye-tracking of sentence reading to the adult studies that mainly employed lexical decision tasks. In another recent study, de Zeeuw, Schreuder, and Verhoeven (2015) used a lexical decision task to investigate differences between Dutch monolingual and Turkish-Dutch bilingual children's use of whole-word and constituent frequencies in compound reading. They used a set of 80 compounds and included whole-word and first and second constituent frequencies as continuous predictors in a regression analysis. Albeit focusing on processing differences between L1- and L2-learners, the results overall suggest a clear role of whole-word frequency for second- to sixth-graders. The effects of the constituent frequencies were less decisive, which might have been due to the additional across-item variance that was introduced because a between-item design has been chosen. As a consequence, it is still without answer which constituent, the first or the second, plays a stronger role in children's compound processing. In studies with adults, the most convincing experimental design to tackle this question is the orthogonal manipulation of constituent frequencies in a set of compounds that is matched on other lexical characteristics, such as length (e.g. Duñabeitia et al., 2007; Juhasz et al., 2003; Andrews et al., 2004) and, preferably, using the same constituents in different constituent-frequency combinations (e.g., Bronk, Zwitserlood, & Bölte, 2013). Employing such an experimental design with children not only presents a more straightforward test of constituent frequency, but also allows relating the results for children more directly to the findings for adults.

Therefore, the present study aims at disentangling the relative contribution of first and second constituent frequencies and their possible interaction with whole-word frequency in children's and adults processing of compound words. To this end, we manipulated the constituent frequencies of compounds in an orthogonal design (frequency/constituent). To further decrease across-item variance, we used pairs of compounds that shared one constituent, while the other constituent differed in frequency (see also Bronk et al., 2013). Given the evidence for the impact of whole-word frequency as a continuous predictor for both adults (Kuperman et al., 2009) and children (de Zeeuw et al., 2015), we also included it as such. If responses are influenced by whole-word frequency only, this would indicate whole-word processing. If responses are influenced by constituent frequencies, this would support decomposition accounts; a first constituent frequency effect would point to recognition via the first constituent, a second constituent frequency effect would suggest a privileged role for the second constituent. If first and second constituent frequencies interact, this would be evidence for parallel processing of the constituents. Finally, interaction effects with whole-word frequency would support the combined use of any information that is available to maximize opportunity for accomplishing the demanding task of reading a complex word.

If lexicalized compounds are recognized as a whole and decomposition is mainly important for compounds that are not (yet) lexicalized (Caramazza et al., 1988; van Jaarsveld & Rattink, 1988), the processing of the same words should change with time. Directly comparing children's and adults' processing thus was a further aim of the present study. Therefore, we had German elementary school children, as well as adults complete a lexical decision task on the same compound words. Early elementary school readers represent the start point of reading development; skilled adult readers represent the expected optimal end point of this development. The direct comparison between performance of those groups on the same experimental set provides key evidence to understand how exactly the processing of compound words develops. Through this, we can gain more insight on the underlying representational mechanisms. Under decompositional accounts, a stronger effect of the first constituent for children would indicate more sequential processing in beginning readers. Under the assumption that whole-word processing takes place for all lexicalized compounds, we would expect to see development from decompositional towards holistic processing from childhood to adulthood as the compounds become lexicalized.

4.3 Method

Participants

Twenty-two elementary school children (13 girls, Mage = 7.8 years, SDage=0.9, age range: 7-9 years) and 22 university students (12 women, Mage = 26.0 years, SDage=2.6, age range: 21-32 years) from the Berlin area were recruited to participate in the study. Testing took place at the test center of the Max Planck Institute for Human Development Berlin. All participants gave informed consent prior to participation: adult gave written consent and for the child participants written consent was obtained from the parents and oral consent was asked from the children. All participants reported to have normal or corrected-to-normal vision and no history of dyslexia. One child had to be excluded from the analysis as it was not capable of carrying out the full experimental session.

Materials

Thirty-two pairs of compounds were selected from the childLex corpus (Schroeder, Würzner, Heister, Geyken, & Kliegl, 2015). All compounds consisted of exactly two concatenated stems, written without interword space according to German orthographic rules. A compound pair always shared one constituent; for half of the pairs the first constituent was shared (e.g., *Handschuh* and *Handtuch*), for the other half the second constituent was shared (*Autobahn* and *Eisenbahn*). Constituent frequency was manipulated in a 2x2-design (first/second constituent, high/low). Thus, four combinations emerged with 16 compounds in each group: high-high (h-h), high-low (h-l), low-high (l-h), low-low (l-l). High constituents had a normalized lemma frequency above 100 and low constituents below 100 (high: M=287.82, SD=228.26, min=105.37, max=1069.97; low: M=43.73, SD=29.91, min=2.54, max=99.48). The normalized lemma frequency of the whole compounds was lower, as this is usually the case for compounds, and ranged between 0.71 and 38.68 (M=5.66, SD=6.18). Across the four groups, compounds were matched on bigram frequency, neighbors (OLD20), number of letters and number of syllables, all t<1, p>.05. Item characteristics are summarized in Table 4.1. A list design was used, such that each participant saw a given constituent only in one combination and saw 32 compounds in total.

In addition to the compound words, 32 pseudowords were created by selecting 64 stems, changing one letter in each stem and then combining two resulting pseudostems into a pseudocompound (e.g. *Stock* "stick" and *Wolf* "wolf" were made into *Stackwalf*). Pseudowords and words were also matched on bigram frequency, number of letters and number of syllables, all $t<1$, $p>.05$.

Table 4.1

Overview over Lexical Characteristics in the Four Frequency Groups and in the Entire Set of Words. Means with Standard Derivations in Parentheses.

	h-h	h-l	l-h	l-l	all
Whole-Word Frequency	8.41 (9.80)	6.03 (5.71)	4.55 (3.68)	3.66 (2.10)	5.66 (6.18)
1st Constituent Frequency	279.4 (226.73)	279.4 (226.73)	44.90 (31.13)	44.90 (31.13)	162.20 (199.36)
2nd Constituent Frequency	296.20 (233.10)	42.56 (29.09)	296.20 (233.10)	42.56 (29.09)	169.40 (208.55)
Length in Letters	9.25 (1.00)	9.25 (1.13)	9.13 (1.20)	9.13 (0.96)	9.19 (1.05)
Neighbors (OLD20)	2.91 (0.36)	2.98 (0.38)	2.91 (0.45)	3.08 (0.39)	2.97 (0.39)
Summed Bigram Frequency	82999 (46738)	85785 (36269)	98705 (42479)	90426 (43143)	89478 (41738)

Procedure

Testing took place individually in a quiet room on a laptop with a 15″ monitor and a refresh rate of 60 Hz. The stimuli were presented in white 20-point Courier New font on black background. Each trial started with a 500-ms fixation cross in the center of the screen, followed directly by a stimulus, which remained on screen until a response was made by the participant. Participants were instructed to decide as quickly and as accurately as possible whether the presented stimulus was an existing German word or not and indicate their decision by pressing the *D* or the *K* key on a standard keyboard, marked red and green. Prior to the experimental trials, four practice trials with feedback (right or wrong answer) were given. For the children, a short break timed by the experimenter was included after half of the experimental trials. Accuracy and reaction times were recorded.

Results

Main data analyses for words were performed using (generalized) linear mixed-effects models as implemented in the lme4 package in the statistical software R. For the response time analysis, incorrect responses (6.90%) and response times below 200 ms or above 8000 ms (0.78%) were removed first and the remaining response times were logarithmically transformed. Next, model criticism based on a simple model including random effects for subject and item was used for further outlier trimming, excluding all data points with residuals exceeding 2.5 standard deviations for the main analyses (3.14 %). Then, a model was fitted to the data including Group (children vs. adults), 1st Constituent Frequency 2nd Constituent Frequency as categorical predictors (high vs. low) and Whole-word Frequency as a continuous centered predictor (logarithmically transformed to the base 10). Their interactions were also entered as fixed effects. Random intercepts were included for Participants and Items. A parallel model was fitted to the error data. Post-hoc comparisons were carried out using cell means coding and single df contrasts with the glht function of the multcomp package and were evaluated using a normal distribution. Mean response times are shown in Table 2. Results for the overall effects tests using contrast coding and Type III sum of squares (using the Anova function in the car package) are summarized in Table 4.3.

Table 4.2
Mean Response Times (ms) and Error Rates (%) for Children and Adults.

	Children		Adults	
	RTs	Errors	RTs	Errors
h-h	2124 (205)	11.30 (3.54)	644 (61)	0.40 (0.82)
h-l	2057 (198)	5.34 (2.50)	611 (57)	1.70 (1.26)
l-h	1985 (191)	12.14 (3.65)	640 (60)	1.25 (1.12)
l-l	2167 (210)	11.74 (3.67)	649 (61)	0.92 (1.01)

The response time analysis revealed a significant main effect of Group, indicating that overall, adults responded faster than children, and a main effect of Whole-word Frequency, indicating that compounds with a higher whole-word frequency were responded to faster. There were no main effects of 1st and 2nd Constituent Frequency, but they entered into an interaction with each other. Post-hoc contrasts revealed that there was a tendency that response times for compounds with a high first constituent were faster than for compounds with a low first constituent when the second constituent was low (h-l vs. l-l: ΔRT=74ms), t=1.93, p=.054. Also, response times were by tendency faster for compounds with a high second constituent than with a low second constituent when the first constituent was low (l-h vs. l-l: ΔRT=74ms), t=1.93, p=.054. However, both effects were only marginally significant.

Table 4.3

Results from mixed-effect models with Group, 1st Constituent Frequency, 2nd Constituent Frequency and Whole-Word Frequency as fixed effects, and Participant and Item as random intercepts.

	χ^2	
	RTs	Errors
Fixed Effects (all *df*=1)		
Intercept	12587*	169*
Group	90.62*	25.80*
1st Constituent Freq	< 1	< 1
1st Constituent Freq × Group	1.76	< 1
2nd Constituent Freq	< 1	< 1
2nd Constituent Freq × Group	3.37	1.50
Whole-Word Freq	9.82*	< 1
Whole-Word Freq × Group	< 1	1.96
1st Constituent Freq × 2nd Constituent Freq	5.22*	< 1
1st Constituent Freq × 2nd Constituent Freq × Group	< 1	2.43
1st Constituent Freq × Whole-Word Freq	5.79*	1.22
1st Constituent Freq × Whole-Word Freq × Group	3.95*	< 1
2nd Constituent Freq × Whole-Word Freq	< 1	< 1
2nd Constituent Freq × Whole-Word Freq × Group	< 1	< 1
1st Constituent Freq × 2nd Constituent Freq × Whole-Word Freq × Group	< 1	< 1
Random Effects		
Participants	1502*	17.66*
Items	32*	< 1

Note. Tests are based on Type III sum of squares and χ^2 values with Kenward-Roger *df*.

Moreover, 1st Constituent Frequency and Whole-word Frequency interacted and were further modulated by a three-way interaction with Group. Post-hoc contrasts showed clearly that for children, the effect of whole-word frequency differed significantly for compounds with a high first constituent compared to a low first constituent, b=.44, t=3.01, p=.003. Whole-word frequency affected response times when the first constituent frequency was high, b=.43, t=5.25, p<.001, but not when it was low, b=.01, t<1, p=.93. For adults, there was no difference in the whole-word frequency effect between compounds with high and low first constituents, b=.14, t=1.02, p=.31. The interaction is shown in Figure 4.1.

Parallel analyses were conducted on the accuracy data. Only a significant main effect of group emerged, indicating that accuracy was higher for adults than for children. No other effects reached significance.

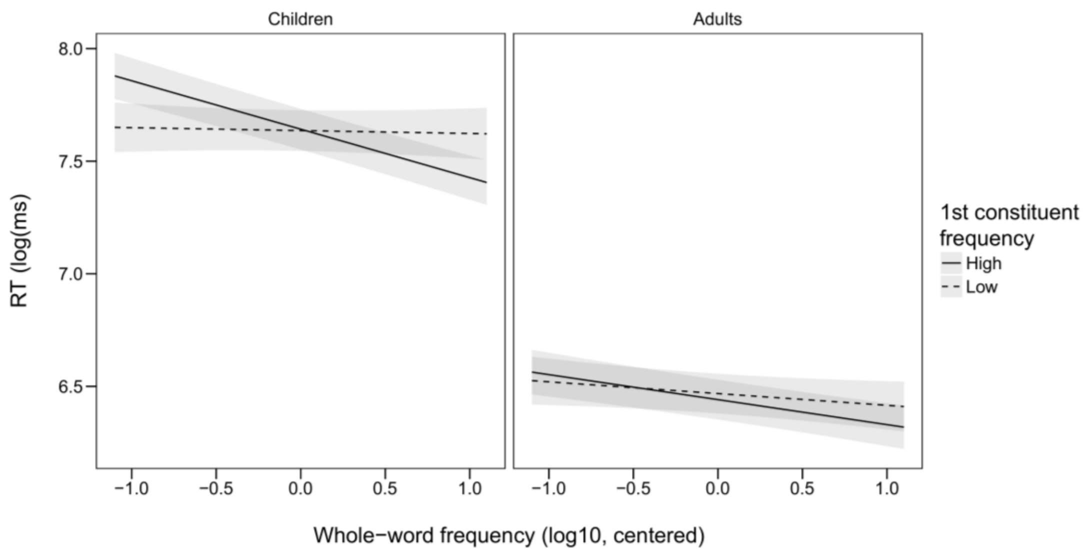

Figure 4.1 Mean Response Times as a Function of Whole-word and 1st Constituent Frequency in Children and Adults.

4.4 Discussion

The present study investigated the role of whole-word frequency and first and second constituent frequencies in the processing of compound words in beginning and skilled readers. The findings provide evidence that whole-word frequency is the primary feature for compound recognition in both children and adults: higher whole-word frequency leads to faster response times. For children, the effect of whole-word frequency additionally interacted with first constituent frequency: whole-word frequency affected processing when the first constituent was of high frequency, but not when it was of low frequency. The results for children thus converge with previous evidence on the special role of the first constituent (Hyönä & Pollatsek, 1998; Taft & Forster, 1976; van Jaarsveld & Rattink, 1988) and support the view that compound processing is decompositional from left to right at the beginning of reading development (Häikio et al., 2011, see also visual acuity hypothesis: Bertram & Hyönä, 2003). The simultaneous importance of whole-word frequency, however, speaks against full-parsing theories, and also against hybrid theories that presume that only one route is chosen or only one route "wins". Decomposition instead seems to interactively co-occur with whole-word processing. This might be best interpreted in an interactive activation framework (e.g., McClelland & Rumelhart, 1981; Taft, 1994), in which representations of the constituents and the whole-word are activated simultaneously. Due to the pronounced left-to-right bias in beginning readers, the first constituent has a greater role in this than the second constituent. One way to think of this process is that upon presentation with a compound (e.g., toothbrush), the initial constituent (tooth) is activated and so are morphologically related words (toothless, toothache, toothpaste) (Schreuder & Baayen, 1995). Thus, compound recognition gains from activation of the constituents, especially the more prominent one, and of the whole-word form itself. In the case that both the first constituent and the whole-word are of high frequency, then activation of the presented compound is fast and strong. If the first constituent is of high frequency, but the whole-word frequency is low, then there might arise inhibition from the constituent and/or higher frequent morphological relatives. If the first constituent is of low frequency, its activation is weak and no or only few morphologically related words can be co-activated, such that whole-word frequency has little influence on recognition.

The results for adults seem to indicate a more whole-word-based strategy that is less influenced by the first constituent. This is most likely due to more holistic and less left-to-right processing in skilled readers and is generally in line with developmental findings by Häikiö et al. (2011). The effect of whole-word frequency independent of first constituent frequency in adults is compatible with full-parsing and hybrid accounts. However, we believe that it should not be concluded from this that adults do not use decomposition. For the experienced adult readers, the words were likely highly lexicalized. Following Caramazza et al. (1988) and van Jaarsveld and Rattink (1988) highly lexicalized compounds do not require decomposition. The same words that children process via a combination of first constituent and whole-word frequency can be processed by adults without resorting to first constituent frequency. This is compatible with hybrid models that assume that length, frequency and/or familiarity determine which route is successful (e.g., Caramazza et al., 1988). Also, it is compatible with interactive hybrid models that suppose that such factors modulate the contribution of whole-word and constituent information (e.g., Kuperman et al., 2009). Furthermore, the observed, albeit weak, interaction effect of first and second constituent frequency also speaks against full-parsing in adults and for at least some amount of activation of the decomposed constituents. The interaction of first and second constituent frequency suggests that the presence of at least one high frequency constituent leads to faster word recognition. This fits with the mechanism suggested above that a highly frequent constituent successfully spreads activation to its morphological relatives, which is not the case for less frequent constituent.

Taken together, our results suggest that whole-word and constituent information is both taken into account interactively in compound recognition. For children, compound recognition seems to be more left-to-right biased with a greater role for the first constituent. The comparison of compound processing in readers at the start point and the end point of reading development provides new evidence in support of interactive hybrid models of complex word recognition and shows that already beginning readers are able to make use of multiple sources of information.

Masked Morphological Priming in German-Speaking Adults and Children: Evidence from Response Time Distributions

CHAPTER 5

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5.1 Abstract

In this study, we looked at masked morphological priming effects in German children and adults beyond mean response times by taking into account response time distributions. We conducted an experiment comparing suffixed word primes (*kleidchen-KLEID*), suffixed nonword primes (*kleidtum-KLEID*), nonsuffixed nonword primes (*kleidekt-KLEID*) and unrelated controls (*träumerei-KLEID*). The pattern of priming in adults showed facilitation from suffixed words, suffixed nonwords and nonsuffixed nonwords relative to unrelated controls, and from both suffixed conditions relative to nonsuffixed nonwords, thus providing evidence for morpho-orthographic and embedded stem priming. Children also showed facilitation from real suffixed words, suffixed nonwords and nonsuffixed nonwords compared to unrelated words, but no difference between the suffixed and nonsuffixed conditions, thus suggesting that German elementary school children do not make use of morpho-orthographic segmentation. Interestingly, for all priming effects, a shift of the response time distribution was observed. Consequences for theories of morphological processing are discussed.

5.2 Introduction

In recent years, much research has investigated the role of morphemes in word recognition. Particularly, the mechanisms and time-course of morphological decomposition have been given much attention. One widely used method to examine morphological processing in adults and children is the masked priming paradigm, in which a morphologically related or a pseudo-morphological prime is presented very shortly before the target. Findings from those studies have given rise to the distinction between early automatic processes based on orthography, therefore called morpho-orthographic decomposition, and subsequent processes based on semantic relationships, called morpho-semantic decomposition (e.g., Rastle, Davis, & New, 2004). Although this distinction is disputed (e.g. Giraudo & Grainger, 2001; Giraudo & Voga, 2014; Feldman, Milin, Cho, Moscoso del Prado Martin, & O`Connor, 2015), skilled readers have repeatedly been shown to exploit morphology in word recognition by using highly automatized rapid morpho-orthographic decomposition (for a review see Rastle & Davis, 2008). Evidence on the mechanisms underlying morphological processing in children has been mixed (Beyersmann, Castles, & Coltheart, 2012; Quémart, Casalis, & Colé, 2011; Casalis, Dusautoir, Colé, & Ducrot, 2009). Whether children's use of morphemes in visual word recognition is similar to those of adults therefore remains a matter of debate. Crucially, previous masked priming studies have only focused on mean response time differences (but see Andrews & Lo, 2013). This might conceal differences that only arise in a certain portion of the response time distribution: priming effects might occur to different degrees for shorter and longer response times. If priming is modulated by the time processing takes to unfold, this would indicate that it is not a general automatic mechanism. Contrasting the response time distributions of truly morphologically related prime-target pairs and pseudo-morphological pairs therefore promises a possibility to distinguish whether the underlying decomposition mechanisms are the same. Moreover, comparing the response time distributions of adults and children could yield new insights as differences would indicate that the underlying processing mechanisms differ between the groups.

Theories of morphological processing vary considerably in their assumptions concerning the underlying mechanisms. Some claim that all known words are, at least initially, retrieved as full forms (e.g. Butterworth, 1983; Giraudo & Grainger, 2001), others state that sublexical decomposition is obligatory (Taft & Forster, 1975; Taft, 2003) and think of it in terms of affix-stripping that acts on any word that appears to have a morphological structure. Form-then-meaning accounts (e.g., Rastle & Davis, 2008) and hybrid models (e.g., Diependale et al., 2009) depict an early sublexical (morpho-orthographic) processing stage, followed by a later meaning-based (morpho-semantic) processing stage (see also Giraudo & Voga, 2014, proposing a sublexical level that is not morphological in nature, but captures the surface structure of affixes, termed morphomes). Form-and-meaning accounts (e.g. Feldman et al., 2015), however, assume involvement of semantics already at the earliest stages of word recognition, rendering the morpho-orthographic/morpho-semantic distinction obsolete, as do models such as the amorphous model (Baayen, Milin, Đurđević, Hendrix, & Marelli, 2011) or the triangle model (Seidenberg & Gonnerman, 2000), that see morphology not as distinct processing units, but as emerging entirely from form-meaning overlap. The different views are often tested by using masked priming experiments.

In the masked priming paradigm, words are preceded by the relatively short presentation (approx. 50 ms) of a related suffixed word (*teacher-TEACH*), a pseudosuffixed word (*corner-CORN*, where 'corner' is not the real suffixed derivate of the stem 'corn') or a non-suffixed control (*turnip-TURN*, where –ip is not a suffix combining with the stem turn) (see Rastle et al., 2004). The general findings from several languages (e.g., Dutch: Diependale, Sandra, & Grainger, 2005; English: Rastle et al., 2004; French: Longtin & Meunier, 2005; Hebrew: Frost, Forster, & Deutsch, 1997; Spanish and Basque: Duñabeitia, Perea, & Carreiras, 2007; see also Rastle & Davis, 2008, for a review) are that stem target recognition is facilitated when preceded by any suffixed prime, regardless of whether it is truly suffixed or pseudosuffixed, relative to any non-suffixed prime. A variation of the masked morphological priming paradigm was introduced by Longtin and Meunier (2005) who used morphologically complex nonword primes that were either interpretable (*rapidifier-RAPIDE*) or non-intertpretable (sportation-SPORT) in comparison to real suffixed word primes (*rapidement-RAPIDE, sportif-SPORT*). They found priming from complex nonword primes, independent of the interpretability. From nonwords with nonmorphological endings (*rapiduit-RAPIDE*) they found no priming effects. Using nonwords as primes has several advantages. A first benefit of the nonword paradigm over the word paradigm is the option to pair different prime types with the same targets, which is intricate and very restricted with words (but see Feldman et al., 2015, Giraudo & Grainger, 2001). Moreover, it circumvents the classification into truly suffixed versus pseudosuffixed words, which is problematic as this is often a continuum rather than two distinct categories (see also Beyersmann, Casalis, Ziegler, & Grainger, 2015). Third, no lexical competition or inhibitory effects can arise from the nonword primes: in a pair like rapiduit-rapide, rapiduit should not interfere with rapide, while in a turnip-turn pair turnip might interfere with turn (Beyersmann, Casalis et al., 2015). Even if a semantic interpretation for a nonword prime is created "on fly" it would necessarily be related to the stem and thus exert a facilitative, but not an inhibitory effect if having an effect from semantics at all. This is important, because it also affects the predicted pattern of priming: when using nonword primes, priming from the stem can be observed also with a non-suffix ending, because facilitation from the stem is not countered by inhibition from the whole word. In a recent study, Beyersmann, Casalis et al. (2015) made use of the nonword paradigm by carrying out a masked primed lexical decision study in which the same target (*TRISTE*) was primes by a suffixed word (*tristesse*), a suffixed nonword (*tristerie*), and a nonsuffixed nonword (*tristald*) in comparison to unrelated words. The results revealed that participants with higher levels of language proficiency showed equal magnitudes of priming across all three conditions, whereas individuals with comparatively lower levels of language proficiency showed significantly more priming in the two suffixed conditions relative to the non-suffixed condition. While the results in the low-proficiency group replicate the findings reported by Longtin and Meunier (2005), the pattern seen in high-proficiency participants suggests that these individuals benefit from the activation of embedded stems, independently of whether they occur in combination with an affix or a non-morphemic ending (for converging evidence, see also Beyersmann, Cavalli, Casalis, & Colé, 2016; Morris, Porter, Grainger, & Holcomb, 2011). These results thus suggest that the visual recognition of morphologically complex letter strings is not uniquely based on morpho-orthographic segmentation mechanisms, but that these are at least complemented to some extent by the activation of embedded stems. Taken together, masked morphological priming studies yield effects indicative of early and automatic decomposition that is independent of a pre-existing semantic relationship between prime and target. The nonword paradigm additionally provides new evidence on the priming of stems as an additional mechanism in masked morphological priming.

Another important issue concerning masked morphological priming, that has gained increasing attention in the recent years, is when and how the observed effects emerge in the course of reading development and how this fits with the different models of morphological processing. However, evidence from masked priming in children is still rather sparse and inconclusive, despite the fact that morphology is known to be of great importance in reading acquisition, particularly in languages that are morphologically productive and have a shallow orthography, such as Finnish, Italian or German. Due to their prominence and high reoccurrence, morphemes appear to be sensible devices to make use of in reading. Especially developing readers benefit from breaking down complex words into smaller parts. Previous studies on morphology in language development have supplied evidence that children use morphological knowledge to learn new complex words (Bertram, Laine, & Virkkala, 2000), as well as to spell words (Deacon & Bryant, 2006). Beyond helping accessing the meaning and spelling of a complex word, morphological structure can also be exploited to recognize written complex words efficiently (Carlisle & Stone, 2005). Therefore, investigation of morphological decomposition in children is interesting not least because it allows drawing inferences important for accounts of reading development.

An initial morphological priming study with children, conducted by Casalis et al. (2009), looked at facilitation from morphologically related primes (*laveur-LAVAGE*) and orthographic primes (*lavande-LAVAGE*) in comparison to unrelated primes and found equal effects of morphological and orthographic priming, thus not indicating morphological, but rather orthographic priming when primes were masked (but morphological priming in an unmasked experiment). However, no pseudosuffixed primes were included. Therefore, it is not possible to further distinguish between morpho-orthographic and morpho-semantic priming mechanisms. Pseudosuffixed priming was examined in a related study with French third, fifth and seventh graders by Quémart et al. (2011), who observed equal priming from both real suffixed and pseudosuffixed primes, but not from nonsuffixed, orthographic primes for children of all grades. The authors propose that children use morpho-orthographic decomposition. These findings are contrasted by evidence from English-speaking children (Beyersmann et al., 2012), showing priming effects only for real suffixed primes, but not for pseudosuffixed or nonsuffixed primes. The authors conclude that priming only arises for semantically related prime-target pairs and morpho-orthographic decomposition is not yet automatized in children. A recent study by Beyersmann, Grainger, Casalis, and Ziegler (2015) and the first using suffixed and nonsuffixed nonword primes with children suggests that priming is modulated by reading proficiency: morpho-semantic priming from suffixed words was evident in children across all grades in elementary school, but more proficient child readers additionally showed effects of embedded stem priming from suffixed and nonsuffixed nonwords. As in Beyersmann et al.'s (2012) earlier findings, there was no evidence for morpho-orthographic processing in primary school children.

Crucially, conclusions about the presence or absence of certain priming effects in both adults and children are usually based on differences in mean of response times to conditions. As Balota, Yap, Cortese, and Watson (2008) point out, relying on differences in means when comparing conditions assumes similar underlying distributions of RTs and a mere shift of the entire distribution. This underscores the likely possibility that RT distributions are differentially skewed. A certain priming condition cannot only shift the whole distribution relative to another condition, but can also affect a certain portion of the distribution. For example, a priming effect can be especially pronounced in longer response times, thus leading to a skew of the distribution. Distributional analyses thus present a promising tool to capture differences in priming effects that might be covered or blurred when using the standard practice of comparing mean RTs. One method to determine differential influences on the RT distribution is by using so-called Vincentiles (Vincent, 1912) or Quantiles. For vincentile or quantile analyses, raw RTs for each participant in a certain condition are ordered from fastest to slowest and grouped into bins (i.e. first 10%, second 10%, etc.). Vincentiles are especially useful to visualize the distribution of RTs in a certain condition: each vincentile can be collapsed across participants and then be plotted. Also, differences between conditions, for example suffixed word primes and unrelated primes, across vincentiles can be plotted to illustrate how the priming effect changes from shorter to longer RTs. Furthermore, they can be used as an informative factor in inferential testing for significance to find out whether short and long reaction times are affected differently by certain primes. The priming effect can remain constant or decrease/increase across vincentiles, thus mirroring a differential impact on certain portions of the distribution. Thus, this technique might provide an informative exploratory extension to the traditional comparison of means.

The vincentile or quantile approach has already provided valuable insights into various processes and limitations of semantic priming (i.e., Balota, 2008; de Wit & Kinoshita, 2015). In the context of masked morphological priming, to our knowledge, it has only been applied once so far. Andrews and Lo (2013) used quantiles to investigate individual differences of masked morphological priming with the word paradigm in adult readers. They compared the RT distributions of priming effects in participants with an "orthographic profile" (i.e. relatively better spelling than vocabulary skills) to those of participants with a "semantic profile" (i.e. relatively better vocabulary than spelling skills). Overall, the authors report a significant distributional shift in the RT distribution for transparent (*teacher-TEACH*) and opaque (*archer-ARCH*) pairs relative unrelated pairs and a significantly smaller shift for form pairs (*brothel-BROTH*). The authors discuss this in terms of a headstart activation from primes to relevant targets. Furthermore, the distributional effects were moderated by the participants' profile. In particular, while all participants showed an increase in priming from transparent pairs across the RT distribution, participants with a semantic profile showed decreased priming from opaque pairs in the slower quantiles, and participants with an orthographic profile showed a slight decrease from form pairs also in the later quantiles. The results by Andrews and Lo (2013) clearly demonstrate that the distributional approach is a promising tool for the exploration of masked morphological priming in different participant samples.

To investigate morphological priming in German adults and children with the nonword paradigm, we carried out a masked priming study using real suffixed words (*kleidchen-KLEID*, "little dress-DRESS", analogous to Eng. *farmer-FARM*), suffixed nonwords (*kleidtum-KLEID*, analogous to Eng. *farmation-FARM*), nonsuffixed nonwords (*kleidekt-KLEID*, analogous to Eng. *farmald-FARM*) and unrelated controls (*träumerei-KLEID*, analogous to Eng. *dreamer-FARM*) as primes. To our knowledge, we are the first to explore suffixed nonword priming in German-speaking individuals.

For adults, we expect increased priming in the two suffixed conditions relative to the control condition, in line with the typical findings from previous studies in other languages (Diependale et al., 2005; Duñabeitia et al., 2007; Frost et al., 1997; Longtin & Meunier, 2005; Rastle & Davis, 2008; Rastle et al., 2004), indicating that the morphemes of the prime are activated in separation, regardless of the lexicality of the prime, thus facilitating target recognition. Moreover, considering recent nonword priming studies (Beyersmann, Casalis, et al., 2015; Beyersmann et al., 2016; Morris et al., 2011), embedded stem priming indicated by facilitation from nonsuffixed nonwords is also expectable.

For children, the case is less clear-cut. If it is true that young children use morpho-orthographic decomposition as evidence for word primes by Quémart et al. (2011) suggest, we would expect priming in both suffixed conditions but not in the non-suffixed condition. However, if German children do not automatically segment all affixed stimuli, priming should only occur from truly suffixed word primes, replicating the Beyersmann et al. (2012) pattern. Importantly, considering that we use nonword primes, which increases the chances for embedded stem priming effects to arise because no conflicting inhibition can occur as in turnip-turn pairs, child readers might also show priming in the nonsuffixed nonword condition (Beyersmann, Grainger, et al., 2015), if they are able to extract stems.

For the exploratory investigation of the RT distributions it is of special interest: (1) whether priming shifts and/or skews the RT distribution, (2) whether the RT distribution is affected differently in the different priming condition. A shift is usually interpreted as reflecting early pre-activation leading to a head start on target processing, while a skew only affecting the longer response times is indicative of a later process such as feedback activation or evidence accumulation (Balota et al., 2008; de Wit & Kinoshita, 2015; Yap, Balota, Tse, & Besner, 2008). In this way, certain patterns of response time distributions can be associated with certain accounts of morphological decomposition. Early automatic pre-activation of the target from all suffixed primes, as indicated by a shift in the RT distribution in the two suffixed conditions, as Andrews and Lo (2013) found for transparent and opaque pairs when averaging across all participants, is compatible with obligatory decomposition accounts (e.g., Taft, 2003), form-then-meaning accounts (e.g., Rastle & Davis, 2008) and hybrid models (e.g., Diependale et al., 2009) due to a headstart from morpho-orthographic segmentation. Form-then-meaning accounts additionally suppose later activation from truly-suffixed words due to feedback from morpho-semantic analysis, as do supralexical accounts (e.g., Giraudo & Grainger, 2001), which could manifest in a skew of the RT distribution in the suffixed word condition. Finally, a shift in all three related conditions would speak in favor of the early activation of the embedded target word, independently of whether it appears with an affix (kleid + tum) or a non-morphemic ending (kleid + ekt). Including quantiles in the analysis thus allows to compare the underlying processes of morphological decomposition and learn about the distinctiveness between early, orthography-based and later semantic-based processing as hypothesized by the different accounts. Considering the patterns for adults and children in conjunction can also shed light on possible differences in the nature of morphological decomposition between skilled and developing readers.

5.3 Method

Participants

Twenty-four university students (13 women, M_{age}=25.2 years, age range: 20–29 years) from the Berlin area participated for monetary reimbursement. Moreover, forty children (20 girls, M_{age}=8.58 years, age range: 7-10 years, grade 2-5) took part in the study for a small compensation. All participants reported to be native speakers of German. The study took place at the test center of the Max Planck Institute for Human Development (MPIB), Berlin. It was carried out with approval of the MPIB Ethics Committee. All adult subjects gave written informed consent in accordance with the Declaration of Helsinki. For the child participants, written consent was obtained from the parents and oral consent was asked from the children.

In order to test whether the adults and children in our study were representative readers of their age group, we used the one-minute-reading test for words and nonwords from the SLRT-II (Moll & Landerl, 2010). Mean percentiles were slightly above the norm for both groups for words (adults: M_{Perc}=68.20, SD_{Perc}=20.28, children: M_{Perc}=57.96, SD_{Perc}=25.67) as well as nonwords (adults: M_{Perc}=71.55, SD_{Perc}=21.87, children: M_{Perc}=53.30, SD_{Perc}=28.92).

Materials

Fifty words were selected as targets. In order to make the experiment also suitable for children, the words were chosen from the childLex corpus (Schroeder, Würzner, Heister, Geyken, & Kliegl, 2015). For each target word, four prime conditions were chosen: a suffixed word prime (*kleidchen-KLEID*), a suffixed nonword prime (*kleidtum-KLEID*), a nonsuffixed nonword prime (*kleidekt-KLEID*) and an unrelated prime (*träumerei-KLEID*). Suffixed word primes were existing suffixed forms of the target words (an English equivalent could be *farmer-FARM*). Suffixed nonword primes were created by combining the target words with a different suffix, thus creating a non-existing derived form (an English equivalent being farmation-FARM). Nonsuffixed nonword primes were a combination of the target words with non-morphemic endings (equivalent to English *farmald-FARM*). Unrelated primes were existing suffixed words with all letters different from the target word. In total then, half of the critical prime conditions were words and half were nonwords and three of the four conditions shared a stem with the target (see Appendix Table A5.1). All prime conditions were matched on length. Each suffix or non-morphemic ending occurred in 5 different contexts per condition (e.g., *kleidchen, stückchen, pferdchen, steinchen, spielchen*). In total, 10 different suffixes and 10 different non-morphemic endings were used, because existing and non-existing combinations used the same suffixes with different stems. Half of the suffixes were of high normalized type frequency (*-ung, -lich, -ig, -nis, -heit*: *M*=1281) and the other half of low normalized type frequency (*-chen, -tum, -lein, -ei, -los*: *M*=173). Likewise, half of the non-morphemic endings were of high type frequency (*-ucht, -men, -atz, -pfen, -am*: *M*=599) and half of low type frequency (*-au, -ekt, -pern, -nauf, -arf*: *M*=141). High and low frequency primes were matched on length, suffix length and non-morphemic ending length across conditions.

Fifty nonword targets were created by selecting 50 words from the childLex corpus (Schroeder et al., 2015) and replacing one letter in each word. Primes for nonwords were created following the same principles as for the word targets with the same suffixes and non-morphemic endings. Nonword and word targets and primes were matched on length.

In order to make the stimulus set dividable by four, six filler target words and six filler target nonwords with their respective primes were added, resulting in a total of 112 targets with four possible primes each. From that, four counterbalanced lists were created, each containing a target word only once, such that participants saw each target only in one of the four prime conditions. Per condition, each participant thus saw 12 items.

Procedure

Participants were tested individually in a quiet room. The experiment was run on a 15″ laptop monitor with a refresh rate of 60 Hz. Stimuli were presented in white 20-point Courier New font in the center of a black screen. Each trial started with a 500-ms forward mask of hash marks followed by a prime in lowercase for 50 ms, directly followed by the target in uppercase. The target remained on the screen until a response was made by the participant. Participants were instructed to decide as quickly and as accurately as possible whether the presented stimuli was an existing German word or not and indicate this by pressing the *D* or the *K* key on a standard keyboard. They were not informed about the prime.

Results

As usually observed for the lexical decision task in a transparent orthography like German, overall response accuracy was rather high for adults (*M*=97.2 %, *SD*=16.6%) as for children (*M*=91.6%, *SD*=27.8%). As a consequence, analyses focused on response times. Moreover, main analyses focused on word targets. Incorrect responses were removed, as were response times below 300ms or above 6000ms (adults: 0%, children: 1.3%). Response times were then logarithmically transformed and further outliers were trimmed for adults and children separately using model criticism based on a simple model including random slopes for subject and item (Baayen and Milin, 2010) and excluding all data points with residuals exceeding 3 standard deviations (adults: 1.5%, children: 1.1%). Descriptive statistics for the four priming conditions are provided in Table 5.1 for adults and children respectively.

Table 5.1

Mean Response Times (in ms) per Prime Type for Adults and Children. Means with different indexes are significantly different at $p < .05$.

	Prime Type			
	Suffixed word	Suffixed nonword	Nonsuffixed nonword	Unrelated word
Adults	599^a	602^a	618^b	634^c
Children	1280^a	1293^a	1297^a	1333^b

Data analyses were performed for adults and children separately using (generalized) linear mixed-effects models (Baayen, Davidson & Bates, 2008) as implemented in the lme4 package (Version 1.1-6; Bates, Maechler, Bolker & Walker, 2014) in the statistical software R. Prime Type (suffixed word vs. suffixed nonword vs. nonsuffixed nonword vs. unrelated word) was entered into the models as a fixed effect. In order to take into consideration possible differences in the response time distributions, Quantile was also included as a fixed effect. Quantiles were computed by sorting the response times from the shortest to the largest into four bins for each participant and priming condition. Suffix Frequency (high vs. low) was entered to control for potential effects due to differential frequencies (see Beyersmann, Casalis, et al., 2015). However, it did not improve the models' fit and was therefore dropped from the analyses. Random intercepts were included for participants and items. Model details are shown in Table 5.2.

Table 5.2 Results from Mixed-Effects Models with Prime Type and Quantile as Fixed Effects, and Participant and Word as Random Intercepts. Model evaluation using Type III sum of squares and Wald χ^2 tests with Kenward-Roger *df*.

	Adults			Children		
	χ^2	*df*	*p*	χ^2	*df*	*p*
Intercept	73206.00	1	< .001	12775.33	1	< .001
Prime Type	113.98	3	< .001	16.26	3	<.001
Quantile	1070.09	9	< .001	1519.97	9	< .001
Prime Type × Quantile	15.36	27	.964	12.96	27	.990

The response time analysis for adults showed a significant main effect of Prime Type, suggesting differential priming effects in the different conditions. Moreover, a main effect of Quantile was present, which was not moderated by Prime Type, indicating that the RT distributions were equally affected in the different conditions. Post-hoc contrasts investigating the main effect of Prime Type were calculated with the multcomp package (Version 1.3-3; Hothorn, Bretz & Westfall, 2008). They revealed significantly faster responses in the suffixed word and suffixed nonword condition compared to the unrelated condition, z=9.43, z=8.60, both p<.05. Responses were also faster in the nonsuffixed nonword condition compared to the unrelated condition, z=4.15, p<.05. Moreover, responses in the suffixed word and suffixed nonword condition differed significantly from the nonsuffixed nonword condition, z=5.31, z=4.50, both p<.05, while there was no difference between the two suffixed conditions, z<1, p>.05. This pattern indicates that both suffixed words and suffixed nonwords are morphologically decomposed in adult readers of German.

In order to explore the main effect of Quantile in more detail, delta plots were used. Delta plots show the difference between two priming conditions directly. For example, Figure 5.1 (left panel) shows the mean response times across quantiles averaged over participants for suffixed words and unrelated words. As one can see, the RTs increase across quantiles in a parallel fashion for both conditions. A delta plot, as in Figure 5.1 (right panel), is created from this by substracting the suffixed from the unrelated condition. The delta plot thus illustrates the priming effect of suffixed relative to unrelated words, which remains constantly above zero across quantiles. This pattern indicates a distributional shift, rather than a skew. Figure 5.2 illustrates a shift for suffixed nonwords and nonsuffixed nonwords relative to unrelated words.

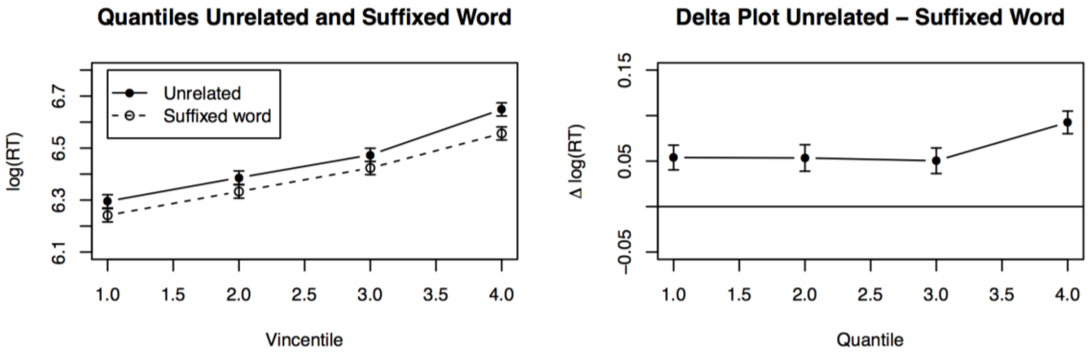

Figure 5.1 Left panel: Mean values for the unrelated and the suffixed word condition for adults. Right panel: Difference between the unrelated and the suffixed word condition for adults (deltaplot).

The linear mixed-effects model for the children's response times showed a significant effect for Prime Type and a significant effect for Quantile, but no interaction. Post-hoc contrasts showed significantly faster responses following suffixed word primes compared to the unrelated condition, z=3.87, p<.05. Responses in the suffixed nonword and nonsuffixed nonword condition were also faster compared to the unrelated condition, z=2.87, z=2.57, both p<.05. However, responses in the suffixed word and suffixed nonword condition did not differ significantly from the nonsuffixed nonword condition, both z=1.27, p>.05, neither did the two suffixed conditions differ from each other, z<1, p>.05. This pattern suggests that children show facilitation from primes sharing the stem with the target, also in the absence of a suffix. To investigate quantiles for children, we again used delta plots as shown in Figure 5.3. Although delta plots for children are more noisy, the pattern overall indicates a moderate distributional shift for all related primes (suffixed word, suffixed nonword and nonsuffixed nonword) relative to unrelated primes.

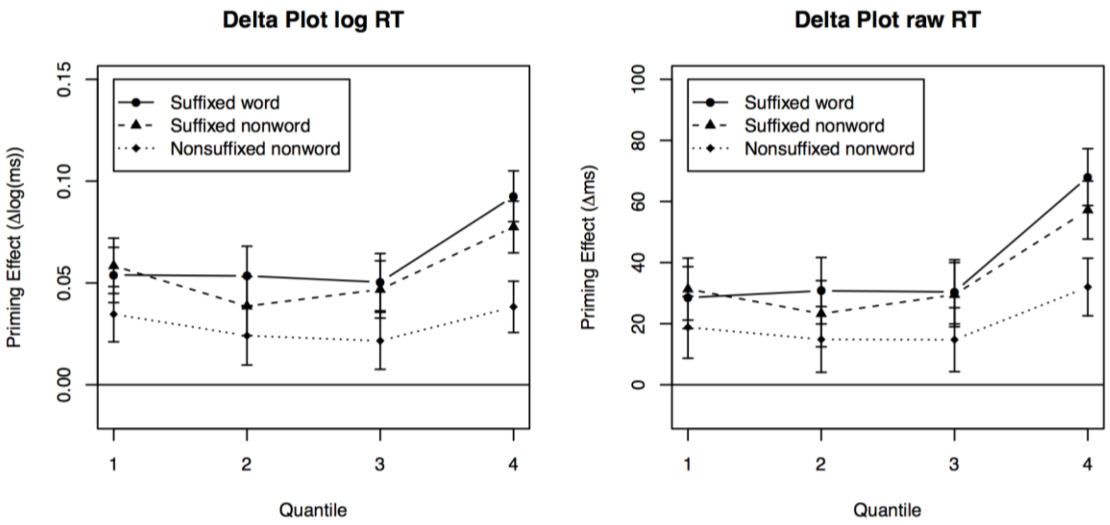

Figure 5.2 Delta plots between conditions for adults. Priming effect of each condition relative to the unrelated condition for each quantile using logarithmically transformed RTs (left panel) and raw RTs (right panel).

We also ran similar analyses for the nonword targets. However, as expected, we did not find a significant effect of PrimeType, neither for adults (χ^2=5.87, *p*>.05), nor for children (χ^2=4.93, *p*>.05) and also no significant interaction of PrimeType with Vincentiles (adults: χ^2=15.31; children: χ^2=6.54, both *p*>.05). The relevant contrasts did not reach significance either.

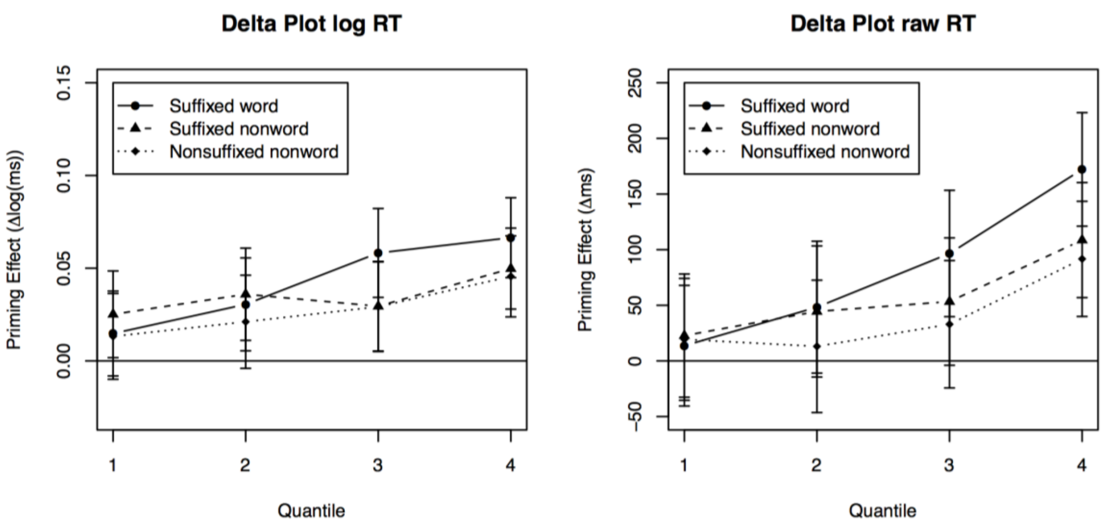

Figure 5.3 Delta plots between conditions for children. Priming effect of each condition relative to the unrelated condition for each quantile using logarithmically transformed RTs (left panel) and raw RTs (right panel).

5.4 Discussion

The present study sought to examine the underlying mechanisms of morphological processing of word and nonword primes in German adults and children beyond mean response times by extending the analysis to response time distributions. Besides replicating previous results for masked morphological priming in German-speaking adults, the aim was to explore whether priming in the nonwo rd paradigm affects the whole RT distribution (shift) or only parts of it (skew) and whether this is different in the different priming conditions, indicating different mechanisms. Secondly, we were interested in how the results for adults pertain to masked priming in elementary school children.

Results for adults showed robust priming effects for suffixed words (*kleidchen-KLEID*) and also suffixed nonwords (*kleidtum-KLEID*) relative to both nonsuffixed nonwords (*kleidekt-KLEID*) and unrelated words (*träumerei-KLEID*). This pattern replicates earlier findings (Longtin & Meunier, 2005; McCormick et al., 2009; Rastle, Davis, & New, 2004) showing that adults automatically decompose morphologically complex letter strings into stem and suffix independently of semantics and regardless of the lexical status, which can be interpreted as morpho-orthographic segmentation (for related evidence for derived nonwords in a non-priming task in German, see Bölte, Schulz, & Dobel, 2010; Bölte, Jansma, Zilverstand, & Zwitserlood, 2009). Additionally, the significant facilitation from nonsuffixed nonwords (*kleidekt-KLEID*) relative to unrelated words (*träumerei-KLEID*) is in line with recent findings using morphologically complex nonword primes (Beyersmann, Casalis, et al., 2015; Beyersmann et al., 2016; Morris et al., 2011) and indicates some amount of embedded stem priming in the absence of an affix, albeit this is significantly smaller than in the presence of an affix. This adds to the growing evidence in favor of an embedded stem priming mechanism in addition to morpho-orthographic segmentation by affix-stripping. Taking into account the RT distribution by use of quantiles, we observed a shift, not a skew, of the RT distribution in the two suffixed conditions as well as in the non-suffixed condition, relative to the unrelated condition. This can be best interpreted in terms of an immediate pre-activation, providing a headstart for target processing. This headstart mechanisms that has also been observed by Andrews and Lo (2013) for transparent, opaque and form-related word pairs thus pertains to the processing of nonword primes.

The results for adults obtained in the present study are in line with morphological processing accounts that suppose early sublexical decomposition, such as obligatory decomposition accounts (e.g., Taft, 2003), form-then-meaning accounts (e.g., Rastle & Davis, 2008) or hybrid models (e.g., Diependaele et al., 2009). While obligatory decomposition and form-then-meaning accounts propose that all complex words must undergo an initial morpho-orthographic segmentation, hybrid models assume that morpho-orthographic decomposition can occur in parallel with whole-word processing of complex words. In all three accounts, successful morpho-orthographic decomposition of the prime would pre-activate the target, manifesting in a shift of the RT distribution. However, strict form-then-meaning accounts (e.g., Rastle & Davis, 2008), which posit a rigid chronological order of semantically blind (morpho-orthographic) and later semantically informed (morpho-semantic) decomposition, fit our results less well. These accounts would predict differences between priming from suffixed words and suffixed nonwords both with regard to magnitude of priming and pattern of the RT distributions, which we did not find. Moreover, our results speak against supralexical accounts (e.g., Giraudo & Grainger, 2001), which presume that morphological decomposition happens after whole-word activation and then sends activation to morpheme representations. Under those accounts, priming from suffixed nonwords is not plausible and a skew rather than a shift of the RT distribution would have been expected due to feedback activation. Amorphous theories (Baayen et al., 2011) that regard morphological effects as the convergence of form and meaning cannot be fully ruled out by our study. However, we consider them less likely due to the finding that suffixed word and nonword primes yielded equal priming in our study, which amorphous models do not account for. Taken together, our results speak in favor of hybrid accounts or obligatory segmentation that is not solely driven by affix-stripping, adding to the growing evidence on stems as salient activation units in morphological processing (Beyersmann, Casalis, et al., 2015; Beyersmann et al., 2016; Morris et al., 2011).

Turning to the results for children, developing readers also showed significant facilitation from real suffixed words compared to unrelated words. In addition, faster response times were observed following suffixed and nonsuffixed nonwords relative to unrelated words. Importantly, in contrast to adults, the difference between the suffixed and nonsuffixed prime conditions did not reach significance in developing readers, which suggests that there was no evidence for morpho-orthographic decomposition by means of affix-stripping in these individuals. Presumably, elementary school children instead activate embedded stems through partially shared orthography, as Beyersmann, Grainger, et al. (2015) reported for proficient child readers. This is consistent with the pattern observed in the quantiles, suggesting that there was a shift rather than a skew in the RT distribution of the suffixed word, suffixed nonword, and non-suffixed nonword conditions. Although the shift pattern was less consistent for children than for adults, it speaks in favor of an early embedded stem activation mechanism in German elementary school children.

With reference to morphological processing accounts, again hybrid models seem to best explain the priming pattern of both mean RTs and RT distributions of the children in our study, because these models incorporate a whole-word processing route that allows for embedded stem priming. Embedded stems are mapped onto orthographic whole-word representations, even if the overlap is only partial (see also Ziegler, Bertrand, Lété, & Grainger, 2014). Embedded stems might thus function as lexical representations that can be activated automatically during the early stages of visual word recognition (Beyersmann, Grainger, et al., 2015). In a transparent language like German, where an alphabetic reading strategy is usually accurate and efficient, elementary school children could still be prone to read sequentially from left to right. Consequently, this would allow for the activation of words embedded at the beginning of the input letter string, independently of what follows (be it suffix or nonsuffix). An interesting test of this assumption would be an analogous masked priming study with prefixed primes that feature the stem in the second position instead of the first position. Another closely related possibility for the interpretation of our results is that children already use some prestage of morpho-orthographic decomposition, in which abstract affix representations are not yet sufficiently fine-tuned to allow the reliable segmentation into stem and affix (see also Castles, Davis, Cavalot, & Forster, 2007). Hence, developing readers would decompose every item that features a stem and a relatively frequent ending. Proper morpho-orthographic segmentation would only be established later on in reading development, arguably through repeated co-activation of stems and their derived forms (see also Beyersmann et al., 2012; Grainger & Ziegler, 2011; Rastle & Davis, 2008). The later acquired morpho-orthographic representations of affixes, would then be used to decompose any stimulus that appears to be morphologically complex (whether it is a truly suffixed word, a pseudosuffixed word or a suffixed nonword), but not stimuli that feature nonsuffix endings. It thus appears that the activation of embedded stems via the whole-word route represents an important prerequisite for the later acquisition of more fine-tuned morpho-orthographic representations throughout reading development. Unfortunately, open questions remain about the nature of the embedded stem priming process in children, in particular whether they happen at a lexical or orthographic level.

Future studies would need to address specifically whether the embedded stem priming effect observed in children should be attributed to higher-order lexical processes or lower-level orthographic processes. This would not only be beneficial for models of morphological processing, but also for models of reading development. Moreover, the replication of the present pattern using other paradigms – for example go/no-go lexical decision, which is less demanding for children (Moret-Tatay & Perea, 2011) – could be helpful in order to ensure the reliability of the effects from the arguably more difficult and specific yes/no decision task. With regard to the distributional analysis, extending the exploratory non-parametric approach to more advanced parametric analyses follow-up studies would profit from aiming at more advanced parametrical methods like ex-Gaussian or Weibull analyses would allow a more precise picture of the distributions of priming effects. However, for those analyses a larger number of data points per condition is crucial to draw sensible conclusions.

In summary, examining masked morphological priming with nonwords beyond mean response times through taking into account response time distributions yielded interesting new insights into the mechanisms of morphological decomposition. Adults showed equal facilitation with a shift of the response time distribution from both suffixed words and suffixed nonwords, indicating morpho-orthographic decomposition as an early and automatic pre-activation process independent of lexical status. They also showed quantitatively smaller, but qualitatively similar facilitation from nonsuffixed nonwords, indicating additional embedded stem priming. Children showed equal facilitation from real suffixed words, suffixed nonwords and nonsuffixed nonwords, suggesting that German elementary school children rely on the activation of embedded stems rather than segmentation of morpho-orthographic reading units by affix-stripping. Our findings suggest that distribution analyses present a promising tool to look beyond mean RTs (Yap et al., 2008). One important extension of our work would therefore be the use of parametrical methods for distributional analyses. This promises to provide more precise insights into the time-course of morphological processing mechanisms and especially the role of embedded stems in skilled as well as developing readers.

General Discussion

CHAPTER 6

The present dissertation has investigated the use of constituent morphemes in complex word recognition in reading development in German. Morphological decomposition in adult readers is thought to be a skill acquired during reading development. Theories of reading development, however, are underspecified with regard to the acquisition of morphological processing. Hence, a developmental perspective on the issue advances the understanding of reading development and skilled morphological processing at the same time. The central goals of this dissertation were to determine *when* and *how* in reading development children make use of morphemes in reading complex words in German and *whether* and *how* the processing mechanisms of developing readers differ from those of adults when directly compared. To this end, four studies were conducted. Study 1 and 2 focused on the developmental time-course and mechanisms of sensitivity to morphological units relative to school-grade and relative to the use of other reading units. Study 3 and 4 compared morphological effects in beginning readers to those observed in skilled readers.

Study 1 investigated the trajectory of the development of morphological effects on lexical decision in a large cross-sectional sample from grade 2 through grade 6, comparing monomorphemic to prefixed, suffixed and compound words and pseudowords. Results imply that beginning readers of German become sensitive to morphology very early in reading acquisition: First effects can be observed as early as in second grade and increase throughout the elementary school years. There is a sequential order of the emergence of morphological effects: Facilitation from compound structure emerges earliest, while suffixes and prefixes do not facilitate reading until later in development. This pattern of results indicates that different morphological types involve distinct processing mechanisms in children, probably due to a more sequential left-to-right processing in beginning readers and a prominence of stems over affixes. Furthermore, the developmental trajectory of morphological effects was found to be moderated by vocabulary knowledge: Children with higher vocabulary knowledge benefit earlier and to a greater extent from morphological structure than children with lower vocabulary knowledge. The findings from study 1 thus determine the developmental trajectory of morphemes as reading units in German and provide insights into some important processing mechanisms.

Study 2 further examined the developmental time-course of morphological processing in visual word recognition and additionally sought to disentangle the influence of two very similar units of analysis in reading: morphemes and syllables. Study 2 used a innovative paradigm that compared the sensitivity to morphemes and syllables in second- and fourth-graders and adults by manipulating the presentation format of multimorphemic and monomorphemic words and pseudowords in a LDT (e.g., *SPI:NAT*, *FAHR:ER, DOS:TOR, HELB:ER)*. Beginning and skilled readers were impacted differently by this disruption and the effect of disruption position also differed for word recognition and pseudoword rejection in the different age groups. Words that were visually disrupted at the syllable-boundary (e.g., *SPI:NAT*) were recognized faster and more correctly by all children, whereas pseudowords disrupted at the morpheme-boundary (e.g., *HELB:ER*) were rejected more slowly by fourth-graders. This indicates that the use of syllable precedes the use of morphemes in development and that the two similar-sized units differently affect word and pseudoword reading. Study 2 thus further shows that morphemes are functional reading units and it informs the developmental time-course of morphemes in relation to other reading units. It also allows further insights into the mechanisms involved in morphological processing in children.

Study 3 investigated the relative contribution of whole-word and constituent information in compound recognition by using a frequency manipulation. It thus addressed an issue that has received a lot of attention in the adult literature, but has been surprisingly understudied in children. Results imply that whole-word frequency and first constituent frequency interactively affect compound recognition in children, while adults rely more on whole-word frequency when reading the same words. This indicates that particularly beginning readers attend to constituent morphemes when reading long complex words. In particular, activation of the first constituent seems to have an impact on compound recognition. Study 3 shows that the frequency manipulation that is commonly used to study compound processing in adults also yields valuable insights about the interactive use of whole-word and decompositional routes in children.

Study 4 was dedicated to the locus of decomposition processes in children and whether they are automatic and sub-lexical or a later supra-lexical process. Masked morphological priming with suffixed words, suffixed nonwords and nonsuffixed nonwords as primes was expanded by an analysis taking into account response time distributions. This approach allowed more precise insights into the underlying time-course of visual word recognition, revealing that similarly to adults, priming effects for children occur very early in time and across the entire RT distribution. The pattern of priming in children further showed facilitation from real suffixed words, suffixed nonwords and nonsuffixed nonwords, but no difference between the suffixed and nonsuffixed conditions. This pattern indicates that decomposition in children is early and automatic, but not driven by affix-stripping. Instead, it is rather based on the embedded stem. Adults showed effects indicative of both affix-stripping and stem priming. The underlying mechanisms of automatic morphological decomposition in children are not (yet) the same as in adults, albeit they are likely also sub-lexical.

Taken together, the four studies confirm that the morphological effects observed in English, Italian and French children are also apparent in an orthographically transparent and morphologically rich language like German. Furthermore, these studies provide important insights for our understanding of the nature and developmental changes of the use of morphemes as reading units. The findings provide a comprehensive outline of the developmental trajectory of morpheme processing in reading acquisition and are fundamental to understanding how children develop into proficient readers that are able to rapidly map form onto meaning. My findings are critical for informing theories of reading acquisition. Moreover, the developmental findings provide novel insights on the dual architecture of models of skilled morphological processing. These issues are discussed in-depth below.

6.1 The development of morphological processing

One of the goals of this dissertation was to provide a comprehensive outline of the developmental trajectory of morphological processing in beginning readers in order to refine models of reading acquisition. The point of departure was the theoretically and empirically driven idea that morphemes, as frequently reoccurring letter sequences with a non-arbitrary form-meaning mapping, are functional reading units for developing readers to break up and understand long complex words. Learning to read usually starts with the decoding of words on a letter-by-letter basis using GPC rules. Morphemes as units of analysis are thought to emerge later on in development.

Current theories are silent about the influence of morphology on reading and previous empirical evidence regarding *when* and *how* this happens is inconsistent.

6.1.1 The developmental trajectory of morphological effects

In order to refine theories of reading acquisition, first of all, the developmental trajectory of sensitivity to morphemes needs to be outlined relative to the number of years of reading instruction in one language and relative to the use of other reading units in reading. Throughout this dissertation, I have repeatedly found that children do not show morphological effects from the very onset of reading acquisition, but already at early stages of development. The results thus confirm reading acquisition theories that assume morphology to emerge at some stage in development, even in transparent orthographies such as German. In particular tackling the question when sensitivity to morphology emerges relative to years of reading instruction, study 1 suggests that morphological processing of compound words occurs already in grade 2 of elementary school, while derived words are readily processed from around grade 3. Overall, reliance on morphemes increases throughout the elementary school years, which is consistent with the predictions of the multiple-route model (Grainger & Ziegler, 2011), which posits that advancement to fine-grained processing should manifest in increased sensitivity to morphological structure.

Concerning the development of sensitivity to morphemes relative to other units, the evidence from study 2 suggests that the use of syllables chronologically precedes the use of morphemes. This can be attributed to the fact that syllables are phonologically defined and are thus at the interface of an orthographic and a phonological reading route, as captured in Häikiö, Bertram, and Hyönä's (2016) extension of the multiple-route model (see Figure 1.2). Furthermore, study 2 suggests that syllables remain important units, despite the slow emergence of morphemes. In light of the linguistic characteristics of the German language, this seems rather surprising. One would expect that the morphological richness of the language leads to an increased bias towards the use of morphemes. As noted earlier, syllable and morpheme boundaries often coincide in German. As a consequence, they might be less well distinguished than in other languages. A contribution of syllabic representations to the evolvement of morphemic representations is conceivable.

Either the syllabic assembly route and the fine-grained route are not distinct at the very beginning and only become separated later on or the path between syllabic assembly and the fine-grained route is bi-directional (cf. Fig. 1.2 (2a), where it is unidirectional). No study in the present dissertation was specifically designed to test between these two possibilities. Hence, the overlap of the syllabic assembly route and morphological decomposition in the fine-grained route is merely a preliminary idea that needs further examination. Nevertheless, it might be useful to be kept in mind during the following paragraph that addresses how morphological decomposition might be learned during reading development.

6.1.2 The detection of form-meaning regularities

What conclusions does the present dissertation allow about how morphological decomposition is learned? The multiple-route model assumes that letter sequences forming affixes children learn to chunk that and can then be detected and stripped off in order to isolate stems. The results from the masked priming experiment presented in study 4 put into question the assumption that children rely on affix-stripping. The observed priming effects even in the absence of a suffix suggest that it is not the affix that is stripped off, but rather the stem that is detected. In line with recent findings from Beyersmann, Grainger, et al. (2015; see also Beyersmann, Casalis, Ziegler, & Grainger, 2015; Beyersmann, Cavalli, Casalis, & Colé, 2016), this points to a special sub-lexical detection mechanism of stems (see also Nation & Cocksey, 2009). Similarly, affix-stripping cannot be used in order to decompose compounds. Thus, the facilitation from compound structure observed in study 1 cannot be explained by an affix-stripping mechanism either. However, if chunking and stripping of affixes is not the means – or at least not the only means – by which children learn to decompose complex words, this poses the question about how separate morpheme representations emerge. The detection of form-meaning regularities clearly presents a sensible explanation. Importantly, our findings from study 1 implicate that, in addition to grade, the developmental trajectory of sensitivity to morphemes also depends on vocabulary knowledge: children with better vocabulary develop sensitivity to morphemes in earlier grades. If differences in the emergence of morphemes as reading units depend on differences in vocabulary, this supports the idea that children built morpheme representations based on form-meaning regularities. Strong representations of the whole-word and representations of many words sharing the same stem and/or the same affix facilitate the detection of regularities; and through this the establishment of morphemes as access units. This basically confirms the idea put forward by Schreuder and Baayen (1995) about the formation of morpheme representations that depend on experience with words. If a child knows the words “Leser”, “lesen”, “lesbar”, “Lesebuch”, “leserlich” he/she can easily discover the form-meaning correspondences and use this information to set up an orthographic representation for the stem “les”. If the child also knows many words with the suffix “bar”, like “kaufbar”, “haltbar”, “tragbar”, he/she will also be able to detect the form-meaning correspondence and set up an orthographic representation for the suffix “bar”. It is notable, however, that stem representations in the orthographic lexicon can be established more easily and thus earlier in development than affix representations, because stems have more salient, univocal and less abstract semantic content (cf. study 1). Affixes are often less unequivocal. For example, the bigram *-er* acts as a suffix denoting a person (as in “Leser”), but also occurs often as a letter string without suffix status (as in “Becher”). The influence from semantics to the orthographic lexicon is illustrated in Figure 6.1. Through the detection of form-meaning correspondences, affixes and stems are equally represented as units in the orthographic lexicon and consequently both should be important for the identification of multimorphemic words.

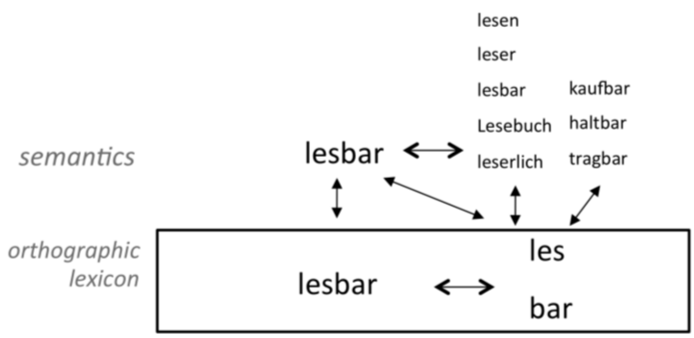

Figure 6.1 Illustration of the establishment of orthographic representations for whole-words, stems, and affixes through the detection of form-meaning regularities via feedback from semantics.

The present dissertation thus supports the idea that morpheme representations of both stems and affixes emerge from the detection of form-meaning regularities in reading development (cf. Rastle & Davis, 2003, 2008).

6.2 The morphological processing mechanisms in children and adults

A second goal of this dissertation was to explore the mechanisms of morphological processing in children and adults at the same time in order to compare them. In particular, I used the same paradigms with children that are typically used with adults. Such an approach has the potential to bring together the research on morphology in developing and skilled reading, which is much too often treated separately. A developmental perspective presents a valuable way to detect differences and similarities between children and adults to gain new insights into the underlying processing mechanisms.

6.2.1 The role of stem and affix representations

As discussed previously, stems most likely are represented in the orthographic lexicon prior to whole-words. This supports the idea that decomposition arises as a means of reading newly encountered items, which are necessary in the early years of reading development. The origin of decomposition in developmental processes is in line with the results presented here, which generally point to more decomposition in the case of pseudowords (study 1 and 2) or unfamiliar words (study 2 and 3). This means that words, which are not (yet) represented in the orthographic lexicon as wholes, need to be decomposed into their constituents in an attempt to find a matching representation. For unfamiliar or novel complex words that are comprised of existing stems and/or affixes, there is a good chance of finding a matching representation for the constituent morphemes. For example, the novel word "Holzbuch" has most likely not been encountered before and therefore has no corresponding whole-word orthographic representation. Its constituent parts, "Holz" and "Buch", however, are rather frequent words and thus very likely to have separate orthographic representations. Morphological decomposition is therefore especially useful in such cases. Moreover, stems are likely represented in the orthographic lexicon earlier in development than affixes, making unfamiliar or pseudocompounds particularly prone to morphological segmentation (cf. study 1 and 3).

The assumption that both stems and affixes become represented as units in the orthographic lexicon deviates from the widely assumed mechanism of sub-lexical affix-stripping (e.g., Taft & Forster, 1975, 1976; Diependale, Sandra, & Grainger, 2009). However, assuming independent orthographic representations for affixes accounts for the pattern of effects found in this dissertation as well as in previous studies, especially with regard to pseudoword reading. Affix-stripping fails to explain increased rejection times to pseudowords featuring a pseudostem + real affix (e.g., "Pauner"). If the affix is stripped off, the pseudostem "paun", for which no orthographic representation is available, should be easy to reject. This does not seem to be the case as the morphological effects for pseudowords in study 1 and 2 show. Consequently, throughout development, affixes likely become independent units of representation in the orthographic lexicon. As such, they can be activated on their own and their activation can be fed forward.

Two further problems with assuming affix-stripping as the main morphological operation have already been mentioned briefly. The first is that affix-stripping cannot account for priming effects in the absence of a suffix (study 4; also Beyersmann et al. 2016; Beyersmann, Casalis, et al., 2015; Beyersmann, Grainger, Casalis, & Ziegler, 2015). The second is that it cannot explain the sub-lexical decomposition of compounds (study 3; also Bronk, Zwitserlood, & Bölte, 2013; de Zeeuw, Schreuder, & Verhoeven, 2015). Both effects, however, can be explained by assuming sub-lexical stem detection. The relevance of stems in children's morphological processing has been witnessed in several experiments in this dissertation. The early and pronounced emergence of compound effects in study 1 and the interactive whole-word and first-constituent frequency effect in study 3 both suggest that the presence of the two stems in a compound effectively bolster word recognition. Stem representations can be expected to be learned more easily and thus earlier in development than affix representations, as mentioned above. Consequently, stem representations might facilitate reading before any facilitatory effects from affixes emerge. The psychological salience of stems results in a stem preference (cf. Cutler, Hawkins, & Gilligan; 1985; for converging evidence from Finnish inflections see Laine, 1999; Lehtonen, Harrer, Wande, & Laine, 2014). Interestingly, the stem preference in children goes hand in hand with a left-to-right bias, especially favoring the stem in the left-most (i.e. first) position. This special role for the first position is supported by the influence of the first-constituent frequency (as opposed to the second-constituent frequency) in study 3. The findings from the present dissertation therefore support the claim made by Smolka, Komlósi, and Rösler (2009; see also Smolka, Gondan, & Rösler 2015) that the stem constitutes a central unit in word recognition – at least in German.

Clearly, the privileged role of the stem in the left-most position needs to be accounted for by any theory of reading acquisition that postulates a role for morphology. Yet, the left-to-right bias is not in agreement with the current version of the multiple-route model, which posits a parallel mechanism operating along the fine-grained route. It is possible, though, that the fine-grained route is more sequential in the beginning and becomes more parallel throughout development. Such an explanation goes in a similar direction as the contribution of the syllabic assembly speculated on above. One way to integrate a left-to-right bias is to weight the contribution of the morphemes to word recognition in the fine-grained route – at least in the beginning of reading development – such that the first morpheme is privileged as an access unit that feeds forward activation. In Figure 6.2 a proposition for a modification of the multiple-route model is outlined, which accounts for the stem preference and the left-to-right bias. Such a modification assumes that morphologically complex input is parsed into constituent morphemes in the fine-grained route, yet instead of stripping off the affix, it activates the orthographic representations whereby activation of the first constituent is earlier and/or stronger. Note that parentheses around whole-words and affixes indicate that those might not yet be available as representations in the orthographic lexicon of beginning readers as they most likely become represented slightly later than stems.

By explicitly assuming that both the stem and the affix are fed forward and activated separately with a left-to-right bias in the orthographic lexicon, the model can account for the longer rejection times for prefixed as opposed to suffixed pseudowords in study 1. Once a prefix representation is available in the orthographic lexicon, the encounter with a prefixed pseudoword (e.g., *Unfats*) strongly activates this prefix representation due to its salient first position. The prefix feeds forward activation, while activation of a stem never happens, thus increasing rejection times.

For suffixed pseudowords, an orthographic affix representation is less disruptive, as the suffix is located in a less salient position.

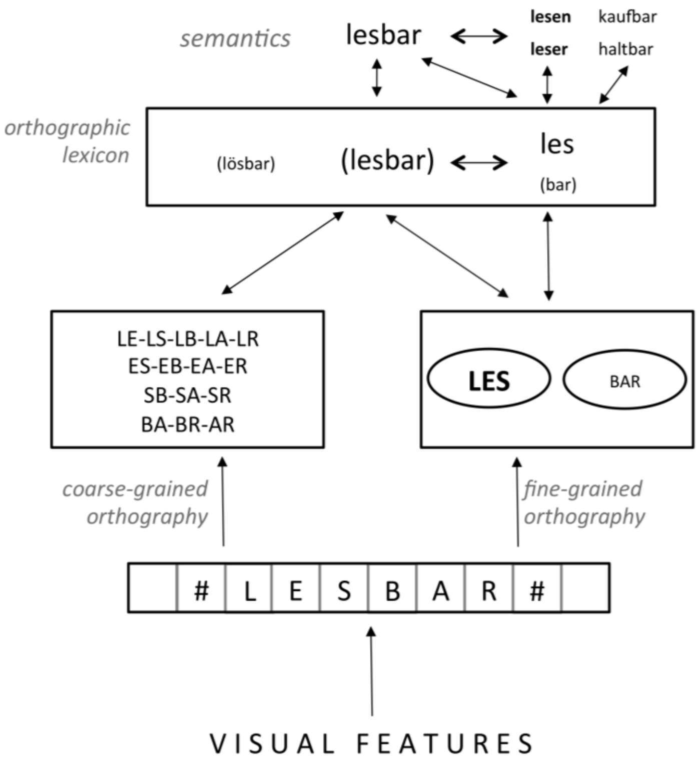

Figure 6.2 A suggestion for a modified model of morphological processing in reading development based on the multiple-route model by Grainger & Ziegler (2011) and its extension by Häikiö, Bertram, & Hyönä (2016). Parentheses indicate that those representations might become represented later. Bold and larger typeface indicates increased salience. Note that only the orthography-based part of the model is depicted, because the initial phonology-based part is assumed to be the same as in the original model in Figure 1.2. The coarse-grained route also remains unchanged.

The stem detection mechanisms also explains why compounds help word recognition from early on in development (study 1), despite the absence of an affix to be stripped-off. The left-to-right bias and the representation of whole-words and stems at the same orthographic level also allow for the interactive activation from whole-word and first constituent that was observed in study 3. Figure 6.3 illustrates the fine-grained processing route for the case of compounds, which is somewhat similar to the segmentation-through-recognition approach described by Andrews, Miller, and Rayner (2004). If a stem is in the privileged first position (indicated by bold and larger typeface), the corresponding whole-word representation receives faster co-activation from two sources: the orthographic lexicon and semantics.

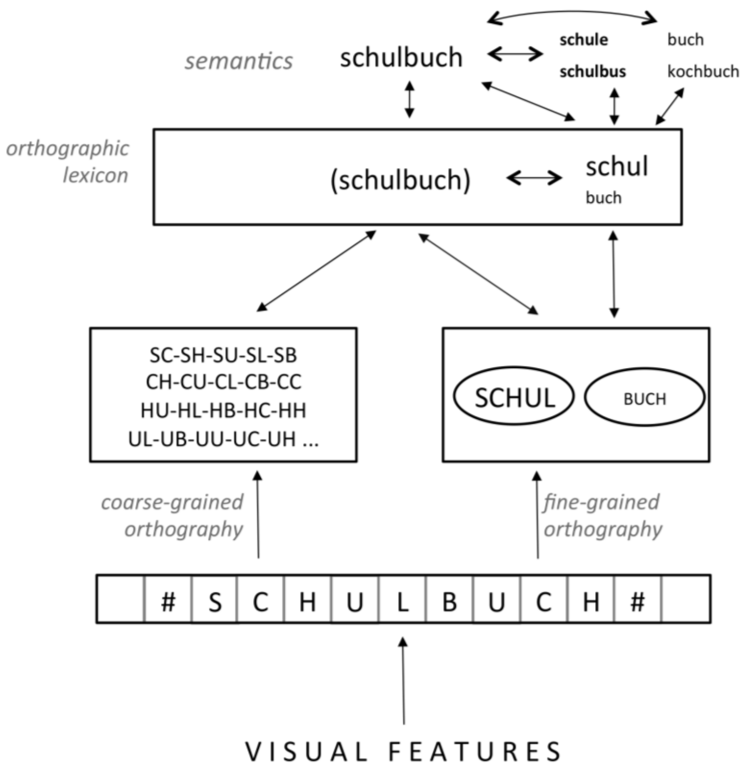

Figure 6.3 Compound processing in the modified multiple-route model. Again, parentheses indicate that those representations might become represented later. Bold and larger typeface indicates increased salience. Only the orthography-based part of the model is depicted, the initial phonology-based part is assumed to be the same as in the original model in Figure 1.2. The coarse-grained route does not show all possible letter combintations.

To summarize, the major difference between the original multiple-route model and the proposed modified version is the incorporation of both stems and affixes as separate orthographic units at the same level as the whole-word orthographic representations. Therefore, in contrast to the corresponding layer in the multiple-route model that is coined "whole-word-orthography", I am suggesting the term "orthographic lexicon". Representation of stems and affixes as units in the orthographic lexicon enables to (1) include a more explicit account of the establishment of morphological units thorough the discovery of form-meaning correspondences, and (2) explain the preference for stems together with the (initial) left-to-right bias of the fine-grained route.

6.2.2 Implications for skilled reading

The extension of the developmental multiple-route model proposed above entails important consequences for models of skilled morphological processing. As became clear, the results reported throughout this dissertation seriously challenge full-listing accounts of morphological processing and storage (e.g., Burani & Laudanna, 1992; Butterworth, 1983), given that recurring morpheme effects were found across different stages in reading development under different experimental paradigms. The evidence from this dissertation further implies that morphemes become represented as separate units in the orthographic lexicon throughout reading acquisition, as outlined above. It is worth noting that it is psychologically implausible that morphological decomposition and the established morpheme representations are "unlearned" once children become skilled readers. Indeed, morphological effects were observed in adults, especially in study 1 and 4. However, the present findings equally speak against obligatory parsing accounts (e.g., Taft & Forster, 1975, 1976), because those fail to explain the absence of morphological effects under other circumstances. For example, my results suggest that adults do not always rely on morphological decomposition. In particular, there was a lack of strong morphological effects for words that should be very common for adults (as compared to children) in studies 2 and 3. In study 2, the adult readers were not affected by the presentation format, regardless whether it drew attention to syllable or morpheme units. In study 3, a whole-word route seemed to determine word recognition, at least in the case of rather familiar compounds. This implies that familiarity affects the extent of decomposition vs. whole-word processing. Moreover, in studies 1 and 2 morphological effects were particularly pronounced for pseudowords. Taken together, these results suggest that morphology is equally, if not even more important for the reading unfamiliar real words, be those pseudowords or unfamiliar real words. This is in line with dual route models incorporating both a whole-word and a decompositional strategy, like the AAM (Caramazza, Laudanna, & Romani, 1988) or the MRM (Schreuder & Baayen, 1995), assuming that the contribution of the two routes depends on word properties such as familiarity or frequency. The frequency effects of whole-words and constituents in study 3, however, indicate that the two routes operate interactively. Neither the one-route-only mechanism, which the AAM (Caramazza, Laudanna, & Romani, 1988) supposes, nor the horse-race fashion, which the MRM (Schreuder & Baayen, 1995) presumes, can account for this, because neither assumes effects of both routes to be reflected in response times. Interactive models seem much more adequate, because they posit that the activation of morpheme constituents adds activation to the whole-word and vice versa (Andrews, Miller, & Rayner, 2004) or that morphemes and whole-words are used as probabilistic sources of information (Kuperman, Bertram, & Baayen, 2008; Libben, 2006). Due to the architecture of the adjusted multiple-route model presented above, this model can also account for the observed interactive effects of whole-words and constituents. The morphologically complex input is parsed into constituent morphemes in the fine-grained route and the constituents are fed forward separately, activating corresponding orthographic representations. At the same time, the coarse-grained route activates the corresponding orthographic representation of the whole-word. In the orthographic lexicon, the whole-word and constituent representations can thus boost each other's activation as far as the corresponding representations are available. Additionally, top-down activation from semantics can occur. Thus this model also incorporates the distinction between an early morpho-orthographic and a later morpho-semantic mechanism, in the same way hybrid models do (e.g., Diependale et al., 2009). The early morpho-orthographic priming effects on top of embedded stem priming observed for adults in study 4 further support the proposed model.

For models of skilled morphological processing, the findings from this dissertation and the adjusted multiple-route model thus imply that decomposition indeed has its origin in processes in reading acquisition. Once the decompositional route is set up to facilitate reading of newly encountered complex words in development, it becomes fine-tuned and can support word recognition in skilled reading. The support from decomposition in skilled readers (1) acts in parallel to whole-word processing, (2) operates sub-lexically, (3) relies on stem detection, (4) interacts with whole-word processing, (5) is critical for the processing of unfamiliar words. In the case of German, which was the language under study in this dissertation, the findings emphasize that the specific linguistic characteristics of the German morphological system might give a special status to sub-lexical decomposition via the stem. This supports prior evidence from studies on German inflections (Drews & Zwitserlood, 1995; Smolka, Zwitserlood, & Rösler, 2007) and derivations (Smolka et al., 2009; Smolka et al., 2015; Smolka, Preller, & Eulitz, 2014).

6.3 Future prospects

The research conducted and discussed in this dissertation advances our understanding of when and how children use morphology in learning to read in German. My findings support a refined model of morphological decomposition in reading development, which can serve as a framework for future studies in this domain of research. Below, I outline a few issues that have not been fully addressed in the present work and require further research.

First of all, how exactly children establish mappings from orthography to semantics needs to be further investigated. My findings support the idea that the formation of morpheme representations occurs via the detection of form-meaning regularities, rather than the chunking of letter sequences based on bigram and trigram frequencies. It is, however, possible that such chunking-mechanisms additionally support the formation of affix representations. Masked priming studies with French and English-speaking children (Beyersmann, Castles, & Coltheart, 2012; Beyersmann, Grainger et al., 2015) suggest that there is a developmental transition from semantics-based to orthography-based representations. In this sense, the initial detection of stems might proceed through form-meaning overlap, but might be "fine-tuned" by chunking of affixes that leads to affix-stripping. The priming effects from primes with non-suffix ending in study 4 can not only be interpreted by embedded stem detection, but it can also be argued that children's suffix-representations are not precise yet, such that they strip any ending. In order to further test the idea of a chunking mechanism, it is important to more specifically test on what ground morphological decomposition takes place. While this dissertation was primarily oriented toward investigating the detection of form-meaning regularities, the other two more structural possibilities to achieve morphological segmentation – infrequent bigrams across morpheme boundaries and frequent bigrams/trigrams at word beginnings/endings – need to be directly tested against the first. Further, the assumptions I made in this thesis about the detection of form-meaning regularities need to be challenged. For this, it will be helpful to inquire more on the role of semantics in child reading. In particular, studying graded effects of semantic transparency on the development of morphological processing can provide interesting insights, as previous studies with adults suggest (e.g., Feldman & Soltano, 1999; Gonnerman, Seidenberg, & Andersen, 2007; Marelli, Amenta, & Crepaldi, 2015; Rastle, Davis, Marslen-Wilson, & Tyler, 2000). Semantics may not only influence the decomposition process, but should also be reflected in the ease with which form-meaning correspondences are learned (cf. Rueckl & Raveh, 1999). Future studies will need to explicitly address how children's representations of morphology in semantics develop and how this influences orthographic representations. Studying the structure and development of children's semantic networks and the relation to their orthographic networks may help us to better understand the influence of vocabulary knowledge on the formation of morphological representations. Longitudinal studies would be ideal for this.

Another issue for future inquiry pertains to processing differences between prefixes and suffixes. In study 1, some important differences were observed, which were attributed to a left-to-right bias here. It is necessary to test whether this bias is a valid explanation. For example, it is possible that prefixes and suffixes are inherently different. In German, in particular, prefixes have certain characteristics that suffixes do not have (e.g. the distinction between prefix verbs and particle verbs and the existence of some prefixes as free morphemes with deviating meaning, which compromises their form-meaning regularity). Hence, considering prefixes and suffixes under the collective term "affixes" likely falls short, because the two types of affixes might be learned and processed differently (see also Smolka et al., 2007).

Moreover, it is worth noting that it is not entirely clear what the mechanisms of morphological decomposition in word recognition are. This dissertation has presented evidence and advocated for both stems and affixes as access units that are represented in the orthographic lexicon. It cannot be ruled out, however, that affixes are instead used as *cues* for word status, that is they do not contribute to the identification of the word, but are merely a hint for participants in a lexical decision task that the presented item likely has word status. This would indeed also be reconcilable with the suffix and prefix effects that were obtained for pseudowords in study 1 and 2. To address this question it would be necessary to directly conduct the same experiments from studies 1 and 2 as naming tasks. If affixes were merely cues for lexical status, the effects seen in lexical decision might not pertain to naming, where no decision about lexicality is required. Such a comparison, however, would only present a first step in disentangling this issue, because LDT and naming diverge in more aspects than the decision stage. For example, lack of affix effects in naming would not necessarily imply that affixes are lexical cues instead of access units, because orthographic access is not mandatory to accomplish reading aloud in a transparent orthography: it can be achieved by letter-by-letter decoding based on GPC rules instead. This could obscure any morphological effects, regardless of the status of affixes as access units or cues for lexicality.

Also, this dissertation has expanded the body of research on morphology in reading using the lexical decision task. Employing LDT was well justified, because it was hitherto underrepresented as a methodology with children, but prevalent in adult research, thus making the comparison of effects between children and adults difficult. Furthermore, LD has been shown to tap more into the direct orthography-semantics pathway than naming, in which most models of reading would place the locus of morphological effects (e.g., Plaut & Gonnerman, 2000; Rueckl & Raveh, 1999). Besides the decision stage that is required in LDT, but not in naming, reading aloud and reading silently can (but must not) differ in the decoding mechanisms involved. Reading aloud requires generating a phonological output code, which – as noted earlier – can be achieved in transparent orthographies also by using GPC rules. The sequential left-to-right nature of GPC-based decoding would even be analogous to the sequential nature of the oral output, which might make readers more prone to use such a letter-by-letter strategy. For LD, activation of an orthographic representation is more crucial (although not necessary), which might make readers more prone to avoid the "detour" via phonology if they are able to do so. Consequently, the use of morphology might differ between tasks. An essential next step is therefore the direct comparison of LDT and naming. Also, research needs to be extended to involve new tasks that are even more closely associated with certain domains, e.g. semantic categorization tasks to tap into semantic aspects of morphological processing or letter search tasks to tap into orthographic aspects of morphological processing. Evidence from a variety of different tasks will likely inform models and advance theoretical accounts in this domain.

Finally, one of the central issues that has been brought up repeatedly throughout this dissertation concerns language-specific differences. It has become clear that linguistic characteristics are important factors that need to be considered in the investigation of the development and use of morphemes as reading units. This will allow us to identify, which aspects of morphological processing are universal and which ones are language-specific. The four studies presented here were able to show that many effects that were previously studied in English, French, and Italian also generalize to German. They also revealed that processing mechanisms in German might be especially tuned to decomposition based on the stem to meet the demands of the productive morphology (cf. Smolka et al., 2009). The present dissertation only provides a comprehensive picture for this one language, which can now only be indirectly compared to the inconsistent evidence that exists in other languages, such as English, Italian, and French. Although it seems like differences are subtler than can be predicted from linguistic differences, the evidence discussed implies that a more targeted test with direct cross-language comparisons would prove especially fruitful in the future. Specific cross-linguistic comparisons will be needed to solve whether the stem preference observed in German is truly language-specific or generalizes to other languages as well. Direct comparisons of English and Hebrew, for example, have shown that reading in the two languages involves systems that differ in their organization and that the morphological richness of Hebrew manifests in greater behavioral effects of morphology (Frost, 2009). To make informative comparisons, however, it needs to be more precisely established how 'rich' and 'impoverished' morphology can be measured: by number of morphemes in a language, morphological productivity, morphological systematicity or other characteristics (cf. Rueckl, 2000; Smolka et al. 2009)?

While empirical evidence on morphological processing in adults and children is enormously growing and leading to new theoretical models, computational implementation and testing is surprisingly rare. Ideally, extensive investigation of morphological processing in reading development is followed not only by theoretical models, but also by the implementation of computational models. A few first attempts have been made with distributed connectionist models (Plaut &

Gonnerman, 2000; Rueckl & Raveh, 1999; Seidenberg & Gonnerman, 2000) that only implicitly entail morphology as overlapping patterns of activation in the orthography-semantics pathway. Distributed connectionist models have received little attention as theoretical models in the present dissertation, albeit they cannot be disqualified on the basis of the present studies. This dissertation has concentrated more on more a localist perspective that explicitly represents morphology. It would be desirable to implement different variants of computational models to compare their performance depending on which assumptions are made for morphological decomposition processes. For example, in a localist interactive-activation model, an implementation of a stem detection mechanism could be compared to an affix-stripping mechanism. In the context of development, it would be particularly interesting to see how a model can learn morpheme representations, either via top-down feedback from semantics or via feedback from the phonological lexicon, possibly mediated by representation of syllabic units, or via exploitation of statistical regularities in orthography (e.g., bigram frequencies). The existing distributed connectionist work could also be expanded with regard to reading development in a natural language. At best, attempts would also include the incorporation of a phonology-based reading route to capture developmental progress. In order to do this, however, some technical challenges need to be overcome, such as how phonological representations for multisyllabic words can be best integrated especially with regard to how morphological structure influences syllable boundaries and stress assignment. Solutions are also needed with respect to how morphological relationships can be captured at a semantic level. Recently, some important steps have been made in this direction by the FRACSS (Functional Representation of Affixes in Compositional Semantic Space) approach by Marelli and Baroni (2015), which simulates morphological representations and operations within the semantic system. The implementation and comparison of different computational models – even using such opposing approaches such as localist and distributed models promises to further enhance our understanding of how the reading system works.

6.4 Final conclusions

The present dissertation investigated how children learn to read complex words. The goal was to examine when and how children make use of morphemes in reading complex words in German and whether processing mechanisms of developing readers are like those observed in adults. This was meant to serve a double purpose: first, to better understand reading development; and second to inform models of morphological processing. The findings of this dissertation were used to devise a refined model of morphology in reading development, which also gives novel insights into the architecture of skilled morphological processing. The proposed refined model assumes that (1) morphological decomposition originates during reading acquisition, (2) orthographic representations of stems and affixes are established during reading development based on the detection of form-meaning correspondences, (3) these representations are activated via stem detection, and (4) and can be used in word recognition interactively with whole-word representations. The refined model provides a framework that will be useful in generating new lines of research to better understand the underlying cognitive mechanisms and structures that map visual symbols onto meaning.

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Appendix

Table A2.1 Exact t- and p-values of the compound, prefix, and suffix effects for words for each age group from study 1.

Age group	Grade 2		Grade 3		Grade 4		Grade 6		Adults
	beg	end	beg	end	beg	end	beg	end	
					Response Times				
Compound effect	*t*=-0.44 *p*=.66	*t*=3.3 *p*<.001	*t*=3.3 *p*<.001	*t*=2.74 *p*=.006	*t*=4.8 *p*<.001	*t*=3.98 *p*<.001	*t*=3.4 *p*<.001	*t*=3.13 *p*=.002	*t*=2.17 *p*=.03
Prefix effect	*t*=-0.63 *p*=.53	*t*=0.9 *p*=.36	*t*=-0.02 *p*=.98	*t*=0.84 *p*=.40	*t*=1.10 *p*=.26	*t*=2.52 *p*=.01	*t*=2.90 *p*=.004	*t*=2.00 *p*=.04	*t*=2.76 *p*=.006
Suffix effect	*t*=-0.74 *p*=.46	*t*=0.78 *p*=.44	*t*=1.23 *p*=.22	*t*=2.35 *p*=.02	*t*=2.09 *p*=.04	*t*=2.86 *p*=.004	*t*=3.51 *p*<.001	*t*=2.51 *p*=.01	*t*=2.09 *p*=.04
					+ 1SD Vocabulary Knowledge				
Compound effect	*t*=1.10 *p*=.24	*t*=4.34 *p*<.001	*t*=5.59 *p*<.001	*t*=4.37 *p*<.001	*t*=7.79 *p*<.001	*t*=4.22 *p*<.001	*t*=4.85 *p*<.001	*t*=3.34 *p*<.001	*t*=2.73 *p*=.006
Prefix effect	*t*=1.32*p* =.19	*t*=2.29*p* =.02	*t*=4.68 *p*<.001	*t*=3.30 *p*<.001	*t*=3.08*p* =002	*t*=2.63 *p*=.009	*t*=2.56 *p*<.009	*t*=1.52 *p*=.13	*t*=2.03 *p*=.04
Suffix effect	*t*=-0.15 *p*=.88	*t*=2.85 *p*=.004	*t*=5.32 *p*<.001	*t*=3.72 *p*<.001	*t*=3.46 *p*<.001	*t*=2.68 *p*=.007	*t*=4.20 *p*<.001	*t*=2.94 *p*=.003	*t*=2.08*p* =.04
					- 1SD Vocabulary Knowledge				
Compound effect	*t*=-1.15 *p*=.25	*t*=1.1 *p*=.27	*t*=0.91 *p*=.36	*t*=-0.39 *p*=.69	*t*=1.42 *p*=.16	*t*=1.92 *p*=.05	*t*=1.47 *p*=.14	*t*=1.81 *p*=.07	*t*=1.25 *p*=.21
Prefix effect	*t*=-3.08 *p*=.002	*t*=-2.59 *p*=.009	*t*=-2.53 *p*=.01	*t*=-1.28 *p*=.20	*t*=-2.06 *p*=.04	*t*=-1.22 *p*=.22	*t*=-2.09 *p*=.04	*t*=-0.71 *p*=.48	*t*=3.21 *p*=.001
Suffix effect	*t*=0.76 *p*=.45	*t*=-2.38 *p*=.02	*t*=-2.09 *p*=.04	*t*=-0.47 *p*=.64	*t*=0.63 *p*=.53	*t*=1.74 *p*=.08	*t*=1.92 *p*=.05	*t*=0.92 *p*=.36	*t*=1.61 *p*=.11
					Error Rates				
Compound effect	*t*=-0.63 *p*=.53	*t*=3.05 *p*=.02,	*t*=2.28 *p*=.02	*t*=3.45 *p*<.001	*t*=2.88 *p*=.004	*t*=3.66 *p*<.001	*t*=3.06 *p*=.002	*t*=3.21 *p*=.001	*t*=3.36 *p*<.001
Prefix effect	*t*=1.20 *p*=.23	*t*=0.76 *p*=.45,	*t*=1.84 *p*=.07	*t*=2.14 *p*=.03	*t*=1.80 *p*=.07	*t*=2.87 *p*=.004	*t*=3.25 *p*=.001	*t*=3.51 *p*<.001	*t*=4.38 *p*<.001
Suffix effect	*t*=0.19 *p*=.85	*t*=0.76 *p*=.45	*t*=-0.08 *p*=.93	*t*=1.27 *p*=.21	*t*=1.98 *p*=.04	*t*=1.64 *p*=.10	*t*=1.08 *p*=.28	*t*=2.43 *p*<.02	*t*=3.18 *p*=.001

Table A2.2 Exact t- and p-values of the compound, prefix, and suffix effects for pseudowords for each age group from study 1.

Age group	Grade 2		Grade 3		Grade 4		Grade 6		Adults
	beg	end	beg	end	beg	end	beg	end	
Response Times									
Compound	$t=-2.06$	$t=-3.70$	$t=-4.77$	$t=-2.11$	$t=-2.94$	$t=-4.63$	$t=-4.39$	$t=-3.48$	$t=-3.09$
effect	$p=.04$	$p<.001$	$p<.001$	$p=.03$	$p=.003$	$p<.001$	$p<.001$	$p<.001$	$p=.002$
Prefix	$t=1.59$	$t=-1.32$	$t=-1.37$	$t=-3.98$	$t=-2.33$	$t=-5.46$	$t=-3.65$	$t=-4.12$	$t=-3.93$
effect	$p=.11$	$p=.19$	$p=.17$	$p<.001$	$p=.03$	$p<.001$	$p<.001$	$p<.001$	$p<.001$
Suffix	$t=1.84$	$t=-0.37$	$t=0.9$	$t=0.70$	$t=-1.30$	$t=-1.16$	$t=0.55$	$t=-0.57$	$t=-0.86$
effect	$p=.07$	$p=.71$	$p=.37$	$p=.48$	$p=.20$	$p=.25$	$p=.58$	$p=.57$	$p=.39$
+ 1SD Vocabulary Knowledge									
Compound	$t=-3.49$	$t=-3.93$	$t=-2.23$	$t=-1.67$	$t=-0.61$	$t=-2.91$	$t=0.40$	$t=-2.39$	$t=-2.38$
effect	$p<.001$	$p<.001$	$p=.03$	$p=.09$	$p=.54$	$p=.004$	$p=.69$	$p=.02$	$p=.02$
Prefix	$t=0.44$	$t=-2.44$	$t=-1.83$	$t=-4.11$	$t=-0.54$	$t=-4.51$	$t=0.10$	$t=-2.59$	$t=-3.69$
effect	$p=.66$	$p=.01$	$p=.07$	$p<.001$	$p=.59$	$p<.001$	$p=.92$	$p=.01$	$p<.001$
Suffix	$t=0.73$	$t=0.69$	$t=1.36p$	$t=2.01$	$t=2.25$	$t=0.94$	$t=2.15$	$t=1.16$	$t=-0.08$
effect	$p=.47$	$p=.49$	$=.17$	$p=.04$	$p=.02$	$p=.35$	$p=.03$	$p=.25$	$p=.94$
- 1SD Vocabulary Knowledge									
Compound	$t=-1.05$	$t=-2.14$	$t=-4.95$	$t=-1.89$	$t=-3.53$	$t=-4.62$	$t=-5.98$	$t=-3.35$	$t=-2.90$
effect	$p=.29$	$p=.03$	$p<.001$	$p=.07$	$p<.001$	$p<.001$	$p<.001$	$p<.001$	$p=.004$
Prefix	$t=1.67$	$t=0.72$	$t=-1.03$	$t=-2.16$	$t=-2.74$	$t=-4.33$	$t=-5.23$	$t=-4.60$	$t=-3.18$
effect	$p=.09$	$p=.47$	$p=.30$	$p=.03$	$p=.006$	$p<.001$	$p<.001$	$p<.001$	$p=.001$
Suffix	$t=1.83$	$t=0.19$	$t=0.02$	$t=-1.28$	$t=-3.20$	$t=-3.69$	$t=0.91$	$t=-2.64$	$t=-1.33$
effect	$p=.07$	$p=.85$	$p=.99$	$p=.20$	$p=.001$	$p<.001$	$p=.36$	$p=.008$	$p=.19$
Error Rates									
Compound effect	$t=-5.70$, $p<.001$								
Prefix effect	$t=-2.00$, $p=.04$								
Suffix effect	$t=1.80$, $p=.07$								

Table A3.1 Stimuli used in the experiment in study 2.

Monomorphemic		Multimorphemic	
Syllable-congruent	Syllable-incongruent	Syllable-congruent	Syllable-incongruent
Words			
BAL:KON	BALK:ON	AH:NUNG	AHN:UNG
DIREK:TOR	DIREKT:OR	AL:TER	ALT:ER
FA:SCHING	FASCH:ING	ARBEI:TER	ARBEIT:ER
GAR:TEN	GART:EN	BÄ:RIN	BÄR:IN
HA:FEN	HAF:EN	DIE:BIN	DIEB:IN
KAPI:TEL	KAPIT:EL	ENKE:LIN	ENKEL:IN
KOM:PASS	KOMP:ASS	FAH:RER	FAHR:ER
KOM:POTT	KOMP:OTT	FLIE:GER	FLIEG:ER
MARZI:PAN	MARZIP:AN	FREUN:DIN	FREUND:IN
MO:TOR	MOT:OR	HEI:ZUNG	HEIZ:UNG
PORZEL:LAN	PORZELL:AN	HEL:DIN	HELD:IN
RE:GAL	REG:AL	KELLNE:RIN	KELLNER:IN
RE:KORD	REK:ORD	KLEI:DUNG	KLEID:UNG
RE:ZEPT	REZ:EPT	KÖNI:GIN	KÖNIG:IN
SCHAU:KEL	SCHAUK:EL	KRIE:GER	KRIEG:ER
SCHOKO:LADE	SCHOKOL:ADE	LAN:DUNG	LAND:UNG
SPIE:GEL	SPIEG:EL	MA:LER	MAL:ER
SPI:NAT	SPIN:AT	PILO:TIN	PILOT:IN
STU:DENT	STUD:ENT	PLA:NUNG	PLAN:UNG
TA:LENT	TAL:ENT	SIE:GER	SIEG:ER
TELE:FON	TELEF:ON	SPIE:LER	SPIEL:ER
TRAK:TOR	TRAKT:OR	WANDE:RUNG	WANDER:UNG
VUL:KAN	VULK:AN	WOH:NUNG	WOHN:UNG
ZIR:KUS	ZIRK:US	ZAH:LUNG	ZAHL:UNG
Pseudowords			
AL:KORD	ALK:ORD	AUBO:RIN	AUBOR:IN
BE:GEN	BEG:EN	EDE:LIN	EDEL:IN
DAU:SEN	DAUS:EN	FEIL:DIN	FEILD:IN
DOS:TOR	DOST:OR	HEI:GUNG	HEIG:UNG
EL:KASS	ELK:ASS	HEL:BER	HELB:ER

FA:MOTT	FAM:OTT	JU:GER	JUG:ER
FRAL:MENT	FRALM:ENT	LAH:RER	LAHR:ER
KA:DON	KAD:ON	LEIRE:RIN	LEIRER:IN
KON:BERT	KONB:ERT	LU:WIN	LUW:IN
KRI:KUS	KRIK:US	PFLO:GER	PFLOG:ER
LEMI:KON	LEMIK:ON	PINA:TIN	PINAT:IN
MARKE:LADE	MARKEL:ADE	RACH:TER	RACHT:ER
MAR:ZOR	MARZ:OR	REU:FUNG	REUF:UNG
MONA:TOR	MONAT:OR	ROD:NER	RODN:ER
PE:KAL	PEK:AL	RUL:DUNG	RULD:UNG
PELI:DAN	PELID:AN	SCHIL:TUNG	SCHILT:UNG
PRI:GAT	PRIG:AT	SCHOLDE:RUNG	SCHOLDER:UNG
PUL:DING	PULD:ING	SCHREU:BER	SCHREUB:ER
SCHAU:BEL	SCHAUB:EL	SONDA:TIN	SONDAT:IN
STIE:PEL	STIEP:EL	TE:GUNG	TEG:UNG
TANIS:MAN	TANISM:AN	TEI:NUNG	TEIN:UNG
TUR:FAN	TURF:AN	WARDE:RER	WARDER:ER
ZE:PENT	ZEP:ENT	WUR:TIN	WURT:IN
ZWIE:GEL	ZWIEG:EL	ZIE:DUNG	ZIED:UNG

Table A5.1 Experimental primes and word targets used in the experiment in study 4 (excluding filler items and nonword targets)

Suffixed word prime	Suffixed nonword prime	Nonsuffixed nonword prime	Unrelated word prime	Word target
stückchen	stücklos	stückau	trepplein	STÜCK
kleidchen	kleidtum	kleidekt	träumerei	KLEID
pferdchen	pferdei	pferdekt	spieglein	PFERD
steinchen	steintum	steinpern	wolkenlos	STEIN
spielchen	spiellein	spielnauf	herzogtum	SPIEL
reichtum	reichlein	reichekt	birnlein	REICH
heiligtum	heiliglos	heiligarf	enkelchen	HEILIG
wachstum	wachslein	wachspern	freudlos	WACHSEN
irrtum	irrchen	irrnauf	endlos	IRREN
eigentum	eigenlos	eigenarf	brauerei	EIGEN
tischlein	tischtum	tischnauf	metzgerei	TISCH
sternlein	sternei	sternarf	kaisertum	STERN
herzlein	herztum	herzekt	kraftlos	HERZ
kindlein	kindei	kindpern	teilchen	KIND
hemdlein	hemdei	hemdnauf	trostlos	HEMD
bäckerei	bäckerchen	bäckerau	tantchen	BÄCKER
zauberei	zauberlein	zauberekt	altertum	ZAUBER
fischerei	fischerlos	fischerau	stimmchen	FISCHER
gärtnerei	gärtnerlos	gärtnerarf	brauchtum	GÄRTNER
prügelei	prügelchen	prügelarf	bildchen	PRÜGELN
hilflos	hilfchen	hilfpern	esserei	HILFE
lautlos	lautchen	lautpern	hexerei	LAUT
arbeitslos	arbeitei	arbeitau	menschlein	ARBEIT
sprachlos	sprachlein	sprachau	besitztum	SPRACHE
spurlos	spurtum	spurnauf	rehlein	SPUR
wohnung	wohnheit	wohnucht	fäulnis	WOHNEN
hoffnung	hoffheit	hoffmen	rundlich	HOFFEN
landung	landig	landucht	wirrnis	LANDEN
impfung	impflich	impfucht	torheit	IMPFEN
drehung	drehlich	drehmen	staubig	DREHEN
grünlich	grünig	grünatz	sammlung	GRÜN
merklich	merknis	merkpfen	erlebnis	MERKEN
glücklich	glückig	glückatz	kribbelig	GLÜCK

ärgerlich	ärgerung	ärgeram	schmutzig	ÄRGERN
sportlich	sportung	sportam	gleichnis	SPORT
rutschig	rutschheit	rutschmen	festlich	RUTSCHEN
schuldig	schuldnis	schulducht	wahrheit	SCHULD
dreckig	drecklich	dreckam	hoheit	DRECK
hungrig	hungrung	hungratz	neuheit	HUNGER
frostig	frostnis	frostam	süßlich	FROST
geheimnis	geheimig	geheimatz	erfindung	GEHEIM
finsternis	finsterung	finstermen	gesundheit	FINSTER
hindernis	hinderheit	hinderam	friedlich	HINDERN
wildnis	wildlich	wildpfen	prüfung	WILD
erlaubnis	erlaubheit	erlaubucht	wanderung	ERLAUBEN
schönheit	schönlich	schönpfen	neugierig	SCHÖN
freiheit	freiung	freipfen	bewegung	FREI
dunkelheit	dunkelnis	dunkelmen	vorsichtig	DUNKEL
krankheit	kranknis	krankpfen	elterlich	KRANK
dummheit	dummig	dummatz	kenntnis	DUMM

Erklärung

Hiermit versichere ich, dass die vorliegende Arbeit meine eigene Forschung präsentiert und ich die Arbeit selbständig und ohne Verwendung anderer als der angegebenen Hilfsmittel erstellt und verfasst haben. Die vorliegende Arbeit hat sich in keinem weiteren Promotionsverfahrens befunden. Kapitel 2-5 dieser Dissertationsschrift wurden in marginal modifizierten Versionen in internationalen Fachzeitschriften veröffentlicht bzw. eingereicht.

Kapitel 2 befindet sich im Druck beim *Journal of Experimental Psychology: Learning, Memory, & Cognition*

Hasenäcker, J., Schröter, P., & Schroder, S. (In Press). Investigating Developmental Trajectories of Morphemes as reading Units in German. *Journal of Experimental Psychology: Learning, Memory, & Cognition.*

Kapitel 3 ist veröffentlicht bei *Applied Psycholinguistics*

Hasenäcker, J., & Schroder, S. (2016). Syllables and morphemes in German reading development: Evidence from second graders, fourth graders, and adults. Applied Psycholinguistics, 1–21. doi:10.1017/s0142716416000412

Kapitel 4 befindet sich in Revision

Kapitel 5 ist veröffentlicht bei *Frontiers in Psychology*

Hasenäcker, J., Beyersmann, E., & Schroder, S. (2016). Masked Morphological Priming in German-Speaking Adults and Children: Evidence from Response Time Distributions. *Frontiers in Psychology, 7*, 1-11, doi:10.3389/fpsyg.2016.00929

Die angeführten Ko-Autoren können bestätigen, dass ich für die Planung, Durchführung, und Auswertung der Studien sowie das Verfassen der entsprechenden Kapitel allein- oder hauptverantwortlich war.

Berlin, den 29.08.2016

Curriculum Vitae

Der Lebenslauf ist in der Onlineversion

aus Gründen des Datenschutzes nicht enthalten.