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THE ROLE OF EMBEDDED WORDS AND MORPHEMES IN READING

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This chapter describes a theoretical framework of complex word reading, as well as a selective empirical review of the morphological processing and visual word recognition literature. We first describe the theoretical foundations of the model and a number of key findings that motivated this approach. The chapter then outlines the backstory by providing a review of the empirical evidence including two lines of reading research. One line of research centres around the investigation of complex (*farmer*) and pseudo-complex words (*corner*) and speaks in favour of a fast-acting segmentation mechanism that decomposes (pseudo)complex words into morphemic subunits (*farm + er; corn + er*) on the basis of superficial morphological structure. The other line of research focuses on the examination of complex nonwords (*farmity*) and provides evidence for a non-morphological mechanism of embedded word activation. Finally, we draw conclusions and outline directions for future research.

The Word and Affix Model of Complex Word Reading

Since the seminal work of Taft and Forster (1975), affixes were thought to be the key to morphological processing (see Rastle & Davis, 2008 for a review), with the idea being that affixes are rapidly "stripped off," which then in turn allows for the isolation and identification of the stem morpheme.[1] Although for many years affix-stripping has provided an influential account for pseudo-morphological segmentation effects (e.g., Aronoff et al., 2016; Kingma, 2013; Longtin & Meunier, 2005; Longtin et al., 2003; Rastle & Davis, 2008; Rastle et al. 2004; Taft, 1981; Taft et al., 1986), the account faces a serious problem: the stripping off of the affix often leaves a word that does not function as a stem. This "garden path" occurs with pseudo-affixed words like "relate" and "corner," which are relatively frequent in languages such as English and French (Baayen, 1993; Colé et al., 1986). Moreover, recent findings have shown that embedded stems can be activated even if accompanied by a non-morphological unit

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(e.g., Beyersmann, Casalis et al., 2015; Morris et al., 2011) and that stems appear to represent prominent units in the reading system (Grainger & Beyersmann, 2017), which are easily accessed and acquired early in children's reading development (Beyersmann, Grainger, et al., 2019). This empirical turn has forced a re-evaluation of the affix-stripping approach (i.e., the sequential process of removing the affix and then isolating the stem morpheme). The Word and Affix model implements a similar process, morpho-orthographic full decomposition, but with the parallel operation of a non-morphological process of edge-aligned embedded word activation combined with the morphological process of affix activation. The Word and Affix model, to be described here, is an updated version of the initial Grainger and Beyersmann model (Grainger & Beyersmann, 2017), including a modified and more detailed description of the mechanisms involved in the recognition of complex words.[2] Several recent findings have led us to reconsider certain aspects of our original model. We therefore note that although the updated model is similar to its predecessor, it is not identical.

The Word and Affix model builds on the idea that stems and affixes have a different status in the reading system. As opposed to affixes, the majority of stems are free-standing words that do not require setting up specialized morphological representations. However, a small subset of stems do not exist as free-standing words (i.e., "bound stems" such as *flate* in *deflate* and *inflate*). Given the evidence that bound stems contribute to morphological processing (e.g., Solomyak & Marantz, 2009; Taft, 1994, 2003; Taft & Forster, 1975), we would argue that this arises from the combination of affix activation and the connectivity created by the semantic representations that are shared by the members of the morphological family of bound stems (e.g., *deflate* meaning the opposite of *inflate*).[3]

Under normal reading conditions, affix processing always operates in the presence of a stem, whereas (embedded) word processing does not require the presence of an affix. This is likely one of the reasons why young children quickly learn to identify embedded stems (which are typically also encountered as free-standing words, with the exception of bound stems) early in their reading development (Beyersmann, Grainger et al., 2019; Nation & Cocksey, 2009), whereas the acquisition of a fast-acting affix-processing mechanism takes more time to develop (Beyersmann et al., 2012; Dawson et al., 2018; Schiff et al., 2012). Moreover, while stems can occur in both initial (*pack* in *packing*) and final (*pack* in *unpack*) positions of a letter string and readers are equally good at picking up on embedded stem units at both "edges" of the letter string (e.g., Beyersmann, Cavalli et al., 2016; Crepaldi et al., 2013; Duñabeitia et al., 2009; Heathcote et al., 2018), affixes have clear positional constraints (e.g., Carden, Barreyro, Segui, & Jaichenco, 2019; Crepaldi et al., 2016; Crepaldi et al., 2010; Liu et al., 2014). Therefore, affix processing requires additional constraints that prevent the reading system from activating affixes in the wrong position (e.g., *er* in *error*). Finally, visual word recognition studies have revealed evidence for two distinct stem- and affix-processing mechanisms (see "Morphological Processing" and "Embedded Word Processing" below), thus providing further evidence for the distinct roles of stems[4] and affixes in reading.

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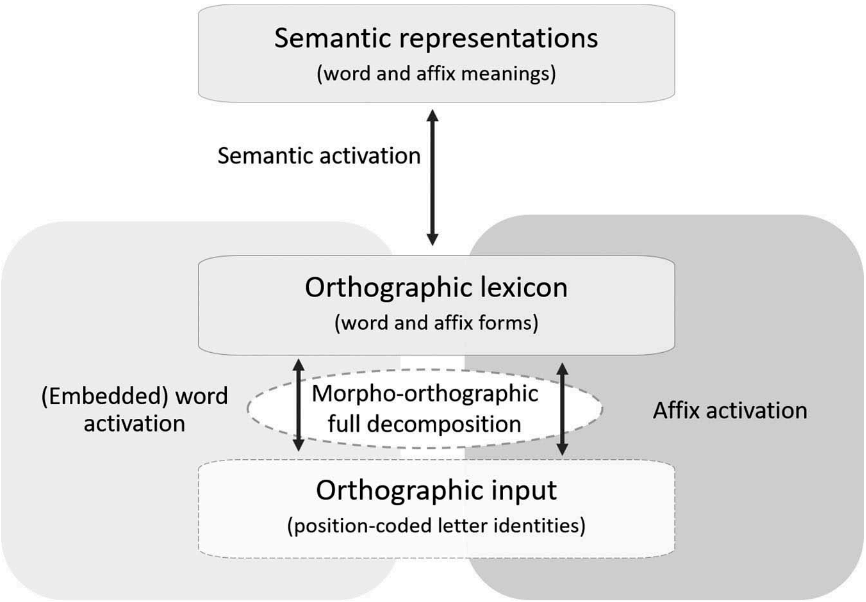

FIGURE 3.1. The "word and affix" model of complex word reading. Orthographic input is mapped onto the orthographic lexicon based on two mechanisms that operate in parallel: (embedded) word activation and affix activation. The principle of "morpho-orthographic full decomposition" operates in the links between the orthographic input (a string of letters) and the entities activated in the orthographic lexicon, by comparing the sum of the letters in the embedded word and the affix with the letters of the input. Representations within the orthographic lexicon are mapped onto a third layer of semantic representations. Connections between layers are bidirectional, thus allowing for bottom-up as well as top-down transfer of information between the three layers.

To account for the outlined differences between stems and affixes, the Word and Affix model implements two different mechanisms within a three-layered reading model (Figure 3.1). During the initial stage of word recognition, orthographic input is mapped onto the orthographic lexicon using two parallel mechanisms: (embedded) word activation (light-grey box, Figure 3.1) and affix activation (dark-grey box, Figure 3.1). The orthographic lexicon contains representations of all word and affix forms that a given reader is familiar with. The active units in the orthographic lexicon are then (i) subjected to a "morpho-orthographic full decomposition" check (dotted box, Figure 3.1), which operates in the links between the orthographic input and the orthographic lexicon; and (ii) mapped onto semantics. Given the bidirectional links between the three processing layers, information can flow both forward and backward. Units in the orthographic lexicon can benefit from semantic feedback if the active constituents are semantically compatible. Below we provide a detailed description of each of the model's features.

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Embedded Word Activation

Embedded word activation is a central ingredient of the model. This mechanism achieves a match between the letters of the orthographic input (*f-a-r-m-e-r*) and the orthographic lexicon, including not only those representations that provide an exact match with the entire input string (*farmer*), but also those that are embedded as an edge-aligned orthographic subset (e.g., the *farm* in *farmer*), thus leading to the simultaneous activation of whole words and embedded words (Kuperman et al., 2008; Kuperman et al., 2009). The activation of embedded words is an entirely non-morphological process that extends to words embedded in morphologically simple words (e.g., the *cash* in *cashew*) Embedded words also represent prominent units in the parafoveal processing of complex words (Hyönä et al., 2020). As a result, the orthographic input is mapped in parallel onto not just one single whole-word representation, but several such representations, including embedded words. Moreover, flexibility in letter-position coding (i.e., coarse-grained letter processing; Grainger & Ziegler, 2011) enables the activation of orthographically underspecified stems (e.g., *ador* in *adorable*; McCormick et al., 2008; McCormick et al., 2009) and orthographically similar words. Embedded word activation is influenced by several factors, including (embedded) word length (Beyersmann, Grainger et al. 2019), word frequency (Duñabeitia et al., 2007; Shoolman & Andrews, 2003), morphological family size (Beyersmann & Grainger, 2018), conditional affix probability (Grainger & Beyersmann, 2020), and edge-alignedness (Beyersmann et al. 2018; Grainger & Beyersmann, 2017). Here, we examine the role of each of these factors.[5]

Embedded Word Length

When the orthographic input contains several embedded words (e.g., *far* and *farm* in *farmer*), the model gives preference to the longer embedded unit (*farm*), which is typically the one that forms the morphemic stem of a suffixed word (Beyersmann, Grainger et al., 2019). The longer embedded unit generally also represents the morphemic stem of prefixed words (e.g., the stem of *prepaid* is *paid* and not *aid*). This idea finds empirical support in the results from a word-naming task (Experiment 2 in Beyersmann, Grainger et al., 2019) showing that participants were more likely to name the longer than the shorter embedded word. Embedded word length thus represents one of the factors that determine embedded word activation strength. The model captures this aspect in the connections between layers, with longer embedded words receiving more bottom-up support compared to shorter embedded units.

Embedded Word Frequency

The second factor determining embedded word activation strength is word frequency. The facilitatory effect of word frequency on word recognition—that is, high-frequency words are processed more efficiently than low-frequency words—

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has been widely replicated in the reading literature (for a review, see Brysbaert et al., 2017). Crucially, morphologically complex words with high-frequency constituents are recognized faster than words with low-frequency constituents (e.g., Duñabeitia et al., 2007; Hyönä & Pollatsek, 1998; Juhasz, Starr, Inhoff, & Placke, 2003; Shoolman & Andrews, 2003; Taft, 1979). The model captures the word frequency effect and the constituent frequency effect by implementing increasingly heavier weightings on the links between the orthographic input and the orthographic lexicon for items with increasing (embedded) word frequency.

Morphological Family Size

Morphological family size is defined as the number of morphologically complex words in which the word or its stem occurs as a constituent (Schreuder & Baayen, 1997), which can vary substantially across different words. Lexical decisions are faster and more accurate with words with a large compared to a small morphological family (e.g., Bertram, Baayen, & Schreuder, 2000; Boudelaa & Marslen-Wilson, 2011; De Jong, 2002; Juhasz & Berkowitz, 2011; Kuperman, Schreuder, Bertram, & Baayen, 2009; Moscoso del Prado Martín, Bertram, Häikiö, Schreuder, & Baayen, 2003), a finding that has been replicated across several languages (for a review, see Mulder, Dijkstra, Schreuder, & Baayen, 2014). Also, embedded word priming effects are modulated by the morphological family size of the embedded word (Beyersmann & Grainger, 2018), with greater priming for stems with larger families. The model captures this effect in the supra-lexical links between the orthographic lexicon and the semantic representation layer. Words from the same morphological family (e.g., *watery, waterless, waterproof*, etc.) are all connected via a higher-level semantic representation of the stem that they share (*water*). Each time a reader encounters a member of the morphological family (e.g., *watery*), it generates partial activity in the lexical representations of other family members (*waterless, waterproof*, etc.), which are all connected to the semantic representation of *water*. The strength of feedback from this supra-lexical representation of the morphological family to the lexical representations of the family members is determined by the size of the family, such that the larger the family the greater the support provided by the family to each of its members (see Giraudo & Grainger, 2001 for an earlier description of the same mechanisms).

Conditional Affix Probability

Conditional Affix Probability (CAP) represents the likelihood that a morphologically simple word will be accompanied by a (pseudo)affix within all words that contain that word at an edge-aligned position (Grainger & Beyersmann, 2020). CAP is highly correlated with the morphological family size measure, but instead of simply providing an estimate of the number of words that can be formed by adding an affix, it also takes into account the number of words that can be formed by adding a non-affix. CAP is calculated by dividing the cumulative frequency of all words that can be formed by adding a derivational affix (cumulative derived word frequency—CDF) by the

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cumulative frequency of all words that can be formed by adding a derivational affix (CDF) or a non-affix (cumulative morphologically simple word frequency—CSF): CAP = CDF/(CDF + CSF). Masked priming results from suffixed words[6] show that non-suffixed word priming is significantly modulated by CAP, where embedded words with high CAP produced more priming than those with low CAP (Grainger & Beyersmann, 2020). This modulating effect is not seen with pseudo-suffixed words, suggesting that the presence of a suffix facilitates embedded word activation independently of CAP. This provides important evidence for the complex interplay between stems and affixes, as described in more detail under "Lexical Inhibition" below.

Edge-Alignedness

The model further predicts that priority is given to words embedded at the "edges" of the letter string, based on the idea that the spaces on each side of the letter string act as anchor points for the encoding of letter position (Fischer-Baum et al., 2011). This prediction was tested in a masked priming study by Beyersmann et al. (2018). Significant priming effects were found for edge-aligned embedded constituents (*pimebook-BOOK*), but not for mid-embedded (*pibookme-BOOK*) or outer-embedded constituents (*bopimeok-BOOK*), suggesting that edge-alignedness is a key factor determining the activation of embedded words. Moreover, studies investigating compound words consisting of two edge-aligned embedded constituents show that real compounds (*headache-HEAD*) and pseudo-compounds (*butterfly-BUTTER*) yield comparable priming effects, with both being significantly stronger than priming in the non-compound (*sandwich-SAND*) control condition (Beyersmann, Grainger et al., 2019; Fiorentino & Fund-Reznicek, 2009). Within the Word and Affix model, the word *butterfly* will, for instance, activate the lexical representations of the word itself and the edge-aligned embedded words *butter* and *fly*. Non-compound primes like *sandwich* fail to produce priming, because they do not comply with the principle of morpho-orthographic full decomposition (see below).

Affix Activation

Parallel to the mechanism of (embedded) word activation, the model implements a second affix activation mechanism, which facilitates the mapping of the input letter string onto existing morpho-orthographic form representations in the orthographic lexicon (Lelonkiewicz et al., 2020). Morphological word formation tends to preserve the precise orthographic form of the affix, whereas the orthographic forms of embedded stems can be compromised (e.g., the affix *-able* remains intact in *adorable*; the affix *-er* remains intact in *runner*, etc.). Therefore, the activation of affixes in our model is based on precise letter position decoding (i.e., fine-grained processing; Grainger & Ziegler, 2011), which ensures that affixes are only identified when the letters of the input provide a precise orthographic match. The mechanism is dedicated to activating affix representations (e.g., *-ity*) independently of whether they are attached to a morphemic stem (*farm-ity*) or a non-stem (*falm-ity*), as long as they are edge-aligned and marked in the correct position (string final for suffixes, string initial for prefixes). The model captures this aspect by implementing affix representations that are tagged with position-specific "boundness" markers in the orthographic lexicon (e.g., *_ity, _er, dis_, un_*, etc.). Affix activation works on the basis of a purely structural, semantically independent analysis of the embedded letter sequences (e.g., Beyersmann, Ziegler, et al., 2016; Rastle et al., 2004). As such, even pseudo-complex words like *corner* activate the representation of the pseudo-suffix -*er*.

Morpho-Orthographic Full Decomposition

The initial affix and embedded word-mapping processes lead to the activation of a set of form representations within the orthographic lexicon, which are then subjected to a morpho-orthographic full decomposition check that is triggered whenever all three of the following conditions are satisfied: (1) an edge-aligned embedded word is activated; (2) this embedded word activation is accompanied either by the activation of an affix or another embedded word aligned to the opposite edge;[7] and (3) a word is activated that matches the length of the input. This process examines whether or not the orthographic input can be exhaustively decomposed into morphemes. It operates by comparing the sum of the letters in the embedded word and the affix with the complete set of input letters. If successful (e.g., in the case of C O R N + E R = C O R N E R), it counterbalances inhibition between the whole word *corner* and the embedded word *corn* and thus maintains the level of activation to the embedded word (see Figure 3.2, mid-panel).

Morpho-orthographic full decomposition is also successful if the activated embedded word is orthographically underspecified (e.g., *ador* in *adorable*). That is, the full decomposition check tolerates minor deviations such as the letter E in ADORE not being present at 5th position in the word ADORABLE. A boost in activation of the embedded pseudo-stem does not occur if the letter string is not exhaustively decomposable into morphemes (as in *cashew*), or if the sum of the embedded word and the affix fails to form a real word (*farm* + *ity* = *farmity*). The latter failure arises because the process of morpho-orthographic full decomposition requires a whole-word match to the complete input string in order to be initiated. However, the embedded word activation mechanism does function with nonwords, such that "farm" is activated upon presentation of *farmity* or *farmald*.

Lexical Inhibition

The challenge for the reading system is that, more often than not, the orthographic input will activate several lexical representations that are simultaneously active within the orthographic lexicon. For word recognition to be successful, the system has to solve the competition between units by selecting the candidate that reaches the highest activation level within the orthographic lexicon. Interactive activation models (e.g., McClelland & Rumelhart, 1981) implement lateral inhibition between co-active

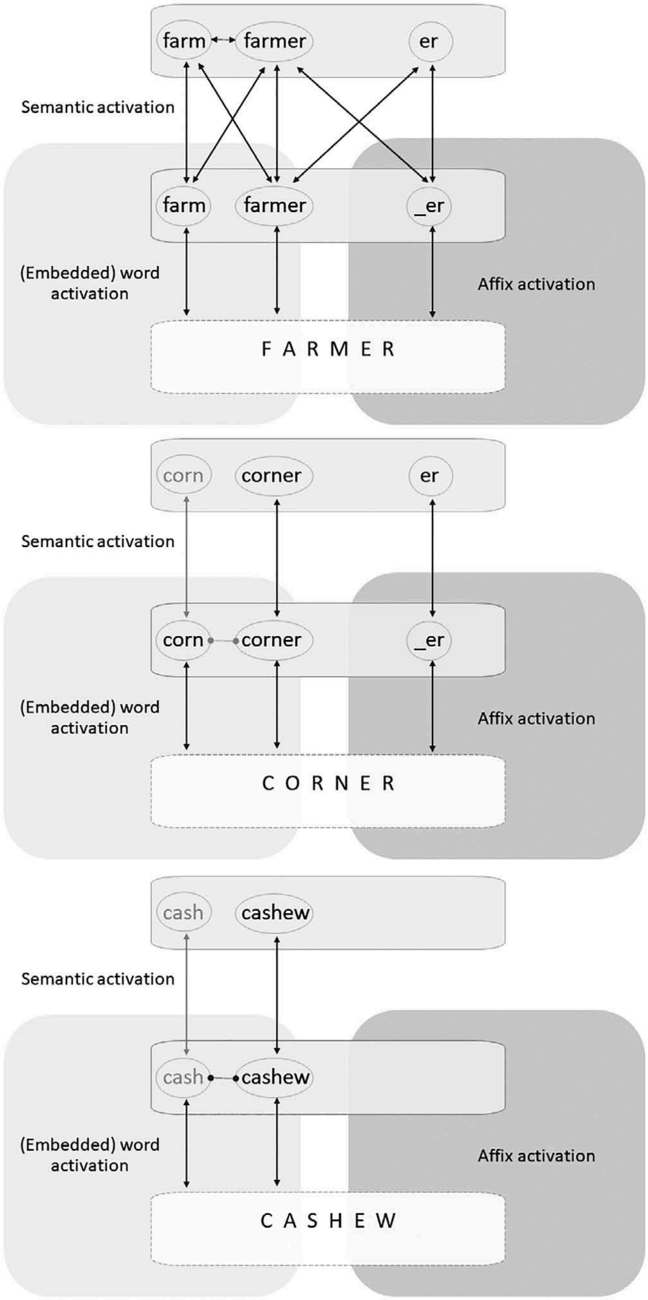

FIGURE 3.2. Detailed description of the model's handling of truly suffixed words (e.g., *farmer*), pseudo-suffixed words (e.g., *corner*), and non-suffixed words (e.g., *cashew*). The success of morpho-orthographic full decomposition with pseudo-suffixed words alleviates the lateral inhibition operating between the whole-word and the embedded word, compared with non-suffixed embedded words.

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word units in order to facilitate this process. Our model posits that—besides the many above outlined factors influencing the strength by which embedded words and affixes are activated in the orthographic lexicon—the presence or absence of a transparent morphological relation between units that are simultaneously active in the orthographic lexicon modulates the degree of lateral inhibition (Grainger & Beyersmann, 2017).

Non-suffixed words (*cashew*) and their embedded words (*cash*) are connected via inhibitory links (Figure 3.2, bottom panel). Similarly, in words with a pseudo-morphological structure, the lexical representations of the whole word (*corner*) and the embedded word (*corn*) share lateral inhibitory connections (Figure 3.2, mid-panel). Here, however, the successful application of the morpho-orthographic full decomposition principle leads to a decrease in lexical inhibition (see dimmed inhibitory links between *corn* and *corner* in Figure 3.2). As a result, the lexical node of *corn* is activated more strongly than the lexical node of *cash*, whose activity is reduced due to unmodified lateral inhibition between the two lexical representations. Thus, the presence of a pseudo-suffix tricks the system into believing that the embedding word and the embedded word are compatible whole-word orthographic representations that should be allowed to remain co-active (Grainger & Beyersmann, 2020). In words with a genuine morphological structure, the whole word and the embedded word are unaffected by lateral inhibition and connected via facilitatory top-down links from semantics (Figure 3.2, top panel).[8]

Semantic Activation

The final stage of the complex word reading is the level of semantic representations which are connected to lexical representations via bi-directional excitatory links.[9] Semantic activation can thus flow from the level of the orthographic lexicon to the semantic level and vice versa. Figure 3.2 describes how words with a genuine morphological structure (*farmer*) benefit from the inter-connectivity between the lexical and semantic levels. The lexical node of *farm* is connected to the semantic nodes of *farm* and *farmer*; the lexical node of *farmer* is connected to the semantic nodes of *farm, farmer*, and *-er*; and the lexical node of *-er* is connected the semantic nodes of *farmer* and *-er*. In contrast to *farmer*, words like *corner* and *cashew* do not share semantic interconnectivity with their embedded words (*corn* and *cash*), and the pseudo-suffix *-er* is not semantically linked to the whole word *corner*. The influence of semantic transparency tends to increase as processing of the orthographic input evolves (see "Semantic Influences on Morphological Processing" below). The model explains this finding because of the time required to activate semantic representations and subsequently provide feedback to ongoing word recognition processes.[10]

Morphological Processing

Following the theoretical portrayal of the model, the next two sections will turn to an empirical description of complex word processing. We will begin with a summary of experimental findings that speak in favor of a mechanism that detects affixes during the early stages of reading. Then, we will discuss results that lay the foundation of the model's morpho-orthographic full decomposition principle. The empirical review primarily centers on studies providing insights into the early, automatic stages of visual word recognition, such as those using the masked primed lexical decision paradigm, or neuroimaging techniques with high temporal resolution, including Electroencephalography (EEG) and Magnetoencephalography (MEG). Finally, we will describe evidence for semantic influences on morphological processing, which the model captures in the form of top-down feedback from semantics.

Evidence for Affix Activation

Evidence for affix activation comes from a recent French lexical decision study comparing four different types of nonwords (note that item examples are provided in English), consisting of stem + suffix (*farm* + *ity*), stem + non-suffix (*farm* + *ald*), non-stem + suffix (*falm* + *ity*), and non-stem + non-suffix (*falm* + *ald*) combinations (Beyersmann et al., 2020). The study showed a graded effect with response latencies being the slowest in the stem + suffix condition, average in the stem + non-suffix and non-stem + suffix conditions, and fastest in the non-stem + non-suffix conditions. This pattern suggests that the presence of morphemes increased the string's resemblance to a real word, thus making it harder to reject it as a nonword (for related findings from reading aloud, see Mousikou et al., 2020).

The critical evidence for affix activation consists in the slower response times in the non-stem + suffix condition compared to the non-stem + non-suffix control condition, showing that affixes are activated even if the whole letter string is not exhaustively decomposable (as in *falmity* or *farmald*, see Figure 3.3). Note that an earlier study by Taft et al. (1986) reported similar findings with prefixed nonwords including bound stems (e.g., *dejoice, tejoice, dejouse, rejouse*: where "de" is a prefix in English and "te" is not, and "joice" is a bound stem while "jouse" is not). Prefixed nonwords were more difficult to classify as nonwords than were non-prefixed nonwords (e.g. *dejoice* vs. *tejoice*), and this difference was larger when the bound stem of the nonword was a genuine stem (*joice*) than when it was not (*jouse*). In our model, the affix effect is explained by affix activation (*de-* in *dejoice/dejouse*). The bound-stem effect is explained by the similarity between *dejoice* and *rejoice*, thus making it harder to reject *dejoice* as a nonword.

Evidence for Morpho-Orthographic Processing

The primary evidence for morpho-orthographic processing comes from masked primed lexical decision studies comparing three types of prime-target pairs: truly suffixed (*farmer-FARM*), pseudo-suffixed (*corner-CORN*), and non-suffixed (*cashew-CASH*). Primes are typically presented in lowercase for about 50 ms, and are immediately followed by the uppercase target (Forster & Davis, 1984). Participants are then asked to quickly decide if the target is a real word or a nonword. Primes are presented so briefly that participants are not aware of their existence, yet facilitatory or inhibitory

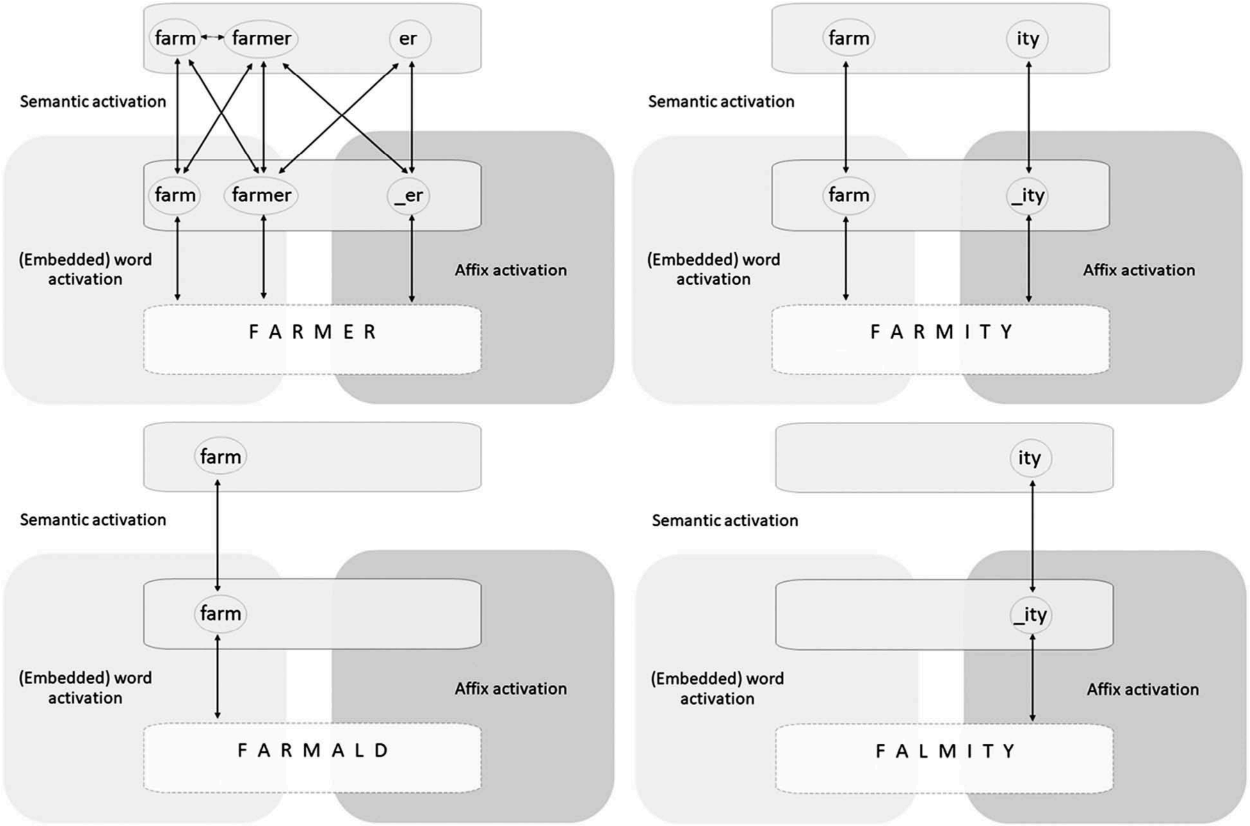

FIGURE 3.3. Detailed description of the model's handling of truly suffixed words (e.g., *farmer*) compared to three types of nonwords: stem + suffix (e.g., *farmity*), stem + non-suffix (e.g., *farmald*), and non-stem + suffix (e.g. *falmity*). The fact that morpho-orthographic full decomposition does not operate with nonword stimuli means that the embedded word "farm" is activated to the same extent by "farmity" and "farmald".

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effects on target performance can be measured, thus shedding light on the early, automatic stages of reading. Masked priming results from skilled readers reveal significant priming for truly suffixed and pseudo-suffixed words, but not for non-suffixed words. This early sensitivity for morphological structure in print suggests that skilled readers rapidly decompose complex words into morpho-orthographic units (*farm + er, corn + er*), independently of whether or not they share a semantic relationship with the whole word (e.g., Amenta & Crepaldi, 2012; Beyersmann, Ziegler et al., 2016; Longtin et al., 2003; Rastle & Davis, 2008; Rastle et al., 2004). The absence of priming in the non-suffixed condition shows that the morpho-orthographic decomposition is not successful in words consisting of an embedded word and a non-morphemic ending (*cashew*, where *ew* is not an affix).

Further evidence for morpho-orthographic processing comes from studies combining masked priming and high-temporal resolution recordings of event-related brain potentials (ERPs; e.g., Beyersmann et al., 2014; Dominguez et al., 2004; Jared et al., 2017; Lavric et al., 2011; Morris et al. 2007; Morris et al. 2008, 2013; Morris et al., 2011; Royle et al., 2012). In the early time windows, ERP responses to true morphological and pseudo-morphological priming are comparable (for converging evidence from MEG, see Lehtonen et al., 2011; Lewis et al., 2011; Solomyak & Marantz, 2009, 2011; but see Jared et al., 2017). In the later time windows, semantic influences on morphological processing are more likely to emerge (see below for more details).

Despite robust evidence for morpho-orthographic decomposition in adults, several masked priming studies with children have shown that morpho-orthographic processing is acquired quite late, not until more advanced stages of reading development (for reviews, see Grainger & Beyersmann, 2017; Rastle, 2018). For instance, Beyersmann et al. (2012) reported significant priming with true morphological primes (*farmer-FARM*) in English-speaking third and fifth graders, but not with pseudo-morphological or non-morphological primes (*corner-CORN* and *cashew-CASH*), suggesting that children in these age groups only decomposed letter strings with a semantically transparent morphological structure. Similarly, Schiff et al. (2012) showed that morpho-orthographic priming did not emerge until high school (but see Quémart et al., 2011). This indicates that morphological processing is primarily guided by semantics during the initial stages of reading acquisition (Stage 1, Figure 3.4).

Semantic Influences on Morphological Processing

Morphemes are defined as the smallest meaningful subunits, but there is debate as to *how early* morphological processing is influenced by semantics (e.g., Cavalli et al., 2016; Feldman et al., 2015; Feldman et al., 2009). Some studies have reported equal magnitudes of priming for truly and pseudo-suffixed words, suggesting that the initial stages of morphological processing are semantically “blind” (e.g., Beyersmann, Ziegler et al., 2016; Longtin et al., 2003; Rastle & Davis, 2008; Rastle et al., 2004). Others have revealed significantly stronger priming with truly

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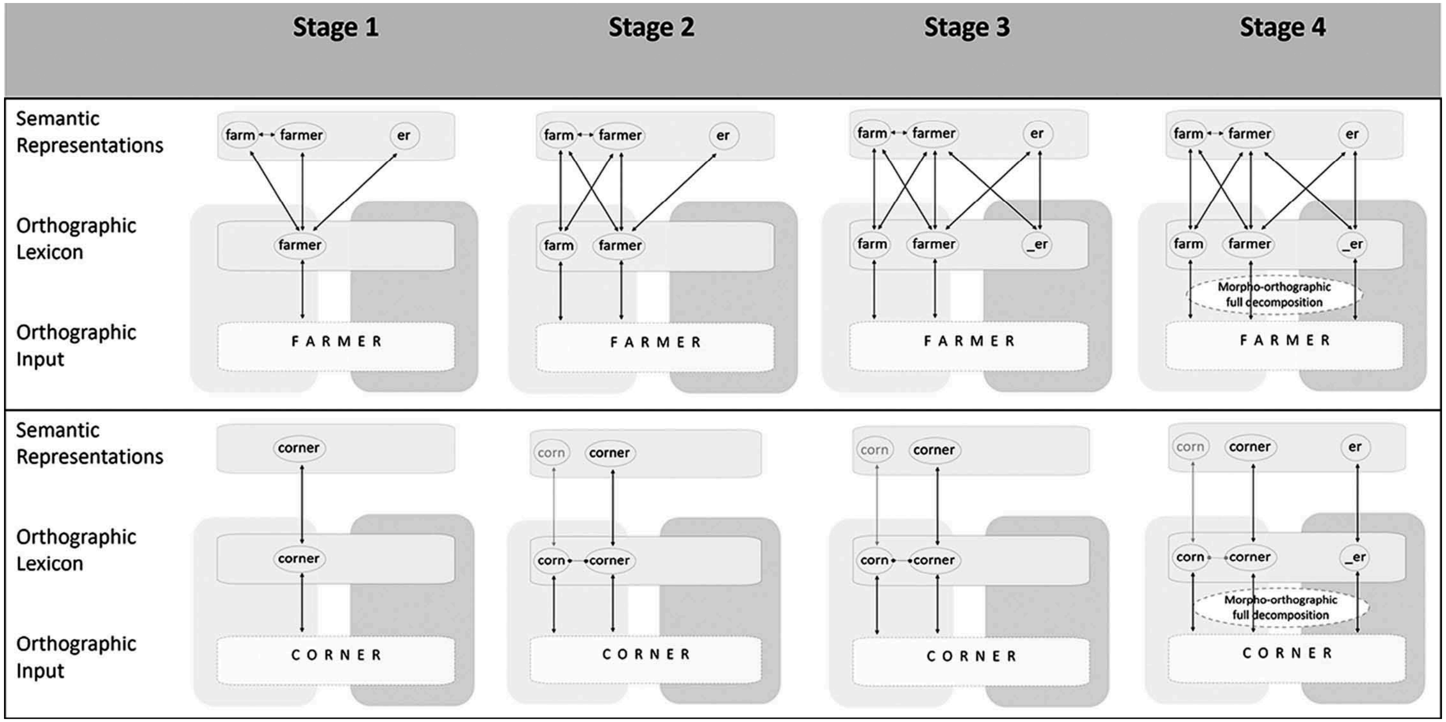

FIGURE 3.4. Four stages of learning to read complex words (updated version of Grainger & Beyersmann, 2017). Stage 1: Acquisition of whole-word orthographic representations that map onto semantic representations. Stage 2: Development of associations between orthographic input and embedded words, including the acquisition of inhibitory links between semantically unrelated lexical representations that are simultaneously active (e.g., between *corn* and *corner*). Stage 3: Acquisition of morpho-orthographic affix representations for semantically transparent morphologically complex words via feedback from semantics. Stage 4: Development of associations between orthographic input and orthographic affix representations, and acquisition of morpho-orthographic full decomposition, leading to a decrease in lateral inhibition between pseudo-suffixed words and their embedded pseudo-stems.

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affixed words, suggesting that semantics modulate the initial stages of visual word recognition (e.g., Feldman et al., 2015; Feldman et al., 2009; Jared et al., 2017; Schmidtke et al., 2017). The latter view is consistent with parallel distributed processing theories (e.g., Gonnerman et al., 2007; Plaut & Gonnerman, 2000) according to which the reading system picks up on statistical regularities, such as the consistency with which the letters of a morpheme are mapped onto semantics.

While the debate continues, the general trend shows that semantic influences increase when participants have more time to thoroughly process the prime. For instance, studies using visible primes have revealed stronger priming with true morphological compared to pseudo-morphological primes (e.g., Lavric et al., 2011; Rastle et al., 2000). Moreover, EEG data shows robust neurological priming in the later time windows with truly complex but not pseudo-complex words (e.g., Beyersmann et al., 2014; Lavric et al., 2011; see also Lavric et al., 2012; Morris et al., 2007). Similarly, a range of other experimental methods tapping into slightly later reading stages have provided evidence for semantic influences on morphological processing, including cross-modal priming experiments with auditory primes (e.g., Diependaele et al., 2005; Kielar & Joanisse, 2011; Marslen-Wilson et al., 1994; Meunier & Longtin, 2007), lexical decision studies with complex targets (Marslen-Wilson et al., 2008), and studies using the flanker task (Grainger et al., 2020).

Semantic feedback also explains why in an unprimed lexical task (Beyersmann et al., 2020) complex nonwords (*farmity*) are harder to reject than nonwords containing only one morpheme (*farmald* or *falmity*) or no morpheme (*falmald*). Complex nonwords like *farmity* do not benefit from the principle of morpho-orthographic full decomposition, because the sum of *farm* and *ity* is not a word. Therefore, under masked priming, comparable magnitudes of priming are typically seen for *farmity-FARM* and *farmald-FARM* (e.g., Beyersmann, Casalis et al., 2015; Beyersmann et al., 2014; Heathcote et al., 2018). In unprimed lexical decisions, however, the longer stimulus presentation duration leads to more semantic activation for complex nonwords like *farmity* compared to *farmald* or *falmity*, thus explaining the larger interference effects in this condition (Beyersmann et al., 2020).

Embedded Word Processing

Studies providing evidence for morpho-orthographic processing (e.g., Beyersmann, Ziegler, et al., 2016; Longtin et al., 2003; Rastle et al., 2004) have recently been paralleled by another body of masked priming research providing evidence for an entirely non-morphological process of embedded word activation (e.g., Beyersmann, Casalis et al., 2015; Morris et al., 2011). The critical comparison in the morphological nonword-priming paradigm is between affixed real words (*farmer-FARM*), affixed nonwords (*farmity-FARM*; consisting of a real stem and a real affix), and non-affixed nonwords (*farmald-FARM*; consisting of a real stem followed by a non-morphemic ending). The results from this widely replicated

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paradigm show that affixed nonwords (*farmity-FARM*) and non-affixed nonwords (*farmald-FARM*) yield comparable magnitudes of priming (e.g., Beyersmann, Casalis et al., 2015; Beyersmann, Cavalli, et al., 2016; Hasenäcker et al., 2016; Heathcote et al., 2018; Morris et al., 2011; Taft et al., 2018), indicating that nonwords produce priming independent of the presence or absence of an affix. Comparable magnitudes of priming are also seen with complex compound nonwords (e.g., *pilebook-BOOK*) and non-compound nonwords (e.g., *pimebook-BOOK*) in line with the idea that embedded word activation is not influenced by the morphological decomposability of the letter string (Beyersmann, Grainger et al., 2019; Beyersmann et al., 2018; Fiorentino et al., 2016).

These findings inspired the development of the Word and Affix model, according to which the input *farmity* is mapped onto the representations of *farm* (via embedded word activation) and *ity* (via affix activation), thus producing significant embedded word priming. The input *farmald* also activates the embedded word *farm*, thus producing equally strong embedded word priming. The magnitude of priming for words embedded in initial and final string position (*subcheap-CHEAP* vs. *cheapize-CHEAP*) is comparable (Beyersmann, Cavalli, et al., 2016; Beyersmann et al., 2018; Crepaldi et al., 2013; Heathcote et al., 2018), but reduced for words embedded in mid position (*pibookme-BOOK*) or outer position (*bopimeok-BOOK*), suggesting that the reading system gives preference to words embedded in edge-aligned string position (Grainger & Beyersmann, 2017).

Results from embedded word priming studies have also been able to shed new light onto how beginning readers process complex words. To examine the nature of embedded word processing in reading development, several recent masked priming studies have applied the complex nonword priming paradigm to a younger population of primary schoolers (Beyersmann, Grainger et al., 2015; Beyersmann et al., 2021; Hasenäcker et al., 2016; Hasenäcker et al., 2020). What is found is that, just like in adults, the size of affixed and non-affixed nonword priming is comparable (*farmity-FARM* vs. *farmald-FARM*), suggesting that children acquire the ability to activate embedded words early in their reading development.

The Word and Affix model captures these developmental aspects in four different stages (Figure 3.4). At Stage 1, children begin to build their orthographic lexicon by acquiring whole-word orthographic representations that map onto semantic representations. Given the wealth of spoken word knowledge that children are already equipped with during the initial reading stages (e.g., Beyersmann et al., 2022; Wegener et al., 2018), the key to Stage 1 is the formation of links between orthographic input and semantics via orthographic whole-word representations. As predicted by Share's (1995) Self-Teaching hypothesis, connections between orthography and semantics are established whenever an unfamiliar orthographic stimulus is successfully phonologically decoded (see also Grainger et al., 2012; Ziegler et al., 2014). Crucially, children already have access to semantic affix representations at Stage 1, based on form-meaning regularities they have been exposed to in their spoken language acquisition (e.g., a *painter* is someone who *paints*, a *teacher* is someone who *teaches*, etc.).

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Stage 2 represents the developmental time point by which children begin to pick up on embedded word units. Masked priming results show that embedded word activation is a mechanism that already develops in second grade in children who are not yet fluent readers (Beyersmann, Grainger et al., 2015). As can be seen in Figure 3.4, the development of associations between the orthographic input and embedded words at Stage 2 is independent of whether or not the embedded word and the whole word are semantically related (i.e., both the embedded units *farm* and *corn* are activated in the orthographic lexicon). The aspect that differentiates between truly complex and pseudo-complex words at this stage is that lateral inhibitory links are established between the lexical representations of pseudo-complex words and their pseudo-stems.

At Stage 3, the morphological parsing system reaches a new level of automatization. Via feedback connections from semantics, the reading system begins to establish affix representations in the orthographic lexicon. For instance, the semantic representations of *farmer* and the affix *-er* send excitatory feedback to the lexical level, leading to the addition of morpho-orthographic affix representations.

At Stage 4, associations are then established between orthographic input and orthographic affix representations. It is only at this final stage that affix activation and the associated principle of morpho-orthographic full decomposition are efficiently applied to any given input sting, including words with a pseudo-morphological structure, leading to a decrease in lateral inhibition between pseudo-suffixed words and their embedded pseudo-stems. Our model predicts that at this fully proficient reading stage, whole-word representations remain accessible in the orthographic lexicon (rather than being replaced) alongside the newly established morpho-orthographic form representations. As a result, the recognition of a (pseudo-) complex word can either be achieved on the basis of its orthographic subunits, or via whole-word processing. Reaching Stage 4 requires many years of reading experience, and as prior results have demonstrated this is typically not the case until high school (Beyersmann et al., 2012; Dawson et al., 2018; Dawson et al., 2021; Schiff et al., 2012), although developmental trajectories may differ across different languages (Beyersmann et al., 2021).

A final piece of evidence that makes critical predictions concerning the developmental stages of complex word reading comes from compound priming studies, which show that compound words (*headache-HEAD*) and pseudo-compound words (*butterfly-BUTTER*) yield comparable magnitudes of priming, with both being significantly stronger than priming with non-compound (*sandwich-SAND*) words (Beyersmann, Grainger et al., 2019; Fiorentino & Fund-Reznicek, 2009). This pattern is already evident in children as young as third grade, the age at which children are not yet showing *corner-CORN* priming, providing evidence for a highly automatized form of compound word segmentation in young children (Beyersmann, Grainger et al., 2019). This has important theoretical consequences, suggesting that there is an early use of the morpho-orthographic full decomposition principle, which is only applied to compound words in early stages of reading development, and then also to affixed words at the later stages of reading development.

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Conclusions and Future Directions

In this chapter, we have looked back over the past two decades of research examining the recognition of complex words during reading. Results from masked priming point to the distinct roles for stems and affixes in this process, with stems representing freestanding lexical units, encountered early in children's reading development (Beyersmann, Grainger et al., 2019; Beyersmann, et al., 2022), and affixes representing more abstract, specialized morphemic units, which children only acquire later once they already master the basic reading skills (Beyersmann et al., 2012; Schiff et al., 2012). The Word and Affix model provides an alternative to the classic affix-stripping approach developed by Taft and Forster (1975) by implementing the parallel operation of two key mechanisms: embedded word activation and affix activation. The model also implements the principle of morpho-orthographic full decomposition, which works by comparing the sum of the activated edge-aligned embedded word(s) and affix(es), and only takes into consideration the lexical status rather than the morphemic status of the embedded (pseudo-)stem (Grainger & Beyersmann, 2020).

Challenges for future research include the role of individual and cross-linguistic differences in morphological processing at different stages of reading development. Morphological priming effects are modulated by individual differences in language proficiency, suggesting that not all readers benefit from morphological processing to the same extent (e.g., Andrews & Lo, 2013; Beyersmann, Casalis et al., 2015; Beyersmann, Grainger et al., 2015; Hasenäcker et al., 2020), but it is not clear what skills exactly enhance the ability to identify morphological structure. Tests of individual differences vary widely between studies, ranging from reading fluency, reading comprehension, spelling proficiency, vocabulary knowledge, and morphological awareness to other non-linguistic measurements. For instance, adults with higher levels of reading fluency and spelling proficiency are more expert in activating embedded words than less proficient participants (Beyersmann, Casalis et al., 2015), and participants with better vocabulary than spelling ability show greater semantic transparency effects than participants with better spelling than vocabulary skills (Andrews & Lo, 2013). What further complicates the picture is that morphological processing is also not uniform across different languages (e.g., Juola, 2008; Kettunen, 2014; Sadeniemi et al., 2008), showing that readers of different languages benefit from morphological processing in different ways (Beyersmann et al., 2020; Frost, 2009; Mousikou et al., 2020; Beyersmann, et al., 2021). Future research will need to carefully tease apart individual proficiency differences within languages, not only to gain a broader, language-universal perspective of complex word reading, but also to inform language-specific teaching programs involving morphological instruction (Bowers & Bowers, 2018).

The Word and Affix model clearly dissociates (embedded) word activation, affix activation and morpho-orthographic full decomposition as three distinct mechanisms that are motivated by a complex set of psycholinguistic data. If it is true that these mechanisms are clearly distinguishable, we would expect to see differences in the neurobiological underpinnings of embedded word and affix processing. What is needed now is a neurocognitive investigation aimed at understanding how these three specific processes are implemented in the literate brain.

Notes

1 "Affix-stripping" and "morpho-orthographic processing" have often been synonymously used to describe the process of decomposing letter strings into morphemic subunits, independently of semantics. Morpho-orthographic processing is based on the same general idea that morphological decomposition only applies in the presence of an affix (i.e., decomposition of *corn* + *er*, but not *cashew*).

2 Interested readers are referred to Grainger and Beyersmann (2017) for more details on the empirical findings that motivated the key components of the original model.

3 See Taft (this volume) for an alternative account of the processing of bound stems.

4 We use the term "stem" to signify the specific status of stems as embedded words under the principle of full decomposition. That is, the stem is the embedded word that combines with an affix to describe the complete stimulus.

5 We note that the here reported list of factors is not necessarily exhaustive. Our focus is on factors that have been explicitly found to influence embedded word processing.

6 To this date, CAP has only been tested with suffixed words, but not prefixed words.

7 Here we focus on the case of affixed-derived words, but the same mechanisms are thought to operate for compound words.

8 The influence of semantic transparency on morphological processing is difficult to detect in a task like masked priming, not only because primes are presented so briefly that there is not enough time for semantic processing to have an impact, but also because the prime and the target are presented in the same spatial location. Results from the Flanker Paradigm, on the other hand, show that when complex words and their embedded words are presented side-by-side (e.g., *farm farmer farm*) the competition for the same spatial location is removed, and significantly stronger flanker effects are observed for semantically transparent complex words compared to pseudo-complex and non-complex words (Grainger et al., 2020).

9 Given the model's focus on the initial stages of complex word recognition, semantics represents the highest form of representation in this context. Although beyond the scope of the current work, we would suggest that semantic features, as exemplified in the semantic representation of derivational affixes, are the key ingredient of this level of representation. However, in order to keep things simple, we describe the operation of semantics at the word level using localist terminology.

10 As opposed to earlier models of complex word recognition (e.g., Diependaele et al, 2009; Grainger & Beyersmann, 2017), the current model does not implement a mechanism of "morpho-semantic decomposition," which was previously used to account for semantic transparency effects in complex word recognition.

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