The Role of Morphology in the Development of Lexical Processing

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Nicola Jane Dawson

Royal Holloway, University of London

Department of Psychology

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Declaration of Authorship

I, Nicola Jane Dawson, hereby declare that this work was carried out in accordance with the regulations of the University of London. I declare that this submission is my own work, and to the best of my knowledge does not represent the work of others, published or unpublished, except where duly acknowledged in the text. No part of this thesis has been submitted for a higher degree at another university of institution.

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Abstract

Morphology is an important source of regularity in the English writing system. Morphemes provide a link between word form (phonology and orthography) and word meaning (semantics and grammar). Skilled readers demonstrate rapid analysis of morphological structure during word recognition which enables efficient access to meaning from print. Children's explicit awareness of morphological patterns emerges early in development, but it is not yet clear how and when they acquire morphological representations that are readily activated during reading. Data from adolescent readers are scarce, but are crucial to addressing this question. A further question relates to the processes by which morphology supports acquisition of lexical knowledge. One argument is that morphological structure helps to bind orthographic, phonological and semantic features of words in memory, resulting in high quality lexical representations. This thesis reports three experimental cross-sectional studies. The aim of the first two studies was to investigate morphological effects in visual word recognition across reading development, and the mechanisms that drive these effects. Findings from these studies revealed that children, adolescents and adults all demonstrated sensitivity to morphological structure during word recognition tasks, but rapid activation of abstract morphological representations appeared to be a late-acquired milestone in reading development, not emerging until mid-to-late adolescence. The third study investigated the role of suffixes in the development of high quality lexical representations in adolescents using a word-learning paradigm. Results indicated that semantic and syntactic properties of suffixes supported learning of mappings between semantics and phonology, but these effects did not extend to online measures of word learning. Together, these findings underline the importance of morphological knowledge for lexical processing, and provide new evidence that the representations that support rapid access to meaning from print continue to develop into late adolescence.

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List of Publications

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Dawson, N., Rastle, K. & Ricketts, J. (under revision). Finding the man amongst many: A developmental perspective on mechanisms of morphological decomposition. *Cognition.*

Ricketts, J., Lervåg, A., **Dawson, N**., Taylor, L. A., & Hulme, C. (under revision). Reading and oral vocabulary development in early adolescence. *Scientific Studies of Reading*.

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CHAPTER ONE

General Introduction and Thesis Overview

Reading is one of the most valuable skills a child will acquire in their lifetime. The ability to translate symbols on a page into meaning opens doors to education, employment, and culture. It permits the transmission of ideas beyond the ‘here and now’, such that individuals can access information and thoughts recorded in other parts of the world, and from other periods in human history. Perhaps most impressively, reading is a cultural invention that has emerged only in the last few thousand years (Manguel, 1996). From an evolutionary perspective, this time frame is too short for reading to be the product of evolution; rather, it is thought that the cognitive functions underpinning reading are parasitic on brain circuitry evolved for other purposes (Dehaene, 2009).

Given its recency in cultural history, skilled, silent reading is an astonishing achievement. For most individuals, reading appears a fluent and effortless process, when in fact it is the product of a hugely complex set of interacting cognitive mechanisms. A reader faced with words on a page must be able to identify those words, disambiguate them from similar words, and activate their meanings. Some words may be recognised directly from the text, while others (e.g., unfamiliar words) require a different strategy: here, readers of alphabetic languages must use their knowledge of the systematic relationship between letters and sounds to access the sound pattern of the word. Meanings of individual words must be integrated across the sentence as a whole and combined with information from syntax. Finally, information from the text and the background knowledge of the reader must be synthesised across the entire passage in order to facilitate comprehension, in the process drawing on skills such as inference-making, working memory, and linguistic knowledge.

As such, learning to read presents no small challenge. Yet the majority of children show remarkable aptitude in acquiring the necessary skills to be reading independently within the first few years of instruction. Beyond this, exposure to the writing system through reading leads to a fine-tuning of the reading system, eventually producing the rapid and fluent recognition of words typical of skilled reading. It is a remarkable achievement, and one which develops over many years. Over the last three decades, reading research has made huge advances in understanding the beginning stages of reading acquisition: how children learn about the relationship between spellings and sounds, and how this can be applied in reading instruction to promote literacy standards. However, attention is beginning to turn now to the skills, experience, and knowledge that allow children to build on this foundation and make the transition from novice to skilled reader (Castles, Rastle, & Nation, 2018). The aim of this thesis is to contribute to this body of knowledge by examining a key component of reading: the knowledge and processing of words. In particular, I focus on the role of morphology, the internal structure of words, and how knowledge about morphology shapes lexical processing in children, adolescents and adults.

The current chapter begins by outlining frameworks of lexical knowledge and reading, and provides an overview of morphology in English and the ways that morphological knowledge supports skilled word recognition. The second part of this chapter provides a brief outline of reading development and the factors that support the transition from novice to skilled reader, before examining the evidence that morphology may be a particularly important source of linguistic knowledge in this process. The final section presents an overview of Chapters 2-4, outlining the aims and hypotheses for each study reported in these chapters.

1.1. Lexical knowledge and lexical processing

Word knowledge is fundamental to human communication. Words constitute the building blocks of meaning that allow individuals to access education and culture, navigate social relationships, and share knowledge. In the early stages of language acquisition, word knowledge involves creating mappings between spoken word forms (phonology) and meanings (semantics)[1] as children build their oral vocabulary. In the process of learning to read, these representations are modified to include an additional source of information: the way that words are spelled (orthography). These components of lexical knowledge are not static, but are part of a dynamic system in which expertise is accumulated incrementally and knowledge refined across multiple exposures (Beck, McKeown, & Kucan, 2002). A principal debate in the psycholinguistic literature is how this knowledge is represented and accessed. This will be considered in more detail in section 1.5.

Since acquisition of lexical knowledge is dependent on language exposure, lexical representations vary in quality across both individuals and items (Andrews, 2015; Perfetti, 2007). The Lexical Quality Hypothesis captures this variation, proposing that high quality representations combine well-specified orthographic information, partly redundant phonological information that is available both directly and indirectly via orthography, and flexible semantic information that can accommodate nuanced and multiple meanings (Perfetti, 2007; Perfetti & Hart, 2002). These three constituents are closely interconnected in memory, generating a representation that is stable, coherent (with close connections between constituents giving the impression of a unitary representation), and reliable across multiple encounters. Individuals with more language experience, and thus more exposure to

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[1] Here, 'semantics' in used in a broad sense to refer to both word meaning and grammatical information (following Perfetti & Hart, 2002)

word forms and their meanings, will have on average higher quality representations than those with less experience. Similarly, at any point in time, individuals will have higher quality representations for some words compared to others. Importantly, the quality of lexical representations is closely associated with efficiency of lexical processing (Perfetti & Hart, 2002). The term *lexical processing* is used variably across the literature, but throughout this thesis it will be used in a broad sense to refer to the recognition of words and access to information about those words. While lexical processing may involve access to lexical information in response to either auditory or written input, the focus here is primarily on lexical processing in the context of reading.

1.2. Morphological regularities

The purpose of written language is to encode meaning. In alphabetic languages such as English, graphemes (letters and letter combinations) are used to represent phonemes (sounds). Languages vary in the extent to which the correspondences between graphemes and phonemes are consistent and predictable (Share, 2008). English has a comparatively deep orthography, meaning that there are many examples of words containing atypical spelling-sound mappings (for example, *yacht*; Katz & Frost, 1992). This arises because a single grapheme can represent multiple different phonemes (e.g., *ou* can be pronounced /ʊ/, /uː/, /aʊ/), just as a single phoneme may be represented by multiple graphemes (e.g., /uː/ is expressed variously as *ue*, *oo*, *oe*, *ou*). Part of this inconsistency can be explained by orthographic context, where spelling-sounds correspondences that appear unusual are actually consistent with the wider context in which they appear. For example, the grapheme *ea* is pronounced /ɛ/ in the word *thread* in contrast to its more common realisation /iː/ in words like *sea*, *tea*, *beach* and *bean*, yet its pronunciation is consistent with other examples in which it is followed by the grapheme *d* (e.g., *dead*, *dread*, *spread*; Kessler & Treiman, 2001; Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). Despite these inconsistencies, the associations between orthographic and phonological units are sufficiently predictable that knowledge of them provides the foundations of reading acquisition. While these mappings provide one source of regularity in English, another stems from the mappings between orthographic and semantic units.

Morphemes are commonly defined as the smallest meaningful unit in a word (Hamawand, 2011). The word *break* is monomorphemic: it is a single lexical structure that cannot be further parsed into meaningful components. Words combining two or more morphemes are morphologically complex; for example, the suffix -*able* attaches to the word *break* to form the complex word *breakable*. Complex words are typically constructed through a combination of free and bound morphemes. Free morphemes may stand alone as words (as in the case of *break* in the above example), and may also combine with other free morphemes to form compound words (e.g., *breakdown*). By contrast, bound morphemes do not stand alone as lexical units, but instead modify the grammatical function, meaning or word class of the word to which they attach (e.g., -*able*). Bound morphemes are usually affixes (prefixes and suffixes), but they may also be stems, as in the example of -*mit* in *permit*, *admit*, and *commit* (Carstairs-McCarthy, 2002).

Another key distinction in morphology is between inflection and derivation, although some have argued that this binary division is too simplistic (Bauer, 2004; Beard & Volpe, 2005; Hacken, 2014). At a basic level, inflectional morphemes change the form of a word to fit the grammatical context, but do not create a new lexeme. The term *lexeme* refers to an abstract representation that links all of the possible grammatically related forms a word can take (Lieber, 2016). The lexeme *walk* can be expressed as *walks*, *walked*, *walking* or *walk*, depending on the grammatical context. Inflectional morphemes function to express, for example, quantity (the plural marker -*s*) and tense (past tense marker -*ed*), but the addition of an inflectional morpheme does not alter the core meaning of the stem. While the purpose of inflectional morphology is primarily grammatical, derivational morphology involves lexical processes that function to create new lexemes from a base morpheme (Lieber, 2004). Thus, a derived word may differ from its stem in meaning, word class, or both. For example, adding the suffix *-able* to the word *break* changes it from a verb into an adjective, while adding the prefix *un-* to the stem *breakable* reverses its meaning. Affix forms can straddle the boundaries between inflection and derivation. For example, the suffix *-er* is a highly productive derivational suffix signalling agency, but the same surface form also functions as a comparative inflectional suffix (e.g., in words such as *higher*). Finally, compounding is similarly classed as a lexical process, whereby new words are formed by concatenating two (or more) base words (e.g., *overactive*, *motorbike*).

Word formation processes open up the potential to create huge numbers of new lexical items that can be understood by other language users. A recent example is the term *Brexit*, coined through the blending of ‘British’ and ‘exit’ to refer to Britain’s exit from the EU. This neologism gave rise to others, including the derivatives *Brexiter* or *Brexiteer* to describe supporters of Brexit. The rapid proliferation and acceptance of new lexical items in response to changing political and cultural climates illustrates the power of word formation processes in capturing and creating new concepts. Nonetheless, word formation is constrained by various combinational properties of morphemes. These constraints may be syntactic (the suffix *-ness* attaches to nouns, but not verbs or adjectives; Lieber, 2009), phonological (e.g., the suffix *-al* can only attach to verbs in which the final syllable is stressed, for example *arrive-arrival*, but not *enter-enteral*; Plag, 2003) or semantic (e.g., the prefix *un-* tends to attach to adjectives that do not already have negative associations, for example *unhappy*, but not *unsad*; Lieber, 2009).

Equally, some affixes are more productive than others, meaning that they are more likely to be used in the formation of new words (Plag, 2018). Two affixes sharing similar semantic and syntactic properties may vary considerably in productivity. Suffixes *-th* and *-ness* both attach to adjectives to create abstract nouns, for example, but use of *-th* is restricted to a small, specific set of words (including *breadth* and *depth* as nominalisations of *broad* and *deep* respectively), while *-ness* can attach to many words*,* and is thus highly productive. Some have argued that productivity of a given affix relates to the 'decomposability' of the words in which that affix appears (Hay & Baayen, 2002; Plag, 2003). For example, affixes appearing in complex words that have a transparent relationship with their stems (e.g., *-er* in *teacher*, *farmer*, *reader*) will facilitate productivity more than affixes appearing in words in which the stem-affix relationship is more opaque (e.g., *-ity* in *activity*, *priority*, *quantity*).

The definition of a morpheme as the smallest unit of meaning is challenged by the existence of semantically opaque morphemes. A common example is the bound stem *mit*, occurring in words such as *permit*, *submit*, and *remit*, which share no apparent overlaps in meaning (Aronoff, 1976). Non-concatenative processes for forming complex words pose similar problems. For example, zero morphs are affixes that are present in an inflected or derived word, but which have no phonological or orthographic realisation (e.g., irregular inflections, such as the plural *sheep*, or derivations that alter word class but not word form, such as conversion of *clean* from an adjective to a verb; Plag, 2003). Even complex words formed through the combination of a free stem and one or more affixes vary considerably in their semantic, phonological and orthographic transparency (Carlisle & Stone, 2005; Marslen-Wilson, Komisarjevsky Tyler, Waksler, & Older, 1994).

Semantic transparency refers to the extent to which the meaning of the complex word can be predicted from its morphological constituents. Typically, inflectional relationships are more semantically transparent than derivational relationships (Plag & Balling, 2016). For example, plural *-s* modifies nouns in a highly predictable manner (the relationship of *cat:cats* is the same as that of *dog:dogs*, despite differences in phonetic realisation), whereas derivational affixes are more variable in how they modify the stem. *Breakable* is semantically transparent: its meaning (‘can be broken’) is clear from the stem *break* and the suffix -*able*, meaning ‘can be *X*ed’, while the meaning of *listless* is more opaque because it cannot be calculated from the sum of its parts. Phonological and orthographic transparency describe the extent to which the pronunciation and spelling of the stem respectively are preserved in the complex word. *Breakable* is both phonologically and orthographically transparent; the spelling and pronunciation of the stem do not change with the addition of the suffix. *Adorable* is phonologically transparent, but orthographically opaque, while *magician* is orthographically transparent and phonologically opaque.

Despite the challenges to the idea of morphemes as ‘units of meaning’ posed by semantically opaque complex words, morphological regularities play an important part in the structure of the English writing system. In the context of monomorphemic words, the relationship between word form and word meaning is arbitrary: two words that are closely related in spelling and pronunciation (e.g., *cat* and *mat*) are not necessarily related in meaning. By comparison, morphological relationships provide strong links between form and meaning in polymorphemic words. These relationships arise through words sharing the same stem (known as morphological families, for example, *break*, *breaking*, *breakable*, *unbreakable*), and through words sharing the same affix (e.g., *breakable*, *loveable*, *readable*, *likeable*). In each case, overlaps in word form correspond to some extent to overlaps in word meaning. Importantly, in English, the relationship between a complex word and its stem is often more salient in written language than in spoken language (Berg & Aronoff, 2017; Rastle, 2018). There are many examples of derived words in which phonological transparency is sacrificed to preserve orthographic transparency (e.g., *magic-magician*, *sign-signify*, *electric-electrician*). Similarly, inflectional suffixes are spelled consistently despite variations in pronunciation arising from phonetic context (e.g., plural -*s* pronounced /s/ in *cats*, and /z/ in *dogs*; Berg, Buchmann, Dybiec, & Fuhrhop, 2014).

These morphological regularities help to account for some of irregularities observed in the mappings between orthography and phonology in English (Rastle, 2018). Berg and Aronoff (2017) found that spellings of affixes were largely distinct from spellings representing the same sequence of sounds elsewhere. They showed that the phoneme combination /əs/ took the orthographic form *-ous* wherever it appeared as an adjectival suffix (e.g., *nervous*, *advantageous*), but not when it appeared in word-final position in non-adjectives (e.g., *bonus*, *genius*). While the prioritisation of morphological regularity introduces inconsistency into the correspondence between phonological (/əs/) and orthographic (*-ous*, *-us*) form, it works to establish a direct link between orthographic form (*-ous*) and semantics (denoting an adjective). Recently, Ulicheva, Harvey, Aronoff, and Rastle (2018) extended this work to 154 English suffixes, demonstrating widespread consistency in the relationships between suffix spellings and their meanings.

For these reasons, understanding of morphology and morphological relationships may be particularly important in developing the skills needed to support rapid access to meaning during reading. However, the review outlined above relates specifically to English morphology. There is currently little understanding of whether writing systems in other languages are similarly structured to reveal systematic links between written form and meaning, or how these patterns may influence the way in which reading skills develop in a given language. In the next section, I turn my attention to reading, starting with a broad outline of the components of reading, before examining specific theoretical models of word reading.

1.3. Components of reading

Successful reading relies on connections between a complex set of skills. The ultimate goal of reading is text comprehension, but this is contingent on many factors. Broadly, reading skills can be divided into two components: word reading and language comprehension. The interaction of these two elements forms the basis of the Simple View of Reading (Gough & Tunmer, 1986 - see Figure 1.1.), which provides a core framework for understanding the processes that support successful reading, and by implication, the deficits underlying different profiles of reading impairment.

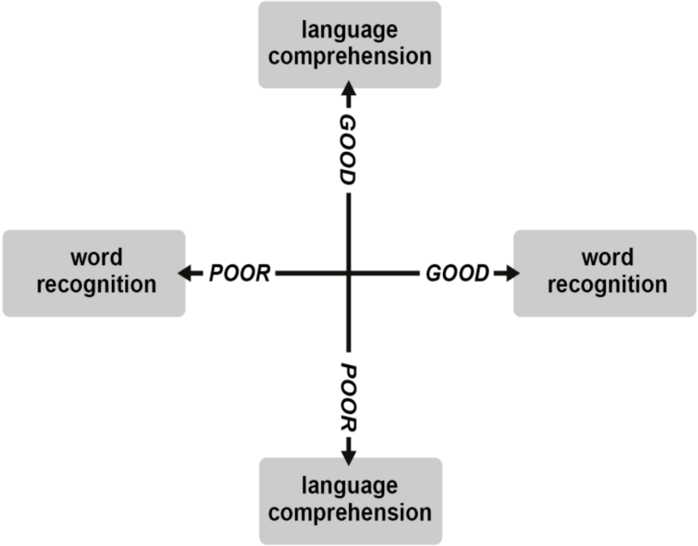

Figure 1.1. The Simple View of Reading, after Gough and Tunmer (1986)

On this view, word recognition[2] and language comprehension skills are both necessary for successful reading comprehension, and neither is sufficient in isolation (Gough & Tunmer, 1986). Readers must be able to identify the words in a text to access meaning, but must also have the requisite language comprehension skills to understand the words and sentences being read. Each of these components varies

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[2] The original Gough and Tunmer (1986) article uses the term ‘decoding’ to refer to word reading via both letter-sound conversion and word recognition more broadly. To avoid confusion with use of the term ‘decoding’ elsewhere in this thesis to refer specifically to the use of letter-sound conversion in reading, I will adopt the term‘word recognition’ in reference to this component of the Simple View of Reading. This is in line with terminology used in later iterations of the Simple View of Reading (e.g., Tunmer & Chapman, 2012).

along a continuum from good to poor, meaning that reading difficulties may arise from deficits in either word recognition or language comprehension, or both. Individuals may have good language comprehension skills but poor word recognition, a pattern typically observed in readers with dyslexia (Tunmer & Greaney, 2010). Conversely, readers who have good word recognition skills but poor language comprehension fit the profile of ‘poor comprehenders’ (Nation, 2005). The differential impairment of word reading and language comprehension in dyslexic and poor comprehender profiles offers some support to the hypothesis that these skills are independent and separable contributors to reading comprehension (Lervåg, Hulme, & Melby-Lervåg, 2018; Sabatini, Shore, Sawaki, & Scarborough, 2010).

The Simple View of Reading has been instrumental in translating research into policy, serving as the conceptual framework for improving standards of reading in schools in England (Rose, 2006). However, its simplicity is both a strength and a limitation (Braze, Tabor, Shankweiler, & Mencl, 2007; Kirby & Savage, 2008). The idea that word recognition and language comprehension are separable and independent constructs has been challenged by findings showing that some components of language comprehension are also associated with word recognition. For example, exception word reading is closely associated with oral vocabulary knowledge (Ricketts, Nation, & Bishop, 2007), and semantic and syntactic knowledge more generally may influence word recognition via word meaning, context or morphology (Kirby & Savage, 2008; Nation & Snowling, 1998a, 1998b; Ricketts, Davies, Masterson, Stuart, & Duff, 2016; Taylor, Duff, Woollams, Monaghan, & Ricketts, 2015).

Such evidence showing that certain aspects of word recognition are constrained by oral language comprehension skills, and in particular vocabulary knowledge, has led some to argue that vocabulary should form a separate component in the model (Braze et al., 2007; Kirby & Savage, 2008). In response, Tunmer and Chapman (2012) maintain that the overall dual-component structure of the Simple View of Reading is sufficient, but acknowledge that the two components may not be entirely independent, with language comprehension contributing to reading comprehension both directly and indirectly via word recognition.

A second issue relates to how the ‘word recognition’ component of the Simple View of Reading should be measured, and whether there should be a separate component for fluency (Adlof, Catts, & Little, 2006; Silverman, Speece, Harring, & Ritchey, 2013). Tunmer and Greaney (2010) suggest that measurement of word recognition should be adapted to reflect the relevant stage of reading development, so that while the use of nonwords to assess decoding ability is appropriate for young children, in older children and adults, assessment of word recognition should include identification of word-specific orthographic forms and word reading fluency.

The Simple View of Reading highlights the importance of word recognition skills for reading comprehension, and it is clear that identifying the words in a text is a necessary foundation for understanding that text. What it lacks is a more precise account of how components of word recognition support comprehension. In his Verbal Efficiency Theory, an early precursor to the Lexical Quality Hypothesis, Perfetti (1985) emphasised the role of processing efficiency, arguing that efficient word reading frees up resources for higher-level processes relating to integration and inference. Perfetti (2007) later highlighted the distinction between speed of processing and efficiency. While increased speed of processing may support reading fluency, which in turn may lead to better comprehension outcomes, it is possible that an individual may be a fluent reader but show poor comprehension. Perfetti (2007) proposed that word reading efficiency corresponds to the ratio between outcome (word identification) and effort (processing time), thereby placing emphasis on the accessibility of lexical knowledge as well as the demands made on processing resources during retrieval. This is reflected in the Lexical Quality Hypothesis, which stresses the importance of word knowledge in addition to processing efficiency in distinguishing between skilled and less skilled readers (Perfetti, 2007; Perfetti & Hart, 2002). As discussed in section 1.1, the Lexical Quality Hypothesis argues that well-specified and closely bound lexical knowledge relating to orthography, phonology and semantics supports representations that are retrieved rapidly and efficiently during reading.

Word knowledge is also central to the Reading Systems Framework, which provides a broad overview of the components that comprise reading comprehension (Perfetti & Stafura, 2014; see also Perfetti, Landi, & Oakhill, 2005). In this framework, reading draws on orthographic, linguistic and general knowledge, and the processes by which these sources of knowledge are integrated (see Figure 1.2.). The Reading Systems Framework places lexical knowledge at the heart of reading comprehension, linking together word identification processes and comprehension processes. Importantly, it is one of the few general theoretical accounts of reading to propose a specific role for morphological knowledge. According to Perfetti & Stafura (2014), morphology influences reading comprehension both directly as part of the linguistic system, and indirectly via the lexicon. This view is supported by empirical evidence showing that morphological knowledge, most commonly measured through morphological awareness tasks, is associated with reading comprehension in children (Deacon, Kieffer, & Laroche, 2014; Deacon, Tong, & Francis, 2017; Kirby et al., 2012; Levesque, Kieffer, & Deacon, 2017, 2018; Nagy, Berninger, & Abbott, 2006) and adults (Guo, Roehrig, & Williams, 2011; Tighe & Binder, 2015), even when factors such as phonological awareness, vocabulary and word reading are controlled, as well as contributing indirectly via word reading (Deacon et al., 2014; Gilbert, Goodwin, Compton, & Kearns, 2014; Levesque et al., 2017) and vocabulary (Kieffer, Biancarosa, & Mancilla-Martinez, 2013).

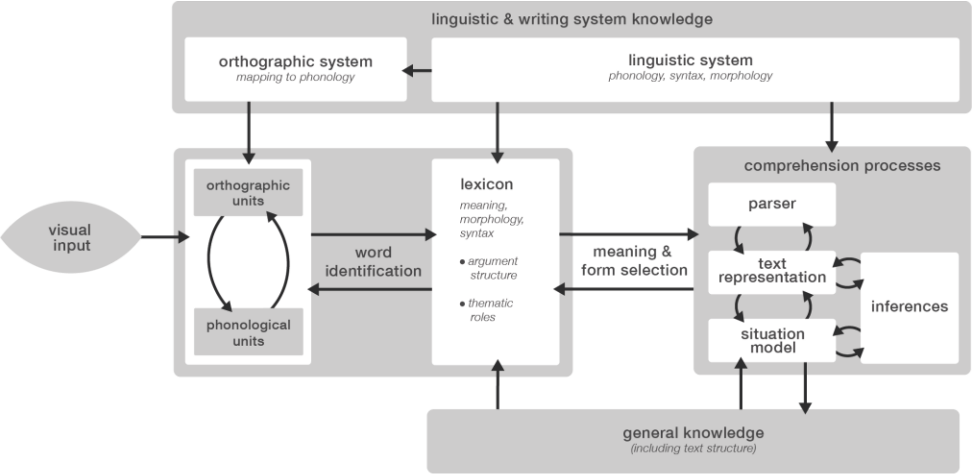

Figure 1.2. The Reading Systems Framework, after Perfetti & Stafura (2014)

At the level of the lexicon, appreciation of morphological relationships between words may function to bind orthographic, phonological and semantic information in memory, resulting in higher quality representations that are readily retrieved during reading (Bowers, Kirby, & Deacon, 2010; Nagy, Carlisle, & Goodwin, 2014). Reichle and Perfetti (2003) used computational simulations to show that repeated encounters with words overlapping in orthographic, phonological and semantic features (e.g., *break*, *breakable*, *unbreakable*, *breaking*) affected the extent to which the stem was familiar and available, with the latter taken as a proxy for lexical quality. Interestingly, stems with high frequency inflected forms (a measure of token frequency) were more familiar and available than stems with low frequency inflected forms, but the same pattern was not observed for derivations. What mattered instead was the number of different derived words containing the stem (i.e. type frequency). Stems that took many derived forms had higher availability, meaning that phonological and semantic information was more readily retrieved from orthographic input, compared to stems with fewer derived forms. However, familiarity was unaffected by type frequency. Reichle and Perfetti (2003) argued that the important factor in the disparate pattern of findings across inflected and derived forms was not the categorical distinction per se, but rather the degree of overlap between orthographic, phonological and semantic features, which tends to be higher for inflections compared to derivations.

In summary, several influential theoretical frameworks of reading emphasise the importance of lexical knowledge and lexical processing for reading comprehension. Morphology may influence word identification processes through direct links from orthography to semantics as a consequence of the way morphological information is represented in the writing system (Berg & Aronoff, 2017; Rastle, 2018; Ulicheva et al., 2018), and also by supporting the development of high quality lexical representations through overlaps in orthographic, phonological and semantic features between morphologically-related words (Reichle & Perfetti, 2003; Verhoeven & Perfetti, 2003). In the following section, I will consider more closely the mechanisms involved in lexical processing by outlining some of the key models of word reading.

1.4. Models of word reading

Theoretical accounts of word reading can be broadly divided into dual-route and connectionist approaches. Essentially both approaches posit that two sets of processes are involved in word reading: alphabetic decoding skills and whole-word knowledge. The outcome is a flexible reading system that can process, at the extremes, words that have no existing lexical representation and therefore must be processed on the basis of grapheme-phoneme correspondence rules (e.g., nonwords), and words that do not adhere to grapheme-phoneme correspondence rules, for which accurate word reading depends largely on lexical knowledge (e.g., exception words). The two approaches differ, however, in whether the reading system requires separate mechanisms for processing these different word types, or whether a single mechanism is sufficient for processing all words. A second distinction relates to the representation of knowledge. Dual route models have traditionally adopted a localist approach, in which linguistic knowledge is represented by localised units (e.g., a single unit representing a grapheme or a word). By contrast, many connectionist models take a distributed approach, whereby knowledge is represented through shared patterns of activation across sets of units, as opposed to corresponding to discrete units. The advent of computational modelling in the last three decades opened the doors to the development of specific, testable models of word reading behaviour based on these theoretical approaches.

The dual-route cascaded model (DRC, Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001 - see Figure 1.3.) is one such model, adopting a localist approach. At its core is the principle that there are two separate routes available for word reading, each involving a different processing mechanism. One is the sublexical route, in which the orthographic input is parsed into graphemes, which are subsequently converted to phonemes on the basis of pre-specified grapheme-phoneme correspondence rules, and then reassembled to produce the phonological output. The second is the lexical route, in which the orthographic input activates the relevant entry in the orthographic lexicon. This orthographic representation then activates the whole-word entry in the phonological lexicon either directly (nonsemantic lexical route), or indirectly via the semantic lexicon (semantic lexical route). Access to the phonological lexicon entry then activates its associated pronunciation. This dual-route architecture permits processing of both novel and exception words. Novel or nonsense words can be read via the sublexical route, making use of grapheme-phoneme conversion rules, while exception words can be processed via the lexical route, where use of grapheme-phoneme correspondences would result in a pronunciation error (e.g., *yacht* pronounced as /jætʃt/). Regular words are successfully processed via either the sublexical or lexical route.

Support for dual-route models comes from the finding that both children and adults may present with one of two separate subtypes of dyslexia, attributable by dual-route theorists to impairments in either the sublexical or lexical route (Coltheart, 2005). Phonological dyslexia is observed in individuals whose nonword reading is impaired relative to their regular and exception word reading: in other words, they have specific difficulties with decoding, which indicates problems with the sublexical processing route (e.g., patient ‘WB’; Funnell, 1983). Regular word reading is unaffected because the lexical route is still available, meaning that the phonological word form can be accessed. Conversely, surface dyslexia refers to the presence of poor exception word reading in the presence of good regular and nonword reading. Individuals with surface dyslexia may attempt to over-regularise exception words (for example, reading *have* as /heɪv/), signalling an overreliance on the sublexical route due to impairments in the lexical route (e.g., patient ‘MP’; Bub, Black, Hampson, & Kertesz, 1988).

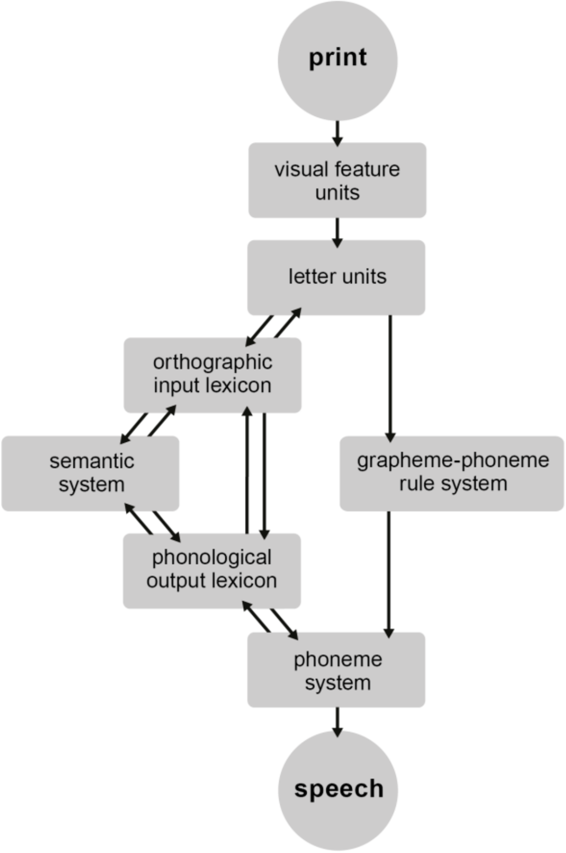

Figure 1.3. The dual-route cascaded model of reading, after Coltheart, Rastle, Perry, Langdon, and Ziegler (2001)

Proponents of an alternative connectionist approach argue that the binary separation of regular and exception words is misleading (e.g., Seidenberg, 2005). They propose instead that consistency of spelling-sound mappings in English varies along a continuum, and that the system is 'quasi-regular' because most exception words contain some level of regularity (Plaut, 1999; Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg, 2005). For example, in *yacht*, the *y* and *t* are pronounced according to usual spelling-sound principles. Within the connectionist framework, the triangle model (Harm & Seidenberg, 2004; Plaut et al., 1996; Seidenberg & McClelland, 1989), posits that word reading involves associations between orthography, phonology and semantics (see Figure 1.4.). These three sources of information are distributed across sets of units, and activation spreads along weighted connections between these units. Repeated activation across the same sets of units and backpropagation of error leads to adjustment of these weights, which corresponds to learning within the model. In this approach, lexical representations are not discrete units, but are generated through the weights of the connections, which determine how sets of units respond to a given input. A layer of hidden units between each component (orthography, phonology and semantics) functions to mediate more complex interactions between input units (Harm & Seidenberg, 2004).

According to the triangle model, associations between orthography, phonology and semantics are learned over the course of reading development, and reflect the statistical properties of the language input, resulting in an emergent 'division of labour' between a phonological pathway and a semantic pathway (Harm & Seidenberg, 2004; Plaut et al., 1996). The phonological pathway involves connections between orthographic and phonological information, and word reading via this pathway involves the conversion of letters into sounds (decoding) to access a word's pronunciation. In the semantic pathway, orthography activates word meaning (semantics), which subsequently activates pronunciation. Simulations of the triangle model have indicated that early on in reading development, words are likely to be read via the phonological pathway. As reading ability develops, there is increasing reliance on the semantic pathway. Additionally, exception words (e.g., *yacht*) rely more heavily on the semantic pathway because the phonological pathway will be less efficient for words that do not have regular spelling-sound correspondences. Thus, the relative contribution of the phonological and semantic pathway to word reading is modified by learning and is dependent on whether regular or exception words are read (see Taylor et al., 2015, for an overview).

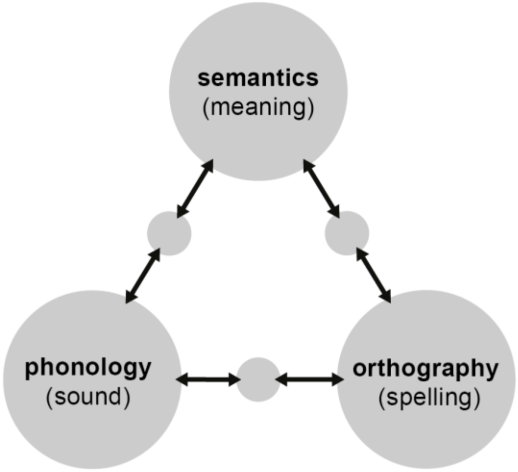

Figure 1.4. The triangle model of reading, after Harm and Seidenberg (2004)

Both the DRC and triangle model have limitations. A major drawback of the DRC is that it has no capacity for learning (Perry, Ziegler, & Zorzi, 2007). Unlike connectionist models, in which model architecture is learned through input based on a set of training stimuli, the DRC is a model of skilled reading behaviour, in which model architecture is pre-specified (although a grapheme-phoneme correspondence learning algorithm was successfully implemented in an early version of the model; Coltheart, Curtis, Atkins, & Haller, 1993). The triangle model, on the other hand, has been challenged on the basis that it shows poor performance on tasks such as nonword reading and lexical decision, and cannot account for serial effects seen in skilled readers (Coltheart, 2006; Perry et al., 2007; Rastle & Coltheart, 2006). A number of more recent computational models of reading have attempted to address some of these issues. The Connectionist Dual Process model (CDP+; Perry et al., 2007), and its later iteration the CDP++ (Perry, Ziegler, & Zorzi, 2010, 2013), combine many of the strengths of the DRC and triangle models, while the ST-DRC (Pritchard, Coltheart, Marinus, & Castles, 2018) adopts the DRC framework to simulate how children acquire orthographic knowledge. The latter will be summarised in more detail in relation to reading development in section 1.6.

The CDP+ (Perry et al., 2007) and CDP++ (Perry et al., 2010, 2013) are fundamentally dual-route models which include a connectionist network that is able to learn grapheme-phoneme correspondences (see Figure 1.5.). Building on the original CDP (Zorzi, Houghton, & Butterworth, 1998), which used a connectionist architecture within a dual-route framework, the CDP+ additionally incorporated the lexical route from the DRC (Perry et al., 2007). However, unlike the DRC's rule-driven grapheme-phoneme conversion process, the sublexical route of the CDP+ includes a two-layered connectionist network (the TLA network) which is able to learn grapheme-phoneme correspondences from the input. While orthographic input took the form of individual letters in the original CDP, the CDP+ instead adopts graphemes as input units, implemented through a graphemic buffer at the input level of the sublexical route. This modification was designed to improve performance on nonword reading tasks relative to its predecessor (Perry et al., 2007), although evidence suggests that it is still inferior to the DRC in producing nonword pronunciations that resemble those of human subjects (Pritchard, Coltheart, Palethorpe, & Castles, 2012).

A later iteration of the model introduced a grapheme parsing mechanism that was able to learn correspondences between letters and graphemes, and categorise graphemes as onsets, vowels, or codas (Perry et al., 2013). Like the DRC and triangle models of reading, the CDP+ is limited to the processing of monosyllabic words. This is a significant challenge for theoretical models of word reading, as the majority of words in English are multisyllabic (Heggie & Wade-Woolley, 2017; Yap & Balota, 2009). To address this, the CDP++ (Perry et al., 2010, 2013) extended the CDP+ model by incorporating additional features that allow it to process both monosyllabic and disyllabic stimuli. Most notably, stress nodes were introduced at the sublexical and output levels to allow the model the capacity to learn and assign stress appropriately based on graphemic input, one of the principal challenges for computational models of multisyllabic word reading (Ktori, Mousikou, & Rastle, 2018; Mousikou, Sadat, Lucas, & Rastle, 2017).

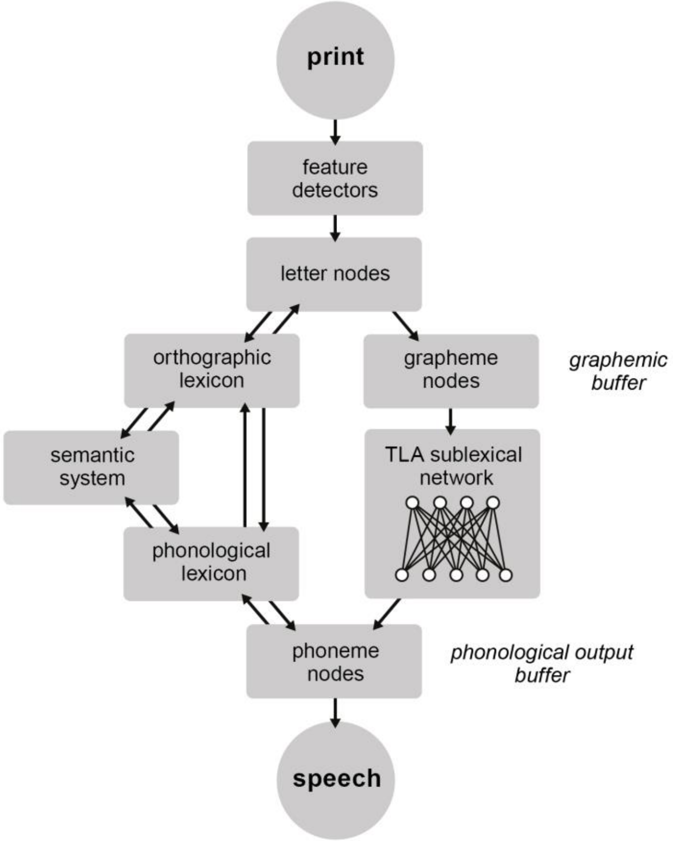

Figure 1.5. The connectionist dual process model of reading (CDP+), after Perry et al. (2007)

In summary, there is broad consensus across the key models of word reading that there are two pathways from print to meaning: one involves the conversion of graphemes into phonemes which activates word meaning, while the other involves direct activation of semantic knowledge from orthography. Because these models have predominantly focused on monosyllabic word reading (with the exception of the CDP++; Perry et al., 2010), processing of morphologically complex items has largely been ignored. However, a number of theoretical accounts have been proposed relating to the storage and activation of morphological knowledge during reading. The following section provides a summary of these different theoretical perspectives, and outlines the empirical case for the importance of morphological structure for lexical processing in skilled readers.

1.5. Morphological processing in skilled reading

The prominence of morphological regularity in the English writing system suggests that appreciation of morphological structure should be important for skilled reading. There is now considerable evidence that this is the case. Investigation of morphological effects in visual word recognition consistently reveals that morphemes are important units of processing, and that analysis of morphological structure occurs rapidly and automatically in skilled readers (for overviews see Amenta & Crepaldi, 2012; Rastle & Davis, 2008). However, the way in which morphological information is represented and accessed has been the source of much debate during this time. One of the most fundamental questions driving this debate is at what level of lexical processing morphemic representations are activated. Localist accounts of morphological processing can broadly be classified into one of three types: sublexical, supralexical and dual route (Baayen, Dijkstra, & Schreuder, 1997; Giraudo & Grainger, 2001; Taft, 2006; Taft & Forster, 1975). All propose that morphemes are activated as discrete units at some level of lexical representation, but differ in whether these units provide access to whole-word representations, or whether activation of morphemic units arises from whole-word access to complex items.

Sublexical accounts propose the former: morphemic units are activated in the initial stages of word recognition and prior to whole-word access (Crepaldi, Rastle, Coltheart, & Nickels, 2010; Rastle & Davis, 2008; Taft & Forster, 1975). Among the earliest researchers to adopt this approach, Taft and Forster (1975) argued that all complex words are stored in decomposed form in the lexicon, such that access to the stem provides a gateway for retrieval of the complex word. In this view, access involves isolating the stem by stripping it of its affixes prior to lexical retrieval. Taft (1994) later revised the affix-stripping component of this account, instead proposing that both stems and affixes form a level of morphological representation situated between orthographic input and whole-word orthographic representation in the context of an interactive-activation framework (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). In more recent adaptations, this morphological level is subsumed by a lemma level; an abstract (i.e. modality-independent) level of representation that mediates between orthographic input and semantic and syntactic information (the AUSTRAL model; Taft, 2006; Taft & Nguyen-Hoan, 2010 - see Figure 1.6.). As such, the lemma level captures correlations between form and meaning, but unlike connectionist accounts (see below), the absence of hidden units means that these relationships are hard-wired.

The lemma level in the AUSTRAL model is hierarchically structured, comprising lemmas for both complex words and their component morphemes. The pathway of activation within the lemma level is dependent on properties of the complex word. Items that are fully transparent (e.g., words containing regular inflections such as the plural *-s* in *cats*) are processed by activation passing from the decomposed morphemic units at the orthographic level to their corresponding lemmas (e.g., *cat* + *-s*). Recognition of such items proceeds directly from this activation without the need for a lemma corresponding to the whole word (Taft, 2015). For derived words, which are generally less semantically transparent, activation from lemmas representing component morphemes must first activate the whole word lemma before recognition can proceed, because the whole word lemma captures semantic and syntactic information that is not available directly from the combination of morpheme-level lemmas (Taft & Nguyen-Hoan, 2010).

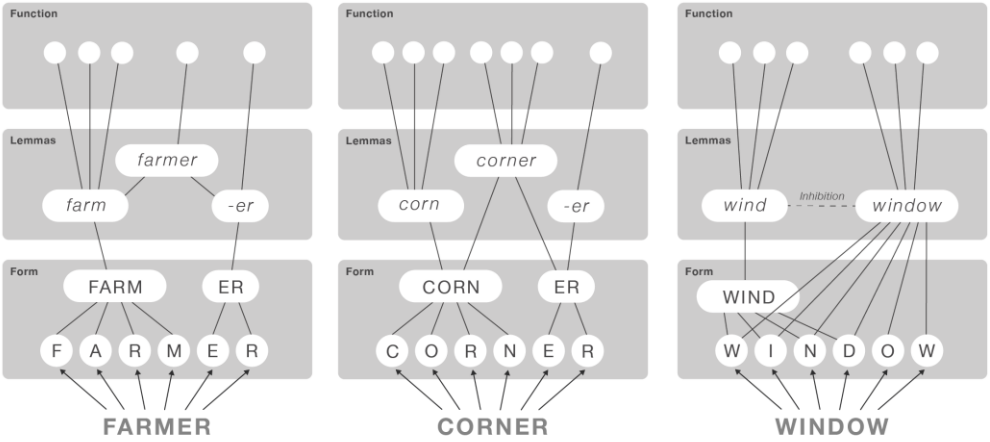

Figure 1.6. The AUSTRAL model, after Taft and Nguyen-Hoan (2010)

Thus processing of complex words takes place at two levels within the AUSTRAL model: firstly at an orthographic level, where complex words undergo obligatory decomposition into their constituent morphemes, and secondly at the lemma level, where activation from these orthographic units combines with feedback from the 'function' level representing semantic and syntactic information (for a similar account, see Crepaldi, Rastle, Coltheart, et al., 2010). This model also provides an account of how items that have a surface, or pseudomorphological, structure are processed. These terms are used to refer to words such as *corner*, which at a form level appear to combine a stem (*corn*) and an affix (*-er*), but which are nonetheless monomorphemic because their meanings are not derived from the meaning of the stem (Rastle, Davis, & New, 2004). According to Taft (2015), items with a pseudomorphological structure will be decomposed at the orthographic level, and these units will activate the whole word lemma directly as opposed to indirectly via lemmas corresponding to constituent morphemes. Recognition is the outcome of competitive activation between *corner* and *corn* at the lemma level, which favours the former because of the additional activation from the orthographic unit corresponding to -*er*.

Supralexical (or whole-word) accounts of morphological processing take a different standpoint, positing that morphological knowledge is activated at a postlexical level of processing (Butterworth, 1983; Giraudo & Grainger, 2001). Retrieval of the whole-word representation in response to either visual or auditory input leads to activation of its morphemic components (stem and affixes), which in turn activate all other words containing those components (Giraudo & Grainger, 2001). Therefore, contrary to sublexical accounts, morphological information is not represented at the form level, but instead resides at a more central level of the lexical processing system in the nature of modality-independent, abstract representations that group together morphological families within the mental lexicon (Giraudo & Voga, 2016).

This approach came to the fore in response to several cross-model and visible priming studies showing that decomposition was dependent on the semantic transparency of the complex word, providing support for the notion that whole-word information influenced morphological processing (Longtin, Segui, & Hallé, 2003; Marslen-Wilson et al., 1994; Rastle, Davis, Marslen-Wilson, & Tyler, 2000). However, fully supralexical accounts have since largely been abandoned because they fail to account for many of the morphological effects observed when readers respond to nonword stimuli (e.g., *quickify*; Longtin & Meunier, 2005; Meunier & Longtin, 2007), or to items with a pseudomorphological structure (e.g., *corner*) in the context of masked priming, which can only arise through sublexical analysis of morphological structure (this is discussed in more detail in relation to morpheme interference and masked priming effects in Chapters 2 and 3). Nonetheless, direct lexical access as an alternative to decomposition still has its place in models that adopt a dual-route, or hybrid, approach.

At their core, dual-route accounts propose that both whole-word retrieval and decompositional processes are involved in recognition of morphologically complex words. These models to some extent address issues relating to the graded nature of semantic, phonological and orthographic transparency across derived words, and can also account for how irregular or zero morph complex items (e.g., *grew*, *clean*) are processed (Vannest, Polk, & Lewis, 2005). However, dual-route theories differ in how they determine which items will undergo direct lexical retrieval, and which will be processed via the decomposition route. Some accounts propose that the two routes operate in parallel, such that the visual input activates both morpho-orthographic and morpho-semantic representations, with the former operating via sublexical units and the latter via whole-word representations (Diependaele, Sandra, & Grainger, 2005, 2009; Kuperman, Bertram, & Baayen, 2008). On this perspective, semantically transparent items are at an advantage because both routes are activated in parallel as opposed to just the morpho-orthographic route in the case of semantically opaque items.

Other dual-route models adopt a ‘race’ approach, in which both whole-word and morphemic representations are activated following input from a letter string, and lexical retrieval is the outcome of activation reaching a specified threshold via the fastest route (Baayen et al., 1997; Caramazza, Laudanna, & Romani, 1988; Schreuder & Baayen, 1995). In one such model, the Augmented Addressed Morphology (AAM) account (Caramazza et al., 1988), activation proceeds more rapidly via the lexical route, such that all known items will be processed in this way, while unfamiliar or novel words will be decomposed. In alternative models, the processing route is dependent on either the surface frequency of the complex word (Alegre & Gordon, 1999), or on the relative frequency of the complex word to its stem (Hay, 2001).

Connectionists take a very different perspective of morphological processing. They highlight the quasi-regular nature of morphological relationships caused by variation across items in formal and semantic transparency, and argue that morphemes should therefore not be viewed as discrete, localised units in the lexicon (Gonnerman, Seidenberg, & Andersen, 2007; Kielar & Joanisse, 2011; Seidenberg & Gonnerman, 2000). Instead, they propose that morphology reflects the co-activation of orthographic, phonological and semantic representations, and consequently, that processing of morphologically complex items proceeds via the same mechanism that handles monomorphemic words (Harm & Seidenberg, 2004). Rather than activation of morphological representations at a particular level of lexical processing (Giraudo & Grainger, 2001; Rastle & Davis, 2008; Schreuder & Baayen, 1995; Taft & Ardasinski, 2006), morphological relationships instead emerge from the overlapping patterns of activation among orthographic, phonological and semantic units, and they will therefore be graded depending on the strength of the correlations between them. A partially transparent word (e.g., *dresser*, which is low in semantic transparency) will result in weaker co-activation compared to a fully transparent word (e.g., *teacher*), and therefore observed morphological effects will also be weaker (Gonnerman et al., 2007). On this view, morphological representations do not correspond to localised knowledge, but rather are distributed across sets of orthographic, phonological and semantic units (Plaut & Gonnerman, 2000; Plaut & McClelland, 2000).

Distributed-connectionist accounts can explain graded effects of semantic transparency in priming (e.g., Gonnerman et al., 2007; Quémart, Gonnerman, Downing, & Deacon, 2017), but, as with supralexical accounts, they are challenged by evidence from masked priming studies, which show that pseudomorphological items such as *corner* prime their stems (*corn*; Rastle, Davis, & New, 2004). Some studies have found these priming effects to be statistically equivalent across morphological and pseudomorphological conditions (e.g., Lavric, Clapp, & Rastle, 2007; Longtin et al., 2003; Rastle et al., 2004); others have found greater morphological priming compared to pseudomorphological priming (e.g., Beyersmann, Castles, & Coltheart, 2012; Diependaele, Duñabeitia, Morris, & Keuleers, 2011). However, in both cases, priming for pseudomorphological pairs has been greater than that observed for pairs overlapping only in orthography (e.g., *freeze-free*), indicating that letter strings that are morphologically-structured are treated differently to non-morphemic letter strings, even in the absence of support from semantics. Importantly, connectionist accounts would predict that priming for pseudomorphological relatives should be no greater than that observed in items overlapping in form only (e.g., *freeze-free*) because correlations between semantic units and form units are equivalent across word pairs (for an alternative perspective, see Baayen, Milin, Rević, Hendrix, & Marelli, 2011).

The way that morphologically complex words are processed is thought to reveal something about how they are represented in memory and accessed during recognition (Taft, 2015). This has most commonly been investigated by manipulating certain properties of complex items and measuring effects on accuracy and reaction times during a lexical decision task, in which participants decide whether a visually-presented letter string is an existing word or not (Amenta & Crepaldi, 2012). Behavioural measures of lexical processing have been extended by priming the target item, and more recently by incorporating ERP, MEG or fMRI measures (Bick, Frost, & Goelman, 2010; Devlin, Jamison, Matthews, & Gonnerman, 2004; Fruchter & Marantz, 2015; Gold & Rastle, 2007; Lavric et al., 2007; Morris, Frank, Grainger, & Holcomb, 2007; Vannest, Newport, Newman, & Bavelier, 2011). Across the literature, there is strong evidence that morphological knowledge is activated during word recognition.

A robust finding in psycholinguistics is that high frequency words (i.e. words occurring more commonly in a language) are processed more rapidly than low frequency words (Becker, 1979; Brysbaert, Mandera, & Keuleers, 2018; Cleland, Gaskell, Quinlan, & Tamminen, 2006; Monsell, 1991). In the case of morphologically complex words, it is not just whole-word frequency that matters, but also the frequency of the stem, known as 'base frequency'. Measures of base frequency vary across the literature. In many earlier studies, researchers defined it as the summed frequency of inflected forms containing the stem (e.g., Alegre & Gordon, 1999; De Jong, Schreuder, & Baayen, 2000), whereas more recently it has been measured as the summed frequency across both inflected and derived forms (Xu & Taft, 2015; Vannest et al., 2011). These studies consistently reveal that complex words with a high base frequency produce faster response times than words with lower base frequency, even when items are matched on surface frequency (Amenta & Crepaldi, 2012; Taft, 1979; Vannest et al., 2011; Xu & Taft, 2015). This effect has been interpreted as evidence that complex words are parsed into their morphemic constituents during recognition, and stored in decomposed form in the lexicon (Taft, 1979 but cf. Giraudo, Dal Maso, & Piccinin, 2016).

Further investigation has identified several factors which constrain base frequency effects (Bertram, Schreuder, & Baayen, 2000; Ford, Davis, & Marslen-Wilson, 2010; Xu & Taft, 2015). For example, semantic transparency has been shown to modulate whether or not base frequency effects are observed (Xu & Taft, 2015). Words that are highly semantically transparent (e.g., *cleaner*) show stronger base frequency effects than words that are partially transparent (e.g., *bookish*), while words that are semantically opaque show no effect of base frequency (e.g., *badger*; Xu & Taft, 2015). These findings appear to undermine full decomposition accounts of morphological processing because according to this view, effects of semantic transparency should only emerge at a postlexical level of processing and therefore base frequency should influence processing irrespective of the semantic transparency of the item (Crepaldi, Rastle, Coltheart, et al., 2010; Rastle & Davis, 2008; Taft & Forster, 1975).

In response, Xu and Taft (2015) proposed an adapted version of the AUSTRAL model (detailed above) that can account for such effects of semantic transparency, while also maintaining a role for obligatory decomposition. They incorporated weighted activation and inhibition connections between lemma units that allow them to interact. These connections are sensitive to semantic transparency, such that two lemma units overlapping semantically (e.g., *farmer* and *farm*) will be connected by an excitatory link, whereas lemma units with a semantically opaque relationship (e.g., *corner* and *corn*) will be connected by an inhibitory link. In masked priming, the lemma corresponding to *farmer* will be activated along with its stem, *farm*, with activation passing between them via the excitatory link. The lemmas for *corner* and *corn* will also both be activated because *corner* is parsed at the orthographic level. However, because *corner* and *corn* share an inhibitory connection, activation of *corn* will quickly be suppressed. Thus, morphological effects of items bearing a pseudomorphological structure will be evident in the earliest stages of word recognition, but will rapidly fade. An important feature of the updated model is that because the connections between lemma units are weighted rather than binary, graded effects of semantic transparency can be captured. Therefore, items such as *dresser* or *lately*, which fall somewhere between *farmer* and *corner* on the continuum of semantic transparency, will have excitatory connections with their stems that are weaker than those between *farmer* and *farm*.

Aside from base frequency, the number morphological relatives of a given base (morphological family size) also influences lexical processing (De Jong et al., 2000; Giraudo & Dal Maso, 2016; Schreuder & Baayen, 1997). Stems with a high type frequency (appearing in many different morphologically complex words) are processed more rapidly than those with lower type frequency (see section 1.3. above for Reichle and Perfetti's [2003] computational implementation of morphological family size effects). However, Schreuder and Baayen (1997) pointed out that morphological family size is actually confounded with base frequency: the number of words containing a given base is likely to be correlated with the token frequency of that base. Subsequent investigation has provided evidence that base frequency effects can be separated from effects of morphological family size (De Jong et al., 2000; Ford et al., 2010; Xu & Taft, 2015). This has relevance for theoretical accounts of morphological processing because base frequency effects are thought to reflect sublexical morphological analysis (Ford et al., 2010; Taft, 2004; Xu & Taft, 2015), while effects of morphological family size are thought to arise at a more centralised level of lexical representation, interacting with whole-word and semantic knowledge and reflecting the influence of morphology on the organisation of the lexicon (Ford et al., 2010; Giraudo & Dal Maso, 2016; Schreuder & Baayen, 1997).

The strongest evidence in support of sublexical analysis of morphological structure comes from studies adopting a masked priming paradigm (as discussed above, and explored in more detail in Chapter 3), or nonword stimuli (e.g., Longtin & Meunier, 2005; Meunier & Longtin, 2007; discussed in Chapter 2). Masked primes have an advantage over cross-modal or visible primes because they are not available for conscious analysis, and therefore researchers can examine the factors involved in the very earliest stages of lexical processing (Forster & Davis, 1984). This is particularly important for testing the claim that all complex items are initially parsed into their constituent morphemes during visual word recognition (Rastle & Davis, 2008). Rastle et al. (2000) varied the stimulus onset asynchrony (SOA; or prime exposure duration) in the context of the priming paradigm to show that both semantically transparent (e.g., *farmer*) and opaque (e.g., *listless*) complex words primed their stems at the shortest SOA (43 ms), whereas priming at longer SOAs (72 ms and 230 ms) was only observed for semantically transparent items. Therefore, form-based decomposition of morphologically-structured letter strings occurs early in the time-course of word recognition, so capturing this process requires the prime to be presented very briefly and not consciously perceptible.

It is clear from the evidence outlined above that skilled readers are sensitive to the internal structure of complex words, and make use of morphemes during word recognition. While the representation of morphological knowledge and the way in which it is activated during lexical processing have been the subject of much debate over the last two decades, overall the evidence appears to favour a level of morphological representation that is defined by orthographic structure. The advantage of this is that provides rapid access to meaningful units within complex words (stems and affixes). While this may also result in unnecessary decomposition of items that do not provide access to meaning from their component morphemes (e.g., *corner*), these types of items do not occur very frequently in English (Rastle & Davis, 2008). In the remainder of this chapter, I will focus on the question of how readers come to acquire morphological representations that are rapidly activated during reading. I will start by outlining some of the key aspects of reading development before turning to the acquisition of morphological knowledge and the role it plays in the development of word reading.

1.6. Reading development

When children embark on the challenge of learning to read, they already have some knowledge of spoken language. This knowledge includes a partially developed phonological lexicon, semantic information and the mappings that connect the two. In the initial stages of reading acquisition in alphabetic languages such as English, children must learn to associate this existing phonological knowledge with novel orthographic information. In other words, they must learn that symbols representing letters correspond to sounds, and that this relationship is systematic and can be harnessed to access meaning (Byrne & Fielding-Barnsley, 1989). Secondly, they must learn how to decode. This requires the ability to translate orthographic units into phonological units, and blend these to form a word that may or may not already exist in their oral vocabulary. For example, a child will learn that the letter c can be pronounced /k/, the letter a as /æ/, and t as /t/ and by combining these sounds will retrieve the correct pronunciation when they read the word *cat*. At this stage of reading acquisition, grapheme-phoneme knowledge, phonemic awareness and RAN are important cognitive factors that are associated with the development of word reading skill (Hulme & Snowling, 2013).

The importance of these cognitive factors in early reading development is reflected in approaches to reading instruction. In the UK, reading is taught through systematic phonics instruction, which has received unequivocal support as the most effective approach for teaching children to read in English (e.g., Ehri, Nunes, Stahl, & Willows, 2001). Phonics instruction involves the explicit teaching of mappings between letters and sounds, and the ways in which sounds combine to form words (Duff, Mengoni, Bailey, & Snowling, 2014). With this system established, children should successfully be able to read regular words that follow these alphabetic principles and contain predictable spelling-sound mappings. Although phonics teaching is mandatory in the UK, it has been less widely adopted in other English-speaking countries (Castles et al., 2018; Washburn, Binks-Cantrell, Joshi, Martin-Chang, & Arrow, 2016).

Given the importance of phonics knowledge for early reading development, it is unsurprising that the vast majority of research has focused on children's phonological awareness, letter-sound knowledge and decoding skill (e.g., Hulme & Snowling, 2013; Melby-Lervåg, Lyster, & Hulme, 2012; Muter, Hulme, Snowling, & Stevenson, 2004). However, successful decoding is not the endpoint of learning to read. The process of converting orthographic units to phonological units letter-by-letter to retrieve meaning is effortful and inefficient. Although decoding still has a role in skilled reading (for example, when reading unfamiliar or low frequency words), once the foundations are established, children can begin to capitalise on larger orthographic units.

Ehri (1995, 2005a, 2005b) summarised the transition from the acquisition of basic alphabetic knowledge and decoding skill to the use of sight word recognition in her phase model of reading development. These phases were not intended to correspond to discrete stages of learning, or to represent a rigid developmental pathway that children follow. Instead they characterise the different sets of strategies and processes that children employ to retrieve meaning from text as their reading develops (Ehri, 2005a). In the earliest phase, the pre-alphabetic stage, children do not yet have any knowledge of the alphabetic system, and so any attempt at reading is achieved through the use of alternate strategies, such as associating general visual features with pronunciations or meaning. The partial alphabetic phase is characterised by an emerging understanding of letter names and grapheme-phoneme mappings. However, this knowledge is incomplete: not all grapheme-phoneme correspondences are familiar, so only partial decoding attempts can be made. By the full alphabetic phase, children's grapheme-phoneme knowledge is more complete. Unfamiliar words can be fully decoded, while some familiar words are now read as sight words: in other words, their pronunciations and meanings are automatically triggered without the need for decoding (Ehri, 2005a).

The final phase is the consolidated phase. Here, grapheme-phoneme connections are chunked into larger units, including syllables, morphemes and other commonly co-occurring letter units. Use of these larger orthographic units helps to facilitate fluent reading because it requires fewer connections for the word to become consolidated in memory. It is interesting to note that while Ehri highlights the role of morphemes as orthographic units that can be connected to pronunciations and meanings, she does not make a distinction between morphemes and other multi-letter units, despite the fact that morphemes encode meaning while syllables, onsets and rimes and other multi-letter units do not. Once orthographic mappings are formed, an item is retained in memory alongside its phonological and semantic features, such that it can subsequently be recognised by sight when encountered in texts.

In Ehri's view, reading development is characterised by a series of overlapping phases in which children make use of increasingly sophisticated strategies to form connections between orthographic units and phonological and semantic knowledge. Consolidation of these mappings in memory supports the development of sight word recognition. The transition from reliance on decoding strategies to recognising words directly from their printed form has been referred to in the literature as ‘orthographic learning’ (Castles & Nation, 2006; Nation, Angell, & Castles, 2007). While Ehri’s phase model examines how factors relating to the reader may contribute to this process, as discussed below, item-specific knowledge is also important.

According to Share's (1995, 2008) self-teaching hypothesis, decoding may itself play an important part in orthographic learning via acquisition of item-specific knowledge. Share argues that in the process of translating letters into sounds to retrieve a known spoken word form, children have the opportunity to focus on the word’s constituent letters and their sequence within the word. This contributes to the development of well-specified orthographic representations for those words, which can eventually be recognised rapidly and efficiently when they are encountered in print. Thus, decoding skill functions as a ‘self-teaching’ mechanism, both in the development of item-specific orthographic knowledge, and in the acquisition of more general knowledge regarding orthographic patterns and regularities in the language (Share, 1995).

One challenge for the self-teaching hypothesis is that, unlike many alphabetic languages, the English writing system is relatively opaque, meaning that spelling-sound mappings are often unpredictable (Share, 2008). English contains many examples of words that cannot be readily decoded, including some of the most commonly occurring words (e.g., *some*, *was*). These are known as exception or irregular words. However, even exception words contain partial regularities. In an example such as *yacht*, the word-initial and word-final consonants are pronounced in accordance with their typical orthography-phonology mappings, meaning that such words can be partially decoded (Share, 1995). In such instances of partial decoding attempts, Share suggests that the context in which the word occurs can be used to resolve ambiguity. This contextual information may be semantic, syntactic or pragmatic, although due to its often ambiguous nature, it is unlikely that context is used as the primary factor in self-teaching (Share, 1995). This proposal has received support from evidence demonstrating that context supports orthographic learning of irregular, but not regular, words (Wang, Castles, Nickels, & Nation, 2011).

Share’s self-teaching hypothesis has been highly influential for theories of reading development because it provides an account of how children independently acquire orthographic knowledge. While direct instruction is necessary for children to learn the mappings between graphemes and phonemes and to develop decoding skills in the early stages of reading development (Ehri et al., 2001), the number of unfamiliar words that children encounter in texts is vast (Nagy & Anderson, 1984), and clearly it is not possible to explicitly teach them all. Therefore, children must generalise their knowledge of spelling-sound correspondence rules, and use this to support independent learning of orthographic forms.

In recent years, Share’s self-teaching hypothesis has been instantiated in two computational models of reading acquisition: one based on the DRC (the ST-DRC; Pritchard et al., 2018), the other on the CDP+ (Ziegler, Perry, & Zorzi, 2014). Ziegler et al. (2014) adapted the CDP+ with the aim of examining how the reading system creates new entries in the orthographic lexicon based on knowledge of a small number of grapheme-phoneme correspondences and an existing phonological lexicon, in line with Share's (1995) claims. They demonstrated that the TLA network (see section 1.4. for an overview of the CDP+ architecture) decodes novel words by converting graphemic units into phonological units in line with a set of prespecified grapheme-phoneme correspondence rules. Where the resulting pattern of phonemes aligns with an existing item in the phonological lexicon (i.e. a successful decoding attempt), then the appropriate entry is activated. This sets up a direct link between the inputted letter string and the pre-existing phonological representation. In turn, activation of the phonological representation instigates the creation of a corresponding entry in the orthographic lexicon, representing the process of orthographic learning. In line with Share’s hypothesis, phonological decoding not only provides opportunities to acquire item-specific orthographic knowledge, but also allows readers to build knowledge of the orthographic system more generally. In the computational model, this learning takes place in the TLA network, as successful activation of an item in the phonological lexicon provides feedback which strengthens the weights on the connections within the network.

Ziegler et al. (2014) argue that the learning mechanism represented in their model offers a more realistic account of how children acquire orthographic knowledge compared to models in which feedback originates from an external source (as in the case of backpropagation of error in the triangle model, for example). While children learning to read may receive some explicit feedback on decoding attempts, as discussed above, this will not be the case for the majority of unfamiliar words that are encountered. Ziegler et al. (2014) also demonstrated that their model was flexible when it came to inaccurate decoding attempts because, although they observed a drop in performance, the model was still able to learn a good proportion of the items it processed.

The self-teaching hypothesis has also been implemented in the ST-DRC (Pritchard et al., 2018). The goal of this model was to specify more precisely how the interaction between phonological decoding and context might support orthographic learning (Pritchard et al., 2018). In this way, it incorporates an additional feature of the self-teaching hypothesis that is not explicitly explored in Ziegler et al.'s (2014) model: the role of context in supporting partial decoding attempts. The ST-DRC adopts the dual-route architecture of the DRC (Coltheart et al., 2001) as outlined in section 1.4., such that words are processed either via a lexical or a sublexical route. The sublexical route is used to model decoding, while orthographic learning is captured by the lexical route. Similarly to Ziegler et al.'s (2014) model, the ST-DRC incorporates a mechanism which allows the two routes to communicate. This takes the form of an interaction between phonological decoding information arising from the sublexical route, and semantic information arising from context.

The ST-DRC proposes that phonological decoding occurs when letter recognition activates corresponding phonemes, which in turn activate phonological representations of known words. It is this activation of a word in the phonological lexicon (i.e. spoken word recognition) that triggers orthographic learning. If the orthographic form of the word is entirely unknown, then a new orthographic node will be created in the orthographic lexicon (i.e. type-based learning). If the orthographic form has previously been encountered, then the relevant node in the orthographic lexicon will be activated, contributing to its consolidation in memory (i.e. token-based learning). In the case of irregular words (e.g., *yacht*), activation of phonemes from graphemes will not directly map onto an existing phonological representation because the correspondence between these units is not entirely rule-driven. In order for orthographic learning to proceed, the ST-DRC incorporates a mechanism by which contextual information can interact with sublexical information to activate phonological, and subsequently orthographic, representations.

The influence of context is modelled in the ST-DRC through the addition of a basic semantic layer, which comprises nodes representing all the words in a reader's spoken word vocabulary. These semantic nodes are directly linked to their relevant counterparts in the phonological lexicon via excitatory connections, whereas they have inhibitory connections with all other words in the phonological lexicon. Contextual information activates possible entries in the semantic layer at the same time that the printed form of the word excites the visual features layer of the sublexical route. Because nodes in the semantic layer are connected with nodes in the phonological lexicon, the relevant phonological form will be activated, while competitors will be suppressed. Thus, information from context (via the semantic layer) and decoding (via the sublexical route) interacts in the phonological lexicon to support word identification, which can then trigger orthographic learning. Through the implementation of this model, Pritchard et al. (2018) found that, unlike orthographic learning of regular words, learning of irregular words was dependent on the availability of contextual information, and performance was better when this was combined with sublexical information representing partial decoding than would be expected if recognition were to proceed from context alone.

One limitation of the ST-DRC, as the authors acknowledge, is that orthographic learning occurs after just one exposure to a novel word. Once the relevant entry in the phonological lexicon is activated, a new orthographic node is created along with its connections to the letter and phonological lexicon layers. However, evidence from readers suggests that orthographic learning is incremental, and evolves over the course of repeated exposures with the orthographic form (Castles, Davis, Cavalot, & Forster, 2007; Castles & Nation, 2006; Nation et al., 2007). The ST-DRC also adopts pre-specified grapheme-phoneme correspondence rules in contrast to Ziegler et al.'s (2014) model, in which learning of grapheme-phoneme consistencies is modelled via the TLA connectionist network. However, the combined strengths of these computational models provide a plausible account of the self-teaching hypothesis by outlining the mechanisms by which children use decoding and context to acquire item-specific orthographic knowledge.

It is clear that the progression from novice to expert reader is dependent on both individual-level factors (readers moving towards decoding strategies that adopt larger units of analysis; Ehri, 1995, 2005a, 2005b), and item-level factors (acquisition of item-specific orthographic knowledge; Share, 1995). Both relate in some way to a third factor: a reader’s experience with written language. The importance of experience is central to the lexical legacy hypothesis (Nation, 2017), which proposes that exposure to words in texts not only supports the consolidation of item-level knowledge, strengthening the quality of lexical representations (Perfetti, 2007; Perfetti & Hart, 2002), but also provides rich and semantically diverse contextual information which allows readers to make links with other words, and to acquire deeper and more refined lexical knowledge. Importantly, it is not just the frequency of encounters with a word in texts that drives word-level knowledge and efficiency of processing, but also the diversity of the contexts in which that word appears (Hsiao & Nation, 2018).

To summarise, in early reading development, the challenge for children is to acquire knowledge of letters and sounds, and to understand how the correspondences between them can be harnessed to access meaning from written text. Far less is understood about how children then go on to become skilled and efficient word readers, such that cognitive resources can be devoted primarily to text comprehension (Perfetti & Stafura, 2014). Share's (1995) self-teaching hypothesis offers some insight into how children acquire item-specific orthographic knowledge, but it does not address how this knowledge becomes fine-tuned and fully specified over time (Andrews & Lo, 2012; Castles et al., 2007). Because so much of the focus has been on early reading acquisition, theories of reading development have primarily been based on how children learn to read monosyllabic words. However, the types of words that skilled readers encounter in texts are overwhelmingly multisyllabic and morphologically complex (Heggie & Wade-Woolley, 2017; Yap & Balota, 2009). Therefore, an understanding of how morphological knowledge relates to reading development, and how developing readers process morphologically-structured items, is crucial in piecing together the mechanisms that underpin the development of skilled reading (Rastle, 2018; Verhoeven & Perfetti, 2003). Some theoretical accounts of reading development acknowledge that morphemes may be important units in the development of ‘orthographic mappings’ (Ehri, 2014), but they also have a special status in that they convey meaning. Rastle (2018) argues that, for these reasons, morphological knowledge may be particularly important in helping to establish a direct pathway from spelling to meaning.

1.7. The role of morphology in reading development

Children start to acquire morphological knowledge from an early age, before they learn to read (Berko, 1958; Brown, 1973). From around 1-2 years of age, children begin to combine free morphemes in their speech production in the context of phrasal utterances (e.g., '*push truck*'), while use of bound morphemes tends to emerge a few months later (Brown, 1973). The earliest acquired bound morphemes are inflectional, and tend to be inflections that occur frequently across a variety of lexical contexts (Bybee, 1995). For example, plural *-s* is typically one of the first bound morphemes that children use in speech, and it attaches to nouns, which are the most commonly used class of words in the early stages of language development (Waxman et al., 2013). Evidence that children learn the rules that govern the use of affixes in words comes from the observation that they show a U-shaped pattern of development, which sees accurate early use of irregular forms (because they have been rote-learned as individual items), followed by a period of over-regularisation as children incorrectly apply morphological rules to irregular items (e.g., producing *goed* instead of *went*). This is superseded by correct production again once children acquire the irregular form (Marcus et al., 1992).

Knowledge of derivational morphology develops over a more protracted period relative to inflectional morphology (Anglin, 1993; Breadmore & Carroll, 2016b; Carlisle, 1988; Deacon & Bryant, 2005; Nagy, Diakidoy, & Anderson, 1993). In a seminal study, Berko (1958) demonstrated that children between the ages of 4 and 7 years could generalise morphological rules to form inflections and compounds based on nonwords, but they had more difficulty using suffixes to create novel derivations. For example, in response to the item, "*this is a dog with quirks on him. He is all covered with quirks. What kind of dog is he? He is a _______ dog*", adult participants all responded with the adjectival derivative *quirky*. However, none of the children did, instead favouring a compound (e.g., '*quirk dog*'). There is considerable evidence to suggest that knowledge of derivational morphology in fact continues to develop into late adolescence (Anglin, 1993; Carlisle, 1988; Nagy et al., 1993; Nippold & Sun, 2008; Tyler & Nagy, 1989). This likely reflects the fact that derivational relationships are overall less semantically, orthographically and phonologically transparent than inflectional relationships (Verhoeven & Perfetti, 2011), and so understanding of derived words is more dependent on item-specific lexical knowledge. Additionally, there are only a limited number of highly productive inflectional affixes in English, while there are a much larger number of derivational affixes which vary more in productivity, an important factor in acquisition (Clark, 2014).

Just as inflectional affixes emerge in children's speech production over time, and generally tend to be acquired in a certain order, certain types of derivational affixes are usually mastered before others. Tyler and Nagy (1989) draw a distinction between neutral and nonneutral suffixes. Neutral suffixes tend to attach to free morphemes, and they form semantically and phonologically transparent complex words (i.e. they do not alter the stress or vowel quality of the stem to which they attach). Examples of these suffixes include *-er*, *-less* and *–ness*. Nonneutral suffixes frequently attach to bound morphemes, and create words that are more opaque both semantically and phonologically, often causing a shift in stress or a change in the vowel of the stem (e.g., *-ity*, *-ify*, *-ian*). Neutral suffixes are generally more productive than nonneutral suffixes because productivity correlates with many of the factors mentioned above, and therefore type and token frequency tends to be higher (Clark, 2014). For these reasons, neutral affixes are more salient in spoken language, and so children have more opportunity to recognise patterns of use across different contexts and subsequently to use them productively at an earlier stage of development.

Interestingly, the semantic properties of a given affix appear to matter more in early acquisition than formal properties. Affixes are polysemous: they take on a range of different meanings depending on context. For example, the suffix *-ise* means ‘to make more X’ in the context of *randomise*, but it means ‘to put into X’ in the context of *hospitalise* (Plag, 2003, 2004). Evidence suggests that children acquire some meanings of affixes before others. For example, agentive use of the suffix *-er* (e.g., *farmer*) emerges before instrumental use (e.g., *hanger*); similarly, the prefix *un-* is used to convey the reversal of an action (e.g., *unlock*) before it is used to create a negative adjective (e.g., *unhappy*; Clark, 2014; Clark, Carpenter, & Deutsch, 1995).

Given that children already have explicit knowledge of morphological regularities and are able to use some morphemes productively when they come to the task of learning to read, it is unsurprising that morphology plays an important part in literacy development. Knowledge of morphological regularities has been shown to be associated with spelling (Deacon, Kirby, & Casselman-Bell, 2009; Nunes, Bryant, & Bindman, 1997; Pacton, Foulin, Casalis, & Treiman, 2013), vocabulary (Anglin, 1993), word reading (Kirby et al., 2012; Kruk & Bergman, 2013; Nagy et al., 2006; Singson, Mahony, & Mann, 2000), and reading comprehension (Carlisle, 2000; Carlisle & Fleming, 2003; Kirby et al., 2012; Nagy et al., 2006). Before examining in more detail the links between morphological knowledge and reading development, it is worth noting that ‘morphological knowledge’ is a very broad term, and as a construct it has been measured using a multitude of different approaches. I use it here as an umbrella term to encompass the insight the reader has into morphological systematicities across the language, and their ability to perceive, manipulate and process morphemic units.

A more specific distinction is between explicit morphological knowledge and morphological processing (Bowers et al., 2010; Goodwin, Petscher, Carlisle, & Mitchell, 2015; Law, Veispak, Vanderauwera, & Ghesquiere, 2018; Nagy et al., 2014). Explicit morphological knowledge is generally measured through tasks that tap morphological awareness, in which readers consciously analyse and manipulate morphemes in words (Carlisle, 1995). Morphological processing refers to the way that implicit morphological knowledge is activated during lexical processing (Bowers et al., 2010; Breadmore & Carroll, 2016a; Goodwin et al., 2015; Nagy et al., 2014).

It is possible that even this distinction does not go far enough (Goodwin et al., 2015; Levesque et al., 2017). Measures of morphological awareness vary substantially across the literature (Deacon, Parrila, & Kirby, 2008). Most commonly these tasks are presented orally and require verbal responses (Carlisle, 2000; Deacon & Kirby, 2004; Kirby et al., 2012; Nunes et al., 1997; Wolter, Wood, & D'zatko, 2009), but there are also examples of tasks that use spellings to assess morphological knowledge (e.g., Wolter et al., 2009). Task demands and content also vary widely. Examples include analogy completion with single words (Kirby et al., 2012; Nunes et al., 1997) and sentences (Deacon & Kirby, 2004; Nunes et al., 1997), sentence completion using words (Carlisle, 2000; Wolter et al., 2009) and nonwords (Nunes et al., 1997), and judgement tasks (Carlisle & Nomanbhoy, 1993). Some focus on inflectional morphology, others on derivation, and most combine the two. Some make demands on syntactic knowledge (e.g., sentence completion tasks), others do not (e.g., analogy tasks). Across items, there is variation in semantic, orthographic and phonological transparency, which is also likely to influence performance (Carlisle, 2003). For example, in an analogy task using phonologically transparent forms (e.g., *farm*:*farmer* – *teach*:[teacher]), children could provide a correct response using a phonological analogy strategy, without activating morphological knowledge. Therefore, it is important for such tasks to also include a number of phonologically opaque items (e.g., *high*:*height* – *deep*:[depth]).

Despite the diversity of measures used to assess morphological awareness, as a construct it has consistently been shown to correlate with word reading and reading comprehension skill. Carlisle (2003) suggests that while children demonstrate implicit knowledge of morphology from an early age (as outlined above), explicit awareness of morphological relationships and morphological structure emerges a bit later, in the primary school years, at a time when children have acquired foundational decoding skills and are building their orthographic lexicon (Ehri, 1995, 2005a; Share, 1995). Children who have developed the ability to analyse morphological structure are at an advantage in the process of acquiring orthographic knowledge because they can infer cues to the spellings, pronunciations and meanings of unfamiliar complex words, all of which may assist them in linking novel orthographic forms to existing lexical representations (Carlisle, 2003; Carlisle & Fleming, 2003; Nagy & Anderson, 1984).

A challenge for researchers examining the relationship between morphological awareness and word reading has been to isolate the contribution of morphological knowledge over and above other linguistic skills. Performance on morphological awareness tasks is correlated with performance on a number of other measures (e.g., phonological awareness, vocabulary and non-verbal reasoning; Deacon & Kirby, 2004; McBride-Chang, Wagner, Muse, Chow, & Shu, 2005) that are also closely associated with word reading ability. Evidence obtained across a number of studies indicates that morphological awareness is associated with word reading skill even once some, or all, of these factors are taken into account (Deacon, Benere, & Pasquarella, 2012; Kirby et al., 2012; Kruk & Bergman, 2013; Kuo & Anderson, 2006; Mahony, Singson, & Mann, 2000; Nagy et al., 2006; Roman, Kirby, Parrila, Wade-Woolley, & Deacon, 2009; Singson et al., 2000). There is also accumulating research suggesting that this relationship is bidirectional (Deacon et al., 2012; Kruk & Bergman, 2013), and that it becomes stronger in the later primary school years (Singson et al., 2000).

The associations between these global measures of morphological awareness and word reading provide some evidence that morphological knowledge is an important component in reading development. However, they cannot shed light on how children come to acquire morphological representations that are activated *during* reading. In attempting to address this issue, researchers have increasingly begun to examine how developing readers process morphemes in real time in the context of online word reading and recognition tasks (Beyersmann et al., 2012; Burani, Marcolini, & Stella, 2002; Carlisle & Stone, 2005; Casalis, Quémart, & Duncan, 2015).

In one of the earliest studies to explore how tacit morphological knowledge might support word reading, Carlisle and Stone (2005) examined the impact of morphological structure on the speed and accuracy of word reading in 39 children aged 7 to 9 years and 33 children aged 10 to 12 years. They compared responses to disyllabic derived words (e.g., *hilly*) with responses to monomorphemic 'pseudoderived' words matched on number of syllables, spelling and word frequency (e.g., *silly*). Both age groups were more accurate reading aloud the derived words compared to the pseudoderived words, providing evidence that morphological structure facilitates word reading in readers as young as 7 years. Other studies have revealed similar findings (Burani, Marcolini, De Luca, & Zoccolotti, 2008; Carlisle & Katz, 2006; Colé, Bouton, Leuwers, Casalis, & Sprenger-Charolles, 2012; Deacon, Whalen, & Kirby, 2011; Laxon, Rickard, & Coltheart, 1992), but word naming as a measure depends on verbal output and is potentially subject to confounding factors such as articulation skill. Furthermore, as children become more independent readers, they increasingly read silently, and therefore word naming is less reflective of reading practices (Kim, Wagner, & Foster, 2011).

As such, online measures such as lexical decision or priming are better placed to capture the automatic processes underlying visual word recognition. This approach to examining morphological processing has not been as widely adopted in the developmental literature as it has in the adult literature, but a growing number of studies now show that children from the age of around seven years demonstrate sensitivity to morphological structure when processing complex words and nonwords (Beyersmann et al., 2012; Burani et al., 2002; Casalis, Dusautoir, Colé, & Ducro, 2009; Lázaro, Camacho, & Burani, 2013; Perdijk, Schreuder, Baayen, & Verhoeven, 2012; Quémart, Casalis, & Colé, 2011; Quémart, Casalis, & Duncan, 2012; Quémart et al., 2017). Specifically, in lexical decision tasks, the presence of a stem or a suffix, or a stem-suffix combination, speeds accuracy and reaction times to complex words, and impedes the classification of nonwords, resulting in lower accuracy and slower reaction times (the ‘morpheme interference’ effect, as detailed in section 1.5; Burani et al., 2002; Casalis et al., 2015; Quémart et al., 2012). Additionally, developing readers, like adults, appear to respond faster to words with a high base frequency (Lázaro et al., 2013), or a large morphological family size (Perdijk et al., 2012), although in both studies, these effects were found to be modified by language experience. Together, these findings lend weight to the idea that, from quite an early stage of reading development, children learn to make use of morphemes as units of recognition in words, and that their developing lexicons are organised on the basis of morphological principles.

Bolstering these conclusions is the fact that this evidence has been gathered from children speaking a variety of different languages. This serves to strengthen the argument that morphemes are important units of analysis across alphabetic languages. As noted in section 1.2., alphabetic languages vary in their orthographic depth (Katz & Frost, 1992; Share, 2008). In ‘deep’ orthographies, such as English, the relationship between graphemes and phonemes is less consistent than in ‘shallow’ orthographies, such as Italian or Finnish, and much of this inconsistency is driven by the preservation of morphology in spelling. It might be expected, then, that children learning to read English may rely more heavily on morphemes as cues to pronunciation than children learning to read in the context of shallow orthographies. However, there is strong evidence that developing readers process morphemic units even in languages such as Italian (Burani et al., 2008, 2002) and Finnish (Vainio, Pajunen, & Häikiö, 2018), supporting the view that morphology is integral to reading across the spectrum of alphabetic orthographies (Verhoeven & Perfetti, 2011).

Nonetheless, on closer examination, there is some evidence of cross-linguistic variation in morphological processing in developing readers that primarily relates to the characterisation of morphological representations. In recent years, the masked priming paradigm has been adopted to extend the investigation of morphological processing in younger readers, drawing on work previously conducted with adults (e.g., Beyersmann et al., 2012; Longtin et al., 2003; Quémart et al., 2011; Rastle et al., 2000, 2004). In the first study to implement this approach with children in the context of morphological processing, Casalis et al. (2009) investigated morphological priming in French-speaking children aged 9-10 years. Participants performed a lexical decision task on suffixed items that were primed by either a morphological relative (e.g., *BAIGNEUR – baignoire*), an orthographic relative (e.g., *BAISSE – baignoire*) or an unrelated control (e.g., *GRAVIER – baignoire*). Prime exposure duration was manipulated to capture both early (75 ms) and later (250 ms) stages of word recognition. The authors found evidence of both morphological and orthographic priming at 75 ms, which was statistically greater than priming in the unrelated condition. At 250 ms, priming was observed only in the morphological condition, and not in the orthographic or unrelated conditions.

Casalis et al. (2009) concluded that the diverging timecourses of morphological and orthographic effects provided evidence that morphological knowledge forms a distinct level of representation in the visual word recognition system that can be separated from the effects of orthographic similarity. While this concurs with conclusions drawn elsewhere (e.g., Rastle et al., 2000), most priming studies with skilled readers show morphological effects that are distinct from orthographic effects even in the early stages of word recognition (e.g., Longtin et al., 2003; Rastle et al., 2004). Casalis et al.'s (2009) finding that morphological priming is indistinguishable from orthographic priming at 75 ms in children could reflect developmental differences, but may also be constrained by a number of methodological limitations. For example, items varied in orthographic overlap between conditions: the target and morphological prime shared a stem, while the orthographic prime did not. Within the orthographic condition itself, there was variation in the degree of orthographic overlap between primes and targets. Because prime duration was manipulated between-subjects, only 26 children participated in the 75 ms condition and 27 in the 250 ms condition. Although these groups were matched on morphological awareness, this was not reported in any detail, leaving open the possibility that the divergent pattern of findings across prime durations was confounded with group differences in morphological or orthographic knowledge. Finally, the absence of a pseudomorphological condition limits the extent to which conclusions can be drawn regarding the nature of morphological representations in developing readers.

Subsequent studies with French developing readers have addressed many of these limitations (Beyersmann, Grainger, Casalis, & Ziegler, 2015; Quémart & Casalis, 2015; Quémart et al., 2011). The pattern that emerges is that, from around the age of 8 years, these children show evidence of both morphological and pseudomorphological priming early on in the timecourse of word recognition, which is distinct from priming observed when prime and target overlap only in orthographic or semantic properties. In the later stages of word recognition, lexical processing is increasingly influenced by the semantic properties of morphemes (Quémart et al., 2011). These effects may be moderated by the phonological and orthographic transparency of the prime (Quémart & Casalis, 2014), and by reading ability (Quémart & Casalis, 2015). On the other hand, English-speaking children appear to rely more on the semantic properties of morphemes when they process complex words. Beyersmann et al. (2012) found that children aged 8-11 years showed priming for word pairs sharing a morphological relationship (e.g., *farmer* – *FARM*), but, unlike the French children in Quémart et al.'s (2011) study, not those sharing a pseudomorphological (*corner* – *CORN*) relationship.

Why might pseudomorphological priming be observed in French, but not English, developing readers? Part of the explanation may arise from differences in linguistic experience. French has a rich system of derivational morphology, while morphology in English is considered to be comparatively sparse (Duncan, Casalis, & Colé, 2009; Lignos & Yang, 2016). This is reflected in patterns of production in early language development. French-speaking children use a range of derivational affixes productively from a young age, whereas English-speaking children tend to favour compounding (Fejzo, Desrochers, & Deacon, 2018). Duncan et al. (2009) also highlight differences in lexical stress: in French, stress consistently falls on the final syllable of a word, whereas in English this pattern is less common. This means that in spoken language, suffixes will commonly be stressed in French and not in English, and they are therefore likely to be more perceptually salient. A small number of cross-linguistic studies directly comparing the development of derivational morphological knowledge in English and French have revealed differences in both morphological awareness (Duncan et al., 2009) and morphological processing (Casalis et al., 2015). Duncan et al. (2009) found that French children had knowledge of a broader range of suffixes and were better at producing both existing and novel derived forms of a given stem than English children matched on level of formal education (Experiment 1) and age (Experiment 2). Casalis et al. (2015) investigated online word and nonword recognition in English and French children aged 7 to 10 years. Using a lexical decision task, they showed that while the presence of morphemes supported recognition of words and impeded the ability to reject nonwords in all children, this emerged across accuracy and response latencies for French children, but only in accuracy for English children.

These insights into cross-linguistic variation are important for two reasons. First, much of the more recent literature on morphological processing in developing readers has involved French-speaking children, in part for the reasons outlined above (Beyersmann, Grainger, et al., 2015; Quémart & Casalis, 2014, 2015). Secondly, these differences highlight the importance of linguistic experience in the acquisition of morphological knowledge. It is less clear how children use this information to form morphological representations that are then activated during explicit and online processing tasks. On one perspective, Rastle and Davis (2008) suggest that once children can read, sensitivity to the probabilities of letter combinations either within or across morphemic boundaries may support the identification of morphemic units in the orthographic input. For example, the word *helpful* contains a low frequency bigram at the morphemic boundary (*pf*), which may function to highlight the point of division between stem and suffix. Equally, the letter combinations that form affixes (e.g., -*ful*) have a high probability of sequential co-occurrence, such that over the course of repeated exposures, children may learn to group these sequences of letters into a single coherent unit.

These accounts involve bottom-up, statistical learning processes which relate specifically to the development of morpho-orthographic representations. Other approaches emphasise the importance of morpho-semantic knowledge. As previously noted, children demonstrate sensitivity to morphological regularities before they learn to read. It seems plausible, then, that they might capitalise on this existing knowledge when encountering morphemes in written language. Schreuder and Baayen (1995) proposed that as a child's vocabulary knowledge grows, they are increasingly exposed to form-meaning regularities across words sharing an affix (e.g., *farm<u>er</u>* is a person who farms, *teach<u>er</u>* is a person who teaches). Based on these regularities, children develop a conceptual representation of the affix (agent that performs the action), and subsequently build an association between that conceptual representation and the letter string that represents it (-*er*), culminating in a form-based 'access representation' (Rastle & Davis, 2008, offer a similar account).

Evidence does suggest that morphological representations are accrued and refined over time. While children show evidence of explicit morphological knowledge and sensitivity to morphological structure during reading, the way in which they process complex words does not always parallel morphological processing in skilled readers. Beyersmann et al. (2012) used a masked priming paradigm with English-speaking developing readers aged 8-11 years and a group of adult controls. They included the three conditions adopted by Rastle et al. (2004): a morphological condition, in which targets are primed by a true morphological relative (e.g., *toaster – TOAST*), a pseudomorphological condition involving word pairs that have the appearance of a morphological relationship (e.g., *corner – CORN*, in which *-er* is an English suffix, but prime and target do not share a semantic relationship) and a form condition, in which prime and target overlap only in orthography (e.g., *freeze – FREEZE*, in which *-ze* is not an English suffix). While their adult controls demonstrated the typical pattern of morphological and pseudomorphological priming in the absence of priming in the form condition, their developing readers only showed priming effects for word pairs sharing a true morphological relationship. These findings suggest qualitative differences in the properties of morphemes that are activated by developing and skilled readers during lexical processing, and possibly point to underlying differences in how morphological information is represented in memory.

As discussed above, French developing readers in Quémart et al.'s (2011) study did show evidence of priming in the pseudomorphological condition, as did their adult controls. Nevertheless, differences emerged in the timecourse of word recognition. At a 60 ms prime duration, both developing and skilled readers showed morphological and pseudomorphological priming; at 250 ms, skilled readers no longer showed pseudomorphological priming, but developing readers did, albeit to a lesser magnitude than morphological priming. Quémart et al. (2011) concluded that although the pattern of priming was similar across developing and skilled readers, the semantic properties of morphemes influenced processing at an earlier stage of word recognition for skilled readers.

Similarly, Quémart and Casalis (2014) showed that in the early stages of word recognition (using a 60 ms prime), processing of complex words in developing readers was affected by either phonological (e.g., *bergerie – BERGER*) or combined phonological and orthographic (e.g., *soigneux – SOIN*) shifts in the stem, whereas adult readers processed these items in the same way that they processed fully transparent items (see also McCormick, Rastle, & Davis, 2008, who similarly found that skilled readers of English were not affected by orthographic shifts in the stem). Later on in the timecourse of word recognition (250 ms), phonological and orthographic shifts did not affect processing in either skilled or developing readers. In line with Quémart et al. (2011), Quémart and Casalis (2014) proposed that these divergent findings reflect an early reliance on form-level properties in morphological processing in developing readers, followed by a later influence of semantics. When these form-level properties are obscured by phonological or orthographic shifts in the stem, decomposition of the complex item is impaired. Once morpho-semantic information is activated, this can supplement morpho-orthographic processing, leading to morphological effects in shift words at 250 ms. Quémart and Casalis (2014) argue that because semantic properties of morphemes are activated at an earlier stage of recognition in skilled readers, they process phonologically and orthographically opaque items in the same way as transparent items even at 60 ms. However, this conclusion somewhat contradicts the findings of Quémart et al. (2011). If adults are sensitive to the morpho-semantic properties of complex words at 60 ms, then differences should emerge at this time point between morphological and pseudomorphological priming, yet Quémart et al. (2011) observed equivalent priming across these two conditions in both their developing and skilled readers.

In summary, developing readers demonstrate sensitivity to morphological regularities early in language development, before they learn to read. However, it is not long before evidence of morphological knowledge also emerges in reading behaviour. From around the age of 7 years, morphological structure facilitates reading aloud (Carlisle & Stone, 2005), and children’s performance in online lexical processing tasks indicates that morphemes form important units of recognition (e.g., Beyersmann et al., 2012; Burani et al., 2002; Casalis et al., 2015). Nevertheless, the vast majority of research examining morphological knowledge in developing readers has focused on children’s explicit awareness of morphological structure, and their ability to analyse and manipulate morphemes in words. While these skills have been shown to relate to both word reading and reading comprehension (Carlisle & Fleming, 2003; Kirby et al., 2012; Kruk & Bergman, 2013), this approach does not directly address the question of how children use morphological knowledge in the process of reading. Studies that have started to examine online morphological processing in developing readers reveal some cross-linguistic inconsistencies (Beyersmann et al., 2012; Casalis et al., 2015; Quémart et al., 2011). Crucially, it is clear that morphological processing in developing readers differs on certain dimensions to morphological processing in skilled readers (Beyersmann et al., 2012; Hasenäcker, Beyersmann, & Schroeder, 2016; Quémart & Casalis, 2014; Quémart et al., 2011); exactly what those dimensions are remains to be determined.

These gaps and inconsistencies reveal the need for a coherent overview of morphological processing across the course of reading development. Such an approach would permit exploration of how and when children develop morphological representations that are activated rapidly and efficiently during reading, as well as helping to identify the properties of morphemes that they attend to as they build these representations. A primary aim of this thesis is to therefore to characterise the development of morphological processing using a cross-sectional approach with children, adolescents and adults.

1.8. Adolescence

Adolescence represents a period of transition and maturation across cognitive, behavioural, social, biological, physical and emotional domains (Ben-Shachar, Dougherty, Deutsch, & Wandell, 2011; Blakemore, 2008; Blakemore & Robbins, 2012; Dumontheil, Apperly, & Blakemore, 2010; Yurgelun-Todd, 2007). It is surprising, then, that such scant attention has been paid to the development of language and literacy skills during this time. Adolescents continue to accrue and refine their linguistic knowledge across a number of areas, including verbal reasoning, understanding and use of figurative language, morphosyntax, and vocabulary (Nippold, 2000, 2007). Neuroimaging data also indicate that the areas of the brain involved in the ventral pathway for reading, associated with direct mappings between orthography and semantics, continue to develop into mid-adolescence (Ben-Shachar et al., 2011). Recent diffusion MRI data also indicate that microstructural properties of the ventral pathway are associated with morphological processing in skilled readers (Yablonski, Rastle, Taylor, & Ben-Shachar, 2018).

The literature reviewed in this chapter provides convincing evidence that knowledge of morphology contributes to the development of skilled word reading. According to Rastle (2018), appreciation of morphological regularities may play a part in establishing a direct pathway from spelling to meaning, leading to rapid and efficient word recognition. From the perspective of the lexical quality hypothesis (Perfetti & Hart, 2002), morphology provides a unique link between form and meaning which may function to strengthen the connections between orthographic, phonological and semantic representations (Reichle & Perfetti, 2003). On both accounts, accumulated exposure to morphological regularities is imperative. To capture developmental changes, it is therefore necessary to examine morphological processing in adolescent readers. Aside from a small number of studies (e.g., Beyersmann et al., 2012; Hasenäcker et al., 2016; Quémart & Casalis, 2014; Quémart et al., 2011), the literatures on morphological processing in developing and skilled readers have been largely separate. In research that has taken a cross-sectional approach, the age range of developing readers is restricted, with almost all limited to children up to the age of 12 years. The overarching aims of this thesis, outlined below, align with an emerging consensus that the transition from novice to skilled reader is currently underspecified and poorly understood (Castles et al., 2018).

1.9. Overview and aims of thesis

The primary aims of this thesis are to a) examine the developmental trajectory of morphological decomposition in visual word recognition in children, adolescents and adults (Chapter 2); b) determine the mechanisms of morphological decomposition in developing readers and investigate how these evolve in line with reading experience (Chapter 3); and c) provide an initial examination of the contribution of morphological knowledge to the development of high quality lexical representations (Chapter 4).

Chapter 2 reports a cross-sectional study investigating the morpheme interference effect in 50 children aged 7-9 years, 37 younger adolescents aged 12-13 years, 36 older adolescents aged 16-17 years, and 33 adults. This task was adopted based on the hypothesis that interference in the rejection of morphologically-structured nonwords provides evidence of morphological decomposition at the sublexical level (Crepaldi, Rastle, & Davis, 2010; Taft & Forster, 1975). Given clear evidence of morphological analysis in visual word recognition in skilled readers (Rastle & Davis, 2008), it is predicted that the morpheme interference effect will be observed in adult readers through lower accuracy and slower reaction times to morphologically-structured nonwords (e.g., *earist*) compared to matched control items (e.g., *earilt*). Evidence of a similar pattern of findings in developing readers would indicate that word recognition processes are similarly attuned to morphological structure from an early stage in reading development. However, while children show knowledge of morphological regularities from an early age (e.g., Berko, 1958), it is less clear whether this knowledge is activated during online processing tasks.

Chapter 3 builds on the aims of Chapter 2 by evaluating whether developing readers capitalise on orthographic properties of morphemes when decomposing complex words, or whether decomposition is dependent on semantic properties. As outlined in section 1.5., skilled readers show evidence of morpho-orthographic decomposition in the earliest stages of word recognition, meaning that morphological effects are observed in items with a surface morphological structure (e.g., *corner*). In section 1.7., I considered the evidence for this effect in developing readers in the context of masked priming studies. On the one hand, Quémart et al. (2011) found equivalent priming for morphological and pseudomorphological relatives in French children aged 8-12 years; on the other, Beyersmann et al. (2012) found evidence of morphological priming only in English-speaking children.

The study reported in Chapter 3 adopts a masked priming paradigm using the stimuli created by Beyersmann et al. (2012) to allow for direct comparisons between studies. The aim was to examine the evidence for changes in mechanisms of morphological decomposition across reading development. Children (*n*= 48), younger adolescents (*n* = 57), mid adolescents (*n* = 48), older adolescents (*n* = 51), and adults (*n* = 52) completed a visual masked prime lexical decision task using three sets of prime-target pairs: morphological (e.g., *toaster – TOAST*), pseudomorphological (sharing an apparent morphological relationship in the absence of a semantic relationship, e.g., *corner – CORN*), and form (sharing an orthographic relationship only, e.g., *freeze – FREE*). Patterns of priming across conditions will be used to indicate the underlying mechanisms by which readers at different stages of reading development segment complex words into their component morphemes.

Chapter 4 investigates the hypothesis that morphological information supports the formation of high quality lexical representations. The study reported in this chapter adopts a novel word learning paradigm, in which younger (*n* = 39) and older (*n* = 39) adolescents were taught definitions of 18 nonwords comprising a nonword stem and an existing suffix (e.g., *clantist*). Half of the definitions were semantically and syntactically congruent with the suffix; the other half were incongruent. Teaching of the mappings between orthography, phonology and semantics took place across two sessions spaced one week apart. Following the second session, online and offline post-tests were conducted to measure learning. Stronger performance in the congruent condition would provide evidence that the semantic and syntactic properties of the suffix directly contributed to the formation of lexical representations.

Together, chapters 2 to 4 explore the hypothesis that morphological knowledge contributes to lexical processing and lexical knowledge. This is achieved by directly examining morphological processing during word recognition (Chapters 2 and 3), and by investigating the role of morphology in the development of lexical representations (Chapter 4), in line with the hypothesis that high quality lexical representations support efficient word recognition (Perfetti & Hart, 2002; Perfetti & Stafura, 2014). From a theoretical perspective, the work reported here addresses important questions regarding the nature and development of morphological knowledge in childhood and adolescence (Rastle & Davis, 2008; Schreuder & Baayen, 1995). Empirically, it contributes to a vastly under-researched period of reading and language development by characterising the role of morphology in reading across adolescence. Finally, it aligns with current concerns in the field of reading research by shedding some light on the factors underpinning the transition from novice to skilled reader.

CHAPTER TWO

Morphological Effects in Visual Word Recognition

2.1. Introduction

This chapter examines whether visual word recognition in developing readers is characterised by rapid analysis of morphological structure as it is in adult readers (see Chapter 1 for an overview). Specifically, a lexical decision task was used to investigate the morpheme interference effect in children, adolescents and adults with the aim of addressing the first research question of this thesis: Do developing readers automatically decompose morphologically structured items during visual word recognition? In adopting a cross-sectional approach across this age range, the study reported in this chapter brings together the developmental and adult literature on morphological processing, which until now has largely been approached separately.

2.1.1. Morphology in reading development

As discussed in Chapter 1, the ability to recognise words rapidly and automatically is fundamental for skilled reading. Research on reading acquisition has focused primarily on the influence of phonological processing because this is a crucial skill that unlocks the mappings between orthographic and phonological units, allowing children to decode words independently (Melby-Lervåg et al., 2012). However, there is also growing evidence that semantics (see Taylor, Duff, Woollams, Monaghan, & Ricketts, 2015 for a review) and morphology (Carlisle & Stone, 2005; Mahony et al., 2000) have an important role to play, particularly once initial decoding skills are established. Morphological knowledge is a broad construct and it is likely that the contribution it makes to reading development is manifold (Nagy et al., 2014). As discussed in the previous chapter, much of the research investigating this relationship has focused on associations between morphological awareness and reading ability (e.g., Deacon & Kirby, 2004; Kirby et al., 2012; Kruk & Bergman, 2013). However, these findings cannot explain how and when this knowledge becomes activated automatically during reading. Addressing this question requires measurements that provide insight into morphological processing in real time, and an approach that encapsulates a broad age range. This chapter reports the first study to track online morphological processing from childhood, through adolescence and into adulthood.

Despite evidence that the contribution of morphological knowledge to reading increases beyond the age of 9-10 years (Singson et al., 2000), studies investigating the influence of morphology on word recognition in adolescence are extremely scarce. Yet, characterising morphological processing during this period may be key to understanding how morphology supports the transition from decoding to rapid word recognition. English spellings represent morphemic as well as phonemic units, so knowledge of morphology can help to resolve some of the apparent irregularities in the mappings between phonology and orthography and contribute to efficient recognition of complex words (Nagy, Berninger, & Abbott, 2006). This may be particularly important once knowledge of grapheme-phoneme correspondences is consolidated, as these connections can be chunked into larger units such as morphemes (Ehri, 2005b). As children move through the education system, the types of words they encounter increasingly comprise multiple, and often layered, morphemic units (Nagy & Anderson, 1984; Nagy & Townsend, 2012). Therefore, recognition of morphologically complex words becomes progressively more important for learning through reading and access to the curriculum.

2.1.2. Morphological effects in skilled reading

Chapter 1 presented an overview of the evidence that morphemes are important units of analysis when skilled readers process words and nonwords. The way that readers respond to morphologically-structured nonwords (e.g., *earist*) poses an interesting question for competing theoretical accounts of how morphological information is represented in the lexicon and accessed during recognition. To recap, these theories broadly fall into one of three camps: the first argues that complex words are automatically decomposed prior to lexical access (the sublexical approach - Rastle & Davis, 2008; Taft, 2004; Taft & Forster, 1975), the second holds the view that morphological structure is analysed once whole-word lexical access has occurred (the supralexical approach; Giraudo & Grainger, 2001), while the third posits a parallel dual-route process, in which both whole-word access and decomposition are available (Baayen et al., 1997; Diependaele et al., 2005, 2009). Evidence of morphological effects arising from nonword stimuli is problematic for supralexical accounts in particular because, by definition, nonwords are not represented in the lexicon and therefore morphological analysis of these items must occur prelexically rather than postlexically (Amenta & Crepaldi, 2012; McCormick, Brysbaert, & Rastle, 2009, but cf. Giraudo & Dal Maso, 2016).

It is clear from the literature with skilled readers that morphologically-structured nonword items are subject to morphological analysis in addition to complex words. In a seminal study, Taft and Forster (1975) showed that nonwords comprising combinations of existing prefixes and stems (e.g., *dejuvenate*) were more difficult to reject in a lexical decision task than nonwords with existing prefixes and novel stems (e.g., *depertoire*), evidenced by increased response latencies and errors. This ‘morpheme interference effect’ was taken as evidence that morphological decomposition occurs prior to lexical access, as longer response latencies for nonwords like *dejuvenate* reflect the additional process of checking the legitimacy of the prefix-stem combination once the stem has been isolated and identified. For novel stems (e.g., *pertoire*), this step is unnecessary as no lexical entry is found. Interestingly, decomposition effects were observed even though the stimuli were created using bound stems (*juvenate* does not stand alone as a word), which according to some accounts are less likely to undergo decomposition than complex items with a more transparent morphological structure (Giraudo & Voga, 2016, but cf. McKinnon, Allen, & Osterhout, 2003). The morpheme interference effect has been replicated in several other languages, including Italian (Burani, Dovetto, Thornton, & Laudanna, 1997; Caramazza et al., 1988), French (Casalis et al., 2015), and Hebrew (Yablonski & Ben-Shachar, 2016).

2.1.3. Morphological processing in developing readers

Despite the wealth of evidence that skilled adult readers automatically decompose morphologically-structured words and nonwords, few studies have addressed online visual processing of complex words in developing readers. This is important to inform theories of visual word processing in relation to morphology, and to establish the developmental trajectory of automatised morphological knowledge. Children from around seven years of age demonstrate that they are aware of, and can manipulate, morphemes in words (e.g., Carlisle, 2003; Kirby et al., 2012; see Chapter 1, section 1.7.). There is also evidence that even young readers capitalise on morphological structure in their reading (Burani et al., 2008; Carlisle & Stone, 2005; Laxon et al., 1992). In recent years, researchers have increasingly turned to online paradigms to investigate morphological decomposition in developing readers, but findings have been mixed (Beyersmann et al., 2012; Burani et al., 2002; Casalis, Dusautoir, Colé, & Ducrot, 2009; Casalis, Quémart, & Duncan, 2015). Evidence from masked priming suggests that English children aged 7 to 10 years do not ‘blindly’ decompose words that appear to have a morphological structure as adults do (Beyersmann et al., 2012), but studies with 8-, 10- and 12-year old French children (Quémart et al., 2011) and 12-year old Hebrew-speaking children (Schiff, Raveh, & Fighel, 2012) have provided some evidence for morpho-orthographic decomposition.

Several studies with nonwords have observed differences in how children respond to stimuli with versus without morphological structure. For example, Burani et al. (2002) used a lexical decision task with Italian children aged 8, 9 and 10 years and a group of adult controls, and found that accuracy was lower for morphologically-structured nonwords compared to nonmorphologically-structured nonwords in all groups, providing some evidence of a morpheme interference effect in children. Importantly though, stimuli across the two nonword conditions were poorly matched, with embedded stems present only in the morphological condition (for example, *mammista*, the equivalent of *motherist* in the morphological condition was matched with *memmosto*, containing a nonword stem, in the nonmorphological condition). It is therefore unclear whether lower accuracy in the morphological condition was due to interference from the suffix, in line with previous findings (e.g., Crepaldi et al., 2010), or due to recognition of an existing stem. In the present study, stimuli were closely matched by adopting morphological and nonmorphological nonwords that share an existing stem.

As discussed in Chapter 1, section 1.7., the influence of morphological structure on children's processing of words and nonwords has been demonstrated using online tasks in several languages such as French (Quémart et al., 2012), Spanish (Lázaro et al., 2013), Dutch (Perdijk et al., 2012) and Italian (Burani et al., 2002), but there is variation in how this effect emerges. For example, in lexical decision tasks involving real words, the presence of a stem slows word recognition in English but not French children, leading to the suggestion that English children are sensitive to embedded words while French children respond to the combination of morphological units (Casalis et al., 2015). In Spanish, complex words containing high frequency bases were recognised more quickly than those with low frequency bases, but this effect did not emerge in accuracy and was only seen in the most skilled readers (Lázaro et al., 2013). On the contrary, Perdijk et al. (2012) only found facilitatory effects of morphological family size on word recognition in less skilled readers.

The lexical decision task reported by Casalis et al. (2015) offers some insight into the activation of morphological representations during reading in English-speaking children, and how this might differ from children learning to read in a derivationally rich language such as French. However, while they report that their real word stimuli were matched for frequency, length and suffixes across languages, they do not state whether they accounted for variation in orthographic familiarity between the nonwords with and without suffixes. This leaves open the possibility that the morphologically-structured nonwords were simply more ‘wordlike’ due to other factors, such as greater orthographic neighborhood size (Perea, 2000). Furthermore, across both nonword types there was inconsistency in orthographic transparency. For example, the nonword *namy* combined the root *name* with the suffix *y* (orthographic shift), yet other items (e.g., *waitery*) preserved the orthography of the root. While this is representative of the way derivational morphemes attach to stems in both English and French, there is evidence that children process words with an orthographic shift differently to words in which the stem is preserved (Lázaro, García, & Burani, 2015), yet this was not controlled across languages or stimuli. The present study addresses these issues by matching morphologically- and nonmorphologically-structured nonwords pairwise on length, summed log bigram frequency and number of orthographic neighbours, and ensuring orthographic transparency across all items.

2.1.4. Aims and hypotheses

In summary, there is substantial evidence that complex words and nonwords are rapidly and automatically processed on the basis of morphological structure by skilled adult readers. At what stage in reading development this level of automaticity is reached is unknown. Children from around the age of seven demonstrate explicit morphological knowledge (Kirby et al., 2012), and there is growing evidence that they are also implicitly sensitive to morphological structure (Burani et al., 2002; Casalis et al., 2015). However, there appear to be qualitative differences in the way children process complex words as compared to adults (Beyersmann et al., 2012). Conclusions from developmental research are further complicated by the variety of languages in which these studies have been conducted. Cross-linguistic generalisations are problematic because morphological structure may be processed differently in English compared to languages with less complex mappings between spelling and sound (e.g., Italian) or a richer system of derivational morphology (e.g., French).

One conspicuous omission in the current literature are online data from adolescent readers. This is important if we are to address the differences in morphological processing between children and adults, and track the emergence of adult-like morphological processing in visual word recognition. The present study investigates morphological decomposition in children (7-9 years), younger adolescents (12-13 years), older adolescents (16-17 years) and adults, using a visual lexical decision task to probe processing of morphological and nonmorphological nonwords. This cross-sectional design provides the opportunity to examine developmental changes as individuals become skilled word readers. The purpose of including two adolescent groups was to take a fine-grained approach to investigating morphological effects during a time when much of the complexity in words that are encountered is driven by morphological structure (Nagy & Anderson, 1984) and knowledge of derivational morphology continues to grow (Carlisle, 1988).

Following Crepaldi et al. (2010), the prediction was that adults would make more errors and show longer reaction times (RTs) when rejecting nonwords comprising a stem and suffix (pseudomorphemic nonwords) relative to nonwords comprising a stem and nonmorphological ending (control nonwords). It was hypothesised that if children are also sensitive to morphological structure, then they too should show lower accuracy for pseudomorphemic nonwords compared to control nonwords. It was less clear whether this effect would emerge in their reaction times, as previous findings have been mixed (Burani et al., 2002; Casalis et al., 2015). While there is no existing evidence that adolescents show a morpheme interference effect in their responses to morphologically-structured nonwords, previous studies have indicated sensitivity to morphological structure in this age group (Goodwin, Gilbert, & Cho, 2013), so it was expected that there would be processing costs in response to pseudomorphemic nonwords for both younger and older adolescents groups.

2.2. Method

2.2.1. Participants

Participants comprised fifty children (7-9 years, *M* age = 8.39, *SD* = .58; 20 female) and 37 younger adolescents (12-13 years, *M* age = 12.67, *SD* = .31; 18 female) recruited from mainstream primary and secondary schools, thirty-six older adolescents (16-17 years, *M* age = 17.04, *SD* = .32; 24 females) recruited from schools and at a school event run at Royal Holloway, University of London, and 31 adults (*M* age = 20.12, *SD* = 1.56; 24 female) who were undergraduate and postgraduate students attending Royal Holloway, University of London. None of the participants had a recognised special educational need, and all spoke English as their first language. Adult participants were paid £5 for their time and travel expenses. The study was approved by the Psychology Departmental Ethics Committee at Royal Holloway, University of London.

2.2.2. Materials and Procedure

Background measures. These were conducted to characterise the sample. Participants completed standardised assessments according to manual instructions in one session, and prior to the experimental task.

Nonverbal ability. This was measured using the Matrix Reasoning subtest of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II; Wechsler, 2013), which is a pattern completion task.

Oral vocabulary. This was measured using the Vocabulary subtest of the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II; Wechsler, 2013), in which participants are asked to verbally define a series of words.

Word reading. This was assessed using the Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE) subtests of the Test of Word Reading Efficiency – Second Edition (TOWRE-2; Torgesen, Wagner, & Rashotte, 2012), in which participants read aloud from a list as many words (SWE) or nonwords (PDE) as they can in 45 seconds.

Morphological awareness. This task was only administered to the youngest age group due to ceiling effects in older participants during pilot testing. Inclusion of this measure meant that it was possible to examine the relationship between children's sensitivity to morphemes in words in the online lexical decision task and their ability to analyse and manipulate morphological structure: in other words, to gauge the relationship between explicit morphological knowledge and morphological processing in the context of word recognition. Morphological awareness was measured using a composite of two existing tasks (see Appendix 2.A.). Part one comprised a word analogy task taken from Kirby et al., (2012) in which participants were provided with a pair of morphologically-related words along with the first word of a second pair, and were asked to identify the missing word (e.g., *decision*: *decide* – *action*: [act]). Participants were given the following instructions: "I am going to ask you to work out some missing words. I say push and then I say pushed; then I say jump, so you should say….. ?" They were then presented with a further five practice items. If a participant gave an incorrect or no response, they were provided with the target item, but no further explanation was given. There were 20 test items in total, 10 of which were inflectional and 10 of which were derivational. Items were administered in a fixed order. Eight of the 20 items could be completed using either a morphological or a phonological manipulation (e.g., *longer*: *long* – *taller*: [tall] for the inflectional items and *mess*: *messy* – *fun*: [funny] for the derivational items). The remaining 12 items contained different phonological changes between the two word pairs, and could thus only be completed using a morphological manipulation (e.g., *high*: *height* – *deep*: [depth]).

Items were repeated once on request, and all items were administered to all participants.

Part two of the morphological awareness measure was a sentence completion task based on Nunes, Bryant and Bindman (1997). Participants were shown a picture and given a verbal description of the picture using a nonword, which replaced either a verb, a noun, an adjective or an adverb. They then had to provide the nonword in a different form to complete the sentence (e.g., *It was a bazing day. He felt very bazed. He stuck out his hands and shouted with*…[baze]). On eight of the ten items, the nonword was presented in two different forms within the description; on the remaining two items it was presented once. For six items, the target response required the addition of an inflection. For two items, participants were required to give the root based on derived forms in the description. On one item, the target response was a derived form, and on the remaining item participants had to give the root based on inflected forms in the description. Participants were given two practice items prior to the test items, and were corrected if they provided an incorrect response to either practice item, but no further explanation was given. Descriptions were repeated once on request, and all participants completed all items. Scores were calculated as a total percentage correct across the two tasks.

Lexical decision task.

Stimuli. The stimuli comprised two sets of nonwords (30 pseudomorphemic and 30 control, see Appendix 2.B.) and two sets of words (30 morphologically complex and 30 monomorphemic), giving a total set of 120 items (drawn from Crepaldi et al., 2010). The words were used as filler items to balance the number of words and nonwords in the task. They were not further analysed because: a) previous findings regarding the influence of morphological structure on real word recognition in lexical decision tasks have been mixed (Casalis et al., 2015; Quémart et al., 2012); b) it would be necessary to account for the changing influence of psycholinguistic factors (such as frequency and number of orthographic neighbours) across age; c) the words were not as closely matched across condition as the nonwords (for example, the stems of the complex words did not overlap orthographically with the monomorphemic items). In the pseudomorphemic condition, English stems were paired with English suffixes (e.g., *earist*) to create a syntactically legal nonword. The control nonwords were created by pairing the same stems with a nonmorphological ending (e.g., *earilt*). These endings were formed by changing one letter of the morphological suffixes used in the pseudomorphemic condition; thus, there was a high level of orthographic similarity between the paired items. Wherever possible, this change was made in a central position to ensure that letters at morphemic boundaries remained the same. Pseudomorphemic and control nonwords were matched on number of letters, syllables, and orthographic neighbours, and summed log bigram frequency (see Table 2.1.).

Table 2.1.

Medians and interquartile ranges for lexical characteristics of nonword stimuli by condition

	Pseudomorphemic		Control	
Lexical characteristics	*Median*	*Interquartile range*[a]	*Median*	*Interquartile range*[a]
Number letters	7.00	1.75	7.00	1.75
Number syllables	2.00	1.00	2.00	1.00
Number orthographic neighbors	0.00	0.00	0.00	0.00
Summed log bigram frequency	15.98	4.17	15.10	4.65

[a] 3rd quartile – 1st quartile

Procedure. The visual lexical decision task was completed individually in a quiet room in school or at the university. Participants were instructed that they would be shown a series of words on the screen, and to indicate using a key press whether or not each was a real word that they knew, as quickly as possible. Participants were shown twelve practice items followed by the experimental items. Each trial began with a black fixation cross, which appeared in centre of the screen for 1000ms, followed by the target, which appeared in lowercase Calibri font in the centre of the screen until a response was made. For the practice items only, participants were given feedback on reaction times and accuracy. Participants were given a short break after every 20 trials. The E-prime 2.0 programme (Schneider, Eschman, & Zuccolotto, 2012a, 2012b) was used to present instructions and stimuli, and to record responses.

2.3. Results

Table 2.2. summarises performance by age group on background measures. Mean scores indicate performance that is close to test norms.

Table 2.2.

Means and standard deviations for background measures by age group

Measure	Children		Younger adolescents		Older adolescents		Adults	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Nonverbal Ability[a]	48.22	9.35	49.51	8.40	50.26	7.36	48.13	11.06
Oral Vocabulary[a]	51.88	7.82	52.92	8.67	55.03	7.39	56.90	6.45
Sight Word Efficiency[b]	106.34	9.98	101.35	14.47	101.94	9.78	109.65	12.82
Phonemic Decoding Efficiency[b]	103.94	10.81	103.24	14.16	104.35	10.60	108.74	8.75
Morphological Awareness[c]	65.20	16.23	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*

Notes. [a]*T* scores; *M* = 50, *SD* = 10; [b]Standard scores; *M* = 100, *SD* = 15; [c]Percentage correct

2.3.1. Confirmatory analyses

Responses (accuracy and RTs) to nonwords in the visual lexical decision task were analysed. Inverse transformations were carried out on RTs to correct for distribution skews and transformed data were used throughout the analyses. RTs for incorrect responses were excluded, amounting to 25%, 23%, 15% and 12% of the data for children, younger adolescents, older adolescents and adults, respectively.

For the analysis, outliers were removed by excluding RTs that exceeded 3.5 standard deviations from the mean for each participant. Figure 2.1. shows mean proportion accuracy and standard error bars for each nonword type by age group. Figure 2.2. shows inverted reaction time raw data points, means, distributions and 95% Highest Density Intervals by nonword type and age group. Note that because RTs are inverted, larger values correspond to shorter RTs.

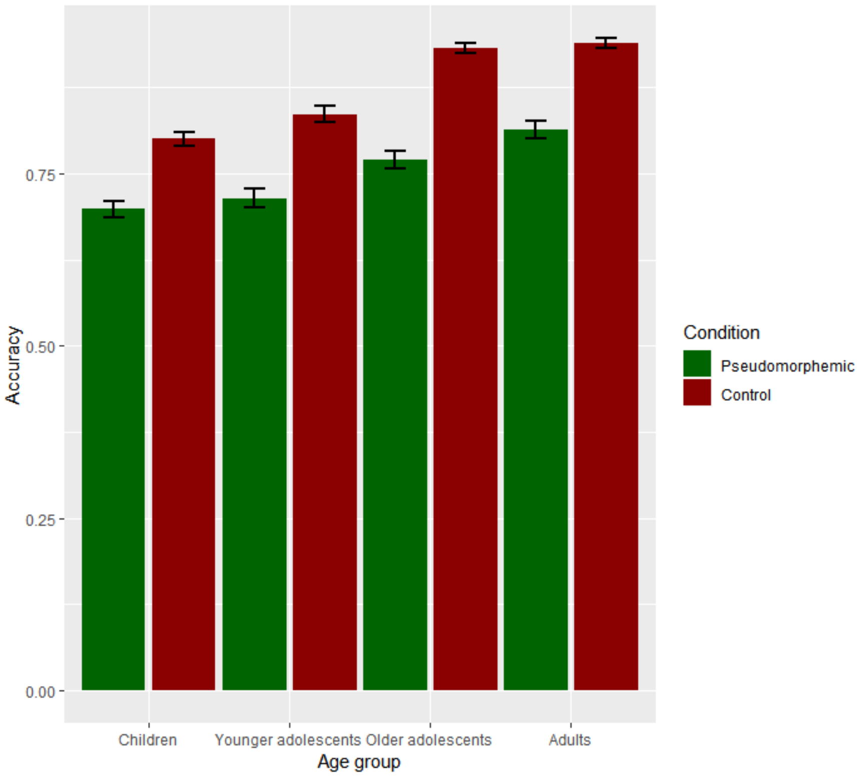

Figure 2.1. Mean proportion accuracy (correct rejections) and standard error bars on the lexical decision task, by nonword type and age group

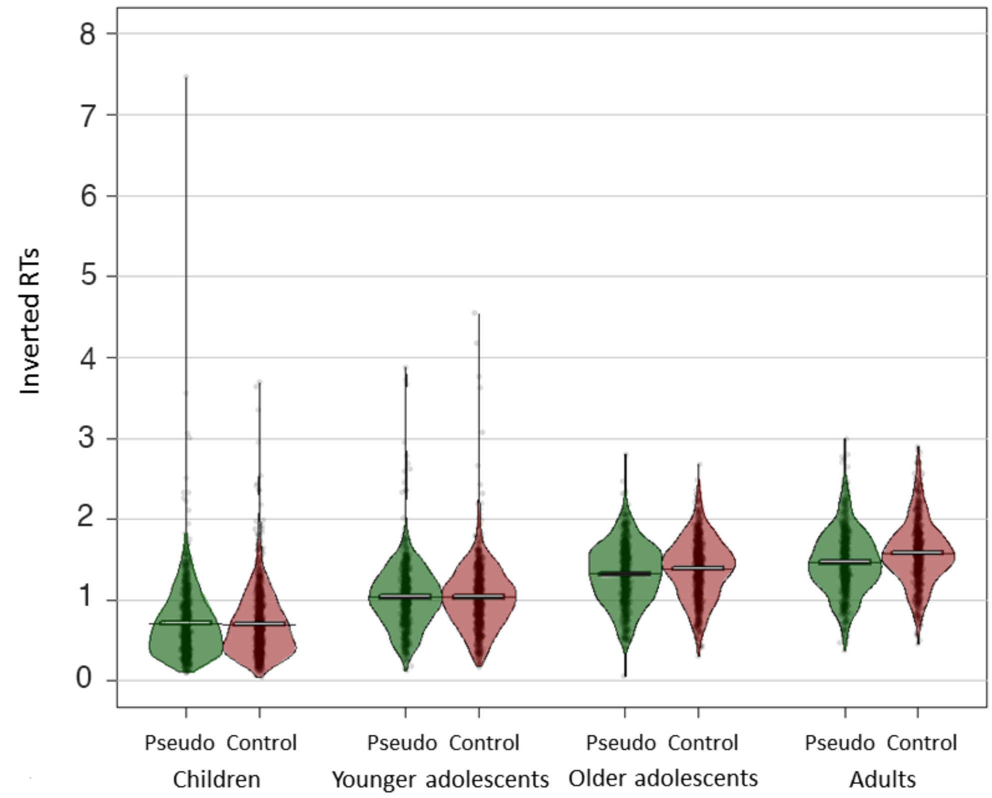

Figure 2.2. Plot showing raw inverted reaction time data points, means, distributions and 95% Highest Density Intervals by age group and condition[3]

R (version 3.3.0; R Development Core Team, 2016) and the lme4 package (version 1.1-12; Bates, Maechler Martin, Bolker, & Walker, 2016) were used to perform a generalised linear mixed-effects analysis of the effect of condition (pseudomorphemic vs. control) and age group (children vs. younger adolescents vs.

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[3] These plots revealed a number of fast RTs amongst children and younger adolescents which may reflect anticipatory responses (Woods et al., 2015). To examine whether these data points should be excluded, an additional trimming measure was applied by removing all RTs less than 300ms. However, removing these outliers did not alter any of the main effects or planned comparisons, so these data were included in the final analysis.

older adolescents vs. adults) on the log odds of accuracy, and a linear mixed-effects analysis of the effect of condition and age group on RTs. For each analysis, condition, age group, and the interaction between condition and age group were entered into the model as fixed effects.[4] By default, R uses treatment coding (Levy, 2014), but for ease of interpretation, the dichotomous factor ‘condition’ was recoded as -0.5 and 0.5 to centre it around 0 (deviation coding; Brauer & Curtin, 2018). The factor ‘age group’ was not recoded, but instead relevelling of the final model was performed to identify estimated coefficients with each age group as the baseline.

The structure of random effects was determined by starting with a maximal model (Barr, Levy, Scheepers, & Tily, 2013), including by-participant and by-item random intercepts, along with by-participant random slopes for the effect of condition, and by-item random slopes for the effect of age group. Where a model failed to converge, or inspection of the correlations between intercepts and slopes of random effects indicated that the model was overparameterised, the random effects structure was simplified following recommendations from Brauer and Curtin (2018).

Accuracy. The final model used for the analysis of accuracy was structured as follows: Model <- glmer (log odds accuracy ~ condition * age group + (1+condition|participant) + (1+age group|item)). The analysis was based on 9240 observations from 154 participants responding to 60 items. Table 2.3. presents a summary of the output from this model.

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[4] Incorporating performance on background measures of reading and vocabulary in models examining accuracy resulted in a failure to converge, indicating that these data lacked sufficient power to explore individual differences. Thus, the final models included just the fixed effects of condition, age and their interaction.

Table 2.3.

Summary of output for confirmatory model examining the effects of condition, age group, and their interaction on lexical decision accuracy

Baseline age group	Fixed effects	Estimate	SE	*z* value
Children (C)	Intercept[a]	1.38	0.16	8.51***
	Condition (pseudomorphemic vs. control)[b]	-0.68	0.21	-3.29***
	Age group (YA vs. C)	0.23	0.21	1.07
	Age group (OA vs. C)	1.01	0.23	4.39***
	Age group (A vs. C)	1.38	0.25	5.44***
	Condition x age group (YA vs. C)	-0.21	0.17	-1.18
	Condition x age group (OA vs. C)	-0.93	0.24	-3.82***
	Condition x age group (A vs. C)	-0.80	0.29	-2.78**
Younger adolescents (YA)	Intercept[a]	1.61	0.19	8.44***
	Condition (pseudomorphemic vs. control)[b]	-0.89	0.25	-3.62***
	Age group (OA vs. YA)	0.79	0.24	3.32***
	Age group (A vs. YA)	1.16	0.26	4.48***
	Condition x age group (OA vs. YA)	-0.72	0.22	-3.32***
	Condition x age group (A vs. YA)	-0.59	0.26	-2.27*
Older adolescents (OA)	Intercept[a]	2.39	0.22	11.09***
	Condition (pseudomorphemic vs. control)[b]	-1.61	0.31	-5.23***
	Age group (A vs. OA)	0.37	0.26	1.43
	Condition x age group (A vs. OA)	0.13	0.25	0.52
Adults (A)	Intercept[a]	2.76	0.24	11.57***
	Condition (pseudomorphemic vs. control)[b]	-1.48	0.34	-4.34***

[a]The intercept represents log odds of accuracy for the baseline age group, averaged across condition; [b]Within the baseline condition

*p< .05 **p < .01 *** p < .001

The intercept for each baseline age group represents the log odds of accuracy for that age group, averaged across condition (because this variable was centred). The *z* value indicates whether the intercept differs significantly from 0. Estimates associated with the fixed effect 'condition' reveal whether there was a difference in accuracy between responses to pseudomorphemic nonwords and control nonwords for that age group. Estimates associated with the fixed effect ‘age group’ show comparisons of overall accuracy between age groups, while estimates associated with the fixed effect ‘condition x age group’ compare the magnitude of the effect of condition between age groups.

Estimates revealed an effect of condition across all age groups: responses to pseudomorphemic nonwords were less accurate than responses to control nonwords. Overall accuracy was greater for older adolescents and adults than for younger adolescents and children. Finally, the effect of condition was greater for older adolescents and adults than for younger adolescents and children, but did not differ between older adolescents and adults, or between younger adolescents and children.

RTs. The final model used for the analysis of RTs was structured as follows: Model <- lmer (RT ~ condition * age group + (1+condition|participant) + (1+age group|item)). Table 2.4. presents a summary of the output from this model. Degrees of freedom and *p* values were estimated using lmerTest.

The intercept for each baseline age group represents the mean of inverted RTs for that age group, averaged across condition (again, because this variable was centred). As previously, estimates associated with the fixed effect ‘condition’ reveal whether there was a difference in RTs between responses to pseudomorphemic nonwords and control nonwords for that age group. Estimates associated with the fixed effect ‘age group’ show comparisons of overall RTs between age groups, while estimates associated with the fixed effect ‘condition x age group’ compare the magnitude of the effect of condition between age groups.

Table 2.4.

Summary of output for confirmatory model examining the effects of condition, age group, and their interaction on lexical decision RTs

Baseline age group	Fixed effects	Estimate	SE	*t* value
Children (C)	Intercept[a]	0.70	0.04	18.04***
	Condition (pseudomorphemic vs. control)[b]	0.01	0.02	0.49
	Age group (YA vs. C)	0.35	0.06	5.89***
	Age group (OA vs. C)	0.63	0.06	10.62***
	Age group (A vs. C)	0.81	0.06	12.97***
	Condition x age group (YA vs. C)	-0.02	0.02	-0.74
	Condition x age group (OA vs. C)	-0.10	0.03	-3.40**
	Condition x age group (A vs. C)	-0.15	0.03	-5.18***
Younger adolescents (YA)	Intercept[a]	1.05	0.04	23.29***
	Condition (pseudomorphemic vs. control)[b]	-0.01	0.02	-0.31
	Age group (OA vs. YA)	0.29	0.06	4.59***
	Age group (A vs. YA)	0.46	0.07	7.05***
	Condition x age group (OA vs. YA)	-0.08	0.02	-3.44**
	Condition x age group (A vs. YA)	-0.13	0.02	-5.72***
Older adolescents (OA)	Intercept[a]	1.34	0.05	28.57***
	Condition (pseudomorphemic vs. control)[b]	-0.09	0.03	-2.92**
	Age group (A vs. OA)	0.17	0.07	2.60*
	Condition x age group (A vs. OA)	-0.04	0.02	-2.04*
Adults (A)	Intercept[a]	1.51	0.05	30.33***
	Condition (pseudomorphemic vs. control)[b]	-0.14	0.03	-4.62***

[a] The intercept represents inverted RTs for the baseline age group, averaged across condition; [b] Within the baseline condition

*p< .05 **p < .01 *** p < .001

Estimates revealed an effect of condition for older adolescents and adults: responses to pseudomorphemic nonwords were slower than responses to control nonwords. This effect did not emerge for children and younger adolescents. Overall RTs were faster for adults compared to all other groups; faster for older adolescents compared to younger adolescents and children; and faster for younger adolescents compared to children. The magnitude of the effect of condition was greater for adults compared to all other groups, and greater for older adolescents compared to younger adolescents and children. There was no difference in the magnitude of the effect of condition between children and younger adolescents.

2.3.2. Exploratory analyses

To investigate whether the morpheme interference effect was associated with individual differences in morphological awareness, separate exploratory analyses were run with the youngest age group (children), who completed the morphological awareness task as part of the background measures battery. For one child, percentage accuracy was calculated based just on their score on the first part of the morphological awareness task as they did not complete the second part. For all other participants, morphological awareness score was calculated as percentage accuracy across the two tasks combined.

For each analysis, the factor ‘condition’ was centred using deviation coding, while percentage accuracy scores on the morphological awareness task were mean-centred. Centering of variables was performed to reduce collinearity and so that estimated coefficients in the model could be interpreted as main effects (Brauer & Curtin, 2018). Generalised linear mixed-effects models were used to examine the interaction between condition (pseudomorphemic vs. control) and morphological awareness score (continuous) on lexical decision accuracy, while linear mixed-effects models were used to examine the effect of the same interaction on RTs.

Table 2.5.

Output for exploratory model examining the interaction between condition and morphological awareness performance on lexical decision accuracy

Fixed effects[a]	Estimate	Standard error	*z* value
Intercept	1.38	0.16	8.54***
Morphological awareness	0.01	0.01	0.94
Condition	-0.64	0.21	-3.04**
Morphological awareness x condition	-0.02	0.01	-2.92**

[a] Because all variables were centred in this analysis, the intercept represents the grand mean, and fixed effects coefficients correspond to main effects.

***p* < .01 *** *p* < .001

Accuracy. The output of the full model is presented in Table 2.5. The results revealed a main effect of condition, replicating findings from the confirmatory analysis for this age group, and a significant interaction between condition and morphological awareness performance, which was driven by a greater morpheme interference effect for participants scoring higher on the morphological awareness task. Figure 2.3. shows this interaction, with lexical decision accuracy for pseudomorphemic and control nonwords plotted against performance on the morphological awareness task.

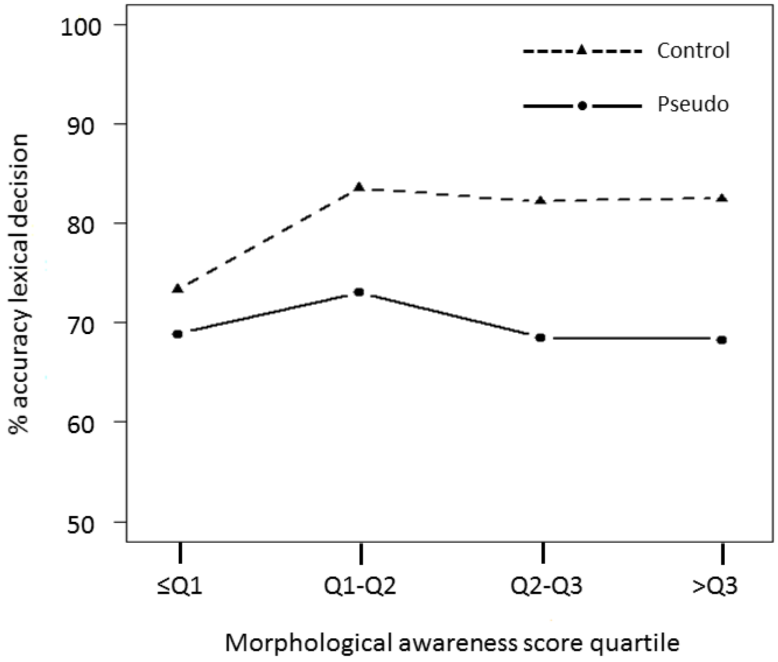

Figure 2.3**.** Plot showing lexical decision accuracy for pseudomorphemic and control nonwords by performance on morphological awareness task (split into quartiles[5])

RTs. Table 2.6. presents the output from the full model. The effects of condition, morphological awareness, and the condition by morphological awareness interaction were all non-significant.

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[5] Morphological awareness scores were grouped into quartiles for visualisation purposes; for analyses, morphological awareness was entered into the model as a continuous variable

Table 2.6.

Output for exploratory model examining the interaction between condition and morphological awareness performance on lexical decision RTs

Fixed effects[a]	Estimate	Standard error	*t* value
Intercept	0.70	0.04	17.63***
Morphological awareness	-0.00	0.00	-0.01
Condition	0.01	0.02	0.60
Morphological awareness: Condition	-0.00	0.00	-1.10

[a]Because all variables were centred in this analysis, the intercept represents the grand mean, and fixed effects coefficients correspond to main effects.

*** *p* < .001

2.4. Discussion

2.4.1. Morpheme interference effect

This study used a lexical decision task to investigate the developmental trajectory of online morphological processing in nonword reading. Accuracy was lower for pseudomorphemic nonwords compared to control nonwords across all age groups; participants were more likely to incorrectly accept nonwords comprising a real stem and suffix (*earist*) than nonwords comprising a real stem and nonmorphological ending (*earilt*). This effect was greater in adults and older adolescents than in children and younger adolescents. The discrepancy in accuracy is consistent with existing adult findings (Crepaldi, Rastle, & Davis, 2010; Taft & Forster, 1975) and provides verification of morphological sensitivity in English-speaking children aged 7-9 (Burani et al., 2002; Casalis et al., 2015). The current study rectifies limitations in stimuli previously used with children (e.g., Burani et al., 2002; Casalis et al., 2015), and for the first time incorporates data from adolescent participants.

The reported findings are inconsistent with supralexical theories that see morphological analysis as taking place after lexical access (Giraudo & Grainger, 2001). Nonwords by definition are not represented in the lexicon. Therefore, if morphological structure is analysed following lexical access, then there should be no difference in responses to pseudomorphemic (*earist*) and control nonwords (*earilt*) because both nonword types will be treated equally. Instead, these data lend support to morpho-orthographic theories that argue that the process of decomposition takes place prior to lexical access (Rastle & Davis, 2008; Taft, 2004), and dual-route models in which both whole-word access and decomposition are available (Baayen et al., 1997).

The RT data were less clear-cut. Both adults and older adolescents were slower to reject the pseudomorphemic nonwords (*earist*) relative to the control nonwords (*earilt*), replicating previous findings with adults (e.g., Crepaldi et al., 2010). This is consistent with Taft and Forster's (1975) theory that complex words are stored in decomposed form in the lexicon, and are stripped of their affixes during recognition. A nonword comprising an existing stem and suffix (*earist*) will result in a lexical entry being retrieved (*ear*). The process of checking the legitimacy of the stem-suffix combination will generate longer RTs compared to nonmorphological nonwords (*earilt*), which are not decomposed and can be rejected once a search of the lexicon reveals no match. However, no difference in RTs was found for children and younger adolescents, corroborating findings from Casalis et al. (2015) that, while French children were slower and less accurate to reject nonwords comprising a stem and suffix, the effect for English-speaking children was limited to accuracy.

Why might morphological effects emerge in accuracy but not RTs in children and younger adolescents? One possibility is that the types of suffixes used in the pseudomorphemic condition influenced response times. Previous studies with children have tended to include only neutral suffixes such as *-y* and *-er* (e.g., Carlisle & Stone, 2005; Laxon et al., 1992), which attach to independent words, do not alter stress in the word to which they attach, and are more productive than nonneutral suffixes such as *-ic* and *-ary* (Tyler & Nagy, 1989; see Chapter 1, section 1.7.). The pseudomorphemic nonwords in the present study contained both neutral and nonneutral suffixes (60% and 40% respectively). It has been argued that the process of decomposition may vary according to suffix type (Hay, 2003) and there is some indication that children's knowledge of these two types of suffix develops differently as they undergo a period of overgeneralisation in the acquisition of neutral, but not nonneutral, suffixes (Tyler & Nagy, 1989). Thus, it is plausible that for the younger age groups, the morpheme interference effect on RTs only emerged for the more predictable, rule-driven neutrally-suffixed nonwords. However, subsequent analyses did not show this to be the case: the difference in RTs did not vary between the neutrally- and nonneutrally-suffixed stimuli in either age group (all *ps* > .05; see Appendix 2.C.).

A second possibility is that the mechanisms driving decomposition may differ between the younger and older age groups, and that children and younger adolescents might rely more heavily on explicit morphological knowledge in their decisions than the older participants. One argument is that the younger age groups may be more sensitive than the older age groups to the presence of an existing stem across both nonword types, independent of the morphological status of the nonword (see Casalis et al., 2015; Giraudo & Voga, 2016). This would slow responses to the control nonwords as well as the pseudomorphemic nonwords, which might account for the absence of an RT effect in the younger age groups. This would not explain the observed differences in accuracy, but slower responses to all nonwords could result in greater reliance on explicit processes to determine lexical status, leading to more errors in the pseudomorphemic condition.

Post-hoc analyses examining the role of semantic interpretability were conducted to further explore the idea that the younger age groups were relying more on explicit morphological knowledge than the older age groups. Semantic interpretability refers to the ease with which morphologically-structured nonwords can be interpreted on the basis of the meanings of their morphological components, similar to the concept of semantic transparency discussed in Chapter 1, section 1.2. in relation to complex words (Longtin & Meunier, 2005). Nonwords such as *trueness* are semantically interpretable: the suffix –*ness* attaches to adjectives to form a noun, the stem-suffix combination is in accordance with English phonotactic rules, and there are equivalent real word examples (e.g., *gentleness*). All 30 pseudomorphemic nonwords were coded as either semantically interpretable or uninterpretable based on the above criteria, resulting in 15 interpretable and 15 uninterpretable nonwords. It was hypothesised that if children and younger adolescents were using explicit morphological knowledge, then they would make more errors rejecting semantically interpretable nonwords compared to uninterpretable nonwords relative to adults and older adolescents. However, post-hoc analysis revealed that accuracy was lower for interpretable nonwords relative to uninterpretable nonwords across all age groups (all *p*s < .05; see Appendix 2.D.), and further, that all age groups except the children were slower to reject the interpretable nonwords relative to the uninterpretable nonwords (all *p*s ≤ .05).

On the surface, the influence of semantics may seem to lend support to supralexical theories of morphological decomposition, in which morphemic units are only accessed once whole-word lexical access has occurred. However, logically, the influence of semantic interpretability must be reliant on the prior decomposition of morphologically-structured nonwords: it is only through the separation of stem and suffix that the interpretability of the combination can be evaluated. Thus, it seems more plausible that the influence of semantics occurs following the process of decomposition. One limitation of the current study is that the measure adopted here does not allow a more direct exploration of this question. Lexical decision tasks do not make it possible to isolate processes relating to form-based decomposition and processes relating to meaning-based decomposition. Further, masked priming and ERP studies indicate that semantics do play a role in the later stages of word recognition (Lavric, Elchlepp, & Rastle, 2012; Rastle et al., 2000), and it is likely that the time taken to respond in a lexical decision task will be sufficient for a semantic influence to emerge. In order to pinpoint the mechanisms driving morphological decomposition across development, a masked priming approach was adopted in Chapter 3 to examine the time course of form- and meaning-based processing in more detail.

2.4.2. Individual differences in morphological awareness

Previous research examining the contribution of morphological knowledge to reading has tended to focus either on morphological awareness or on morphological processing in online tasks. As discussed in Chapter 1, section 1.7., these two approaches may in fact measure very different facets of morphological knowledge, and little is known about the relationship between them (Law et al., 2018). As a preliminary investigation into whether explicit knowledge about morphemes in words corresponds to activation of morphemes during visual word recognition, exploratory analyses were conducted with the youngest age group, who completed the morphological awareness task along with the other background measures. The results indicated a significant interaction between morphological awareness ability and condition in relation to lexical decision accuracy, but not RTs. The interaction revealed that children with better morphological awareness showed a greater morpheme interference effect, supporting the idea that the ability to explicitly reflect on and manipulate morphemes in words is associated with activation of morphological units during word recognition. It is unsurprising that this effect did not emerge in the RT data because no difference between conditions was observed for this age group in the main analysis.

The relationship between morphological awareness and morphological processing warrants future investigation. While an association between these skills may seem obvious, this is not necessarily the case. Morphological awareness tasks vary greatly in presentation modality, content and cognitive demands (Deacon, Parrila, & Kirby, 2008; see Chapter 1, section 1.7. for an overview), and they are often closely correlated with other skills, such as vocabulary ability, phonological awareness and nonverbal reasoning (Deacon & Kirby, 2004; McBride-Chang, Wagner, et al., 2005). Secondly, the morphological awareness tasks adopted in this study were presented orally and required a verbal response, while the lexical decision task tapped morphological processing in the visual domain. In general, morphology is more salient in written compared to spoken language, and here indeed, the nonwords used in the lexical decision task were fully transparent with regards to morphological structure, whereas the morphological awareness task comprised many items that were phonologically opaque. Finally, it is possible that the lexical decision task could have activated modality-specific morphological representations, but the association between the two tasks appears to lend support to the argument that on some level, both tasks tap into centralised morphological knowledge, at least in children.

This relationship may provide a fruitful avenue for investigating whether children rely more on explicit morphological knowledge during word recognition tasks compared to more skilled readers, as discussed above. If this were the case, it might be expected that there would be a closer association between morphological awareness and morphological effects in visual word recognition for developing compared to skilled readers, if skilled readers have had the opportunity to develop well-specified morphological representations at the orthographic level of lexical access. This was not possible in the present study because the morphological awareness task was not administered to the older age groups due to ceiling effects in piloting. A primary aim for future investigation should be to develop measures of morphological awareness that are sensitive to performance in older age groups. Based on factors outlined in Chapter 1, section 1.7., these might incorporate a larger number of semantically and phonologically opaque items (see Chapter 5 for further discussion).

2.4.3. Conclusions

It is clear from the findings reported here that over the course of adolescence, there is some transition in how morphologically-structured letter strings are processed during visual word recognition. This may reflect ongoing development and consolidation of tacit morphological knowledge, driven by increasing exposure to morphologically complex words across different contexts (Nagy et al., 2014). Specifically, adolescents encounter many morphologically complex words in academic texts that are not explicitly taught (Nagy & Anderson, 1984); therefore, the process of morphological decomposition may help to support comprehension. Further, according to Ehri's (2005a) stages of reading development, ‘chunking’ of grapheme-phoneme correspondences into larger units such as morphemes speeds sight word recognition. If chunking of suffixal units is slower to develop than chunking of lexical units, then this would support the idea that children and younger adolescents process the nonword stem initially, leading to slower RTs across both nonword types, while adults and older adolescents process morphologically-structured nonwords as recognisable stem-suffix units. Thus, these findings may reflect an influence of automatised tacit morphological knowledge in the older age groups that has not yet emerged in the younger age groups.

It is likely that these changes are associated with the development of related skills, such as word reading and vocabulary. According to Nagy et al. (2014), sensitivity to morphemes in words should be linked to greater efficiency in reading those words. Meanwhile, vocabulary acquisition provides opportunities for exposure to the links between the orthography, phonology and semantics of morphemic units across different contexts (Reichle & Perfetti, 2003; Schreuder & Baayen, 1995). While measures of vocabulary and reading ability were obtained as part of the battery of background measures, they were not included in the final models. In part, this was because they were not selected for the purpose of exploring these relationships. For example, the word reading efficiency measure comprised both monomorphemic and complex words, and the vocabulary measure captured depth of vocabulary knowledge rather than breadth (Ouellette, 2006). Arguably, vocabulary depth may not be as closely associated with tacit morphological knowledge as vocabulary breadth because it relates to the richness of semantic representations rather than multiple exposures to morphemic units across different contexts.

In conclusion, the older adolescent group responded to the nonword manipulation similarly to the skilled adult readers, indicating that, like adults, they rapidly process morphological structure. The younger adolescent group showed a similar pattern of results to the children: the accuracy data suggested some sensitivity to morphemic units, but there was little evidence that nonwords were processed at speed on the basis of morphological structure, as this effect did not emerge in RTs. Taken together, these results indicate some changes over the course of adolescence in the way morphologically structured letter strings are processed. This parallels continuing development in explicit morphological knowledge (e.g., Nippold & Sun, 2008), increasing exposure to morphologically complex words in different contexts (Nagy & Anderson, 1984), and ongoing changes in the cortex relating to visual word processing (Ben-Shachar et al., 2011). Taking these findings as a starting point, the following chapter provides a closer examination of the mechanisms underpinning morphological decomposition in visual word recognition, and how these might change across reading development.

CHAPTER THREE

Mechanisms of Morphological Decomposition

3.1. Introduction

Chapter 2 reported evidence that children as young as seven years are sensitive to morphological structure in visual word recognition, but that rapid activation of stems and suffixes in the context of an online task is not observed until late adolescence. These findings raise an important question: what factors drive these changes in morphological processing? The current chapter builds on the work reported in Chapter 2 by exploring the mechanisms that underpin morphological decomposition processes, and how these evolve across reading development. As outlined in Chapter 1, section 1.5., evidence suggests that skilled readers decompose morphologically-structured items into stem and affixes regardless of the semantic relationship between the complex word and its stem (e.g., Rastle, Davis, & New, 2004). According to sublexical accounts, this reflects a level of word recognition in which morphological decomposition is based purely on analysis of orthographic structure (Rastle & Davis, 2008; Taft, 2006). How and when developing readers start to show evidence of morpho-orthographic analysis is not yet known.

The experiments reported in this chapter adopt a masked priming paradigm to capture the early stages of lexical processing (Rastle et al., 2000). This was necessary to examine the theory that orthographically-defined morphological representations form the initial units of analysis during word recognition. Experiment 1 investigates the evidence for morpho-orthographic decomposition in developing readers. As in Chapter 2, participants were drawn from a wide age range, allowing a fine-grained exploration of morphological processing from childhood through adolescence. The aim of this experiment was to investigate the second research question of the thesis: What are the mechanisms underpinning morphological decomposition in children and adolescents, and how do these change in line with reading development? Experiment 2 reports findings from a control group of adults who completed the same task, while Experiment 3 reports a follow-up study with adult participants, designed to examine the influence of prime exposure duration on observed patterns of priming.

3.1.1. Morpho-orthographic decomposition in skilled readers

A key theoretical question in the literature on morphological processing is whether decomposition is dependent on the semantic relationship between the complex word and its stem (see Chapter 1, section 1.5. for an overview). Sublexical accounts posit that complex words are initially analysed on the basis of morphemes defined orthographically, a process termed 'morpho-orthographic segmentation' (Rastle, Davis, & New, 2004; see also Rastle & Davis, 2008 and Taft & Forster, 1975). On this perspective, the semantic relationship between the complex word and its stem does not influence recognition immediately, but becomes important in the later stages of lexical processing (Rastle et al., 2000). Sublexical models of morphological processing, such as the AUSTRAL model (Taft, 2006; Taft & Nguyen-Hoan, 2010), hypothesise that morphological analysis initially takes place at the level of orthography, prior to activation of whole-word or component representations at the lemma level. Therefore, any item that has the appearance of being morphologically-structured is segmented in the initial stages of recognition, even when that structure is pseudomorphological (as in the case of monomorphemic words such as *corner*, which combines a stem, *corn*, and a suffix, -*er*).

Empirical support for sublexical accounts of morphological processing comes primarily from masked priming studies, in which skilled readers respond to targets that are primed by a true morphological relative (e.g., *toaster – TOAST*), a pseudomorphological relative (e.g., *corner – CORN*) and a prime related only in form (e.g., *freeze – FREEZE*). Because primes are displayed for a very brief duration (usually 60 ms or less), they are not consciously perceived by the respondent. This makes it possible to examine the earliest stages of word recognition, prior to the emergence of lexical influence (Rastle et al., 2000), and it minimises the likelihood that responses reflect conscious analysis of morphological structure. Typically, masked priming experiments adopting such a set up with skilled readers reveal equivalent priming across morphological and pseudomorphological conditions, which is greater than that observed in form-only conditions (Rastle et al., 2004; see also Longtin, Segui, & Hallé, 2003 for similar findings in French readers). This pattern of priming is thought to reflect the fact that complex items are decomposed if they are orthographically parsable into a stem and affix, irrespective of whether those components contribute meaning to the complex word as a whole. The fact that priming in both the morphological and pseudomorphological conditions is statistically greater than that observed in the form condition indicates that the effects are specifically morphological, and not a more general effect of orthographic overlap.

3.1.2. Morphological decomposition in developing readers

As outlined in Chapter 1, section 1.7., morphological knowledge is thought to be an important factor in the transition from effortful decoding in young readers to the rapid and proficient word recognition of skilled adult readers (Castles et al., 2018; Rastle, 2018). The cross-sectional lexical decision experiment reported in Chapter 2 presented evidence that both skilled and developing readers decompose morphologically-structured letter strings into their morphemic components during visual word recognition. However, while this effect was observed in both accuracy and reaction times in older adolescents and adults, in children and younger adolescents it was only observed in the accuracy measure.

Evidence of a morpheme interference effect across all age groups suggests that decomposition occurs at a sublexical level, even for younger readers: if this were not the case, responses to morphologically- and nonmorphologically-structured nonwords should be identical given that neither type is associated with an existing lexical representation. However, as discussed in Chapter 2, the absence of an RT effect in the younger age groups, coupled with slower reaction times overall, means that decisions in these groups potentially involved a more strategic analysis of morphological structure than in the older groups. It is possible, then, that when real word items are used in place of nonwords, slower and more strategic processing of morphological structure in developing readers translates to a greater reliance on lexical-semantic knowledge during decomposition than seen in skilled readers. Additionally, decomposition of morphologically complex items on the basis of orthography requires a certain level of orthographic expertise. As outlined in Chapter 1, section 1.7., children demonstrate knowledge of morphological regularities before they even begin learning to read, but little is known about how they begin to associate this knowledge with morphemes in printed form (Rastle & Davis, 2008).

It seems likely, then, that the ability to recognise orthographic units as morphemes rapidly in the context of online processing builds over time in line with morphological knowledge more generally, and with reading experience. This aligns with Ehri's (1995, 2005a, 2005b) phase theory of reading development, in which recognition of words on the basis of their component morphemes represent an advanced level of ‘chunking’. Accumulated exposure to morphological patterns and complex words in texts is likely to be crucial for building representations that are activated independent of semantic context. In their model of morphological processing, Schreuder and Baayen (1995) proposed that an important stage in acquiring morphological knowledge is the development of representations of bound morphemes (affixes). This process is initiated through monitoring of the lexicon for form-meaning regularities, eventually leading to the development of modality-specific form representations (see Chapter 1, section 1.7. for an overview). Support for the idea that children’s knowledge of affixes undergoes a protracted period of consolidation comes from recent evidence indicating that children make use of embedded stem activation when processing morphologically-structured nonwords, whereas skilled adult readers benefit from the combination of a stem and suffix (Beyersmann, Grainger, et al., 2015; Grainger & Beyersmann, 2017; Hasenäcker et al., 2016; Lázaro et al., 2018; Meunier & Longtin, 2007).

Empirical examination of form-based morphological decomposition in developing readers has produced mixed findings, as highlighted in Chapter 1, section 1.7. In Beyersmann et al.'s (2012) study, priming effects were observed for word pairs that shared a true morphological relationship, but not for those sharing a pseudomorphological or orthographic relationship. In their older age group (10-11 years), they further observed an inhibitory priming effect for orthographically-related pairs: responses to targets preceded by a related prime were slower than to those preceded by an unrelated prime. This differed from the pattern of findings in their adult controls, who showed priming effects in the morphological and pseudomorphological conditions, but not in the form condition (although the magnitude of priming was greater in the morphological than in the pseudomorphological condition). These data support the view that morpho-orthographic decomposition processes emerge relatively late in reading development. This resonates with ERP data indicating that, even by 12 years, efficiency in form-level processing is still developing (Eddy, Grainger, Holcomb, Mitra, & Gabrieli, 2014), and with fMRI data revealing ongoing changes to the ventral pathway (associated with direct print-meaning mappings and morphological processing; Yablonski, Rastle, Taylor, & Ben-Shachar, 2018) into mid-adolescence (Ben-Shachar et al., 2011).

By contrast, Quémart et al. (2011) found that French children aged 8-12 years showed equivalent priming across true morphological and pseudomorphological word pairs, suggesting that, contrary to Beyersmann et al.'s (2012) findings with English-speaking children, participants did rely on surface morphological structure when processing complex words. This discrepancy may be explained in part by recent evidence indicating cross-linguistic differences in efficiency of morphological processing between French and English-speaking children (Casalis, Quémart, & Duncan, 2015). However, Quémart et al.'s (2011) findings also contradict those of Beyersmann et al. (2015), who found that higher-proficiency French-speaking children rely on embedded stem activation and not morpho-orthographic decomposition to process morphologically-structured nonwords. To date, investigation of developmental trends in morpho-orthographic decomposition has been limited by the absence of adolescent readers, which leaves open the question of how and when readers develop orthographically-defined morphological representations. The inconclusive findings and limited scope across the developmental literature highlight a clear need for a comprehensive cross-sectional examination of morpho-orthographic decomposition in developing readers.

3.1.3. Aims and hypotheses

In summary, masked priming paradigms have been widely deployed to investigate the processes responsible for the segmentation of morphologically complex words during word recognition. Evidence from skilled readers points towards a morpho-orthographic decomposition mechanism that operates on the basis of apparent morphological structure, independent of semantic overlap (e.g., Longtin et al., 2003; Rastle et al., 2004). It is less clear whether a similar process is involved in visual word recognition in developing readers (e.g., Beyersmann et al., 2012; Quémart et al., 2011). Evidence from English-speaking children suggests that this morpho-orthographic mechanism is not yet established (Beyersmann et al., 2012), which raises an obvious question: at what stage during reading development does this mechanism emerge? Until now, the focus has been almost exclusively on developing readers in mid-late childhood or on skilled adult readers, but data from adolescent readers are crucial if we are to address this question. The aim of the present study was to investigate the mechanisms driving morphological decomposition in children and adolescents. Specifically, the paradigm established in previous masked priming studies (e.g., Beyersmann et al., 2012; Rastle et al., 2004) was adopted here to examine whether there is evidence for a morpho-orthographic segmentation mechanism across this developmental period, and whether this is influenced by reading experience. A cross-sectional design was used, which included children and adolescents ranging in age from 9 to 18 years.

Based on robust morphological priming effects in children and adults in previous studies (e.g., Beyersmann et al., 2012; Rastle et al., 2004), it was expected that priming would emerge for targets sharing a true morphological relationship with their prime (*toaster – TOAST*; morphological condition) across the entire age range, in the absence of priming when primes and targets overlapped only in form (*freeze – FREE*; form condition). Given that previous findings with English-speaking children (Beyersmann et al., 2012) revealed no evidence of pseudomorphological priming, while evidence of morpho-orthographic decomposition has repeatedly been shown in adult readers (Rastle et al., 2004), it was predicted that priming for words sharing an apparent morphological relationship in the absence of any semantic influence (*corner – CORN*; pseudomorphological condition) would emerge gradually in line with reading experience. Based on the findings reported in Chapter 2, it was expected that mid adolescence would represent a particularly important period of development in this respect.

3.2. Experiment 1

3.2.1. Method

Participants. A total of 204 children and adolescents from South-East England took part, ranging in age from 9 to 18 years (*M* age = 13.74 years, *SD* = 2.68; 110 female). Participants were sampled from four age groups: Children (9-10 years, *M* age = 9.77, *SD* = 0.27; n = 48, 20 female), younger adolescents (12-13 years, *M* age = 13.21, *SD* = 0.31; n = 57, 27 female), mid adolescents (14-15 years, *M* age = 14.65, *SD* = 0.33; n = 48, 23 female), and older adolescents (16-18 years, *M* age = 17.22, *SD* = 0.58; n = 51, 40 female).

Children were recruited from mainstream primary schools, and adolescents from mainstream secondary schools and sixth form educational settings. None of the participants had a recognised special educational need, and all spoke English as their first language. Sixth form college participants were entered into a prize draw to win a £25 Amazon voucher as a reward for participation. Informed consent was obtained from participants aged 16 years and over, and from parents of participants under 16 years. The study was approved by the University Research Ethics Committee at Royal Holloway, University of London.

Materials and procedure.

Background measures. Standardised assessments measuring nonverbal reasoning, oral vocabulary and word and nonword reading efficiency were administered according to manual instructions. These were identical to the measures outlined in Chapter 2, section 2.2.2. In addition, a morphological awareness task was administered to all participants. This differed from the tasks outlined in Chapter 2, as it was selected to be appropriate for a wider age range than the previous measures. The task was taken from Beyersmann, Castles, and Coltheart (2012), and assessed derivational morphological awareness. Twenty items were presented orally in a sentence completion format: half required participants to produce the appropriate derived form of a given stem (e.g., *"Human. The kind man was known for his …" [humanity]*); the other half required participants to produce the stem of a derived word (e.g., *"Popularity. The girl was very …" [popular]*). Within each set, half of the items involved a phonological shift between the stem and derived form (e.g., *major – majority*), while the other half did not (e.g., *perform – performance*). Participants responded verbally. A score of 1 was awarded for each correct response and 0 for an incorrect or no response, resulting in a maximum possible total score of 20. See Appendix 3.A. for the full list of items.

Masked priming task.

Stimuli. Stimuli were taken from Beyersmann et al. (2012) and comprised three sets of 34 prime-target pairs: morphological (sharing a true morphological relationship, e.g., *toaster* – *TOAST*), pseudomorphological (sharing an apparent morphological relationship in the absence of a semantic relationship, e.g., *corner* – *CORN*), and form (sharing an orthographic relationship only, e.g., *freeze* – *FREE*). The amount of orthographic overlap between prime and target was matched across conditions, as was word length in letters, neighborhood size and frequency for both primes and targets (Beyersmann et al., 2012). Each target was also paired with an unrelated prime (e.g., *grocery* – *TOAST*), so that for each set of 34 targets, half were presented with a related prime and half with an unrelated prime. Prime-target pairings were counterbalanced across two lists, such that participants saw each target only once. Appendix 3.B. provides a full list of experimental stimuli. An additional 34 unrelated prime-target pairs (e.g., *giving* – *ROPE*) were included to reduce the proportion of related word pairs, as well as a set of 134 nonword targets for the purposes of the lexical decision task. Unrelated and nonword prime-target pairs were identical across the two lists.

Procedure. The masked priming task was completed individually or in pairs in a quiet area of school or college. Participants were presented with both written and verbal instructions informing them that they would see a series of real and nonsense words on the screen and that their task was to decide whether each was a real word or not as quickly as possible. DMDX (Forster & Forster, 2003) was used to present stimuli and record reaction times (RTs) and accuracy of responses. In each trial, a forward mask of hashtags was presented for 800ms in the centre of the screen, followed by the prime in lowercase font, which was displayed for 50ms in line with Beyersmann et al. (2012). This was followed by the target in uppercase font, which participants were asked to classify as either a real word or a nonword by pressing the right or left shoulder button respectively on a Gioteck VX-2 game controller. Target items remained on screen for a maximum of 5000ms, or until participants made a response. Prior to the experimental trials, participants were presented with eight practice items. Experimental trials were randomized, and included one break in the middle. In total, the procedure took approximately 10-15 minutes.

3.2.2. Results and discussion

Table 3.1. presents performance on background measures by age group. Mean T scores and standard scores on standardised assessments show that performance for each age group is broadly in line with test norms.

Table 3.1.

Means and standard deviations for background measures by age group

Measure	Children (9-10 years)		Younger adolescents (12-13 years)		Mid adolescents (14-15 years)		Older adolescents (16-18 years)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Nonverbal Ability[a]	47.77	9.38	47.07	8.42	49.13	10.65	47.35	10.27
Oral Vocabulary[a]	53.85	10.84	50.89	8.46	52.38	5.93	52.43	8.93
Sight Word Efficiency[b]	99.38	9.70	100.04	12.59	100.77	13.71	100.33	12.16
Phonemic Decoding Efficiency[b]	104.35	13.05	102.39	11.63	102.92	10.77	102.00	10.89
Morphological awareness[c]	16.36	1.92	18.17	1.83	18.50	1.41	19.33	0.95

[a]T scores: *M* = 50, *SD* = 10; [b]Standard scores: *M* = 100, *SD* = 15; [c]Raw scores; max = 20

R (version 3.4.3; R Developement Core Team, 2017) and the lme4 package (version 1.1-15; Bates, Maechler, Bolker, & Walker, 2015) were used to run linear mixed-effects models examining the effect of condition (morphological vs. pseudomorphological vs. form), prime type (related vs. unrelated), and age (in months) on inverted RTs. Generalised linear mixed-effects models were used to examine the effects of the same three predictors on log odds of accuracy. The accuracy data were not used as a direct measure of priming, but were reported for reference because the RT data comprised correct responses only. Condition, prime type, age in months, and the condition x prime type x age in months interaction were entered into the model as fixed effects. In all analyses reported below, the factor ‘prime type’ was centred using deviation coding and the variable ‘age’ mean-centred and scaled to reduce multicollinearity between the main effects and their interaction, and to minimise the likelihood of model nonconvergence.

Following Barr, Levy, Scheepers, and Tily (2013), a maximal random effects structure was adopted, incorporating by-participant and by-item random intercepts, along with by-participant random slopes for the effects of condition, prime type, and the condition x prime type interaction, and by-item random slopes for the effects of prime type, age, and the prime type x age interaction (i.e. random slopes were included for all within-subject and within-item predictors and their interactions). In instances where the maximal model failed to converge, modifications were made following recommendations from Brauer and Curtin (2018) and Matuschek, Kliegl, Vasishth, Baayen, and Bates (2017) until the most complex model supported by the data was identified. The final model structure is reported for each analysis below.

Table 3.2.

Mean percentage accuracy and RTs with SDs (outliers removed) by condition and prime type

Condition	Prime type	Average % accuracy	Average RT in ms (correct responses)
Morphological			
	Related	97.20 (16.49)	751 (387)
	Unrelated	96.68 (17.92)	784 (387)
Pseudomorphological			
	Related	91.96 (27.19)	820 (441)
	Unrelated	93.62 (24.44)	824 (426)
Form			
	Related	93.86 (24.02)	816 (397)
	Unrelated	94.82 (22.17)	802 (404)

Accuracy. Average response accuracy for the primed lexical decision task was high (see Table 3.2.). One participant scored below 75% accuracy, and was removed from the analysis. A further participant was excluded due to a software error during the running of the experiment. All other data were included in the analyses.

The final model used for the analysis of accuracy was structured as follows: Model <- glmer (log odds accuracy ~ condition * prime type * age_months + (1+condition*prime type|participant) + (1+prime type+age_months|item)). Analysis was based on 20604 observations from 202 participants responding to 102 items. Table 3.3. presents a summary of the output from this model.

The structure of the analyses tables presented in this chapter are similar to those reported in Chapter 2. Because the factor 'condition' comprised three levels, it was necessary to relevel the model to extract the relevant coefficients for each condition. The column labelled 'baseline condition' indicates which level of 'condition' is functioning as the reference level. The estimated value for the intercept corresponding to that baseline represents the log odds of accuracy (or mean inverse RT) for that condition, averaged across prime type and age in months (because these predictors were centred). Estimates relating to the fixed effects 'prime type', 'age' and 'prime type x age' are simple effects *within* the baseline condition. Comparisons between conditions are shown by estimates of fixed effects 'prime type x condition', 'age x condition' and 'age x condition x prime type'.

Inspection of estimated coefficients of fixed effects revealed that the effect of prime type approached significance in the form condition, with responses to unrelated primes more accurate than responses to related primes, but was not significant in either the morphological or pseudomorphological conditions. Overall, responses were more accurate to items in the morphological condition than in the pseudomorphological or form conditions, and accuracy did not differ between the pseudomorphological and form conditions.

Age was a significant predictor of accuracy in all three conditions, with older readers providing more accurate responses overall. The age by prime type interaction was significant in the pseudomorphological condition, showing that responses to related primes became increasingly less accurate compared to responses to unrelated primes as age increased. The three-way interaction between age, prime type and condition showed that this effect was significant relative to the form condition, but not the morphological condition.

Reaction times. In addition to the removal of two participants as described above, four individual data points were removed from the analysis due to display errors recorded by DMDX for those items. RTs for correct responses were included in the analyses, and inverse transformations were performed on raw RTs to correct for distribution skews. These transformed RTs were used throughout the analyses. Finally, outliers were removed by excluding inverse RTs that exceeded 3.5 standard deviations from individual participant means, amounting to 0.14% of RT data for correct responses. Figure 3.1. shows inverted RTs by condition, prime type and age. Note that because RTs are inverted, higher values correspond to faster responses.

Table 3.3.

Summary of generalised linear mixed-effects model examining the effects of condition, prime type, age, and the condition x prime type x age interaction on lexical decision accuracy

Baseline condition	Fixed effects	Estimate	SE	*z* value
Form (F)	Intercept[a]	3.26	0.16	20.92***
	Prime type (related vs. unrelated)[b]	-0.30	0.15	-1.93†
	Age (months)[b]	0.20	0.08	2.62**
	Condition (M vs. F)	0.70	0.22	3.18**
	Condition (P vs. F)	-0.12	0.21	-0.59
	Prime type x age[b]	0.16	0.12	1.33
	Prime type x condition (M vs. F)	0.37	0.24	1.58
	Prime type x condition (P vs. F)	0.28	0.20	1.38
	Age x condition (M vs. F)	0.03	0.10	0.28
	Age x condition (P vs. F)	0.10	0.08	1.19
	Age x condition x prime type (M vs. F)	-0.26	0.18	-1.50
	Age x condition x prime type (P vs. F)	-0.38	0.16	-2.37*
Pseudomorphological (P)	Intercept[a]	3.14	0.15	20.48***
	Prime type (related vs. unrelated)[b]	-0.02	0.14	-0.12
	Age (months)[b]	0.30	0.07	4.02***
	Condition (M vs. P)	0.83	0.22	3.75***
	Prime type x age[b]	-0.22	0.10	-2.10*
	Prime type x condition (M vs. P)	0.09	0.23	0.39
	Age x condition (M vs. P)	-0.07	0.10	-0.75
	Age x condition x prime type (M vs. P)	0.11	0.18	0.64
Morphological (M)	Intercept[a]	3.96	0.17	23.33***
	Prime type (related vs. unrelated)[b]	0.07	0.19	0.38
	Age (months)[b]	0.23	0.09	2.46*
	Prime type x age[b]	-0.11	0.14	-0.75

[a] The intercept represents log odds of accuracy for the baseline condition, averaged across age in months and prime type; [b] Within the baseline condition

† $p < 0.1$ * $p < .05$ ** $p < .01$ *** $p < .001$

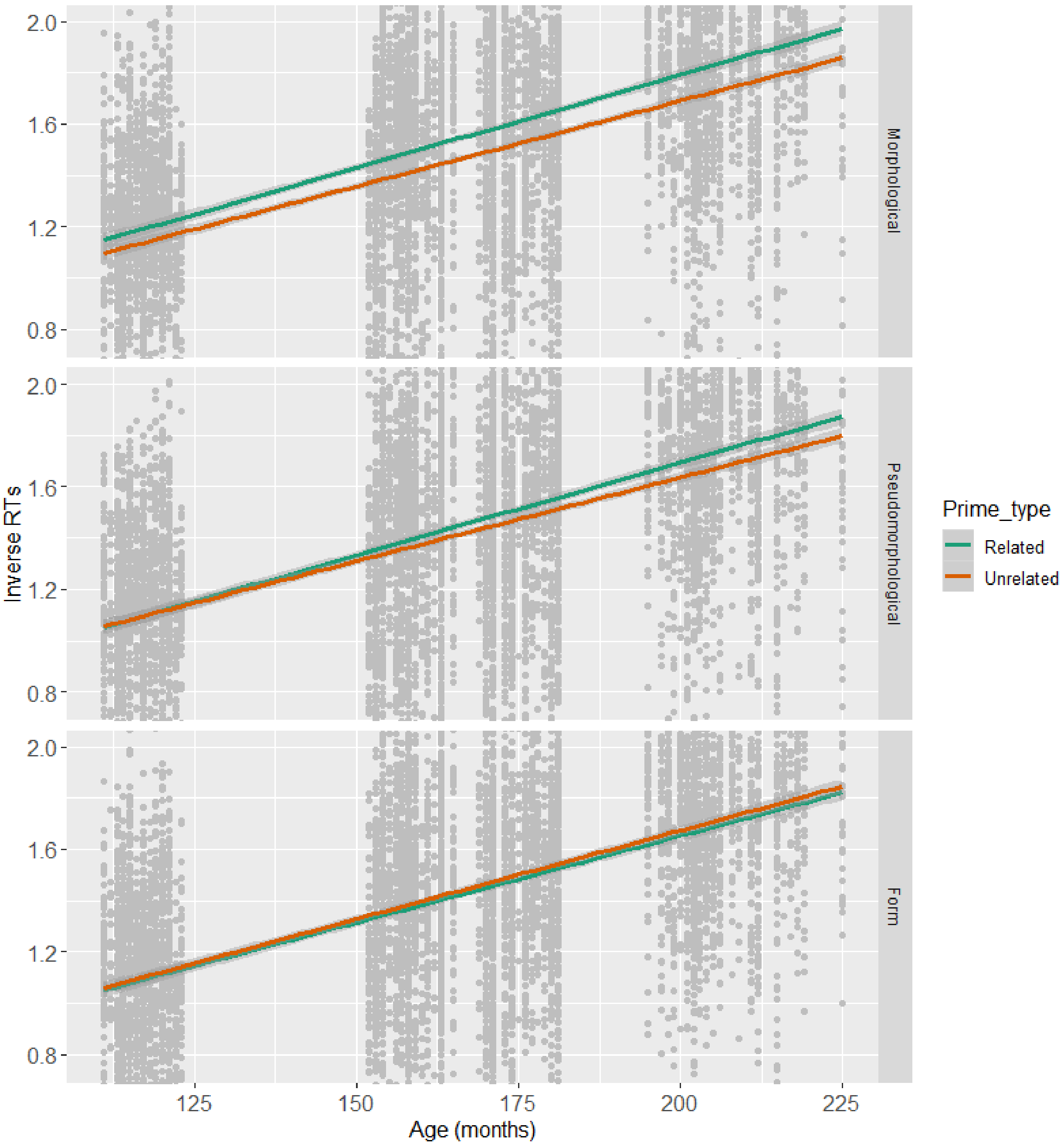

Figure 3.1. Plots showing inverted reaction time data points by condition, prime type and age

The final model used for the RT analysis was structured as follows: Model <- lmer (RT ~ condition * prime type * age_months + (1+condition*prime type|participant) + (1+prime type:age_months|item)). Following removal of RTs for incorrect responses and outliers as described above, 19483 observations from 202 participants responding to 102 items were analysed. Table 3.4. presents the output from this analysis. Examination of estimated coefficients revealed a main effect of prime type in all three conditions, with faster responses to targets preceded by related compared to unrelated primes in the morphological and pseudomorphological conditions (i.e. a significant priming effect), and faster responses to unrelated compared to related primes in the form condition (i.e. a significant inhibition effect). The condition by prime type interaction showed that priming in the morphological condition was statistically greater than priming in the pseudomorphological and form conditions. Additionally, priming in the pseudomorphological condition was statistically greater than priming in the form condition.

Turning to the effect of age, the three-way interaction between condition, prime type and age revealed a trend towards priming effects in the morphological and pseudomorphological conditions increasing in line with age relative to priming effects in the form condition. However, for both comparisons, this effect was only marginally significant. The two-way interaction between age and prime type was significant in both the morphological and pseudomorphological conditions, where the magnitude of priming increased with age. This interaction was not significant in the form condition, indicating that the difference in RTs to related and unrelated primes was relatively stable across development.

Finally, there was a significant effect of age in all three conditions: responses from older participants were faster overall. The age by condition interaction was not significant at any level, indicating that reaction times decreased as a function of age at a similar rate across conditions.

Table 3.4.

Summary of linear mixed-effects model examining the effects of condition, prime type, age, and the condition x prime type x age interaction on lexical decision RTs

Baseline condition	Fixed effects	Estimate	SE	*t* value
Form (F)	Intercept[a]	1.41	0.02	67.95***
	Prime type (related vs. unrelated)[b]	-0.02	0.01	-2.16*
	Age (months)[b]	0.22	0.01	15.15***
	Condition (M vs. F)	0.08	0.02	3.44***
	Condition (P vs. F)	-0.00	0.02	-0.07
	Prime type x age[b]	-0.00	0.01	-0.39
	Prime type x condition (M vs. F)	0.10	0.01	8.19***
	Prime type x condition (P vs. F)	0.05	0.01	3.79***
	Age x condition (M vs. F)	0.00	0.01	0.75
	Age x condition (P vs. F)	0.00	0.01	0.33
	Age x condition x prime type (M vs. F)	0.02	0.01	1.92†
	Age x condition x prime type (P vs. F)	0.02	0.01	1.74†
Pseudomorphological (P)	Intercept[a]	1.41	0.02	64.13***
	Prime type (related vs. unrelated)[b]	0.03	0.01	3.23**
	Age (months)[b]	0.22	0.02	13.71***
	Condition (M vs. P)	0.08	0.02	3.50***
	Prime type x age[b]	0.02	0.01	2.05*
	Prime type x condition (M vs. P)	0.05	0.01	4.01***
	Age x condition (M vs. P)	0.00	0.01	0.38
	Age x condition x prime type (M vs. P)	0.00	0.01	0.10
Morphological (M)	Intercept[a]	1.49	0.02	69.21***
	Prime type (related vs. unrelated)[b]	0.08	0.01	8.73***
	Age (months)[b]	0.22	0.02	14.47***
	Prime type x age[b]	0.02	0.01	2.17*

[a]The intercept represents inverse reaction times for the baseline condition, averaged across age in months and prime type; [b]Within the baseline condition

†p < 0.1 *p< .05 **p < .01 *** p < .001

Previous findings have indicated that skilled readers process morphologically complex words via a morpho-orthographic mechanism that automatically decomposes items with a surface morphological structure (e.g., Longtin et al., 2003; Rastle et al., 2004), but it is not known how or when this mechanism is acquired in relation to reading development. The purpose of this study was to examine for the first time the evidence for morpho-orthographic decomposition across late childhood and adolescence. A sample of 202 children and adolescents ranging in age from 9 to 18 years completed a masked prime lexical decision task in response to targets that were preceded by a) morphologically-related primes (*toaster – TOAST*; morphological condition), b) primes sharing a surface morphological relationship with the target in the absence of semantic overlap (*corner – CORN*; pseudomorphological condition), and c) primes that overlapped only in form with the target (*freeze – FREEZE*; form condition).

Analyses with condition, prime type and age as predictors revealed significant priming effects in the morphological and pseudomorphological conditions: response times to related primes were faster than to unrelated primes. These effects were not simply due to orthographic overlap between the targets and their primes because the magnitude of priming in both the morphological and pseudomorphological conditions was statistically greater than that observed in the form condition. In fact, a significant inhibitory effect was observed for word pairs sharing a purely orthographic relationship, with faster responses to unrelated compared to related primes. Additionally, the magnitude of priming in the morphological condition exceeded that observed in the pseudomorphological condition, in line with some previous findings from skilled readers (e.g., Beyersmann et al., 2012; Diependaele, Duñabeitia, Morris, & Keuleers, 2011, but cf. Rastle et al., 2004). These graded effects provide evidence for a morpho-orthographic decomposition mechanism, but suggest that this is tempered by effects of semantic transparency. There was a significant interaction between prime type and age in both the morphological and pseudomorphological conditions, indicating that the magnitude of priming in both conditions increased with age. Finally, there was a trend towards a greater contrast between priming in these conditions and that observed in the form condition in line with age, but this did not reach significance in either comparison.

These findings replicate previous studies demonstrating morphological priming in both adults (Longtin et al., 2003; Rastle et al., 2004) and children (Beyersmann et al., 2012; Hasenäcker et al., 2016; Quémart et al., 2011, 2017), and provide robust evidence that readers as young as 9-10 years rapidly decompose semantically transparent complex words during word recognition. The interaction with age indicates that the effect becomes stronger in line with reading experience. Similarly, the presence of pseudomorphological priming aligns with evidence from skilled readers (Rastle & Davis, 2008; Rastle et al., 2004), indicating a decomposition mechanism that operates on the basis of orthographically-defined morphemic units (morpho-orthographic decomposition), such that items with a pseudomorphological structure (e.g., *corner*) are parsed into their constituent morphemes in the same way as true morphologically-structured items (e.g., *toaster*) in the early stages of visual word recognition. However, this priming effect was similarly contingent on age: as age increased, so did the magnitude of pseudomorphological priming. This clearly aligns with Beyersmann et al. (2012)'s findings with English-speaking 8-11 year olds and adults, in which they found no evidence of morpho-orthographic priming with children, but observed the usual pattern of morphological and pseudomorphological priming in adults.

This pattern of findings suggests that semantic transparency is the primary factor influencing decomposition of morphologically complex words in younger readers, and that rapid analysis of morphological structure on an orthographic level emerges once individuals reach a certain level of reading experience. Figure 3.1. indicates that mid-adolescence may be an important developmental period in relation to the emergence of morpho-orthographic decomposition, resonating with the findings reported in Chapter 2, which uncovered differences in morphological processing between younger and older adolescents.

There was a significant inhibition effect in the form condition that did not interact with age, indicating that the effect was relatively stable across reading development. This inhibition effect was not predicted, although it is not without precedence, as Beyersmann et al. (2012) observed a similar pattern in their group of 10-11 year olds. They proposed that inhibition may arise from lexical interference in instances where there is no overlapping lexical representation between prime and target. However, by this account, inhibition should also have been observed in the pseudomorphological condition, as representations of *corn* and *corner* do not overlap semantically either. The AUSTRAL model of morphological processing (Taft, 2006; Taft & Nguyen-Hoan, 2010) can account for this pattern of priming because, on this view, the lemma for *corner* is activated from form-level units corresponding to *corn* and *-er*, such that the lemma for *corn* will already be activated prior to presentation of the target (*CORN*). On the other hand, the lemma for a monomorphemic item that does not contain a pseudosuffix, such as *window*, is activated directly from its corresponding grapheme units, while both the form-level unit and lemma corresponding to *wind* are activated. Taft and Nguyen-Hoan (2010) suggest that the absence of a form-level unit for *-ow* leads to rapid suppression of *wind*, which could interfere with subsequent recognition when the target is presented.

Despite priming in the morphological and pseudomorphological conditions increasing with age, there was only a trend towards this increase being distinct from changes in priming in the form condition. In other words, this pattern of priming permits only tentative conclusions about age-related increases in morpho-orthographic decomposition (indexed through pseudomorphological priming in the absence of form priming). One issue with adopting chronological age as a proxy for developmental stage of reading is that, for older students in particular, reading ability may reflect individual differences in accumulated exposure to words in texts over a number of years, rather than age specifically (Nation, 2017). Thus, the reading proficiency levels of individuals within an academic year group may overlap considerably with both younger and older children. Given the theoretical argument that morpho-orthographic decomposition depends on representations of morphemes at the level of orthography (Taft, 2006; Xu & Taft, 2015), orthographic knowledge may be a better predictor of morpho-orthographic decomposition than chronological age.

Recent investigations into individual differences in morphological decomposition lend support to this idea. Andrews and Lo (2013) adopted a masked priming paradigm with skilled readers using the same three conditions as in the current study. They also measured semantic knowledge via a vocabulary task and orthographic knowledge via a combination of two spelling tasks. They found that individuals who presented with stronger semantic knowledge relative to orthographic knowledge showed markedly greater priming in the morphological condition than in the pseudomorphological condition. By contrast, individuals with stronger orthographic relative to semantic knowledge demonstrated stronger pseudomorphological priming effects coupled with weaker morphological priming effects. Individual differences in reading and language proficiency have also been shown to modulate priming effects using nonword primes in French children (Beyersmann, Grainger, et al., 2015) and adults (Beyersmann, Casalis, Ziegler, & Grainger, 2015) respectively.

As all participants in this study completed an assessment of word reading efficiency as part of the battery of background measures, it was possible to investigate whether participants with better orthographic knowledge (measured through word reading skill) would show stronger evidence of morpho-orthographic decomposition. To examine this question, analyses were run with raw scores on the

TOWRE sight word efficiency measure (Torgesen et al., 2012) entered into the models in place of age.

A generalised linear mixed effects model was run to examine the effects of word reading, condition and prime type, and their three-way interaction, on log odds of accuracy, while a linear mixed effects model was used to examine the effects of the same predictors on inverted RTs. Predictor variables were scaled and centred as before, and the structure of random effects was determined using the principles outlined previously.

Accuracy. The final model used for the analysis of accuracy was structured as follows: Model <- glmer (log odds accuracy ~ condition * prime type * word reading + (1+condition*prime type|participant) + (1+prime type*word reading|item)). Estimated coefficients of fixed effects revealed a main effect of word reading in all three conditions: participants scoring higher on the word reading task were more accurate overall. No other comparisons were significant (see Table 3.5.).

Reaction times. The final model used for the RT analysis was as follows: Model <- lmer (RT ~ condition * prime type * word reading + (1 + condition + prime type|participant) + (1 + prime type|item)). Table 3.6. presents the output from this analysis. Examination of estimated coefficients revealed a main effect of word reading ability in all three conditions: participants with better word reading were faster in their responses overall. The two-way interaction between word reading and prime type approached significance in the pseudomorphological condition, indicating a trend towards a greater magnitude of priming in line with increased word reading ability. Finally, the magnitude of priming in the pseudomorphological condition relative to the form condition increased significantly in line with word reading ability (see Figure 3.2. for a summary of the effects of condition, prime type and word reading ability on RTs).

Table 3.5.

Summary of generalised linear mixed-effects model examining the effects of condition, prime type, word reading, and the condition x prime type x word reading interaction on lexical decision accuracy

Baseline condition	Fixed effects	Estimate	SE	*z* value
Form (F)	Intercept[a]	3.25	0.16	20.82***
	Word reading (raw score)[b]	0.25	0.07	3.43***
	Prime type x word reading[b]	-0.05	0.13	-0.37
	Word reading x condition (M vs. F)	0.03	0.10	0.34
	Word reading x condition (P vs. F)	0.07	0.08	0.85
	Word reading x condition x prime type (M vs. F)	-0.09	0.19	-0.49
	Word reading x condition x prime type (P vs. F)	0.05	0.17	0.27
Pseudomorphological (P)	Intercept[a]	3.13	0.15	20.30***
	Word reading (raw score)[b]	0.32	0.07	4.38***
	Prime type x word reading[b]	-0.00	0.12	-0.01
	Word reading x condition (M vs. P)	-0.04	0.10	-0.38
	Word reading x condition x prime type (M vs. P)	-0.14	0.19	-0.73
Morphological (M)	Intercept[a]	3.97	0.17	23.27***
	Word reading (raw score)[b]	0.29	0.09	3.14**
	Prime type x word reading[b]	-0.14	0.15	-0.92

Note. Only comparisons involving fixed effect of word reading are reported here; for all other comparisons, see Table 3.3.

[a] The intercept represents log odds of accuracy for the baseline condition, averaged across word reading and prime type; [b] Within the baseline condition

†p < 0.1 *p< .05 **p < .01 *** p < .001

Table 3.6.

Summary of linear mixed-effects model examining the effects of condition, prime type, word reading, and the condition x prime type x word reading interaction on lexical decision RTs

Baseline condition	Fixed effects	Estimate	SE	*t* value
Form (F)	Intercept[a]	1.41	0.02	63.85***
	Word reading (raw score)[b]	0.19	0.02	11.98***
	Prime type x word reading[b]	-0.01	0.01	-0.95
	Word reading x condition (M vs. F)	0.01	0.01	0.99
	Word reading x condition (P vs. F)	0.00	0.01	0.56
	Word reading x condition x prime type (M vs. F)	0.02	0.01	1.60
	Word reading x condition x prime type (P vs. F)	0.02	0.01	2.07*
Pseudomorphological (P)	Intercept[a]	1.41	0.02	60.84***
	Word reading (raw score)[b]	0.20	0.02	11.21***
	Prime type x word reading[b]	0.02	0.01	1.88†
	Word reading x condition (M vs. P)	0.00	0.01	0.36
	Word reading x condition x prime type (M vs. P)	-0.01	0.01	-0.49
Morphological (M)	Intercept[a]	1.49	0.02	65.54***
	Word reading (raw score)[b]	0.20	0.02	11.75***
	Prime type x word reading[b]	0.01	0.01	1.25

Note. Only comparisons involving fixed effect of word reading are reported here; for all other comparisons, see Table 3.4.

[a] The intercept represents mean inverse RTs for the baseline condition, averaged across word reading and prime type; [b] Within the baseline condition

†$p < 0.1$ *$p < .05$ **$p < .01$ *** $p < .001$

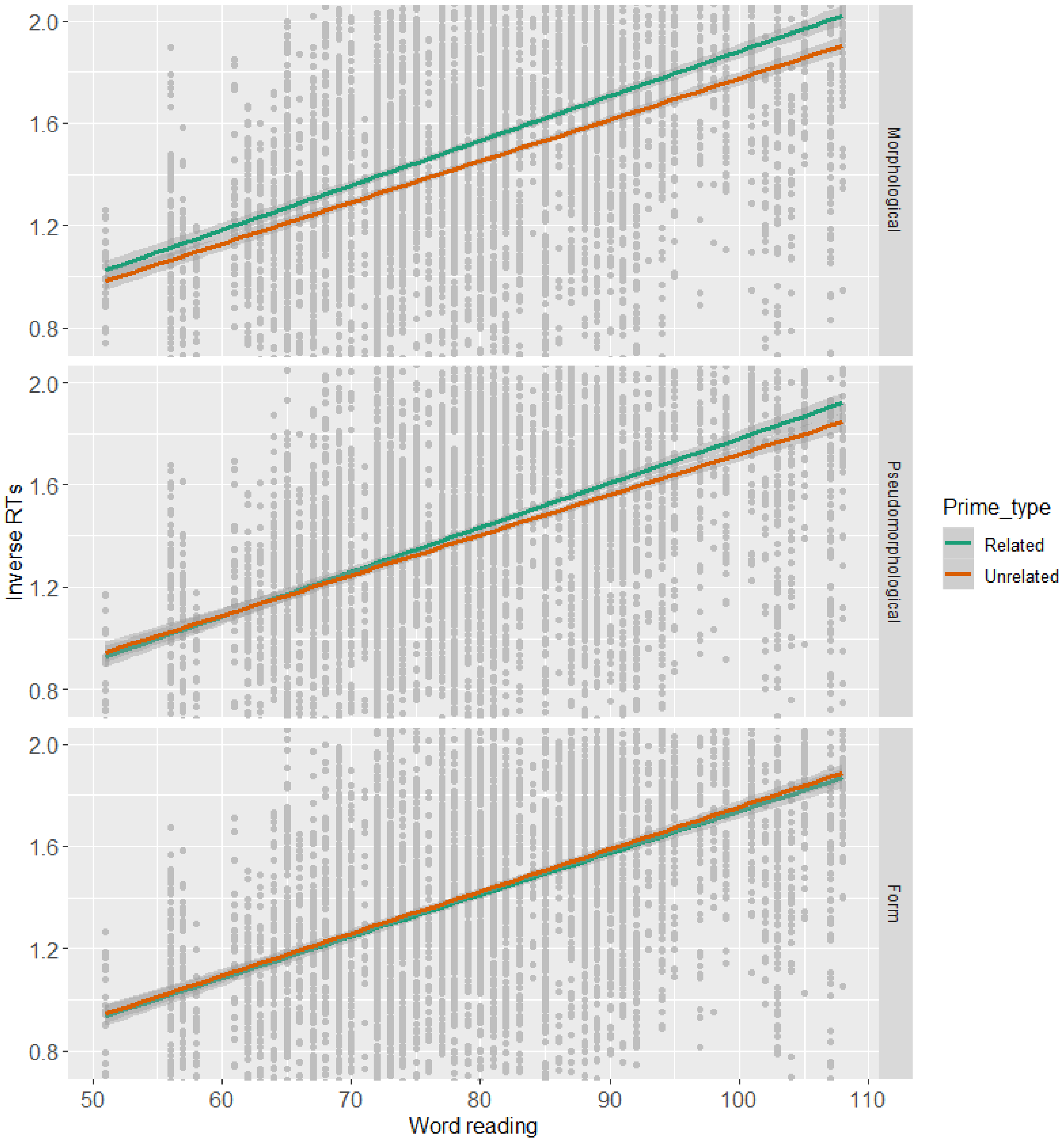

Figure 3.2. Plots showing inverted reaction time data points by condition, prime type and word reading raw score

Exploratory analyses were conducted to examine whether individual differences in word reading efficiency predicted patterns of priming across morphological, pseudomorphological and form conditions. Specifically, it was hypothesised that morpho-orthographic decomposition (evidenced through priming in the pseudomorphological condition) may be particularly constrained by word reading ability.

The results revealed a main effect of word reading ability in all three conditions, with faster responses associated with higher scores on the word reading measure. There was a trend towards greater priming in the pseudomorphological condition in line with word reading ability, with no such effect observed in either the morphological or form conditions. Interestingly, the increase in priming in the pseudomorphological condition in line with word reading ability was statistically larger than that in the form condition. This indicates that the profile of pseudomorphological priming in the absence of form priming, previously observed in skilled adult readers (Beyersmann et al., 2012; Rastle et al., 2004), is stronger in individuals with better word reading skills.

These findings resonate with those of Andrews and Lo (2013), who found greater evidence of pseudomorphological priming in individuals with better orthographic relative to semantic knowledge, although in their study spelling was used to measure orthographic knowledge. There is also partial agreement with the results reported in Beyersmann, Grainger, et al. (2015), who found that reading proficiency predicted suffixed nonword priming (e.g., *tristerie* – *TRISTE*), but not suffixed word priming (e.g., *tristesse* – *TRISTE*) in French children aged 7-11 years. Suffixed nonword priming provides evidence of morpho-orthographic decomposition because, as with pseudomorphological items like *corner*, there is no semantically interpretable relationship between the complex word and its stem. However, Beyersmann, Grainger, et al. (2015) also found that reading proficiency modulated priming in their nonsuffixed nonword condition (e.g., *tristald* – *TRISTE*), the equivalent of form-related pairs (*window* – *WIND*) in the present study. This was not the case here, as reading proficiency predicted the extent to which pseudomorphological priming was distinct from form-only priming.

These divergent findings could be due to differences in the way that real (e.g., *window*) and nonword (e.g., *tristald*, or *windald* for an English equivalent) nonsuffixed items are processed. According to the AUSTRAL model (Taft, 2006; Taft & Nguyen-Hoan, 2010) outlined in section 3.2.2., for real word items like *window*, the lemmas corresponding to both *wind* and *window* are activated, albeit the first from its associated form-level unit, and the latter directly from grapheme units. Crucially, activation of the lemma for *window* leads to rapid inhibition of *wind*. Conversely, processing of a nonword item such as *windald* will result in activation of the lemma for *wind*, but no simultaneous activation of a lemma corresponding to the whole word. The absence of inhibition of *wind* is likely to result in greater priming of the subsequent target, *WIND*, than is observed when the prime is a real word. If skilled readers are more sensitive to the presence of embedded stems, as argued by Beyersmann, Casalis, et al. (2015) elsewhere, then priming for nonsuffixed nonword items would increase alongside reading proficiency. This proposal is supported by empirical evidence showing that orthographically-related nonword primes are facilitative of target word processing, while orthographically-related word primes are inhibitive (Davis & Lupker, 2006).

Additionally, the children comprising the Beyersmann, Grainger, et al. (2015) sample were comparatively young, ranging from 7 to 11 years. This may have limited the extent to which reading proficiency could account for patterns of priming across conditions. In the present study, Figure 3.1. indicates that pseudomorphological priming does not emerge until around mid-adolescence, so it is likely that Beyersmann, Grainger, et al. (2015) were unable to detect differences in priming across suffixed and nonsuffixed nonword conditions in their restricted age and reading ability range.

The analysis conducted here provides some useful insights into the skills that underpin morpho-orthographic decomposition. Specifically, it highlights the importance of word reading ability in the emergence of orthographically-defined morphological representations. However, the reading measure employed here was intended primarily to characterise the reading level of the sample as a whole, rather than to provide a measure of individual differences in orthographic knowledge. Indeed, many of the items included in the measure are not morphologically complex. An aim for future research might be to examine whether the relationship between reading proficiency and morpho-orthographic decomposition reflects a general level of orthographic expertise, or whether it is best captured through specific measures of word reading, spelling or morphological knowledge. Such analysis will help to guide understanding of how reading experience promotes rapid, form-level analysis of morphological structure during reading.

3.3. Experiment 2

As discussed in Chapter 2, part of the aim of this work was to bring together the literatures on morphological processing in developing and skilled readers. Existing research on morphological processing in skilled readers using the masked priming paradigm is extensive (see Chapter 1, section 1.5. for an overview), but while there is considerable evidence for morpho-orthographic decomposition across many studies (Gold & Rastle, 2007; Longtin et al., 2003; Rastle et al., 2004), there has been some variation in how (or whether) this effect is observed (Andrews & Lo, 2013; Diependaele et al., 2011; Jared, Jouravlev, & Joanisse, 2017; Morris et al., 2007). The stimuli used in the current study were developed to be suitable for children (Beyersmann et al., 2012), and while Beyersmann et al. (2012) did find evidence for morpho-orthographic decomposition in their adult control group, the effect was smaller than that observed in the morphological condition. Therefore, an adult control group was included in the present study to add to the existing body of literature on morphological priming in skilled readers, replicate Beyersmann et al.

(2012)'s findings with adults using the same set of stimuli, and align data from skilled readers with the data from developing readers reported in Experiment 1.

3.3.1. Method

Participants. Fifty-two adults (*M* age = 20.38, *SD* = 4.58 with one missing data point for age; 45 female) participated in this second experiment. All were undergraduate and postgraduate students attending Royal Holloway, University of London. As before, none of the participants had a recognised special educational need, and all spoke English as their first language. Participants were either awarded course credit or paid £5 for their time. The study was approved by the University Research Ethics Committee at Royal Holloway, University of London.

Materials and procedure.

Background measures. Participants completed the same measures of nonverbal reasoning, vocabulary, word reading, nonword reading, and morphological awareness as participants in Experiment 1.

Masked priming task. Stimuli and procedure were identical to those outlined in Experiment 1 (see section 3.2.1. above).

3.3.2. Results and discussion

Table 3.7. presents adult performance on background measures. Mean T scores and standard scores on standardised assessments indicate that performance is in line with test norms.

Table 3.7.

Means and standard deviations for background measures (adult participants)

Measure	*M*	*SD*
Nonverbal Ability[a]	50.24	7.33
Oral Vocabulary[a]	53.41	5.94
Sight Word Efficiency[b]	104.60	11.97
Phonemic Decoding Efficiency[b]	102.11	9.18
Morphological awareness[c]	19.57	0.62

[a]T scores: *M* = 50, *SD* = 10; [b]Standard scores: *M* = 100, *SD* = 15; [c]Raw scores; max = 20

As before, R (R Developement Core Team, 2017) and the lme4 package (Bates, Maechler, Bolker, & Walker, 2015) were used to run linear mixed-effects models examining the effects of condition (morphological vs. pseudomorphological vs. form) and prime type (related vs. unrelated) on inverted RTs. To supplement the RT data, generalised linear mixed-effects models were used to examine log odds of accuracy across condition and prime type. In each analysis, condition, prime type, and the condition x prime type interaction were entered into the model as fixed effects. By-participant and by-item random intercepts were included along with by-participant random slopes for the effects of condition, prime type, and their interaction, and by-item random slopes for the effect of prime type. Where a model failed to converge, the same procedure was followed as outlined in section 3.2.2. Table 3.8. shows percentage accuracy and trimmed RTs by condition and prime type.

Table 3.8.

Mean percentage accuracy and RTs (outliers removed) with SDs by condition and prime type (adult participants)

Condition	Prime type	Average % accuracy	Average RT (correct responses)
Morphological			
	Related	97.40 (15.93)	542 (160)
	Unrelated	97.62 (15.24)	581 (180)
Pseudomorphological			
	Related	94.91 (21.99)	598 (213)
	Unrelated	94.34 (23.11)	610 (255)
Form			
	Related	94.68 (22.45)	598 (199)
	Unrelated	96.95 (17.22)	585 (184)

Accuracy. Analysis was based on 5304 observations from 52 participants responding to 102 items. Table 3.9. shows the output from this model. Examination of estimated coefficients of fixed effects from the full model revealed that overall accuracy was greater in the morphological compared to the pseudomorphological condition, and there was a trend towards greater accuracy in the form condition compared to the pseudmorphological condition. Additionally, in the form condition, responses to related primes were less accurate than responses to unrelated primes, and there was a trend towards this difference being greater than the difference between prime types in the pseudomorphological condition.

Table 3.9.

Summary of generalised linear mixed-effects model examining the effects of condition, prime type, and the condition x prime type interaction on lexical decision accuracy (Experiment 2)

Baseline condition	Fixed effects	Estimate	SE	*z* value
Form (F)	Intercept[a]	4.15	0.33	12.64***
	Prime type (related vs. unrelated)[b]	-0.93	0.41	-2.25*
	Condition (M vs. F)	0.21	0.40	0.52
	Condition (P vs. F)	-0.62	0.36	-1.72†
	Prime type x condition (M vs. F)	0.38	0.50	0.75
	Prime type x condition (P vs. F)	0.77	0.43	1.78†
Pseudomorphological (P)	Intercept[a]	3.53	0.25	13.91***
	Prime type (related vs. unrelated)[b]	-0.16	0.34	-0.47
	Condition (M vs. P)	0.83	0.36	2.32*
	Prime type x condition (M vs. P)	-0.39	0.47	-0.83
Morphological (M)	Intercept[a]	4.36	0.31	14.26***
	Prime type (related vs. unrelated)[b]	-0.55	0.44	-1.25

[a] The intercept represents log odds of accuracy for the baseline condition, averaged across prime type; [b] Within the baseline condition

†p < 0.1 *p< .05 **p < .01 *** p < .001

RTs. As before, inverse transformations were carried out on RTs for correct responses, and outliers that exceeded 3.5 standard deviations from individual participant means were removed. This amounted to 0.64% of the data. Figure 3.3. shows raw RT data points, means, distributions and 95% Highest Density Intervals for each condition (morphological, pseudomorphological and form) and prime type (related and unrelated).

The final model was structured as follows: Model <- lmer (RT ~ condition * prime type + (1+prime_type+condition|part) + (1+prime_type|target)). Following removal of RTs for incorrect responses and outliers as described above, analysis was based on 5081 observations from 52 participants responding to 102 items. Table 3.10. shows output from the model. Estimated coefficients of fixed effects showed that overall reaction times were faster in the morphological condition compared to the pseudomorphological and form conditions. There was a significant priming effect in the morphological condition: responses were faster when targets were preceded by related compared to unrelated primes, but no priming effect was observed in either the form or pseudomorphological conditions. Finally, the magnitude of priming was significantly greater in the morphological condition compared to both the pseudomorphological and form conditions, but priming in the pseudomorphological condition was also greater than that in the form condition.

Table 3.10.

Summary of linear mixed-effects model examining the effects of condition, prime type, and the condition x prime type interaction on lexical decision RTs (adult participants)

Baseline condition	Fixed effects	Estimate	SE	*t* value
Form (F)	Intercept[a]	1.81	0.03	52.75***
	Prime type (related vs. unrelated)[b]	-0.02	0.02	-1.12
	Condition (M vs. F)	0.08	0.03	3.15**
	Condition (P vs. F)	-0.01	0.03	-0.33
	Prime type x condition (M vs. F)	0.15	0.02	5.90***
	Prime type x condition (P vs. F)	0.05	0.02	2.03*
Pseudomorphological (P)	Intercept[a]	1.80	0.04	50.08***
	Prime type (related vs. unrelated)[b]	0.03	0.02	1.57
	Condition (M vs. P)	0.09	0.02	3.57***
	Prime type x condition (M vs. P)	0.09	0.02	3.84***
Morphological (M)	Intercept[a]	1.89	0.03	54.86***
	Prime type (related vs. unrelated)[b]	0.12	0.02	6.71***

[a]The intercept represents log odds of accuracy for the baseline condition, averaged across prime type; [b]Within the baseline condition

†p < 0.1 *p< .05 **p < .01 *** p < .001

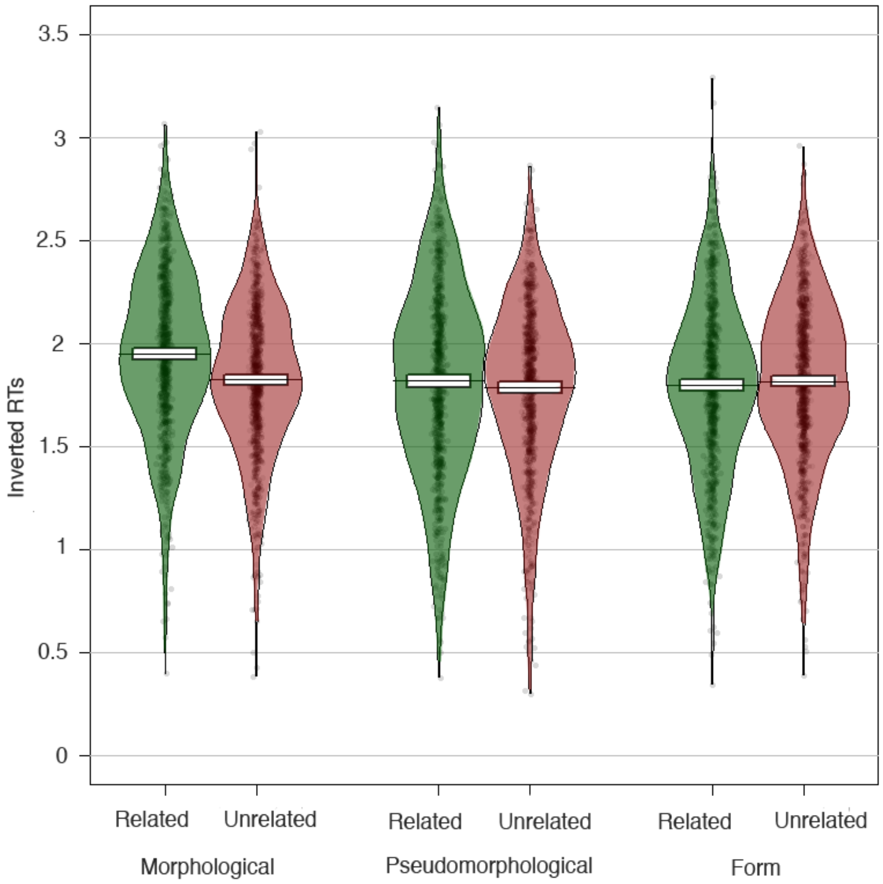

Figure 3.3. Plot showing inverted reaction time data points, means, distributions and 95% Highest Density Intervals by condition and prime type (Experiment 2)

Experiment 2 was conducted with a control group of skilled adult readers. The results revealed a significant priming effect in the morphological condition, but no priming in either the pseudomorphological or form conditions. The magnitude of morphological priming was statistically greater than in the pseudomorphological and form conditions, and priming in the pseudomorphological condition was also greater than that observed in the form condition, arising from a trend towards priming in the pseudomorphological condition coupled with a trend towards inhibition in the form condition.

The absence of pseudomorphological priming in this group was surprising. It suggests that, for these readers, decomposition of morphologically-structured words was dependent on the semantic relationship between the prime and target. However, the pattern of priming in the pseudomorphological condition was distinct from priming in the form condition, which suggests that items with a pseudomorphological structure (e.g., *corner*) were processed via different mechanisms from form controls, such as *window*. The absence of pseudomorphological priming contradicts previous research that has found statistically equivalent priming across morphological and pseudomorphological conditions (Gold & Rastle, 2007; Lavric et al., 2007; Longtin et al., 2003; Rastle et al., 2004), or smaller pseudomorphological relative to morphological priming effects (Beyersmann et al., 2012; Diependaele et al., 2011). However, a small number of studies similarly did not find convincing evidence for morpho-orthographic decomposition (Andrews & Lo, 2013; Jared et al., 2017; Morris et al., 2007).

One factor that may account for these discrepancies is prime duration. Clear evidence for morpho-orthographic decomposition has tended to arise from studies adopting short prime durations (42 ms in Rastle et al., 2004 and Lavric, Clapp, & Rastle, 2007; 46 ms in Longtin et al., 2003), while a more ambiguous picture emerges when prime exposure exceeds 50 ms. Rastle et al. (2000) demonstrated an increasing semantic influence on priming at longer prime durations, and morpho-orthographic effects were not observed when primes were partially or fully visible. Additionally, evidence suggests that in skilled readers, semantic effects become apparent earlier on in the word recognition process compared to developing readers (Quémart et al., 2011), possibly due to faster lexical processing overall. The prime duration of 50 ms adopted in the current study is slightly longer than in previous priming experiments with skilled readers (see above), but this was necessary to align with the study by Beyersmann et al. (2012), and to allow sufficient time for developing readers to process the stimuli. From a methodological perspective, this approach made it possible to examine morphological processing across a very large age range. Nevertheless, it is possible that while a prime duration of 50 ms was sufficient to capture the early stages of word recognition in younger readers, for skilled readers, the time-course of decomposition was already more advanced, leading to an increasing effect of semantic transparency in the adult group.

A second potential confound is that Experiments 1 and 2 were presented via a laptop LCD screen. This was to allow testing to take place in schools in Experiment 1, and Experiment 2 was run with an identical set-up. Previous masked priming experiments have been presented via CRT monitors (e.g., Beyersmann et al., 2012; Rastle et al., 2004), and it is possible that this difference resulted in small variations in perception of prime duration. To investigate these potential explanations for the absence of pseudomorphological priming, a third experiment was run with a new group of adult readers using the same stimuli, but with a reduced prime exposure duration of 35 ms. To eliminate the possibility that deviation from previous findings was due to the type of screen used to present the experiment, Experiment 3 was run using a CRT monitor in a laboratory setting.

3.4. Experiment 3

The 35 ms prime used in this experiment was selected to provide a sufficient contrast to the 50 ms prime used previously, and was similar to SOAs used in other adult studies demonstrating morpho-orthographic effects (Gold & Rastle, 2007; Marslen-Wilson, Bozic, & Randall, 2008). Evidence of morpho-orthographic priming in this experiment would indicate that prime duration was the primary factor in the emergence of semantic effects for skilled readers in Experiment 2.

3.4.1. Method

Participants. Sixty-one adult participants attending university took part in Experiment 3 (*M* age = 21.50, *SD* = 2.76; 46 female, 1 not reported). As previously, all were native English speakers who had no identified special educational need. None of the participants had taken part in Experiment 2, and each was paid £5 for their time. The study was approved by the University Research Ethics Committee at Royal Holloway, University of London.

Materials and procedure. Participants completed only the masked priming task in this experiment.

Stimuli. Primes and targets were identical to those used in Experiments 1 and 2.

Procedure. The masked priming task was completed individually in a quiet, dimly-lit room at the university. The procedure was the same as outlined in Experiments 1 and 2, with the exception that in each trial the prime was displayed for 35 ms as opposed to 50 ms. Additionally, the task was presented on a CRT screen via a desktop computer and responses were made using a button box in line with previous protocols (e.g., Rastle et al., 2004).

3.4.2. Results and discussion

Average response accuracy percentages and raw trimmed RTs are shown in Table 3.11. One participant scored below 75% accuracy overall and was removed from further analysis. One data point was removed from the analysis due to a reported display error by DMDX. As previously, inverse transformed RTs of correct responses only were included in the analysis. RTs that exceeded 3.5 standard deviations from individual participant means were removed, amounting to 0.17% of the data for correct responses. Figure 3.4. shows raw RT data points, means, distributions and 95% Highest Density Intervals for each condition (morphological, pseudomorphological and form) and prime type (related and unrelated).

Table 3.11.

Mean percentage accuracy and RTs (outliers removed) by condition and prime type (Experiment 3)

Condition	Prime type	Average % accuracy	Average RT (correct responses)
Morphological			
	Related	97.75 (14.85)	511 (172)
	Unrelated	96.27 (18.95)	529 (156)
Pseudomorphological			
	Related	91.37 (28.09)	543 (178)
	Unrelated	95.19 (21.41)	548 (215)
Form			
	Related	93.43 (24.79)	555 (212)
	Unrelated	94.02 (23.72)	548 (204)

As in Experiments 1 and 2, the effects of condition (morphological vs. pseudomorphological vs. form) and prime type (related vs. unrelated) on log odds of accuracy and inverted RTs were examined using generalised linear mixed-effects models and linear mixed-effects models respectively. The structure of random effects was determined following procedures outlined in section 3.2.2.

Accuracy. Analysis was based on 6119 observations from 60 participants responding to 102 items. Output from this model is reported in Table 3.12. Estimated coefficients of fixed effects revealed that overall responses were more accurate in the morphological condition compared to the pseudomorphological and form conditions. There was a significant main effect of prime type in the morphological and pseudomorphological conditions: in the morphological condition, responses to targets preceded by related primes were more accurate than to targets preceded by unrelated primes, while the reverse was true in the pseudomorphological condition. The two-way prime type by condition interaction revealed that the effect of prime type differed significantly across morphological and pseudomorphological conditions.

Table 3.12.

Summary of generalised linear mixed-effects model examining the effects of condition, prime type, and the condition x prime type interaction on lexical decision accuracy (Experiment 3)

Baseline condition	Fixed effects	Estimate	SE	*z* value
Form (F)	Intercept[a]	3.20	0.21	15.29***
	Prime type (related vs. unrelated)[b]	-0.13	0.27	-0.48
	Condition (M vs. F)	0.92	0.32	2.85**
	Condition (P vs. F)	-0.11	0.25	-0.44
	Prime type x condition (M vs. F)	1.16	0.54	2.13*
	Prime type x condition (P vs. F)	-0.55	0.36	-1.52
Pseudomorphological (P)	Intercept[a]	3.09	0.20	15.77***
	Prime type (related vs. unrelated)[b]	-0.68	0.27	-2.54*
	Condition (M vs. P)	1.03	0.33	3.14**
	Prime type x condition (M vs. P)	1.71	0.52	3.25**
Morphological (M)	Intercept[a]	4.12	0.29	14.11***
	Prime type (related vs. unrelated)[b]	1.03	0.48	2.14*

[a]The intercept represents log odds of accuracy for the baseline condition, averaged across prime type; [b]Within the baseline condition

†p < 0.1 *p< .05 **p < .01 *** p < .001

RTs. Following removal of outliers and RTs for incorrect responses as described above, analysis was based on 5783 observations from 60 participants responding to 102 items. The final model was structured as follows: Model <- lmer (RT ~ condition * prime type + (1+prime_type*condition|part) + (1+prime_type|target)). Estimated coefficients of fixed effects showed that overall responses (averaged across prime type) were faster in the morphological condition compared to the pseudomorphological and form conditions. The effect of prime type was significant in the morphological condition, and approached significance in the pseudomorphological condition, with faster responses to targets preceded by related compared to unrelated primes. In the morphological condition (but not the pseudomorphological condition), this priming effect was statistically greater than that observed in the form condition. However, there was no difference in the magnitude of priming between the morphological and pseudomorphological conditions.

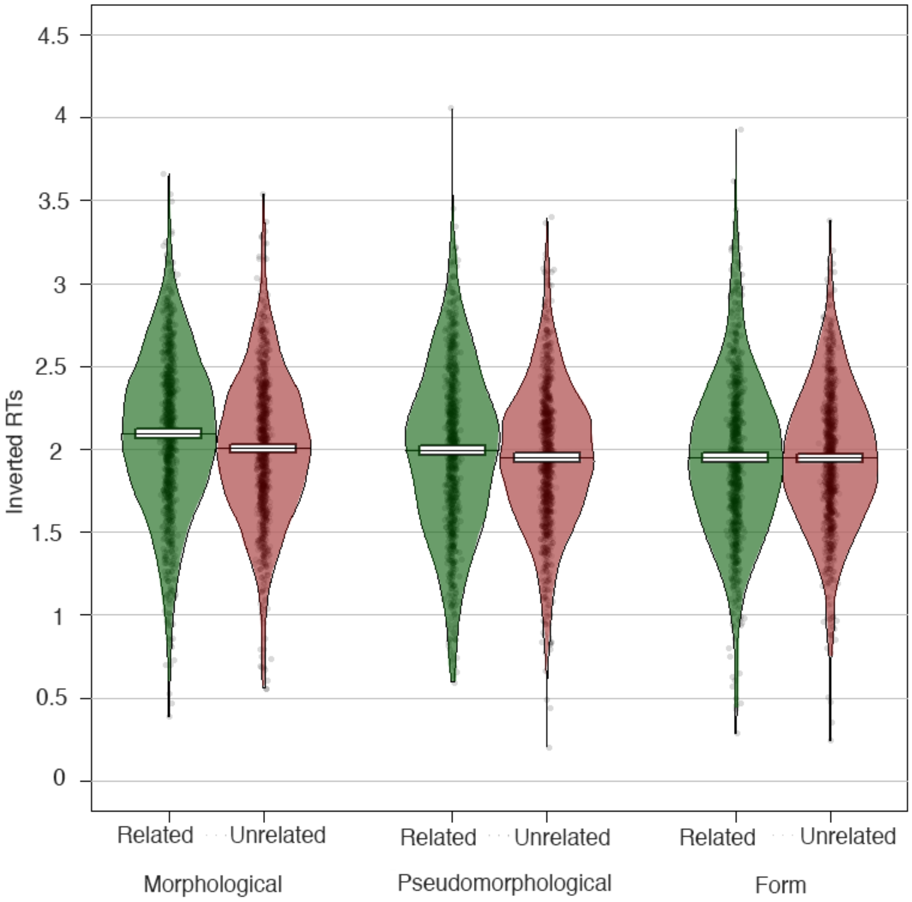

Figure 3.4. Plot showing inverted reaction time data points, means, distributions and 95% Highest Density Intervals by condition and prime type (Experiment 3)

Table 3.13.

Summary of linear mixed-effects model examining the effects of condition, prime type, and the condition x prime type interaction on lexical decision RTs (Experiment 3)

Baseline condition	Fixed effects	Estimate	SE	*t* value
Form (F)	Intercept[a]	1.95	0.04	51.23***
	Prime type (related vs. unrelated)[b]	0.00	0.02	0.13
	Condition (M vs. F)	0.10	0.03	3.93***
	Condition (P vs. F)	0.02	0.03	0.64
	Prime type x condition (M vs. F)	0.08	0.03	2.63*
	Prime type x condition (P vs. F)	0.04	0.03	1.27
Pseudomorphological (P)	Intercept[a]	1.97	0.04	52.10***
	Prime type (related vs. unrelated)[b]	0.04	0.02	1.87†
	Condition (M vs. P)	0.08	0.03	3.29**
	Prime type x condition (M vs. P)	0.05	0.03	1.53
Morphological (M)	Intercept[a]	2.05	0.04	53.10***
	Prime type (related vs. unrelated)[b]	0.09	0.02	4.08***

[a] The intercept represents mean inverted RT for the baseline condition, averaged across prime type; [b] Within the baseline condition

†$p < 0.1$ *$p < .05$ **$p < .01$ *** $p < .001$

The aim of Experiment 3 was to examine whether the absence of pseudomorphological priming in our adult data in Experiment 1 could be attributed to the use of a longer prime duration compared to previous studies (Longtin et al., 2003; Rastle et al., 2004), or to alterations in perception of visual stimuli introduced by the use of a laptop LCD screen. The adjusted prime duration of 35 ms was intended to capture an earlier stage of word recognition for skilled readers, and the use of a CRT monitor to present the stimuli ensured that perceived prime duration was comparable to previous studies. The findings revealed significant morphological priming, a trend towards pseudomorphological priming, and no priming for form-related pairs. Priming in the morphological condition was statistically greater than in the form condition, but not the pseudomorphological condition, and there was no difference in priming between the pseudomorphological and form conditions.

This pattern of results was again unexpected. It strongly suggests that morphological decomposition was influenced by the semantic properties of the complex words, and not driven by rapid analysis of morpho-orthographic structure as observed in previous studies with skilled readers (Beyersmann et al., 2012; Longtin et al., 2003; Rastle et al., 2004).

An important consideration when comparing results from the current study to adult studies demonstrating morpho-orthographic effects is that the stimuli were selected to be suitable for developing readers. Across the stimuli set, prime and target frequency and target orthographic neighborhood size (N) were higher than those adopted by Rastle et al. (2004) (a comparison of psycholinguistic characteristics across conditions and studies can be found in Appendix 3.C.). These factors may have influenced how items were processed by skilled readers. It is well established that high-frequency words are processed more rapidly than low-frequency words (Brysbaert et al., 2018) which could give rise to semantic effects earlier on in the time course of word recognition. Some evidence suggests that frequency effects decrease as a function of language exposure, driven primarily by reduced error for low-frequency items (Monaghan, Chang, Welbourne, & Brysbaert, 2017). It is likely that for skilled adult readers with high levels of language exposure, the stimuli adopted here were consistently processed quickly and efficiently relative to greater variability in our developing readers. However, post-hoc analyses revealed that the frequency of the related prime (measured using the Zipf scale; van Heuven, Mandera, Keuleers, & Brysbaert, 2014) was not predictive of the magnitude of priming observed across conditions (see Appendix 3.D.). Similarly, while there was an effect of target frequency across all conditions, with faster reaction times to higher frequency targets, this did not interact with prime type, indicating that the pattern of priming across conditions was not predicted by target frequency either.

A further consideration is that pseudomorphological priming effects may have been constrained by the high N of target words. Forster and Davis (1991) identified the ‘density constraint’ – that form priming is only observed for words that are selected from low-density neighbourhoods. As the relationship between items such as *corn* and *corner* is form-based, high N across target stimuli may have suppressed priming in the pseudomorphological and form conditions, but not in the morphological condition. These item characteristics are particularly pertinent for the most skilled readers because word frequency and N change as a function of language experience: accumulated exposure to words determines how frequently those words are encountered, and how many close competitors are likely to be represented in the lexicon (Castles, Davis, & Letcher, 1999). This possibility was again explored in post-hoc analyses (see Appendix 3.C.), with orthographic neighbourhood size measured using OLD20 (Yarkoni, Balota, & Yap, 2008). Results indicated that higher orthographic neighbourhood size was associated with suppression of priming in the pseudomorphological condition relative to the morphological and form conditions, although in both cases, this was only a trend (*ps* < .10). It is possible that limited variation in frequency and N within this stimuli set made it difficult to detect the influence of these factors on priming.

Stimuli-level characteristics cannot account for the difference between the patterns of priming observed in Experiments 2 and 3, and those reported for skilled adult readers by Beyersmann et al. (2012), because stimuli were identical across studies. However, one potential source of disparity could relate to the structure of the linear mixed-effects models used in the analyses. As outlined above, the approach here was to adopt a maximal random effects structure for all models initially, simplifying only when a model did not reach convergence (Barr et al., 2013). In all analyses, by-participant and by-item random slopes were included in addition to random intercepts. This meant that the models not only accounted for different baselines across participants and items (random intercepts), but also the fact that the effects of condition, prime type and their interaction may vary across participants, and that the effect of prime type may vary across target items (random slopes). By contrast, Beyersmann et al. report only by-participant and by-item random intercepts in their random effects structure, which effectively makes the assumption that the slopes of the fixed effects are uniform across participants and items. Indeed, when the dataset from Experiment 3 was analysed using an intercepts-only model, the priming effect in the pseudomorphological condition was significant (*t* = 2.34).

Finally, given that there was a trend towards pseudomorphological priming in Experiment 3, and a significant difference in magnitude of priming between the pseudomorphological and form conditions in Experiment 2, it is possible that these experiments simply lacked sufficient power to detect the overall pattern of priming observed in previous studies. Sample size was based on the number of participants typically included in such experiments (e.g., n = 62 in Rastle et al. [2004]; n = 42 in Beyersmann et al. [2012]; and n = 43 in [Longtin et al., 2003]), but may not be adequate given the complexity of the analyses used. To examine the evidence for this, post-hoc analysis was conducted in which data from the adult participants in Experiments 2 and 3 were combined, and the factor ‘group’ was added to the model to capture any differences in patterns of priming arising from prime duration or presentation of the experiment. The analysis not only revealed a significant pseudomorphological priming effect (*t* = 2.32), but also indicated that priming in the pseudomorphological condition was statistically greater than priming in the form condition (*t* = 2.13), thus replicating the effects observed elsewhere with skilled readers (Beyersmann et al., 2012; Gold & Rastle, 2007; Longtin et al., 2003; Rastle et al., 2004). There was no interaction with group, suggesting that this effect did not vary in line with prime duration or the type of screen on which stimuli were presented.

3.5. General Discussion

The primary purpose of the work outlined in this chapter was to examine the mechanisms underpinning morphological decomposition in developing readers. Of particular interest was the developmental period from late childhood to late adolescence, as findings reported in Chapter 2 indicated that this might be a particularly important phase of reading development in relation to processing of morphologically complex items. Additionally, this age range has been much neglected in previous research in this field, despite evidence that children do not consistently process morphological structure in the same way as skilled adult readers (Beyersmann et al., 2012; Hasenäcker et al., 2016; Quémart et al., 2011).

Experiment 1 provided evidence for a morphological decomposition mechanism that is based, in the first instance, on analysis of orthographic structure, thus aligning with sublexical accounts of morphological processing (Rastle & Davis, 2008; Taft, 2006; Taft & Forster, 1975). Additionally, this is modulated by age and reading ability, with older, more able readers demonstrating stronger evidence of morpho-orthographic decomposition. These findings point to the importance of reading experience in the development of orthographically-defined morphological representations, as accumulated exposure to form-meaning regularities over time facilitates activation of morphological units when they are encountered in texts (Reichle & Perfetti, 2003). In relation to Schreuder and Baayen's (1995) account of morphological processing, along with evidence of stem activation in younger readers (Beyersmann, Grainger, et al., 2015; Grainger & Beyersmann, 2017; Hasenäcker et al., 2016; Lázaro et al., 2018), it seems plausible that an important factor in the development of morphological processing is the acquisition of affix representations. If these start at the conceptual level and over time become linked to form-based representations that function as units of access, as argued by Schreuder and Baayen (1995), then this would account for the influence of semantic transparency on morphological processing earlier on in reading development, and the subsequent emergence of an orthographic level of morphological representation that gives rise to decomposition of items such as *corner*.

It is important to note that priming in the pseudomorphological condition was weaker than that observed in the morphological condition. This is contrary to Rastle et al. (2004) and Longtin et al. (2003) among others, who found equivalent priming across these conditions, but it does align with Beyersmann et al. (2012), Diependaele et al. (2011), and Morris et al. (2007). According to recent sublexical models (Xu & Taft, 2015), effects of semantic transparency do not preclude the existence of a morpho-orthographic decomposition mechanism. Decomposition of items such as *corner* which bear no semantic relation to their stems (*corn*) can only be achieved through a parsing mechanism that initially operates independently of semantics. However, it seems likely that semantic properties exert an influence very quickly, leading to suppression of a pseudostem through lexical competition with the whole word (Taft, 2015; Taft & Nguyen-Hoan, 2010). This process may be particularly rapid for higher frequency items such as those used in the present study, given that recognition of these items is more efficient overall (Brysbaert et al., 2018), which could account for some of the variation in the strength of pseudomorphological priming observed across different studies.

Turning to the Experiments 2 and 3, the absence of strong evidence for pseudomorphological priming in skilled adult readers was surprising, particularly considering that Experiment 1 seemed to indicate a linear increase with age and reading ability. While it was hypothesised that the unexpected pattern of priming in Experiment 2 may reflect semantic effects arising from a slightly longer prime duration than adopted elsewhere, Experiment 3 revealed that this was unlikely to be the case. Interestingly, when the data from the two experiments were combined, the typical pattern of pseudomorphological priming in the absence of form priming did emerge. This suggests that the initial experiments may have been underpowered, and that the effects observed here are relatively weak compared to similar studies.

One challenge of adopting the same stimuli across such a wide age range is that properties such as word frequency and orthographic neighborhood size (N) depend on language exposure, and their influence on word recognition may not be uniform across reading development (Monaghan et al., 2017). In this instance, stimuli were selected to be suitable for developing readers (Beyersmann et al., 2012), and frequency and N were high. These factors are known to influence decomposition processes (Forster & Davis, 1991; Forster, Davis, Schoknecht, & Carter, 1987) and speed of processing (Brysbaert et al., 2018), which in turn may determine whether morpho-orthographic decomposition is observed, particularly in the most skilled readers. However, variation in these factors was limited across the stimuli set. Future research could incorporate items that range more broadly across the spectrum of such psycholinguistic variables to tease apart their effects at different stages of reading development.

The experiments reported here address a substantial gap in the existing literature by examining morpho-orthographic decomposition across an extensive period of reading development. The data corroborate previous evidence that morphologically complex words are processed on the basis of their constituent morphemes from mid-late childhood onwards, but also provide new evidence that while the semantic properties of complex words govern decomposition for less experienced readers, a mechanism that operates automatically on the basis of orthographic morphological structure emerges during adolescence. The pattern of results observed here concurs with findings from Chapter 2 showing that efficiency of morphological processing undergoes a protracted period of development, particularly when compared to explicit morphological knowledge, and that mid-adolescence represents an important transitional phase. It also resonates with accumulating evidence that the visual word processing system continues to develop into adolescence (Ben-Shachar et al., 2011; Eddy et al., 2014). These findings have wider implications for theories of reading development, and in particular underline the importance of exposure to morphological regularities in establishing rapid access to meaning from print.

CHAPTER FOUR

The role of derivational suffixes in word learning

4.1. Introduction

As discussed in Chapter 1, section 1.4., several of the most influential models of reading propose a central role for word knowledge (Coltheart et al., 2001; Harm & Seidenberg, 2004; Perfetti & Hart, 2002; Perfetti & Stafura, 2014; Perry et al., 2007; Plaut et al., 1996). Depending on theoretical perspective, well-developed knowledge about words provides an alternative pathway to decoding for word reading, is associated with stronger connections between orthographic, phonological and semantic units, and results in higher quality lexical representations that can be efficiently retrieved during reading. Word knowledge may contribute to successful reading comprehension both directly, by supporting understanding of the words in a text, and indirectly by increasing efficiency of word recognition (Perfetti & Stafura, 2014). In children, adolescents and adults, word knowledge is closely associated with reading outcomes (Braze et al., 2016, 2007; Clarke, Snowling, Truelove, & Hulme, 2010; Duff & Hulme, 2012; Nation & Cocksey, 2009; Nation & Snowling, 2004; Ouellette, 2006; Ouellette & Beers, 2010; Perfetti, 2007; Ricketts et al., 2007, 2016). Specifically, readers with better oral vocabulary skills show advantages in regular and irregular word reading (Nation & Cocksey, 2009; Nation & Snowling, 2004; Ouellette & Beers, 2010; Ricketts et al., 2016, 2007) and reading comprehension (Braze et al., 2016, 2007; Clarke et al., 2010; Nation & Snowling, 2004; Ouellette & Beers, 2010; Ricketts et al., 2007), offering support for the theoretical accounts outlined above.

In this chapter, I examine how morphological information may support acquisition of new word knowledge by strengthening links between word form (phonology and orthography) and word meaning (semantics and grammar). The aim of the experiment reported here was to provide proof of concept that information carried by suffixes might be used in the formation of new lexical representations, acquired in the context of explicit instruction.

4.1.1. Vocabulary development

Children begin building oral vocabulary knowledge in infancy (Hamilton, Plunkett, & Schafer, 2000). As a first step, they must be able to segment the speech stream into frequently co-occurring phonological units, forming the basis of phonological representations that can then be associated with meaning (Jusczyk & Aslin, 1995; Saffran, Aslin, & Newport, 1996). The challenge of establishing these associations should not be underestimated: a given phonological form might represent any one of a vast number of possible referents in a child’s environment (Samuelson & McMurray, 2017). This issue of referential ambiguity has led researchers to suggest that certain factors may constrain how children form links between phonological representations and their meanings. For example, some have argued that children are predisposed to associate novel phonological forms with whole objects as opposed to their parts, and to attach novel labels to objects for which no label yet exists (respectively termed the whole object assumption and mutual exclusivity assumption; Markman, 1990). In later vocabulary development, syntactic knowledge may also be harnessed to guide acquisition of word meaning, particularly in the case of verbs, a process known as ‘syntactic bootstrapping’ (Fisher, Gertner, Scott, & Yuan, 2010; Gleitman, 1990).

More recently, researchers have begun to move the focus away from the idea of innate, language-specific knowledge and biases, and instead turn their attention towards the role of general learning mechanisms in vocabulary acquisition (Samuelson & McMurray, 2017). For example, statistical learning has been explored in relation to language development across a number of areas, including speech perception (Saffran et al., 1996), syntax (Kidd, 2012; Kidd & Arciuli, 2016) and word learning (Yu & Smith, 2007). From a statistical learning perspective, language knowledge is acquired implicitly through exposure to statistical regularities and co-occurrences in the input, such that children (and adults) can learn in the absence of direct instruction or feedback. Statistical learning is not limited to acquisition of language: it has also been observed in non-linguistic domains, and even in other species (Aslin, 2017). In relation to vocabulary acquisition, statistical learning can account for how children learn mappings between phonological forms and object referents (Smith & Yu, 2008; Yu, 2008; Yurovsky, Fricker, Yu, & Smith, 2014), and how existing lexical knowledge supports learning of new vocabulary items (Yu, 2008; Yurovsky et al., 2014).

The facilitatory effects of prior word knowledge are reflected in the trajectory of vocabulary growth in infancy. Children's acquisition of new vocabulary items starts slowly, but undergoes rapid proliferation in the second year of life, widely referred to as the 'vocabulary spurt' (Bloom, 1973; McMurray, 2007). One challenge to the statistical learning approach comes from evidence that children can map a phonological form to a referent following a single exposure, a process termed 'fast mapping' (Carey & Bartlett, 1978), which for a long time was thought to be a factor in this rapid acquisition of new words. However, fast mapping has been shown to be highly transient, such that word-object mappings are forgotten after even short delays (e.g., 5 minutes in Horst & Samuelson, 2008). Additionally, fast mapping may not be such an efficient strategy outside of controlled laboratory settings because naturalistic environments introduce a greater degree of referential ambiguity (Yurovsky et al., 2014). Thus, in isolation, it is not a sufficient mechanism to account for how children acquire knowledge of words. Recent approaches favour the view that word learning is not an 'all-or-nothing' phenomenon, but that lexical knowledge is accumulated gradually over the course of repeated exposures across multiple contexts (Beck, McKeown, & Kucan, 2002; Hsiao & Nation, 2018; Kucker, McMurray, & Samuelson, 2015; Nation, 2017; Smith & Yu, 2008; Swingley, 2010; Yu & Smith, 2007; Yurovsky et al., 2014, but cf. Trueswell, Medina, Hafri, & Gleitman, 2013; Medina, Snedeker, Trueswell, & Gleitman, 2011).

Beyond infancy, children’s vocabulary knowledge continues to grow at a remarkable rate. Some estimates suggest that children acquire an average of 9 new words per day between the ages of 18 months and 6 years (Carey, 1978), and that by age 10, children know the meanings of around 20,000 different words (Nippold, 2007). This raises an important question: what constitutes ‘knowing’ a word? The process of forming a connection between a phonological representation and a referent represents only the most basic level of word learning. Vocabulary learning is a dynamic and multifaceted process (Beck, McKeown & Kucan, 2002), and unlike many areas of linguistic knowledge, learning continues into adulthood (Paris, 2005).

Nagy and Scott (2000) identified five aspects of word knowledge that they considered to be important. First, they argued that word knowledge is incremental, such that children acquire new information about a word and consolidate existing lexical knowledge across repeated exposures to the item. This aligns with statistical learning approaches (e.g., Kucker et al., 2015), and with the idea of ‘extended mapping’ as a complement to fast mapping (Carey & Bartlett, 1978). It also fits with a growing interest in the role of contextual diversity in the acquisition of lexical knowledge (Hsiao & Nation, 2018; Nation, 2017). Secondly, word knowledge is not a single construct. Rather, it involves the synthesis of knowledge across a range of dimensions, including meaning, syntactic features, morphological relationships, and links to other words. In literate individuals, knowledge of a word likely also includes orthographic information (Perfetti & Hart, 2002). Thirdly, many words are polysemous: the same orthographic or phonological form may be associated with more than one meaning. Clearly, as children’s vocabulary knowledge expands, mappings between form and meaning must become better specified to account for these overlaps. Relatedly, knowledge of word meaning is dependent in part on knowledge of other words. For example, a child may overextend the label ‘dog’ to refer to both dogs and wolves until they also acquire the word ‘wolf’ and develop an awareness of the features that disambiguate the two (Clark, 1973). Finally, Nagy and

Scott (2000) argued that word knowledge is heterogeneous because the information required to understand and use a word will differ depending on the type of word it is. For example, function words (e.g., *although*, *the*) carry little semantic information compared to a word such as *table*, but they perform an important syntactic role.

Children can acquire knowledge about words both through direct instruction, and incidentally through exposure to spoken and written language in the absence of any specific emphasis on learning (Beck et al., 2002; Nagy, Anderson, & Herman, 1987). Incidental word learning accounts for the majority of children's vocabulary acquisition, given that the number of words they are exposed to during the school years far outweigh that which can feasibly be taught via direct instruction (Nagy & Anderson, 1984), and that classroom vocabulary instruction is limited in both scope (Apthorp et al., 2012), and the amount of time allocated to it (Connor et al., 2014). However, the contexts in which words appear vary in the amount of grammatical or semantic information they provide (Herman, Anderson, Pearson, & Nagy, 1987), and as such, incidental word learning from context can be slow and result in misinterpretation (McKeown & Beck, 2004).

Explicit vocabulary instruction has been shown to be effective in promoting reading comprehension (Elleman, Lindo, Morphy, & Compton, 2009) and oral language skills (Marulis & Neuman, 2010). Children acquire at least some vocabulary knowledge through direct instruction, particularly once they reach school age (Beck & McKeown, 2007; McKeown, Crosson, Moore, & Beck, 2018; Penno, Wilkinson, & Moore, 2002). Beck et al. (2002) argue that effective vocabulary instruction should extend beyond matching words with definitions or synonyms, and aim to capture more nuanced relationships between words and their contexts. They propose a three-tiered framework for selecting words to be taught during instruction, highlighting in particular the need to target 'tier two' words: words that are familiar to mature language users, are more characteristic of written language than of conversational language, and which are not tied to a specific domain (e.g., *precede*).

Beck et al. (2002) suggest that vocabulary instruction that is interactive, rich in meaning, and emphasises contextual diversity can help to build the foundational vocabulary knowledge children need to access texts independently as they move through the education system.

Many factors may influence the ease with which readers acquire new word knowledge. Existing vocabulary levels, understanding of syntax, and background knowledge, may all constrain the extent to which a reader is able to identify the meanings of unfamiliar words and integrate the meanings of new words into their vocabulary (Swanborn & de Glopper, 2002). At the word level, morphological structure can provide important cues to word meaning. Knowledge of the stems of complex words, combined with familiarity with a range of affixes, can guide interpretation of an unfamiliar word. For example, a child encountering the word *unstoppable* for the first time is already likely to be familiar with the word *stop* (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012). This knowledge, combined with an understanding, however implicit, of the semantic and syntactic functions of the affixes *un-* and *-able* provides the child with a foundation on which to build knowledge of the meaning of the complex word (McCutchen & Logan, 2011; Nagy & Anderson, 1984; Nippold & Sun, 2008).

4.1.2. The role of morphological knowledge in word learning

Evidence points towards a clear, and possibly reciprocal, relationship between morphological awareness and vocabulary knowledge, even when potential confounds such as phonological awareness and word reading ability are controlled (McBride-Chang, Cho, et al., 2005; McBride-Chang et al., 2008; McBride-Chang, Wagner, et al., 2005; Nagy et al., 2006; Sparks & Deacon, 2015; M. Spencer et al., 2015). Sparks and Deacon (2015) assessed morphological awareness and vocabulary ability longitudinally in 100 children in Grades 2 and 3, and found that morphological awareness at Grade 2 predicted change in vocabulary knowledge between Grades 2 and 3, while the reverse was not true. These findings lend some support to the hypothesis that morphological knowledge drives vocabulary development, but as these data are correlational, and only examine general relationships, it is not possible to draw conclusions about how children use morphological knowledge to infer and learn the meanings of words.

Another line of research has attempted to capture the processes involved in vocabulary acquisition directly. In a seminal study, Anglin (1993) showed that children’s vocabulary development depends to a large extent on their knowledge of morphologically complex words. He tested 6, 8 and 10-year old children’s understanding of base, inflected, compound, and derived words, and extrapolated from their responses to provide estimates of total vocabulary size and the proportion of known words accounted for by each morphological word type. Knowledge of all word types increased with age, but derived words showed by far the biggest increase, particularly between 8 and 10 years. A similar pattern was observed when knowledge of different morphological word types was calculated as a proportion of total vocabulary size: the contribution of base and inflected words to overall vocabulary knowledge declined with age, while the proportion of derived words increased. The protracted trajectory of derived word knowledge resonates with findings elsewhere in the literature showing that mastery of derivational affixation in English-speaking children is slower to develop than mastery of inflection and compounding (Berko, 1958; Derwing & Baker, 1986; Fejzo, Desrochers, & Deacon, 2018; see Chapter 1, section 1.7. for an overview).

Anglin (1993) argued that children’s vocabulary size estimates may reflect not only learned items, but also the ability to infer the meanings of unfamiliar words through morphological analysis. He examined children’s responses for evidence of ‘morphological problem-solving’, in which meanings of words were calculated through processes such as morphological analogy (e.g., comparing *treelet* to *piglet*) and isolation of a known stem. Evidence that children used such strategies to define, produce, or select the target word correctly was observed across all three age groups, but the proportion of known complex words whose meanings were determined in this way increased significantly with age, rising from 56% at age 6 to 65% at age 10. Anglin's findings indicate that, at least in part, the rapid proliferation of children's word knowledge during the primary school years can be linked to their ability to perceive and manipulate morphemes in words.

The ability to capitalise on morphological knowledge to support comprehension of novel words may be particularly important in later education. As children transition from learning to read to 'reading to learn', access to curriculum content is increasingly dependent on comprehension of academic vocabulary, which is often encountered for the first time in texts. As Nagy and Anderson (1984) highlighted, many of these words are low frequency and comprise multiple layers of affixation, originating from both Greek and Latin (Nagy & Townsend, 2012). Interestingly, it is these types of words in particular that may lend themselves to the kind of morphological analysis described by Anglin (1993). In examining the frequency distribution of complex words in school texts, Nagy and Anderson (1984) discovered that items at the lower end of the frequency spectrum tended to be more semantically transparent, and thus available for morphological analysis, than higher frequency complex words. Therefore, as children move through the education system and encounter larger numbers of morphologically complex and unfamiliar words in texts, knowledge of word formation processes may play an increasingly important role in the ability to access and understand academic material, and to acquire new vocabulary from texts.

In these later years of schooling, there appears to be corresponding growth in some aspects of derivational morphological knowledge (Nippold & Sun, 2008; Wysocki & Jenkins, 1987). Tyler and Nagy (1989) argued that different aspects of morphological knowledge may develop at different rates, identifying three key areas of knowledge relating to derivational morphology: relational, syntactic and distributional. Relational knowledge describes the ability to identify morphological structure in words and make links between words sharing a stem (e.g., understanding that *education* is associated with *educative*). Syntactic knowledge is the awareness that derivational suffixes signal word class, such that the -*ness* in *mildness* determines that it is a noun, while the -*ise* in *silverise* signals a verb. Finally, distributional knowledge refers to understanding of selectional constraints, for example, that -*ness* attaches to adjectives, but not verbs. Tyler and Nagy (1989) found that children from the age of 9-10 showed evidence of relational knowledge, while syntactic and particularly distributional knowledge was still developing in 11-12 and 13-14 year olds.

A third approach to examining the relationship between morphology and vocabulary has been to evaluate the effects of explicit morphological instruction on word learning (Baumann, Edwards, Boland, Olejnik, & Kame'enui, 2003; Bowers & Kirby, 2010; Bowers et al., 2010; Ford-Connors & Paratore, 2015; Good, Lance, & Rainey, 2015; Goodwin, 2016; Goodwin & Cho, 2016; Harris, Schumaker, & Deshler, 2011). The purpose of such interventions is to stimulate 'word consciousness' through an understanding of morphological structure and patterns. The term 'word consciousness' refers to a multifaceted set of skills that reflect a level of meta-linguistic awareness and an appreciation of word learning practices, which lay the foundations for students to acquire new words independently (Scott & Nagy, 2009). Although morphological intervention studies vary widely in the amount and intensity of instruction, the words and affixes that are targeted, and the language abilities of participants, almost all indicate improvements in knowledge of targeted items compared to a control group or an alternative intervention, with some additionally revealing generalisation to novel items (e.g., Bowers & Kirby, 2010; Good et al., 2015).

As summarised above, the literature examining the relationship between morphological knowledge and word learning has tended to fall into one of three camps: one which explores general relationships between morphological awareness and vocabulary development, another that characterises how children and adolescents spontaneously use morphological analysis to infer word meaning, and a third that investigates the effects of explicit morphological instruction on learning of target items and transfer to untaught items. However, much less attention has been directed towards the process of word learning itself, and the role that morphology might play in the acquisition of lexical representations that bind together information about word form (phonology and orthography) and word meaning (semantics and grammar).

According to the lexical quality hypothesis (Perfetti & Hart, 2002), well-integrated knowledge about orthography, phonology and semantics supports the development of high-quality lexical representations that are stable, coherent, and efficiently retrieved via input from any one of these three constituents. In the context of new word learning, variation in lexical quality emerges rapidly, with skilled comprehenders demonstrating better semantic learning of unknown words after just 50 minutes of exposure compared to less skilled comprehenders (Perfetti, Wlotko, & Hart, 2005). However, lexical quality is also constrained by item-level properties. For example, instances in which a single word form corresponds to multiple word meanings (e.g., *bank*), or in which a single phonological form corresponds to two orthographic forms, and two meanings (e.g., /kɔːt/ realised as *court* and *caught*), pose a threat to lexical quality because the one-to-one mappings between orthography, phonology and semantics are compromised (Perfetti & Hart, 2002).

From a theoretical perspective, then, morphological structure may support lexical quality. Morphemes are unique linguistic units because they introduce a level of systematicity to the otherwise arbitrary relationship between word form and word meaning. This occurs in two ways. Firstly, words that share the same stem (i.e. morphological families) also overlap in meaning. Secondly, affixes provide cues to word class and word meaning, and function relatively systematically across different words (Ulicheva et al., 2018). Reichle and Perfetti (2003) used computational modelling to demonstrate how exposure to words sharing a stem might build lexical quality by increasing availability of the stem in subsequent retrieval tasks (see Chapter 1, section 1.3). However, less attention has been directed towards overlaps in affixes. In their model of morphological processing, Schreuder and Baayen (1995) proposed that mappings between form and meaning are mediated by concept nodes, which exist for both stems and affixes (see also the AUSTRAL model; Taft, 2006, 2015). Based on this theory, it might be predicted that close ties between morphological units (e.g., affixes) at the form level and whole-word meaning will facilitate lexical quality in newly-formed representations.

The study reported in this chapter took a novel approach to examining the role of morphology in the development of high quality lexical representations. This was done by manipulating the relationship between properties of the suffix (semantic and syntactic) and the meaning of the whole-word item. Within a word learning paradigm, a set of novel suffixed items were taught through explicit instruction, half of which corresponded to definitions that were congruent with the typical semantic and syntactic properties of the suffix; the other half of which were incongruent. Following two training sessions, word learning was assessed through a series of online and offline post-tests designed to tap components of lexical quality. Two groups of adolescents were included in this study: younger adolescents (12-13 years) and older adolescents (16-18 years). This permitted exploration of developmental effects across an age range that is of particular interest, given the findings reported in Chapters 2 and 3.

If properties of suffixes contribute directly to the quality of new lexical representations, then learning should be stronger when the definition corresponds to the usual semantic and syntactic properties of the suffix (congruent condition) compared to when this relationship is compromised (incongruent condition). Secondly, if the ability to harness morphological information to support word learning is influenced by accumulated experience of affixes and their syntactic, semantic and combinational properties across a range of contexts, then the congruency effect may be greater for older adolescents compared to younger adolescents (Nippold & Sun, 2008; Tyler & Nagy, 1989).

4.2. Method

4.2.1. Participants

Participants were 39 younger adolescents (*M* age = 13.25, *SD* = 0.33, 18 female) and 39 older adolescents (*M* age = 18.21, *SD* = 1.09, 36 female). The younger adolescent group was recruited from a mainstream secondary school based in the South-East of England. The older adolescent group comprised participants recruited from a Sixth Form college (*n* = 21), also in the South-East of England, who were entered into a prize draw to win a £40 Amazon voucher for their participation, and first year Psychology undergraduate students (*n* = 18) attending Royal Holloway, University of London, who participated in return for course credits. Because all first year undergraduates were eligible to participate in studies that awarded course credits, it was not possible to set inclusion criteria for this group. Therefore, this group was oversampled (original *n* = 31), and those who spoke English as an additional language (*n* = 8) or who reported a history of special educational needs (*n* = 2) were excluded following data collection. Additionally, software failure during the running of the experiment resulted in the exclusion of a further three participants. The study was approved by the University Research Ethics Committee at Royal Holloway, University of London. The final sample comprised participants who were all native English speakers, none of whom had a known special educational need.

4.2.2. Materials and procedure

Background measures. Standardised measures of nonverbal reasoning, oral vocabulary and word and nonword reading efficiency were conducted to characterise the sample, as outlined in Chapters 2 and 3. Morphological awareness was also assessed using the same task described in Chapter 3, section 3.2.2.

Word learning task.

Stimuli. Stimuli comprised a set of 18 nonwords and 18 definitions (see Appendix 4.A.). Nonwords were formed by combining a CCVCC phonotactically and orthographically legal nonword stem with one of three existing suffixes: -*ist*, -*ise* or -*ful*. Derivational suffixes were selected because derivation is closely tied to lexical processes, while inflection relates primarily to grammar (Carstairs-McCarthy, 2002). These particular suffixes were chosen because they are acquired relatively early in development (Clark, 2014; Clark & Cohen, 1984) and are likely to be well known by adolescent readers (Mahony, 1994). Each suffix creates a different part of speech (noun, verb and adjective, respectively), and all can be considered 'neutral' on Tyler and Nagy's (1989) definition. All nonword items comprised 8 letters corresponding to either 7 or 8 phonemes, and had no existing orthographic neighbours (based on the CELEX written database and calculated using N-watch; Davis, 2005). Mean log bigram frequency was similar across items (see Appendix 4.A. for item characteristics). For each nonword, two definitions were created. One was congruent (syntactically and semantically) with the suffix; the other was incongruent. For example, the suffix -*ist* most commonly forms an agent noun (Laws & Ryder, 2014), so the congruent definition for the nonword item *clantist* was '*a person who investigates crop circles'*, while the incongruent definition was '*to ruin the taste of something'*.

Two lists were then created, each containing all 18 nonwords and all 18 definitions. Pairing of nonwords and definitions was counterbalanced across lists, such that each nonword was matched with its congruent definition in one list and an incongruent definition in the other list. Thus, each list contained 9 items that had a congruent nonword-definition pairing, and 9 items that had an incongruent nonword-definition pairing. In both lists, each suffix appeared three times in the congruent condition and three times in the incongruent condition. For example, in list 1, *clantist* was paired with the definition '*a person who investigates crop circles*' (congruent); in list 2, it was paired with ‘*to ruin the taste of something*’ (incongruent). Participants were randomly assigned to list 1 (n = 38) or list 2 (n = 40).

Procedure. Testing took place across two sessions, spaced one week apart, and these were completed individually or in pairs in a quiet room in school, college or at the university. Session 1 comprised the first learning session and the majority of background measures, while Session 2 comprised the second learning session, any remaining background measures, and the post-tests. Unless otherwise stated, the E-prime 2.0 programme (Schneider, Eschman, & Zuccolotto, 2012a, 2012b) was used to present instructions and stimuli and to record responses throughout all experimental tasks and post-tests. Figure 4.1. presents a summary of the procedure.

Learning session 1. In the first learning session, participants completed a series of computerised tasks designed to familiarise them with the phonological, semantic and orthographic features of the nonwords. Each task followed a test-response-feedback format to promote learning (Karpicke & Blunt, 2011). In Task 1, participants were presented with the nonwords in a sentence context that gave cues to meaning (for example, ‘*as the lead clantist, Rav arrived at the field early to study the mysterious shapes in the corn’*), and were asked to guess the definition. Participants were then provided with the correct definition, and in Task 2, were asked to select the target definition from a choice of three, receiving feedback on their accuracy. In Task 3, each definition was presented on the screen and via audio recording, and participants were asked to recall the item aloud. Feedback was provided, which included the target pronunciation.

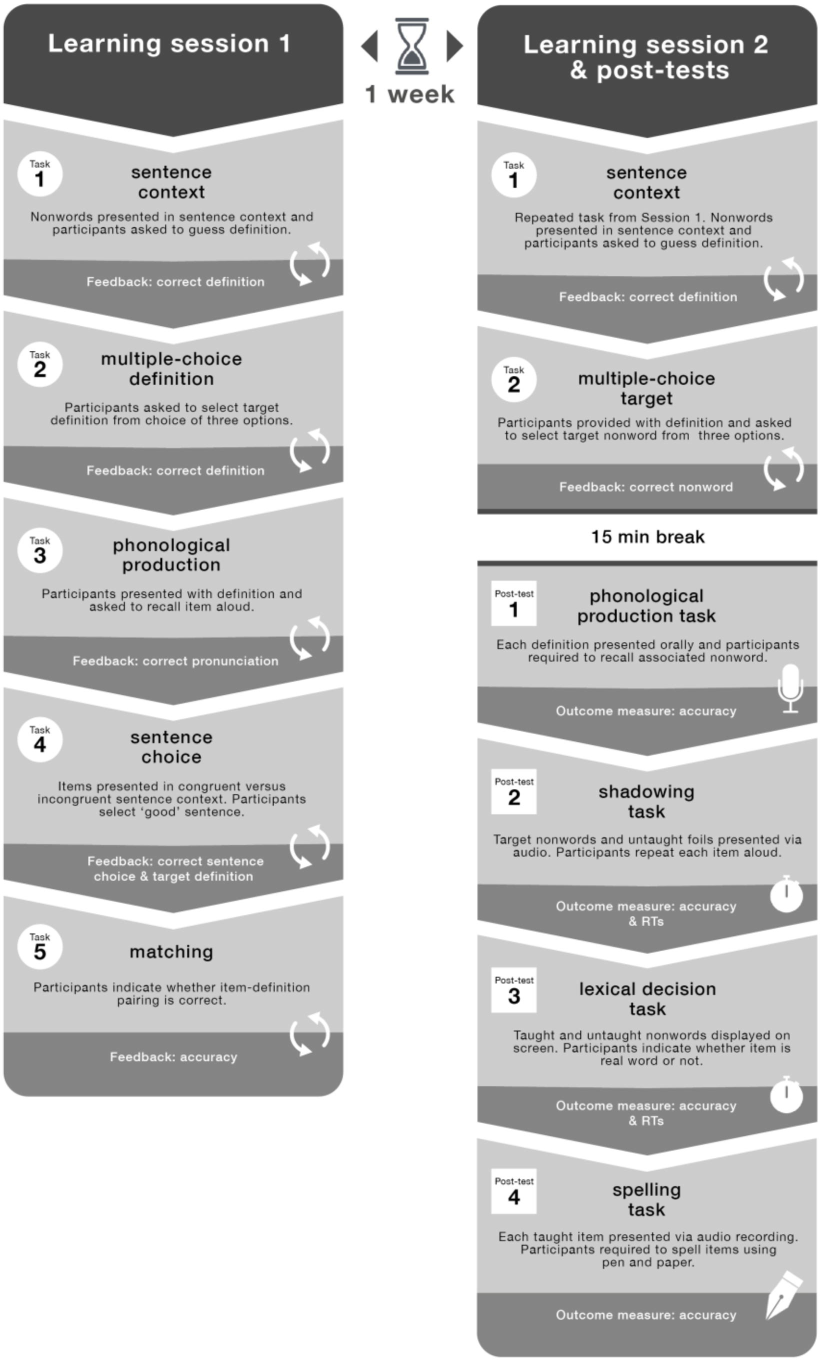

***Figure 4.1*.** Summary of procedure

In Task 4, participants were presented with the item in the context of two sentences. One was congruent with the taught definition, but did not provide additional cues to meaning; the other was incongruent. For example, if the definition for *clantist* was '*a person who investigates crop circles'*, then the congruent sentence was '*Abby trained for several years as a clantist'* while the incongruent distractor was '*Lucy worried that she might clantist the cake'*. Participants were asked to select the 'good' sentence for the given item, and were provided with feedback on accuracy. In the final task, each of the items was displayed on the screen followed immediately by either its associated definition or a distractor, which was randomly sampled from the 17 other definitions. Participants were required to indicate whether the pairing matched by pressing *m* or *z* on the keyboard.

Learning session 2. The second learning session comprised two tasks, and followed the same test-response-feedback structure as Session 1. Task 1 from the first session was repeated, and participants were asked to recall aloud the definition based on seeing and hearing the item in the context of a sentence. Feedback included modelling of the correct definition. In Task 2, participants were presented with each definition in turn and were required to select from a choice of three nonwords: the target item and two distractors. The distractors were both other taught items, one sharing a suffix with the target; the other comprising a different suffix. Feedback on accuracy also included the target item.

Post-tests. Four post-tests were conducted at the end of the second session, following a break of approximately 15 minutes while participants completed an unrelated activity. These were completed in set order as outlined below:

1. Phonological production task. Each definition was presented orally in random order and participants were required to respond verbally with the associated nonword. Responses were audio recorded and later phonetically transcribed.
2. Shadowing task. Learning of phonological forms was assessed using a shadowing task (Bates & Liu, 1996; Liu, Bates, Powell, & Wulfeck, 1997). This

was a speeded task in which the 18 taught nonwords and 18 untaught foils were presented in random order via audio recordings, and participants were required to repeat each item aloud as quickly and accurately as possible. Untaught foils were derived from each of the taught items by substituting two phonemes: the vowel in the taught nonword ‘stem’ was replaced by an alternate vowel, and one phoneme was substituted from the suffix to create a nonmorphological ending (e.g., the foil for *clantist* was *clontilt*). Stimuli were delivered and responses were recorded using DMDX software (Forster & Forster, 2003). Two practice items were presented at the start of the procedure.

3. Lexical decision task. Stimuli comprised the 18 taught items (e.g., *clantist*), 18 nonword items that were created by recombining the taught stems with taught suffixes (e.g., *clantful*), 18 nonword items that combined untaught stems (created by substituting the vowel in the taught stem) with taught suffixes (e.g., *clontist*), 18 nonword items that combined taught stems with untaught suffixes (e.g., *clantify*) and 18 nonword items in which the stem contained a vowel substitution and the suffix also contained a letter/phoneme substitution (e.g., *clontilt*). These nonwords were presented visually one at a time along with 72 real words, and participants were instructed to indicate by pressing a letter on the keyboard whether or not each was a real word that they knew, as quickly as possible. Participants were shown twelve practice items followed by the experimental items. Each trial began with a black fixation cross, which appeared in centre of the screen for 1000ms, followed by the target, which appeared in lowercase Calibri font in the centre of the screen until a response was made. For the practice items only, participants were given feedback on reaction times and accuracy. Participants were told to classify taught items as nonwords. This was so that comparisons could be made across responses to different nonword types

without the additional confounds associated with comparing ‘yes’ vs. ‘no’ responses (e.g., reaction times, handedness).

4. Spelling task. Participants were presented with each taught item via audio recording and were required to spell the item using pen and paper.

4.3. Results

Table 4.1. summarises performance by age group on background measures. Mean scores indicate that both age groups performed close to test norms on standardised measures.

Table 4.1.

Means and standard deviations for background measures by age group

Measure	Younger adolescents (*M* age = 13.25)		Older adolescents (*M* age = 18.21)	
	M	*SD*	*M*	*SD*
Nonverbal ability[a]	46.05	7.81	51.76	9.72
Oral vocabulary[a]	49.85	7.37	54.97	8.93
Word reading efficiency[b]	98.51	11.62	105.49	13.65
Nonword reading efficiency[b]	100.64	11.72	104.95	9.89
Morphological awareness[c]	18.20	1.65	19.39	0.87

[a]T scores: *M* = 50, *SD* = 10; [b]Standard scores: *M* = 100, *SD* = 15, [c]Raw scores: max. = 20

4.3.1. Phonological-semantic learning

Recall of mappings between phonology and semantics was indexed through performance on the phonological production task. Oral responses were audio recorded and later phonetically transcribed. Two accuracy scores were calculated and analysed. The general accuracy score was a binary measure: responses were scored as correct, and were awarded a score of 1, if they matched exactly the target phonological production, while all deviations from the target production, or instances in which a participant gave no response, were marked as incorrect and awarded a score of 0. The second accuracy score used Levenshtein phonological distances to give a continuous measure of accuracy (the graded accuracy score). These scores captured the phonological proximity of responses to target pronunciations, based on the number of substitutions, deletions, additions and transpositions. Levenshtein distances were calculated using the stringdist package (van der Loo, 2014) in R and were inverted to give a similarity score between 0 and 1, where 0 represented complete dissimilarity and 1 represented complete similarity. Figures 4.1. and 4.2. show mean proportion general accuracy and mean Levenshtein similarity score respectively.

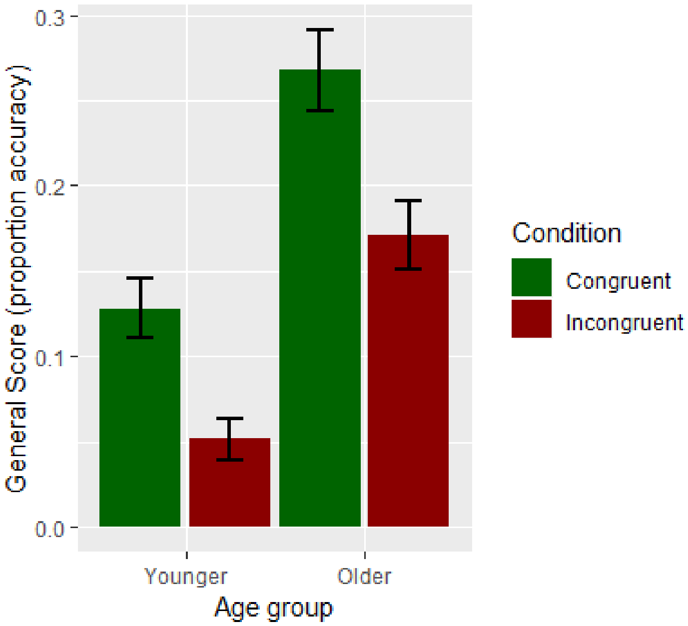

Figure 4.2. Mean proportion accuracy with standard error bars by condition and age group (phonological production task)

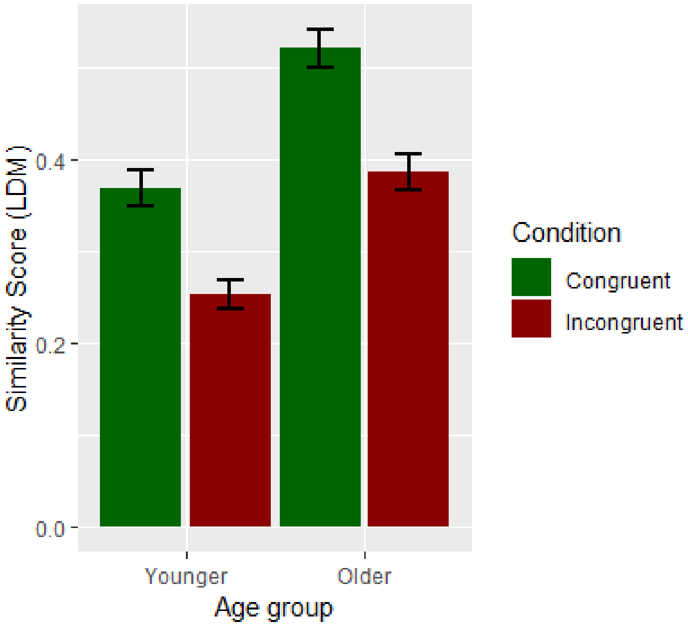

Figure 4.3. Mean graded accuracy score with standard error bars by condition and age group (phonological production task)

R (version 3.4.3; R Core Team, 2017) and the lme4 package (version 1.1-15; Bates, Maechler, Bolker, & Walker, 2015) were used to analyse general accuracy (using generalised linear mixed-effects models with log odds of accuracy as the dependent measure) and graded accuracy (using linear mixed-effects models with similarity score as the dependent measure). In both analyses, condition (congruent vs. incongruent), age group (younger vs. older adolescents), and the condition by age group interaction were entered into the model as fixed effects. Both factors were centred using deviation coding. The structure of random effects was determined by identifying the maximal model (Barr et al., 2013), which included by-participant and by-item random intercepts, along with by-participant random slopes for the effect of condition, and by-item random slopes for the effect of age group. In both analyses, the models converged using the maximal random effects structure, so no modification procedures were required. Both analyses were based on 1404 observations from 78 participants responding to 18 items.

General accuracy. The final model for general accuracy was as follows: Model <- glmer (log odds accuracy ~ condition * age group + (1+condition|partipant) + (1+age group|item)). Output from this model is summarised in Table 4.2., and shows a significant effect of condition (congruent > incongruent) and a significant effect of age group (older adolescents > younger adolescents), but no condition by age group interaction.

Table 4.2.

Summary of generalised linear mixed-effects model examining the effects of condition, prime type, and the condition x prime type interaction on general phonological production accuracy

Fixed effects	Estimate	SE	*z* value
Intercept	-2.41	0.24	-10.02***
Condition (congruent vs. incongruent)	0.98	0.25	3.96***
Age group (older vs. younger)	1.51	0.40	3.79***
Condition x age group	-0.47	0.39	-1.21

*** p < .001

Graded accuracy. The final model for general accuracy was as follows: Model <- lmer (levenshtein.similarity ~ condition * age group + (1+condition|partipant) + (1+age group|item)). Output from this model is summarised in Table 4.3, and reveals the same pattern of results as above: a significant effect of condition (congruent > incongruent), a significant effect of age group (older adolescents > younger adolescents), but no condition by age group interaction.

Table 4.3.

Summary of linear mixed-effects model examining the effects of condition, prime type, and the condition x prime type interaction on graded phonological production accuracy

Fixed effects	Estimate	SE	*t* value
Intercept	0.38	0.02	19.24***
Condition (congruent vs. incongruent)	0.13	0.02	7.17***
Age group (older vs. younger)	0.14	0.04	3.55***
Condition x age group	0.02	0.04	0.53

*** p < .001

4.3.2. Shadowing

Each participant’s response to each item was audio recorded and saved as a separate audio file by DMDX (Forster & Forster, 2003). Following testing, each audio file was processed by manually marking stimulus onset time and response onset time using CheckVocal software (Protopapas, 2007), by an experimenter who was blind to the congruency condition. Stimulus onset time was calculated separately on each audio file because it varied slightly across different recordings of the same item.

Shadowing reaction times (RTs) were calculated as the time in milliseconds between stimulus onset and response onset. This approach was taken to allow for formulation of responses prior to the offset of the stimulus (Marslen-Wilson, 1973), and is in line with procedure adopted elsewhere (e.g., Mitterer & Ernestus, 2008). Because stimulus length varied marginally across items, stimulus duration was calculated for each item. To ensure that this measure was as accurate as possible, stimulus duration was calculated twice for each item, once using CheckVocal and once using Praat software (Boersma & Weenink, 2017), and mean stimulus length across the two measures was included as a covariate in the final models. Stimulus duration did not vary systematically across trained (*M* = 817.44, *SD* = 88.78) and untrained (*M* = 830.48, *SD* = 96.53) conditions, *t*(34) = -0.42, *p* = .676. Shadowing data were only available for half of the older adolescent group (the participants recruited from university).

General learning. To examine general learning of phonological form, accuracy and RTs were compared between the 18 trained items and 18 untrained foils.

Accuracy. Figure 4.3. shows mean proportion accuracy for trained vs. untrained items by age group. Four individual data points were removed due to a software audio recording error; three from the younger adolescent group and one from the older adolescent group. Analysis was based on 2048 observations from 57 participants responding to 36 items. R and the lme4 package were used to perform a generalised linear mixed-effects analysis of the effects of familiarity (trained vs. untrained), age group, and their interaction, on log odds of accuracy. The factors ‘familiarity’ and ‘age group’ were centred using deviation coding.

As before, the maximal random effects structure was identified, which included by-participant and by-item random intercepts, along with by-participant random slopes for the effect of familiarity, and by-item random slopes for the effect of age group. The final model was structured as follows: Model <- glmer (log odds accuracy ~ familiarity * age group + (1+familiarity|participant) + (1+age group|item)). Table 4.4. summarises the output from this model. Estimated coefficients showed a significant effect of familiarity, with higher accuracy in responses to trained vs. untrained items. The effect of age group was not significant, but there was a trend towards a significant familiarity by age group interaction.

Table 4.4.

Summary of generalised linear mixed-effects model examining effects of familiarity, age group, and their interaction on log odds of accuracy in the shadowing task

Effects	Estimate	Standard error	*z* value
Intercept	2.34	0.20	11.70***
Familiarity (trained vs. untrained)	1.65	0.36	4.65***
Age group (older vs. younger)	0.31	0.29	1.06
Familiarity x age group	-0.74	0.44	-1.67†

$^{\dagger}p < 0.1$ *** $p < .001$

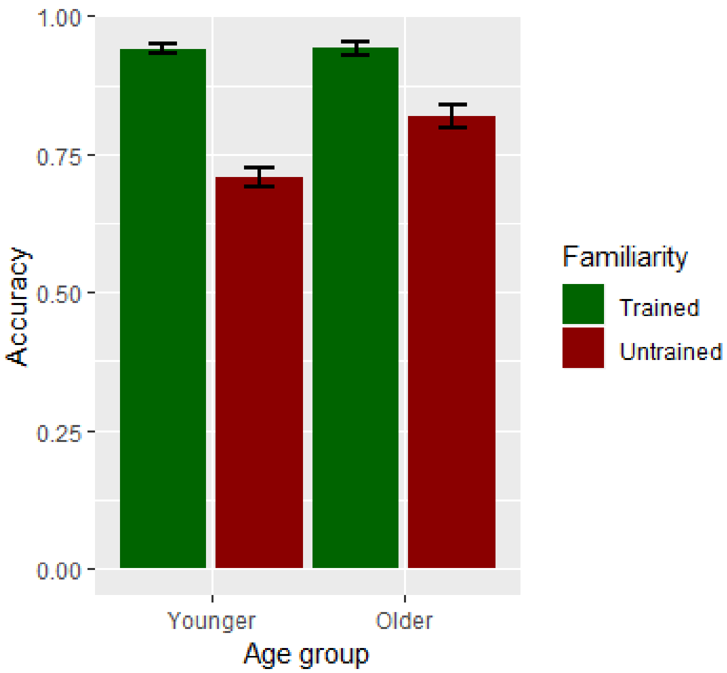

Figure 4.4. Mean proportion accuracy with standard error bars for trained vs. untrained items by age group (shadowing task)

Reaction times. Shadowing RTs for correct responses only were included in the analysis. Figure 4.4. shows mean inverted RTs by familiarity condition (trained vs. untrained) and age group (older vs. younger). Analysis was based on 1723 observations from 57 participants responding to 36 items. Analysis of the effects of familiarity, age group, and their interaction, on inverted shadowing RTs was conducted using linear mixed-effects models. To account for the small variations in length across recorded stimuli, stimulus duration was included as a covariate in the model. Centring of variables was performed as previously. The final model again included the full random effects structure: Model <- lmer (inverse RTs ~ familiarity * age group + familiarity*stimulus duration + (1+familiarity*stimulus duration|participant) + (1+age group|item)). Table 4.5. summarises the output from this model. The intercept represents the grand mean across familiarity condition, age group and stimulus duration, and coefficients correspond to main effects. There was a significant effect of familiarity, with shorter RTs to trained compared to untrained items. There was also a significant effect of stimulus duration: longer stimulus durations were associated with longer RTs. No other effects were significant.

Table 4.5.

Summary of linear mixed-effects model examining effects of familiarity, age group, the familiarity x age group interaction, and stimulus duration on inverse RTs in the shadowing task

Effects	Estimate	Standard error	*t* value
Intercept	0.89	0.02	35.55***
Familiarity (trained vs. untrained)	0.05	0.01	5.28***
Age group (older vs. younger)	-0.01	0.05	-0.21
Stimulus duration	-0.02	0.00	-4.04***
Familiarity x age group	0.01	0.01	0.64
Familiarity x stimulus duration	-0.01	0.01	-1.18

***p* < .01 *** *p* < .001

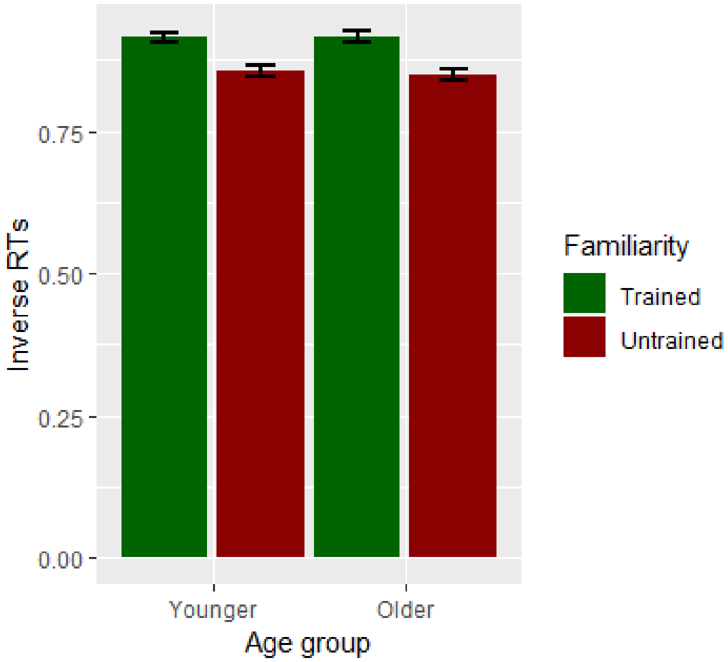

Figure 4.5. Mean inverted RTs with standard error bars for trained vs. untrained items by age group (shadowing task)

Learning of congruent vs. incongruent items. To examine whether learning of phonological form differed across items that were congruent with their definitions compared to items that were incongruent, analyses of accuracy and RTs were conducted on trained items only. In each analysis, congruency (congruent vs. incongruent), age group, and their interaction were entered into the model as fixed effects. A generalised linear mixed-effects model and a linear mixed-effects model were used to examine the effects of these predictors on accuracy and RTs respectively. Variables were centred, and a maximal random effects structure was used in each analysis.

Accuracy. Figure 4.5. shows average proportion accuracy for congruent vs. incongruent items by age group. Within this subset of the data, three individual data points were removed due to a software audio recording error; two from the younger adolescent group and one from the older adolescent group. Analysis was based on

1023 observations from 57 participants responding to 18 items. The final model was structured as follows: Model <- glmer (log odds accuracy ~ congruency * age group + (1+congruency|participant) + (1+age group|item)). Table 4.6. summarises the output from this model. Response accuracy did not differ significantly between items taught in the congruent compared to the incongruent condition, and neither was age group a significant predictor of accuracy. The congruency x age group interaction was also not significant.

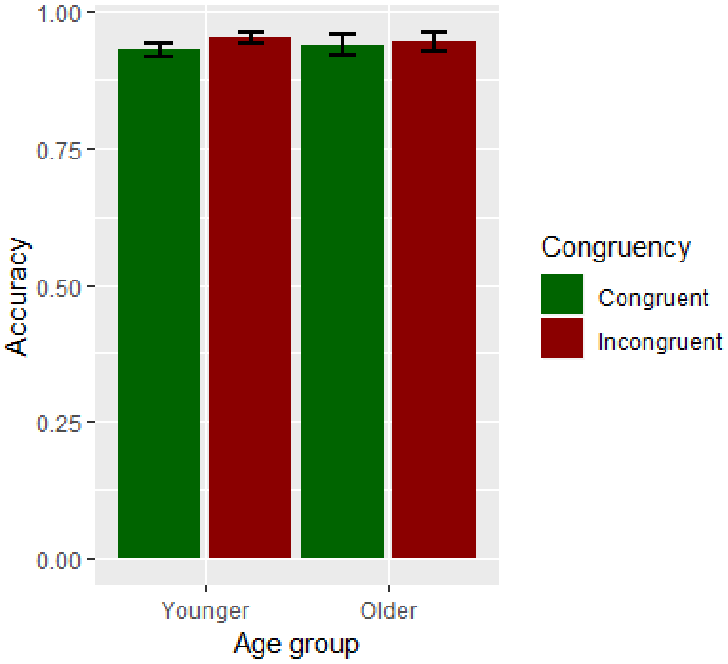

Figure 4.6. Mean proportion accuracy with standard error bars for congruent vs. incongruent items by age group (shadowing task)

Table 4.6.

Summary of generalised linear mixed-effects model examining effects of congruency, age group, and their interaction on log odds of accuracy in the shadowing task

Effects	Estimate	Standard error	*z* value
Intercept	3.03	0.24	12.63***
Congruency (congruent vs. incongruent)	-0.41	0.41	-1.01
Age group (older vs. younger)	-0.06	0.38	-0.15
Congruency x age group	0.32	0.59	0.54

*** *p* < .001

RTs. As before, shadowing RTs for incorrect responses were excluded, and inverse transformations were carried out. Figure 4.6. shows mean RTs by congruency condition (congruent vs. incongruent) and age group (older vs. younger). Analysis was based on 962 observations from 57 participants responding to 18 items. Linear mixed-effects models were used to examine the effects of congruency, age group, and their interaction, on shadowing RTs. Variables were centred, and stimulus duration was again included as a covariate in the model. The final model included the full random effects structure: Model <- lmer (inverse RTs ~ congruency*age group + congruency*stimulus duration + (1+congruency*stimulus duration|participant) + (1+age group|item)). Table 4.7. summarises the output from this model. The intercept represents the grand mean across congruency condition, age group and stimulus duration, and coefficients correspond to main effects. There was again a significant effect of stimulus duration, with longer durations associated with slower RTs. No other effects were significant.

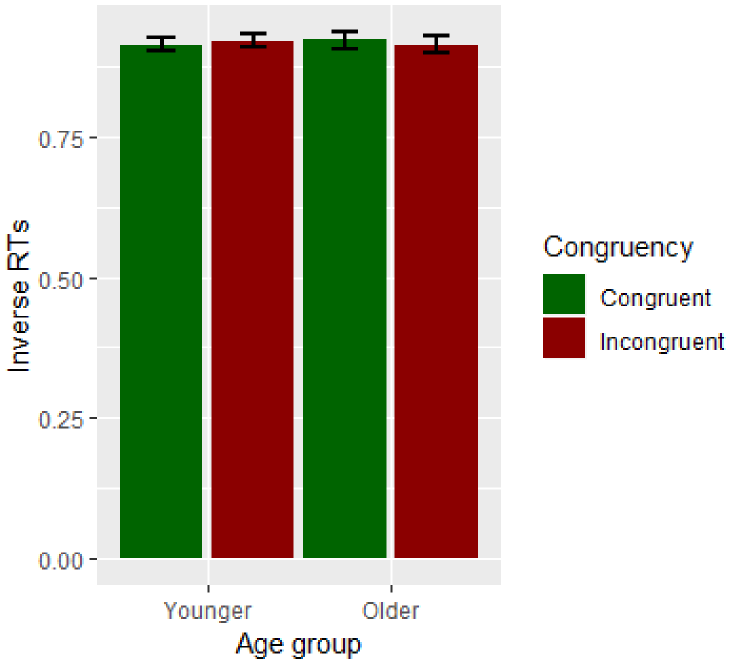

Figure 4.7. Mean inverted RTs with standard error bars for congruent vs. incongruent items by age group (shadowing task)

Table 4.7.

Summary of linear mixed-effects model examining effects of congruency, age group, their interaction, and stimulus duration on inverse RTs in the shadowing task

Effects	Estimate	Standard error	*t* value
Intercept	0.91	0.02	36.63***
Congruency (congruent vs. incongruent)	-0.00	0.01	-0.28
Age group (older vs. younger)	-0.01	0.05	-0.31
Stimulus duration	-0.02	0.01	-4.23***
Congruency x age group	0.01	0.02	0.87
Congruency x stimulus duration	0.01	0.01	1.13

***p* < .01 *** *p* < .001

4.3.3. Lexical Decision

Accuracy and RTs to nonwords in the lexical decision task were analysed. General learning of target items was investigated by comparing response accuracy and RTs to trained items (e.g., *clantist*) compared to a) items with untrained stems (e.g., *clontist*), and b) distant nonwords, in which both stem and suffix were untrained (e.g., *clontilt*). Evidence of learning was indexed through interference in rejection of trained nonword items compared to nonwords with untrained stems, and distant nonwords (similar to the morpheme interference effect outlined in Chapter 2). The untrained stem condition was necessary to detect genuine training effects, given that the suffix was likely to be already familiar to participants, and therefore that lower accuracy and slower RTs to trained items compared to distant nonwords may simply reflect sensitivity to the presence of the suffix.

The effect of congruency was investigated by comparing accuracy and RTs to trained items (*clantist*) and recombined items (e.g., *clantful*; comprising a trained stem paired with a different trained suffix), that were taught in the congruent vs. incongruent condition. If stronger lexical representations were formed for items taught in the congruent condition, then a congruency effect would be expected for trained items, with greater interference observed for congruent vs. incongruent items. On the basis of sublexical theories of morphological decomposition (Taft & Forster, 1975), it was hypothesised that representations of items taught in the congruent condition may be more likely to be encoded and stored in decomposed form compared to items that were taught in the incongruent condition. Given that the latter do not provide links between form and meaning, it was expected that they may be more likely to be stored as whole-word items. This question was investigated by examining responses to recombined items: if items taught in the congruent condition were more likely to be represented in decomposed form, then a greater interference effect would be expected when that stem was combined with a different suffix.

Inverse transformations were carried out on RTs to correct for distribution skews and transformed data were used throughout the analyses. RTs for correct responses only were included. For the analysis, outliers were removed by excluding RTs that exceeded 3.5 standard deviations from the mean for each participant.

General learning. Figure 4.7. shows mean accuracy and standard errors for trained, untrained stem and distant nonwords by age group. Figure 4.8. shows inverted reaction time raw data points, means, distributions and 95% Highest Density Intervals by nonword type and age group. Generalised linear mixed-effects models and linear mixed effects models were used to analyse the effects of nonword type (trained vs. untrained stem vs. distant), age group (older vs. younger) and their interaction on log odds of accuracy and inverted reaction times (respectively) in the lexical decision task. As previously, the full random effects structure was specified in each analysis unless the maximal model failed to converge, in which case simplification procedures were followed until the most complex model supported by the data was identified.

Accuracy. The final model used for the analysis of accuracy was structured as follows: Model <- glmer (log odds accuracy ~ nonword type * age group + (1+nonword type|participant) + (1+ age group|item)). Table 4.8. presents the output from this model. Inspection of estimated coefficients revealed a significant effect of nonword type: averaged across age groups, accuracy was lower for trained nonwords compared to both untrained stem and distant nonwords, indicating greater interference effect in nonword rejections. There was also a trend towards lower accuracy for untrained stem nonwords compared to distant nonwords. There was a main effect of age group in each condition, with older adolescents producing more accurate responses overall compared to younger adolescents.

Table 4.8.

Summary of generalised linear mixed-effects model examining the effects of nonword type, age group, and the nonword type x age group interaction on lexical decision accuracy

Baseline condition	Fixed effects	Estimate	SE	*z* value
Distant	Intercept[a]	4.60	0.40	11.64***
	Nonword type (trained vs. distant)	-1.60	0.43	-3.75***
	Nonword type (untrained stem vs. distant)	-0.82	0.43	-1.90†
	Age group (older vs. younger)[b]	2.29	0.68	3.36***
	Nonword type x Age group (trained vs. distant)	-1.20	0.71	-1.70†
	Nonword type x Age group (untrained stem vs. distant)	-0.97	0.69	-1.40
Untrained stem	Intercept[a]	3.78	0.31	12.13***
	Nonword type (trained vs. untrained stem)	-0.78	0.35	-2.20*
	Age group (older vs. younger)[b]	1.32	0.52	2.56*
	Nonword type x Age group (trained vs. untrained stem)	-0.23	0.56	-0.42
Trained	Intercept[a]	3.00	0.24	12.31***
	Age group (older vs. younger)[b]	1.09	0.41	2.63**

[a]The intercept represents log odds of accuracy for the baseline condition, averaged across nonword type and age group; [b]Within the baseline condition

†p < 0.1 *p< .05 **p < .01 *** p < .001

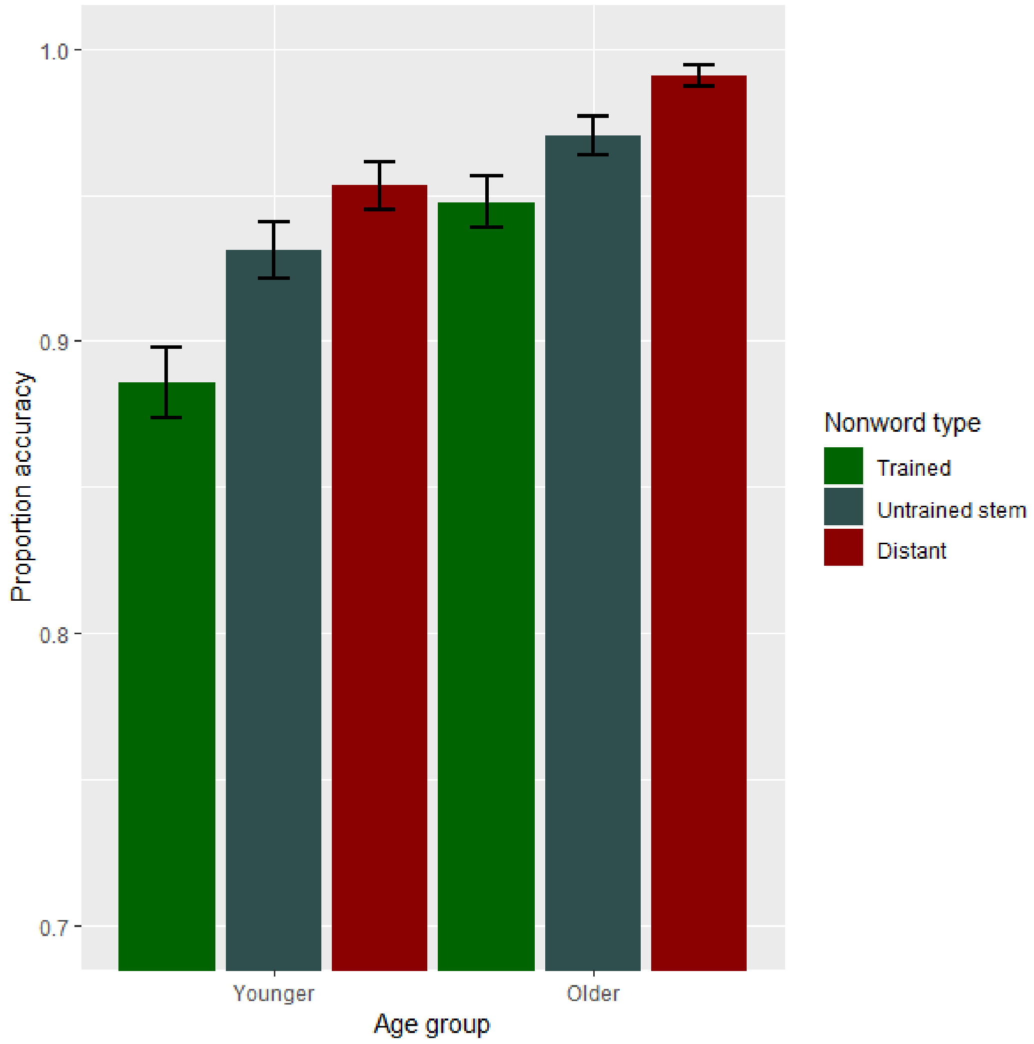

Figure 4.8. Mean proportion lexical decision accuracy (i.e. correct rejections) with error bars by nonword type and age group

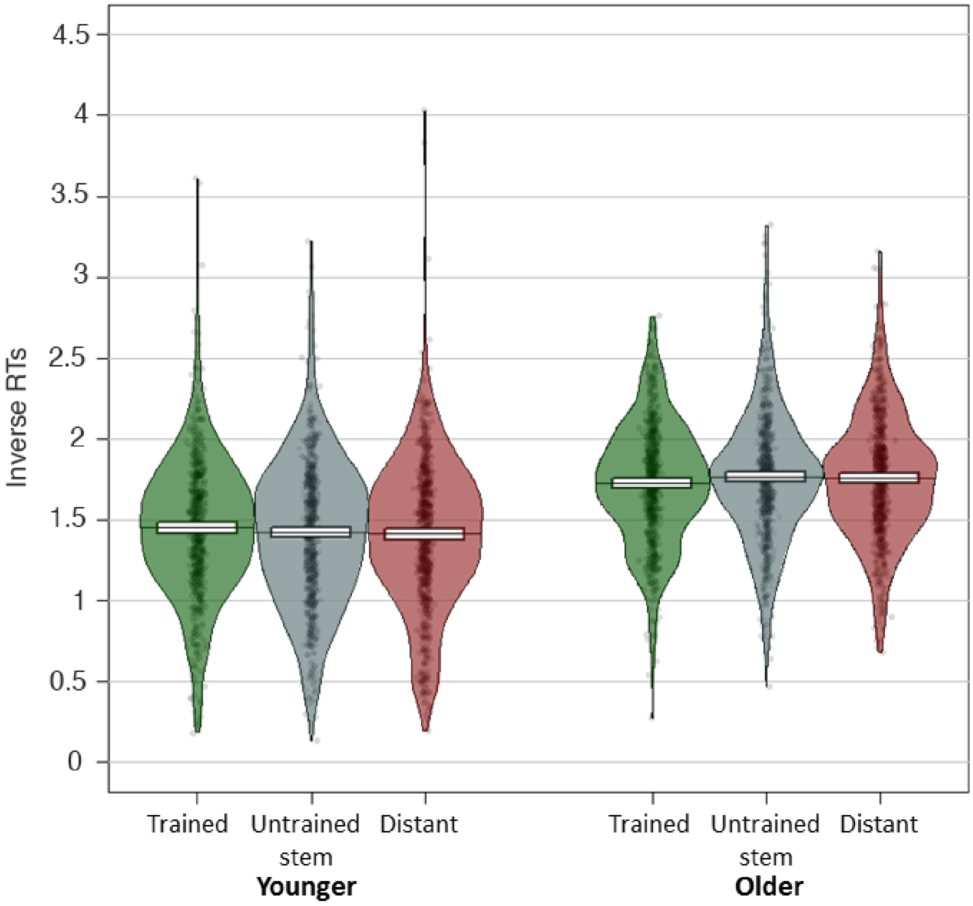

Figure 4.9. Mean inverted RTs for lexical decision responses, with raw data points, distributions and 95% Highest Density Intervals by age group and nonword type

RTs. Inspection of plots generated from the trimmed data revealed a number of remaining outliers in the younger adolescent group. Closer investigation showed that these arose primarily from one participant who showed large variation in response times, hence a number of responses of less than 100 ms were not removed by the trimming procedure. Given that lower estimates of simple reaction times are around 200 ms (Woods, Wyma, Yund, Herron, & Reed, 2015), it is highly likely that such responses were initiated prior to the stimulus being displayed. Therefore, all RTs less than 200 ms were removed from the data prior to analysis.

The final model used for the analysis of reaction times was structured as follows: Model <- lmer (inverse RTs ~ nonword type * age group + (1|participant) + (1|item)). Table 4.9. presents the output from this model. Inspection of estimated coefficients revealed a significant effect of age group, with older adolescents responding faster than younger adolescents in all three conditions. There was no effect of nonword type, although there was a significant nonword type by age group interaction, with older adolescents responding more slowly to trained vs. distant nonwords than younger adolescents. There was a trend towards a similar pattern between trained vs. untrained stem nonwords, but this did not reach significance.

Table 4.9.

Summary of linear mixed-effects model examining the effects of nonword type, age group, and the nonword type x age group interaction on lexical decision reaction times

Baseline condition	Fixed effects	Estimate	SE	*t* value
Distant	Intercept[a]	1.58	0.03	50.91***
	Nonword type (trained vs. distant)	-0.00	0.02	-0.04
	Nonword type (untrained stem vs. distant)	0.01	0.02	0.36
	Age group (older vs. younger)[b]	0.35	0.06	6.33***
	Nonword type x Age group (trained vs. distant)	-0.06	0.03	-2.04*
	Nonword type x Age group (untrained stem vs. distant)	-0.01	0.03	-0.29
Untrained stem	Intercept[a]	1.59	0.03	51.12***
	Nonword type (trained vs. untrained stem)	-0.01	0.02	-0.39
	Age group (older vs. younger)[b]	0.34	0.06	6.17***
	Nonword type x Age group (trained vs. untrained stem)	-0.05	0.03	-1.74[†]
Trained	Intercept[a]	1.58	0.031	50.70***
	Age group (older vs. younger)[b]	0.29	0.06	5.27***

[a] The intercept represents average inverse RTs for the baseline condition across nonword type and age group; [b] Within the baseline condition

[†] $p < 0.1$ *$p < .05$ **$p < .01$ *** $p < .001$

Congruency. Figure 4.9. shows mean accuracy and standard errors for trained and recombination nonwords by congruency and age group. Figure 4.10. shows inverted reaction time raw data points, means, distributions and 95% Highest Density Intervals for the same predictors. Generalised linear mixed-effects models and linear mixed effects models were used to analyse the effects of nonword type (trained vs. recombined), age group (older vs. younger), congruency (congruent vs. incongruent) and the nonword type x age group x congruency interaction on log odds of accuracy and inverted reaction times in the lexical decision task. The full random effects structure was specified unless the maximal model failed to converge, in which case simplification procedures were followed until the most complex model supported by the data was identified.

Table 4.10.

Summary of generalised linear mixed-effects model examining the effects of nonword type, congruency and age group, and the nonword type x congruency x age group interaction on lexical decision accuracy

Fixed effects	Estimate	SE	*z* value
Intercept[a]	3.43	0.21	16.05***
Nonword type (trained vs. recombination)	-0.94	0.29	-3.24**
Age group (older vs. younger)	1.08	0.37	2.91**
Congruency (congruent vs. incongruent)	0.33	0.30	1.09
Nonword type x Age group	-0.43	0.44	-0.99
Nonword type x Congruency	0.28	0.44	0.64
Age group x Congruency	-0.27	0.44	-0.61
Nonword type x Age group x Congruency	0.38	0.77	0.50

[a] The intercept represents log odds of accuracy averaged across nonword type, congruency condition and age group. Estimated coefficients correspond to main effects.

$^{\dagger}p < 0.1$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

Accuracy. The final model used for the analysis of accuracy was structured as follows: Model <- glmer (log odds accuracy ~ nonword type * age group * congruency + (1 + nonword type + congruency|participant) + (1+ age group + congruency|item)). Table 4.10. presents the output from this model. Estimated coefficients revealed a significant effect of nonword type: across age groups, accuracy was lower for trained nonwords compared to recombined nonwords, indicating greater interference in nonword rejections. There was also a significant effect of age group, with higher accuracy in the older age group compared to the younger age group. No other effects were significant.

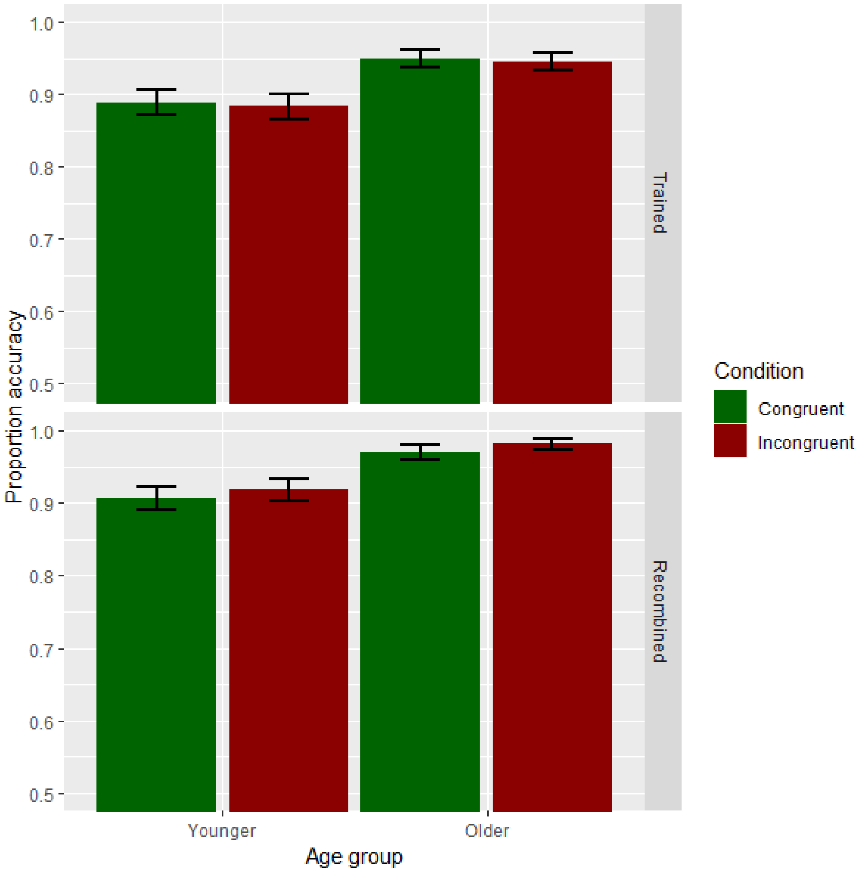

Figure 4.10. Mean proportion lexical decision accuracy with error bars by age group, nonword type, and congruency

RTs. The final model used for the analysis of reaction times was structured as follows: Model <- lmer (inverse RTs ~ nonword type * age group * congruency + (1+nonword type*congruency|participant) + (1+age group*congruency|item)). Table 4.11. presents the output from this model. Inspection of estimated coefficients revealed a significant effect of age group, with older adolescents responding faster than younger adolescents to both nonword types. No other effects were significant.

Table 4.11.

Summary of linear mixed-effects model examining the effects of nonword type, condition, and age group, and the nonword type x condition x age group interaction on lexical decision reaction times

Fixed effects	Estimate	SE	*t* value
Intercept[a]	1.58	0.03	55.36***
Nonword type (trained vs. recombination)	0.00	0.02	0.20
Age group (older vs. younger)	0.30	0.06	5.40***
Congruency (congruent vs. incongruent)	-0.02	0.02	-0.86
Nonword type x Age group	-0.03	0.03	-0.79
Nonword type x Congruency	0.00	0.04	0.07
Age group x Congruency	-0.00	0.04	-0.06
Nonword type x Age group x Congruency	0.05	0.07	0.77

[a] The intercept represents inverse RTs averaged across nonword type, congruency condition and age group. Estimated coefficients correspond to main effects.

† $p < 0.1$ * $p < .05$ ** $p < .01$ *** $p < .001$

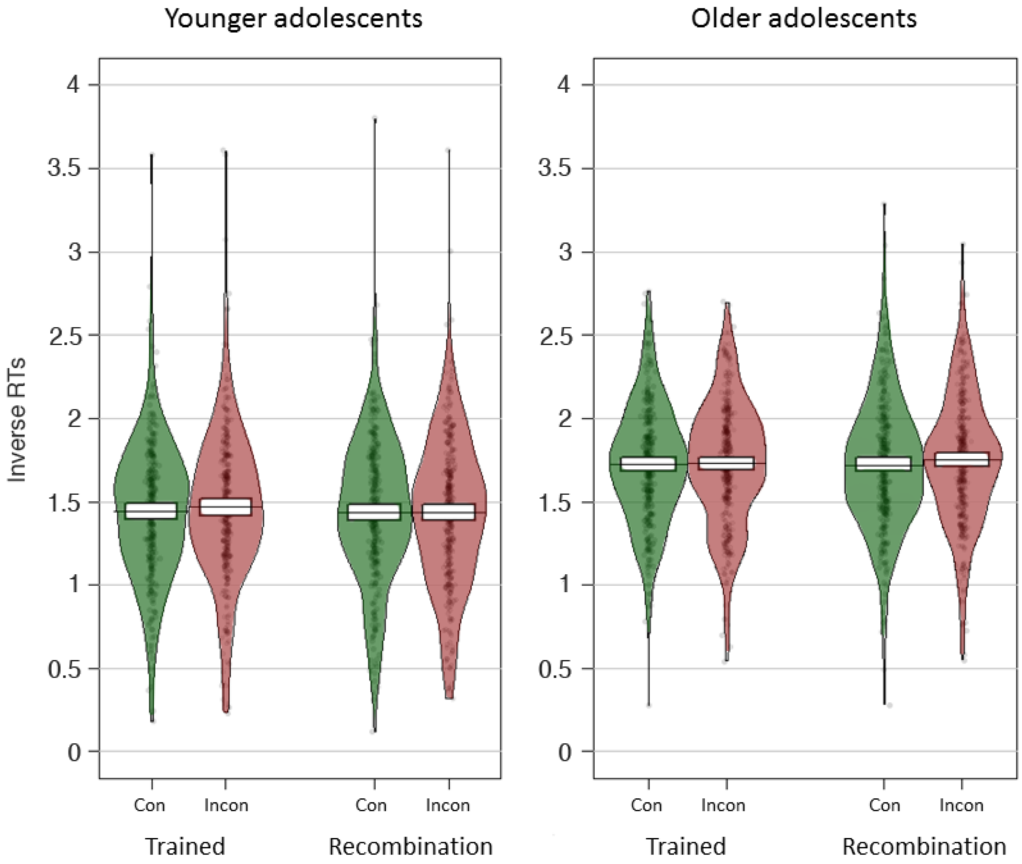

Figure 4.11. Mean inverted RTs for lexical decision responses, with raw data points, distributions and 95% Highest Density Intervals by age group, congruency, and nonword type

4.3.4. Spelling

Participant's written responses in the spelling task were scored as correct or incorrect, and awarded a score of 1 or 0 respectively. Illegible responses were removed from the analyses. Two participants did not complete the spelling task due to time constraints. It was expected that performance on this task would be near ceiling, given that participants could rely on their existing knowledge of grapheme-phoneme correspondences to spell the items correctly. Therefore, in order to probe the possible influence of congruency on orthographic learning, a second score was calculated for accuracy of suffix spellings. Because each participant was exposed to each suffix with equal frequency in the congruent and incongruent conditions, poorer accuracy of suffix spellings in the incongruent compared to the congruent condition would indicate weaker encoding of these letter string sequences during word learning.

General spelling accuracy. Figure 4.11. shows mean proportion spelling accuracy for congruent vs. incongruent items by age group. Analysis was based on 1362 observations from 76 participants responding to 18 items. Generalised linear mixed-effects models were used to examine the effects of congruency (congruent vs. incongruent), age group, and their interaction, on log odds of general spelling accuracy. The factors ‘congruency’ and ‘age group’ were centred using deviation coding.

The maximal random effects structure was identified, which included by-participant and by-item random intercepts, along with by-participant random slopes for the effect of congruency, and by-item random slopes for the effect of age group. The final model was structured as follows: Model <- glmer (log odds accuracy ~ congruency * age group + (1+congruency|participant) + (1+age group|item)). Table 4.12. summarises the output from this model. Estimated coefficients revealed a significant effect of age group, with older adolescents more accurate in their spellings than younger adolescents. No other effects were significant.

Table 4.12.

Summary of generalised linear mixed-effects model examining effects of congruency, age group, and their interaction on log odds of general spelling accuracy

Effects	Estimate	Standard error	*z* value
Intercept	3.23	0.33	9.87***
Congruency (congruent vs. incongruent)	0.26	0.34	0.77
Age group (older vs. younger)	1.98	0.47	4.25***
Congruency x age group	0.44	0.50	0.88

*** *p* < .001

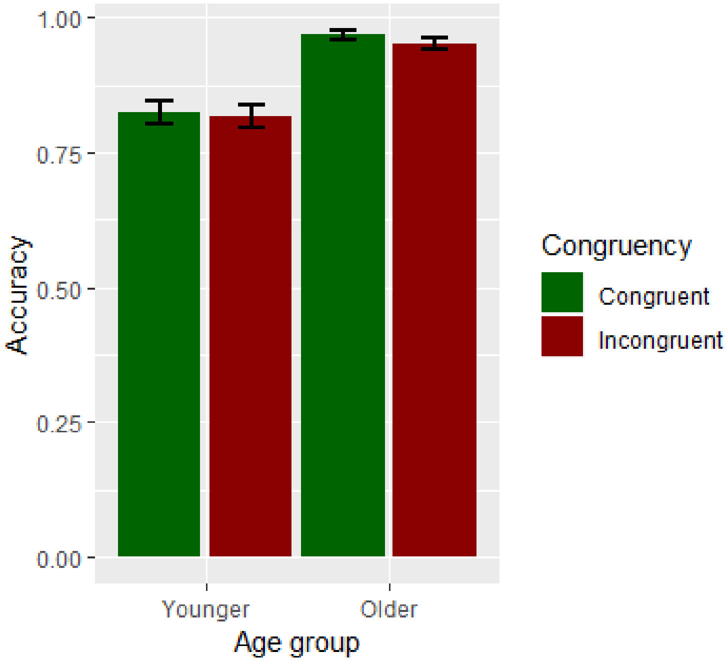

Figure 4.12. Mean proportion spelling accuracy with standard error bars for congruent vs. incongruent items by age group

Suffix spelling accuracy. Figure 4.12. shows mean proportion suffix spelling accuracy for congruent vs. incongruent items by age group. Analysis was based on 1361 observations from 76 participants responding to 18 items. Generalised linear mixed-effects models were used to examine the effects of congruency (congruent vs. incongruent), age group, and their interaction, on log odds of suffix spelling accuracy. The factors 'congruency' and 'age group' were again centred using deviation coding.

The final model was structured as follows: Model <- glmer (log odds accuracy ~ congruency * age group + (1+congruency|participant) + (1+age group|item)). Table 4.13. summarises the output from this model. Estimated coefficients again revealed a significant effect of age group, with older adolescents more accurate in their suffix spellings than younger adolescents. No other effects were significant.

Table 4.13.

Summary of generalised linear mixed-effects model examining effects of congruency, age group, and their interaction on log odds of suffix spelling accuracy

Effects	Estimate	Standard error	*z* value
Intercept	4.60	0.82	5.59***
Congruency (congruent vs. incongruent)	-0.58	0.63	-0.92
Age group (older vs. younger)	2.87	1.06	2.71**
Congruency x age group	0.24	0.99	0.24

*** $p < .001$ ** $p < .01$

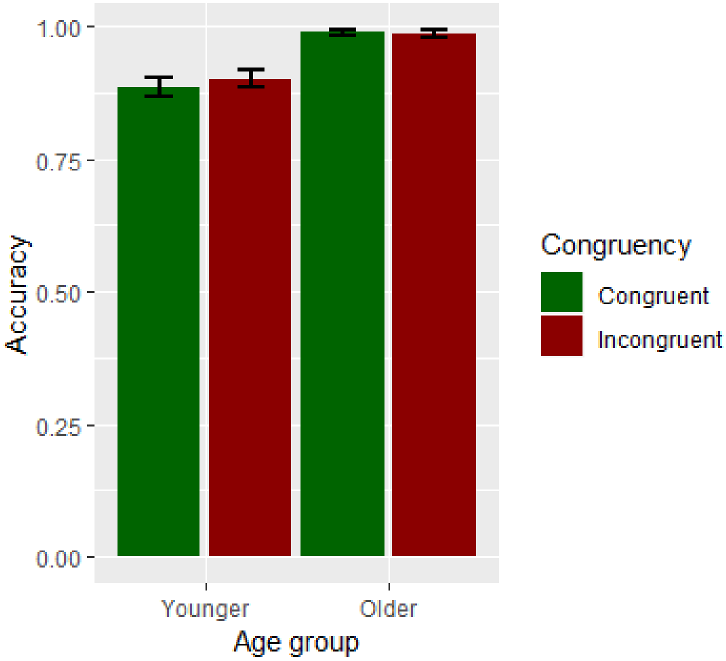

Figure 4.13**.** Mean proportion suffix spelling accuracy with standard error bars for congruent vs. incongruent items by age group

4.4. Discussion

The purpose of the study reported in this chapter was to examine how morphology contributes to the development of lexical representations in the context of word learning. Specifically, it was argued that because morphemes provide links between word form (orthography and phonology) and word meaning (semantics and grammar), morphological structure may support lexical quality, which is contingent on strong connections between these components (Perfetti & Hart, 2002). The focus in this study was on the semantic and syntactic properties of suffixes, which provide cues to word class and word meaning.

Seventy-eight adolescents completed a word learning task in which the meanings of 18 suffixed nonword items were taught. The relationship between the suffix (i.e. its semantic and syntactic properties) and the meaning of the whole-word item was manipulated, such that half of the items were taught in a ‘congruent’ condition, and half in an ‘incongruent’ condition. Post-test measures were designed to capture semantic, phonological and orthographic learning, and incorporated both online and offline tasks.

4.4.1. Effects of congruency

Semantic learning was assessed by measuring the strength of the association between the trained definition and the phonological form of the nonword. Participants were provided with the definition and were asked to recall the item associated with that meaning (the semantic-phonological production task). Results revealed greater accuracy for items taught in the congruent condition compared to the incongruent condition, and this was the case for both older and younger adolescents. This effect was observed using both a general accuracy measure, in which responses were recorded as correct or incorrect, and a graded measure of accuracy designed to capture more nuanced variation across participants and items.

These findings appear to support the proposal that the semantic and syntactic information conveyed by the suffix helps to establish links between word form and word meaning during the acquisition of new lexical representations. When this information was available (i.e. the properties of the suffix were congruent with whole-word meaning), learning of semantics-phonology mappings were stronger than when the information was not available. This finding has both theoretical and practical implications. Theoretically, it aligns with the argument that morphological knowledge may contribute to lexical knowledge and lexical processing by supporting the development of high quality lexical representations (Nagy, Carlisle, & Goodwin, 2014; Reichle & Perfetti, 2003; Verhoeven & Perfetti, 2011). From an educational perspective, it suggests that adolescents capitalise on morphological information in words to support learning, and that promoting understanding of morphological relationships may be a means to enhancing acquisition of new vocabulary in the context of literacy (Baumann et al., 2003; Bowers & Kirby, 2010).

Phonological learning was measured using shadowing (Bates & Liu, 1996; Liu et al., 1997), a speeded repetition task in which participants were presented with audio recordings of trained items and untrained foils. Given that this task has been shown to involve access to phonological information stored at the lexical level (Slowiaczek, 1994), it was expected that there would be a) a general familiarity effect, with higher accuracy and shorter RTs for trained items compared to untrained items; and b) a congruency effect, with higher accuracy and shorter RTs for items trained in the congruent compared to the incongruent condition. A general learning effect was observed in both accuracy and RTs, in line with predictions, but there was no effect of congruency.

Next, access to representations of trained items via orthographic input was measured using a lexical decision task, in which interference in nonword rejection was used as evidence of learning. General learning was measured by comparing responses to trained items with responses to nonwords containing an untrained stem, and to distant nonwords, which comprised an untrained stem and a nonsuffixal ending. There was a clear effect of familiarity in the accuracy data: error rates were higher in response to trained items compared to both untrained stems and distant nonwords. This could not be attributed simply to the presence of a suffix in the trained items because suffixes were identical across the two conditions. Nevertheless, there was evidence that the presence of a suffix may partially account for the interference effect, because responses to untrained stem items were less accurate than responses to distant nonwords. As both items were untrained and contained the same stem, differences in accuracy could only arise from the presence of the suffix. This aligns with morpheme interference effect described in Chapter 2, and indicates that this effect is present even when the suffix is not combined with a meaningful stem, at least in adolescent readers.

The learning effect in the lexical decision accuracy data was not replicated in the RT data. While older adolescents were faster in their overall responses compared to younger adolescents, there was no main effect of nonword type. However, there was a significant age group by nonword type interaction, indicating that the difference in RTs to trained vs. distant nonwords was greater for the older adolescents compared to the younger adolescents, and there was a trend towards a similar pattern in the trained vs. untrained stem comparison. The absence of an RT effect suggests that analysis of nonword structure may have been based on strategic rather than implicit processes.

Turning to the congruency effect, neither the lexical decision accuracy or RT data revealed any evidence of superior learning in the congruent condition, and this was the case for both trained and recombined nonwords. A similar pattern was observed in the spelling post-test. Spelling was more accurate overall in the older adolescent group, but there was no effect of congruency in either the general measure of spelling, or in spellings of suffixes. These findings are in line with the absence of a congruency effect in the shadowing task, but are surprising when considering the clear differences between conditions in the semantic-phonological production task. Why might a congruency effect be observed in the latter, but not in the speeded and written measures of learning?

One possible explanation is that the semantic-phonological production task was the only measure to explicitly test the link between semantics (i.e. the definition of the item) and word form (i.e. its phonological form). Although shadowing and lexical decision tasks are thought to activate representations in the phonological and orthographic lexicons respectively (Coltheart, 2004; Slowiaczek, 1994), they could be completed without drawing on lexical-semantic knowledge at all, given that participants responded to trained items as nonwords in the lexical decision task. Similarly, the spelling task could be completed by drawing on general knowledge of phoneme-grapheme correspondences, possibly coupled with pre-existing suffix knowledge. Because morphological structure provides links between word form and meaning, it may be that the benefits for lexical quality are best captured by tasks that specifically examine these connections, as opposed to more general measures of lexical quality.

A second possibility is that because overall performance was higher on the online and spelling measures, given that the tasks were less challenging, they may not have been sensitive enough to capture an effect of congruency after exposure to the target items on just two separate occasions. Indeed, learning rates as evidenced by the semantic-phonological production task were low, with mean scores of less than 30% on the general accuracy measure. A number of factors may have contributed to poor levels of recall. Firstly, items were highly confusable: each suffix attached to six different items, and each stem had the same phonotactic structure (CCVCC). Secondly, exposure to items and their meanings was limited, with participants completing just two training sessions. Although these sessions were designed to maximise learning (for example, by using a test-feedback procedure, providing contextual information, varying the tasks, and allowing sleep consolidation between sessions; Henderson, Weighall, Brown, & Gaskell, 2012; Karpicke & Blunt, 2011), it is well established that lexical knowledge builds over repeated encounters across a diverse range of contexts (Hsiao & Nation, 2018; Nagy & Scott, 2000). Therefore, the procedures adopted in the current study may have failed to produce sufficient variation in lexical quality to examine the effect of congruency with less sensitive measures.

4.4.2. Effects of age group

The comparisons across age group are interesting. It was expected that the effect of congruency may be greater for the older adolescents than for the younger adolescents, given the argument that knowledge of syntactic, semantic and combinational properties of affixes develops as a consequence of accumulated experience with those affixes across a diverse range of stems (Nippold & Sun, 2008; Tamminen, Davis, & Rastle, 2015; Tyler & Nagy, 1989). Contrary to predictions, there was no interaction between congruency and age group in the phonological production task, indicating that suffix information was equally facilitative for word learning in younger and older adolescents. However, a main effect of age group was observed across most tasks, with older adolescents outperforming younger adolescents on overall phonological production accuracy, lexical decision speed and accuracy, and both general and suffix spelling accuracy. No differences were observed on the shadowing task, meaning that age-related changes were primarily associated with tasks tapping orthographic or semantic representations.

These effects of age align with findings reported in Chapters 2 and 3, in which processing efficiency increased across adolescence, between the ages of 12-13 years and 16-18 years. It was argued that those changes related to ongoing developments in how morphological knowledge was represented at the level of orthography. While there was no evidence here of advances in morphological knowledge with age, this is likely to be because the word learning paradigm made demands on different components of morphological knowledge compared to previous experiments. While the focus in the lexical decision tasks of Chapters 2 and 3 was on the rapid activation of morphologically-structured orthographic representations, the emphasis in the word learning task was primarily on establishing links between phonology and semantics. Therefore, it is probable that participants were drawing on knowledge of phonological, semantic and syntactic properties of suffixes, and not their orthographic properties.

Evidence suggests that morphological knowledge during this period is best conceptualised as a multidimensional construct, comprising a general ‘morphological knowledge’ component, and a number of more specific dimensions reflecting various facets of morphological knowledge activated during different tasks (Goodwin et al., 2015). It is entirely plausible, then, that advances in morphological knowledge across adolescence are not universal, but reflect pockets of consolidation in specific domains. For example, it could be that knowledge of the semantic and syntactic properties of early-acquired suffixes, such as those used in the present experiment, is already consolidated by early adolescence, but that this information continues to feed into the structuring of orthographic representations, leading to increasingly efficient activation during lexical processing.

4.4.3. Limitations and future directions

The study reported in this chapter provides some evidence that morphological information feeds into the development of new lexical representations. However, the use of artificial stimuli limits the scope of these conclusions. The inclusion of nonword stems was necessary to ensure that participants had no pre-existing knowledge of the items. Nevertheless, this created an imbalance between the suffixes, which were likely to be familiar to participants, and the stems, which were entirely novel. With the exception of fully-transparent complex words (e.g., inflections), it is rare that the properties of the suffix function entirely independently from the meaning of the stem. Rather, the relationship between the stem, suffix, and whole word is more nuanced, and cues to meaning may be drawn from the stem as well as the suffix. Linked to this is the absence of a baseline measure of suffix knowledge. These suffixes were selected because they are early-acquired and are thus highly likely to be known by adolescents (Clark & Cohen, 1984; Mahony, 1994). However, measures of individual differences in pre-existing suffix knowledge would permit more detailed exploration of the extent to which readers capitalise on morphological knowledge in the context of word learning, and how this might feed into the development of high quality lexical representations.

The suffixes selected for this experiment could all be considered ‘neutral’ on Tyler and Nagy's (1989) definition: they tend to attach to free stems and do not alter the phonological form of the stem. They also modify the meanings of complex words in a relatively consistent manner (Plag, 2003). These properties may be manipulated in future research to gain a better understanding of which properties of suffixes individuals attend to during word learning. Through careful design, it would also be possible to tease apart the effects of semantics and the effects of word class. In the present study, the incongruent definition referenced an entirely separate part of speech to the target suffix. It is therefore possible that differences in learning may have stemmed from interference in the incongruent condition, rather than facilitation in the congruent condition when suffix information was available. A more nuanced approach could be implemented by adopting the same part of speech across both conditions, but varying the congruency between the semantic properties of the suffix and the definition (for example, *clantist* might refer to '*a person who investigates crop circles*' in the congruent condition, and '*a place under the sea*' in the incongruent condition).

This chapter reported on a novel approach to examining the question of how, and whether, morphological information contributes to the development of high quality lexical representations in adolescent readers. On the basis of evidence that readers across adolescence are sensitive to morphological structure (see Chapters 2 and 3), it was expected that they would capitalise on suffixes in complex words to establish links between word form and word meaning. Overall, there was some evidence that the semantic and syntactic properties of suffixes supported learning of novel items. However, this effect was not observed across all tasks. This could reflect the high overall performance in the speeded measures and spelling task, meaning that there was insufficient variation to capture an effect of congruency, or it could be because these tasks did not measure the strength of the links between word form and meaning.

An explicit instruction approach was adopted here to maximise the likelihood of observing learning effects. While this is a useful starting point for examining proof of concept, it may be more naturalistic to explore whether morphological structure supports lexical quality in the context of incidental word learning from texts (Herman et al., 1987; Swanborn & de Glopper, 2002). This is likely to be particularly relevant for adolescent readers, given the increasing focus on 'reading to learn' and the large proportion of morphologically-complex, low-frequency, but semantically interpretable words that such readers are likely to encounter (Anglin, 1993; Nagy & Anderson, 1984). Nevertheless, the findings reported in this chapter provide a first step towards identifying the mechanisms by which morphological knowledge may support the development of high quality lexical representations that underpin efficient lexical processing.

CHAPTER FIVE

General Discussion

The purpose of this thesis was to examine the role of morphology in the development of lexical processing, incorporating data from children, adolescents and adults. The primary aims were to track morphological decomposition in visual word recognition across reading development; to determine the information that drives decomposition processes in developing readers, and how this relates to reading experience; and to probe whether semantic and syntactic information contained in suffixes influences the quality of newly-formed lexical representations.

Morphology is thought to be important for reading development because it is a source of regularity in the mappings between word form and word meaning. In English, these regularities are particularly salient in orthography, and this is reflected in the substantial amount of evidence indicating that skilled readers capitalise on morphemes as units of processing in visual word recognition (Crepaldi, Rastle, & Davis, 2010; Rastle et al., 2004; Taft & Forster, 1975). Children develop an awareness of morphological patterns from an early age, before they learn to read (Berko, 1958; Brown, 1973), and from around 7 years, they start to show evidence that they can explicitly reflect on and manipulate morphemes in words (Carlisle, 2000). Far less is known about when this knowledge is activated online during lexical processing. This is important because sensitivity to morphological consistencies in the writing system may support the emergence of reading via a direct pathway from print to meaning (Rastle, 2018), thus increasing efficiency of word recognition and supporting reading comprehension (Perfetti, 2007; Perfetti & Hart, 2002).

In this chapter, I will evaluate the evidence presented in Chapters 2, 3 and 4, and consider how these findings contribute to current understanding of how children acquire and represent morphological information in the context of reading development. I will also discuss the implications of these studies for theories of morphological processing and models of reading development. Finally, I will consider the limitations of the present work and offer some future directions.

5.1. Morphological processing in visual word recognition

As outlined in Chapter 1, section 1.5., it is well established that skilled readers are sensitive to the presence of morphemes in words (Amenta & Crepaldi, 2012). This conclusion emerges from robust evidence that complex words are parsed into their constituent morphemes as part of the recognition process (morphological decomposition; Rastle & Davis, 2008). In relation to developing readers, the literature on morphology has predominantly focused on the relationship between morphological awareness and literacy skills (Carlisle, 1995, 2000; Deacon & Kirby, 2004). However, increasing evidence suggests that, across a number of alphabetic languages, children also process morphological structure during reading (Beyersmann et al., 2012; Burani et al., 2002; Casalis et al., 2009; Lázaro et al., 2013; Quémart et al., 2017). To date, research on morphological processing in developing and skilled readers has been largely separate, limiting the conclusions that can be drawn about how morphological knowledge evolves in line with reading development. The work reported in this thesis addresses this gap by providing a comprehensive overview of morphological processing across reading development, and particularly by incorporating data from adolescent readers.

The findings reported in Chapters 2 and 3 (Experiment 1) support the premise that children in the later primary school years process morphological structure during word recognition. In Chapter 2, a lexical decision task was used to examine responses to morphologically-structured nonwords (e.g., *earist*) and non-morphologically-structured (control) nonwords (e.g., *earilt*). Results revealed a significant effect of condition: children were less accurate when they responded to morphologically structured nonwords compared to control nonwords. This suggests that the presence of a stem-suffix combination interfered with children’s decisions to reject the item as a word, providing evidence that they were sensitive to sublexical morphological features. In Chapter 3, responses to real complex words were examined using a masked priming task. Analysis was based on lexical decision response times to a stem (e.g., *TOAST*), which was preceded very briefly by a morphologically-related prime (e.g., *toaster*) or an unrelated control prime (e.g., *grocery*). Across the entire age range, responses were faster to targets that were preceded by a morphological relative compared to targets preceded by an unrelated control prime. These findings provide further corroboration that lexical processing of complex words is characterised by morphological decomposition, even in young readers.

However, the experiments reported in both Chapter 2 and Chapter 3 revealed differences in how developing readers processed morphological structure compared to skilled readers. In Chapter 2, the morpheme interference effect emerged in both accuracy and reaction times (RTs) for adult readers, but only in accuracy for children. I argued that this may reflect underlying differences in the information used to process morphological structure, with skilled readers sensitive to the stem-suffix combination, and developing readers more reliant on the presence of the stem. This may lead to slower RTs across both pseudomorphemic (*earist*) and control (*earilt*) nonwords in the latter, which would allow time for conscious analysis of nonword structure. This could in turn account for the morpheme interference effect in accuracy in the youngest readers, with nonwords containing two familiar components (i.e. a known stem and a known suffix, e.g., *earist*) more likely to be accepted as potential words.

How does this theory align with evidence reported in Chapter 3? Here, while decomposition of morphologically complex words (e.g., *toaster*) was observed across the age range, this appeared to be driven by the semantic properties of morphemes in younger readers. Evidence of decomposition based on morpho-orthographic structure (as in items such as *corner*) emerged in line with age and reading ability. If less skilled readers are primarily reliant on the presence of a known stem in processing of complex words (Beyersmann, Grainger, et al., 2015; Beyersmann, Grainger, & Castles, 2019; Grainger & Beyersmann, 2017), then why was priming not observed in all three conditions (morphological, pseudomorphological, and form), given that all items contained an existing stem? The answer may lie in the representation of form units, specifically those corresponding to affixes. In the context of the AUSTRAL model of morphological processing, Taft and Nguyen-Hoan (2010) argued that recognition of items such as *window*, which are monomorphemic and do not contain a pseudosuffix, proceeds via activation of the lemma corresponding to the whole word (directly from grapheme units) and activation of the lemma corresponding to stem, *wind* (from its form-level unit). However, this activation of *wind* is rapidly suppressed because the second component of *window*, -*ow*, is not activated due to the absence of a corresponding form-level unit or lemma.

Applied to less experienced readers, it could be argued that form-level representations of affixes (e.g., -*er*) are still developing (see, for example, Schreuder & Baayen, 1995), such that items such as *corner* and *toaster* are initially processed via similar mechanisms to items such as *window*. That is, lemmas corresponding to the whole word (i.e. *corner*, *toaster*) may be activated directly from grapheme units, while form-level units are activated for the stems (*corn*, *toast*; Taft & Nguyen-Hoan, 2010). In the case of *toast*, activation of the corresponding lemma will be reinforced by excitatory links with the lemma for *toaster* (based on semantic and syntactic information feeding in from the function level), while *corn* will be inhibited by *corner*, leading to priming of the stem in the first instance, and not in the second. Responses to *corner* differ between developing and skilled readers because inhibition from the whole-word lemma is more rapid when that lemma does not fully map onto form-level representations (as in the case of *corner* for developing readers, and *window* for all readers). Turning to processing of morphologically-structured nonwords such as *earist* in developing readers, only the form and lemma units corresponding to the stem will be activated because no lemma corresponding to the whole word exists. Lexical decisions may then be more reliant on semantic and syntactic information retrieved at the function level, including knowledge that -*ist* is a possible unit of meaning, while -*ilt* is not.

What is not known is why, with reading experience, representations of affixes come to be defined orthographically. Recent insights into the structure of the English writing system and how it supports direct links between orthography and semantics may shed some light on this. As outlined in Chapter 1, section 1.2., morphological regularities are more salient in written English than they are in spoken English (Rastle, 2018). There are numerous examples of complex words in which the stem is preserved in the orthography, but not in the phonology (e.g., *magician*). Recently, attention has turned to how spellings of affixes provide strong cues to meaning, and specifically, word class (Berg & Aronoff, 2017; Rastle, 2019; Ulicheva et al., 2018).

Ulicheva et al. (2018) measured the extent to which the spellings of 154 English suffixes denoted a particular word class (*diagnosticity*), as well as the consistency with which a given suffix spelling was used to signal a particular word class compared to other possible spellings for that sound sequence (*specificity*). They found high levels of diagnosticity and specificity across most suffixes, indicating that the availability of multiple possible grapheme-phoneme mappings permits the emergence of strong associations between specific sequences of letters (i.e. suffixes) and their meanings. Ulicheva et al. (2018) further showed that variation in diagnosticity and specificity of suffix spellings predicted performance on a number of behavioural measures of reading, spelling and word class categorisation in adult readers, providing evidence of sensitivity to the statistical co-occurrences of suffix spellings and word class.

These findings suggest that the onset of literacy may provide children with new insights into the role of affixes and their links to word meaning. Take, for example, the suffix -*ous*. The most common pronunciation, /əs/, also occurs in word-final position in a number of monomorphemic words (e.g., *bonus*, *focus*; Berg & Aronoff, 2017), some of which also include an existing pseudostem in their phonological, but not orthographic, form (e.g., *bone*, *folk*). Therefore, the links between suffix form and meaning are to some extent masked by the ‘noise’ of other items sharing the same word-final sound sequence, but not overlapping in meaning. Once children are exposed to the *spellings* of words containing the -*ous* suffix, regularity in meaning becomes more apparent. Experience with the written form of the suffix facilitates a distinction between items ending in /əs/ that take the -*ous* spelling and signal an adjective, and non-adjectival items ending in /əs/ that take a variety of different spellings (e.g., -*us*). For these reasons, the process of learning to read may foster awareness of more detailed patterns of association between word form and meaning due to the largely unique relationship between suffix spellings and word class (Berg & Aronoff, 2017; Ulicheva et al., 2018).

Clearly, recognition of these regularities will take time to build, given that children will need to encounter written forms of affixes across a sufficient number of items for statistical patterns to emerge. Additionally, texts designed to promote independent reading in younger readers often prioritise regularity in grapheme-phoneme mappings over vocabulary breadth or morphological complexity (for example, decodable texts incorporated into phonics programmes; Solity & Vousden, 2009). However, as reading skills develop, children are more likely to encounter words in texts that comprise a broader range of affixes and multiple layers of affixation (Nagy & Anderson, 1984; Nagy et al., 2014). This proliferation of exposure to morphological regularity in texts provides further indication that changes in morphological processing between late childhood and late adolescence may reflect consolidation of affixes as ‘units of meaning’, represented at the level of orthography. In section 5.6., I consider how existing computational models of word reading may be adapted to capture sensitivity to morphological regularities in the context of orthographic learning.

In summary, the findings reported in Chapters 2 and 3 indicate a gradual fine-tuning of morphological knowledge across reading development, such that representations of morphemes are initially acquired at a conceptual level on the basis of form-meaning regularities, but eventually culminate in form-based representations that are less closely tied to meaning, and are activated rapidly during word recognition. In line with Schreuder and Baayen (1995), it seems plausible that affix representations undergo a more protracted period of development than representations of stems, given that their semantic function is generally less transparent (Tyler & Nagy, 1989, 1990). Acquisition of morphemic representations at the level of orthography may reflect the gradual accumulation of experience with the structure of the English writing system, in which spellings of affixes provide strong cues to word meaning (Berg & Aronoff, 2017; Rastle, 2019; Ulicheva et al., 2018). Based on this proposal, it is unlikely that age alone is the driving force behind the development of morphological knowledge and its role in lexical processing. In the next section, I consider how reading experience may contribute to the developmental changes observed across this work.

5.2. The role of reading experience

In the field of reading research, attention has primarily been directed towards early reading development and the acquisition of knowledge about links between orthography and phonology (Hulme & Snowling, 2013). However, there is an increasing drive towards capturing how readers transition from primary dependence on decoding to skilled and fluent word recognition (Castles et al., 2018; Nation, 2017; Rastle, 2018). Underpinning this work is a consensus that reading experience is crucial.

In relation to morphology, experience with words in texts provides exposure to morphological regularities. In particular, it draws attention to links between morphemes represented as orthographic units and their meanings. As discussed in Chapter 1, section 5.2., there are many examples of words in which morphological structure is more salient in the printed form of the word than it is in its spoken form (e.g., *magician*). Therefore, reading experience may contribute directly to the formation of morphological representations at the level of orthography. The exploratory analysis outlined in Chapter 3, section 3.2.3. seems to support this argument, as it revealed that word reading ability predicted the strength of pseudomorphological priming relative to form priming, indicating that evidence of morpho-orthographic decomposition is stronger in more skilled readers. However, reading ability is not a direct measure of reading experience, so further investigation is warranted to tease apart this relationship.

From a theoretical standpoint, accumulated experience of individual morphemes across different lexical contexts should support recognition of those morphemes in words in subsequent encounters (Nagy et al., 2014; Verhoeven & Perfetti, 2003). The computational model outlined by Reichle and Perfetti (2003) demonstrated the importance of stem frequency in relation to lexical retrieval, with token frequency driving the effect for inflected forms, and type frequency driving the effect for derived forms. In other words, the stems of derived words – derivation being the primary focus of the present work – are more available for retrieval when they are encountered with a range of affixes. Of course, frequency measures based on corpus data only provide an approximation of individual reader experiences. An individual who reads extensively is more likely to encounter stems combined with a range of different affixes than an individual who reads less, particularly when those stems occur relatively infrequently overall.

The same could be argued in relation to affixes: varied text exposure provides opportunities to encounter affixes attached to a wide variety of stems, which may help the reader to refine and extend knowledge of their semantic and syntactic properties. This experience may feed into the development of modality-specific representations of affixes, as argued by Schreuder and Baayen (1995), while at the same time, the activation of such representations may facilitate detection of morphological structure in unfamiliar items, thus providing further opportunity to strengthen form-meaning links in memory.

Tamminen, Davis, and Rastle (2015) highlighted the importance of contextual diversity for affix acquisition in a nonword learning paradigm with skilled readers. They showed that the ability to generalise new learning of suffixes to novel items was greater when those suffixes were paired with a more diverse range of stems during exposure. These ideas align more broadly with Nation's (2017) proposal that lexical quality, and thus lexical processing, reflect the culmination of a reader’s experience with that word. Experience that is rich, diverse, and forges links to other words promotes detailed, nuanced lexical knowledge. Recent evidence provides initial support for the lexical legacy hypothesis, indicating that the diversity of semantic contexts that words appear in corresponds to variation in how those items are processed in word recognition tasks (Hsiao & Nation, 2018).

In Chapter 4, I took a different approach to examining the relationship between morphological regularities and lexical quality by manipulating the links between semantic and syntactic properties of suffixes and word meaning, and measuring the impact on acquisition of new lexical representations. The results provided some support for the theory that morphology strengthens the links between orthographic, phonological and semantic representations, although this effect only emerged in the task that specifically tested these associations, and not in measures of phonological or orthographic knowledge in isolation. One explanation is that, in the context of the word learning paradigm, the suffixes provided an instant cue to meaning when they aligned with the taught definition, such that these effects could be observed after a small number of exposures. However, it is likely that a greater number of exposures would be necessary for the effect of congruency to emerge in orthographic and phonological representations, particularly given the hypothesis that variation in lexical quality in the context of reading emerges over time (Nation, 2017).

5.3. Morphological awareness and morphological processing

While the primary focus of this thesis was on morphological processing in the context of word recognition and word learning, measures of morphological awareness were gathered as part of the battery of assessments run with each participant. In Chapter 2, exploratory analyses were conducted to examine the link between performance on the morphological awareness task in the youngest age group (children aged 7-9 years), and their sensitivity to morphological structure in the lexical decision task (indexed by the strength of the morpheme interference effect in their accuracy data). The results revealed a greater morpheme interference effect for participants scoring higher on the morphological awareness task. This provides some validation that these tasks were tapping into a common underlying set of knowledge or skills, particularly given that the morphological awareness task was presented verbally, while the lexical decision task was visual.

However, more detailed investigation is required to identify whether the two tasks measure an underlying construct that can be labelled ‘morphological knowledge’, or whether the association is driven by more general linguistic knowledge. One way to address this question would be to investigate the link between explicit and implicit morphological knowledge at the level of individual morphemes. For example, if an individual performed well on items involving the suffix -*ist*, and poorly on items containing the suffix -*ity* in the morphological awareness task, then it might be predicted that the morpheme interference effect would be greater for items containing -*ist* compared to -*ity* in the lexical decision task. It was not possible to explore this type of relationship here because suffixes in the morphological awareness task were not matched to suffixes in the lexical decision task.

A second consideration is that the relationship between morphological awareness and morphological processing may evolve in line with reading development. The analysis performed in Chapter 2 was based only on data from the youngest age group. Given the hypothesis that morphological processing is based primarily on the semantic properties of morphemes in less experienced readers, it might be expected that the relationship between morphological awareness and processing would weaken over time as activation of morphemic representations during visual word recognition becomes more detached from their meanings. Unfortunately, it was not possible to explore this question in this thesis, largely due to ceiling effects in the morphological awareness tasks in more experienced readers.

This raises a broader issue regarding the need for morphological awareness tasks that capture explicit morphological knowledge at later stages of reading development. Such tasks would need to encompass variation in phonological, orthographic and semantic transparency, and include sufficient numbers of lower transparency items to reveal individual differences amongst more experienced readers. Inclusion of a wider range of affixes than is typically seen in such tasks would provide additional scope for differentiating performance, and these might include both neutral and nonneutral suffixes, as well as prefixes (Clark, 1998; Tyler & Nagy, 1989). Morphological awareness measures should ideally incorporate more than one task and adopt different formats to reduce reliance on task-specific skills, such as vocabulary knowledge or reasoning ability. Additionally, inclusion of nonword items may help to minimise the influence of pre-existing lexical knowledge. Finally, adding a timed component to metalinguistic tasks may provide insights into the efficiency with which individuals retrieve and apply morphological knowledge in novel contexts. Careful construction of such tasks may help to inform theories about the development of explicit morphological knowledge and its relationship to morphological processing beyond late childhood.

5.4. Implications for theories of morphological processing

Turning, then, to the theoretical implications of the work presented here. Overall, the findings reported in this thesis provide support for theoretical accounts that posit a role for sublexical processing of morphological structure (Diependaele et al., 2009; Kuperman et al., 2008; Rastle & Davis, 2008; Rastle et al., 2004; Taft & Forster, 1975). Specifically, more experienced readers showed evidence of a morpheme interference effect in both accuracy and RTs in Chapter 2, and some evidence of morpho-orthographic decomposition in Chapter 3. These findings cannot be explained by supralexical accounts (Giraudo & Grainger, 2001), which argue that morphological analysis arises at a post-lexical level of processing. Nor can connectionist accounts accommodate evidence of morpho-orthographic decomposition, as they propose that morphological effects arise from correlations between form and meaning (Gonnerman et al., 2007). Because the semantic overlap between *corner* and *corn* is equivalent to the semantic overlap between *window* and *wind*, priming across these conditions should be equivalent.

However, the evidence from developing readers was mixed. As discussed above, while lexical decision accuracy was impeded by morphological structure (indicating a level of sublexical analysis), the masked priming paradigm revealed no evidence of morpho-orthographic decomposition. It is worth considering that the use of nonwords in the lexical decision task in Chapter 2 meant that readers were unable to draw on lexical-semantic knowledge to make their responses, but this does not preclude the possibility that they may do so when responding to real word items, as in the priming task.

As outlined above, the AUSTRAL model (Taft, 2006; Taft & Nguyen-Hoan, 2010; Xu & Taft, 2015) provides a plausible interpretation of the pattern of findings observed across studies in developing readers. One of its strengths is that it combines elements of both localist and connectionist models (Taft, 2006), and is thus able to account for graded effects of semantic transparency via weighted connections at the lemma level, while also retaining localist representations of morphemes at the orthographic level that can account for decomposition of items such as *corner*. However, it was designed to outline the processes underpinning recognition of complex words in skilled readers, and not to provide an account of how morphemic representations evolve in line with reading experience. For this reason, it is helpful to align the AUSTRAL model with the proposals made by Schreuder and Baayen (1995) in relation to the development of affix representations. Nevertheless, there is a clear need for a comprehensive, theoretical model of morphological processing that can accommodate not only the endpoint, but also the pathways by which morphological representations are acquired and refined in line with linguistic experience.

5.5. Implications for models of reading

Unlike theoretical accounts of morphological processing, many models of word reading do accommodate aspects of reading development (Harm & Seidenberg, 2004; Pritchard et al., 2018; Ziegler et al., 2014). However, as noted in Chapter 1, these models are largely limited to processing of monomorphemic, monosyllabic items (with the exception of the CDP++; Perry, Ziegler, & Zorzi, 2010, 2013), despite the fact that the majority of English words children eventually learn to read are morphologically complex (Nagy & Anderson, 1984). More broadly, morphology has been neglected in almost all of the most well-established frameworks and models of reading. The Simple View of Reading is underspecified, but it is likely that morphological knowledge feeds into both word recognition processes (Amenta & Crepaldi, 2012) and language comprehension (Anglin, 1993). The Lexical Quality Hypothesis (Perfetti & Hart, 2002), triangle model of reading (Harm & Seidenberg, 2004) and DRC (Coltheart et al., 2001) all relate to monosyllabic word reading. However, the principles outlined by the Lexical Quality Hypothesis have been explored in relation to morphological regularities (Reichle & Perfetti, 2003; see also Chapter 4), and the architecture of the triangle model has been adopted by distributed-connectionist models of morphological processing (e.g., Gonnerman et al., 2007), although the latter fails to explain some behavioural findings (e.g., morpho-orthographic decomposition).

More recently, the Reading Systems Framework (Perfetti & Stafura, 2014) does posit a role for morphology at two levels: firstly, as part of the lexicon (i.e. item-specific knowledge), and secondly, as a source of linguistic knowledge more broadly. However, just as with the Simple View of Reading, this framework takes a broad perspective of reading, and therefore the mechanisms by which morphological knowledge is activated across these domains remain unclear. Recent advancements in computational models of word reading that include an orthographic self-teaching mechanism perhaps provide the best starting point for considering how acquisition of morphological knowledge via reading experience might unfold.

The ST-DRC (Pritchard et al., 2018) and Ziegler et al.'s (2014) adaptation of the CDP+ each model orthographic learning via a self-teaching mechanism (Share, 1995; see Chapter 1, section 1.6.). Taking Ziegler et al.'s (2014) model as an example, phonological decoding involves conversion of the orthographic input to phonemes based on existing knowledge of a small number of grapheme-phoneme correspondence rules. This subsequently activates the appropriate entry in the phonological lexicon, which triggers the creation of a corresponding representation in the orthographic lexicon. The ST-DRC (Pritchard et al., 2018) proposes a similar mechanism, but additionally incorporates a simple semantic layer in the lexical route through which contextual information supports orthographic learning in the case of partial decoding attempts (e.g., irregular word reading).

I propose that this inclusion of a semantic component could be harnessed to model orthographic learning of morphologically-related items in such a way that orthographic representations are eventually structured morphemically. If the creation of a new entry in the orthographic lexicon receives input from the semantic system as well as the phonological lexicon, then pre-existing sensitivity to overlaps in meaning among morphologically-related words may feed into the structuring of new orthographic representations. For example, in an initial decoding attempt, complex words such as *farmer* would be fully decoded, and the corresponding entry in the phonological lexicon activated, along with its associated semantic node (i.e. 'a person who farms'). This would result in the creation of a new whole-word entry in the orthographic lexicon (orthographic learning). However, if a child is already familiar with the meanings of morphological relatives of *farmer* (e.g., *farm*, *farms*, *farming*), then the node for *farm* may also be activated in the semantic lexicon, feeding into the orthographic lexicon directly, and via the phonological lexicon. This would result in the creation of a second orthographic representation (*farm*), or if such an entry already existed, its activation. Each encounter with a morphological variant of the stem, *farm*, would strengthen the orthographic representation of the stem and its links to phonology and semantics, as well as activating the orthographic representation of the complex word.

The same process may operate across affixes. If a child is familiar with the meanings of *writer* and *teacher*, they might also develop linked phonological and semantic nodes for the suffix -*er*, again resulting in the creation of a corresponding entry in the orthographic lexicon when that suffix is encountered in print. However, given that children are less likely to be sensitive to the meanings of affixes than stems (Tyler & Nagy, 1989, 1990), and that the associations between affix form and meaning are less salient in phonology than in orthography (Berg & Aronoff, 2017; Ulicheva et al., 2018), activation from semantic system to the orthographic lexicon may be weaker for affixes than for stems. Therefore, a greater number of exposures across different contexts would be required for entries in the orthographic lexicon to become consolidated. For affixes that provide strong cues to meaning via their spellings (e.g., -*ous*), representations in the semantic system may also be strengthened via feedback from the orthographic lexicon.

Because activation also spreads from the orthographic lexicon to the letter nodes (Perry et al., 2007), repeated activation of stems and suffixes in the orthographic lexicon may eventually culminate in a restructuring of the input to the orthographic lexicon, either via the creation of a separate layer of morpheme nodes, or through grouping of letter nodes into morphemes (similar to the form level of representation in the AUSTRAL model; Taft, 2006; Taft & Nguyen-Hoan, 2010). This morphemic parsing mechanism would account for morpho-orthographic effects, as morphological analysis would take place prior to input from semantics. By this account, these effects would not occur for all items simultaneously, as factors such as frequency and semantic transparency would influence the strength of stem and suffix representations in the orthographic lexicon (relative to the whole-word representation). Therefore, at any point in time, input at the letter level may be structured morphemically for some stems and affixes, while others, represented in the orthographic lexicon, still receive input from the semantic system.

Clearly, there remains much to be specified in this account. Firstly, the architecture of the lexical route does not necessitate input from the semantic system, and there is currently no mechanism for learning in place (Coltheart et al., 2001; Perry et al., 2007). It may be that interactions between the phonological lexicon, semantic system and orthographic lexicon would be better captured via an associative network (similar to the TLA network; Ziegler et al., 2014), or a full connectionist network. However, input from semantics is limited and underspecified across most models of word reading, perhaps reflecting the challenges inherent in capturing the complexity of semantic information. Secondly, the CDP+ (Perry et al., 2007), ST-DRC (Pritchard et al., 2018), and Ziegler et al.'s (2014) adaptation of the CDP+ do not offer a mechanism for processing of multisyllabic words. The CDP++ (Perry et al., 2010) does, but it is limited to reading disyllabic words. While there have been recent advancements in understanding of stress assignment in disyllabic word reading (Ktori et al., 2018; Mousikou et al., 2017), there is still much to be learned about processing of polysyllabic words before we can begin to unite the literature on morphological processing with models of word reading.

5.6. Adolescence

One of the primary outcomes from the work reported in this thesis is evidence that the reading system in adolescence is increasingly attuned to morphological regularities in the input. This aligns with neuroimaging data showing that the ventral reading pathway, which continues to develop into adolescence (Ben-Shachar et al., 2011) and is associated with direct spelling-meaning access, is implicated in morphological processing (Lewis, Solomyak, & Marantz, 2011; Yablonski et al., 2018). Adolescence represents an important period of change across biological, cognitive and social domains (Sawyer, Azzopardi, Wickremarathne, & Patton, 2018). Ongoing structural and functional developments in the adolescent brain underpin many behavioural and social changes typically observed during this time, such as risk-taking, impulsivity, and emotion regulation (Ahmed, Bittencourt-Hewitt, & Sebastian, 2015; Casey, Getz, & Galvan, 2008).

However, reading stands apart from other areas of development because it is a cultural innovation that emerged comparatively recently in human history. As such, it is highly unlikely that evolutionary restructuring of the brain has given rise to a specific region dedicated to reading. Rather, it is argued that the cognitive processes that underpin reading make use of, and are constrained by, existing brain circuitry established at an earlier evolutionary time point (the neuronal recycling hypothesis; Dehaene, 2005; Dehaene & Cohen, 2007). Therefore, areas of the brain used in spoken language processing and object recognition are reappropriated for the purposes of reading within a comparatively short time-frame, as a consequence of the brain’s plasticity (Dehaene & Cohen, 2007). This account explains how the ventral visual stream becomes increasingly retuned towards word recognition in adolescence, culminating in a visual word form area that is functionally specialised for recognition of plausible visual word forms within a given script (Dehaene, 2005).

One question that emerges from this hypothesis is whether the transition towards reading via the ventral pathway, and the corresponding decrease in reliance on the dorsal pathway, occurs during adolescence because of the brain's plasticity during this period, evidenced by widespread structural and functional reorganisation in other areas (Casey et al., 2008; Kanwal, Jung, & Zhang, 2016; Kilford, Garrett, & Blakemore, 2016), or whether it occurs once a given threshold of exposure to statistical regularities in the orthographic input is reached. In the latter instance, it would be expected that increased sensitivity to visual word forms in the ventral pathway would be observed in an individual of any age following an equivalent number of years of reading experience. It could be that the two factors combine, resulting in a period of development during adolescence that, for the majority of children commencing reading instruction at age 4-5 years, is particularly amenable to the reappropriation of the ventral stream – evolved primarily for object recognition – for the purposes of accessing meaning directly from the printed forms of words.

A broader issue relates to the very definition of adolescence. At a superficial level, it describes the period of transition between childhood and adulthood, but pinpointing more precise boundaries has proved challenging. Typically, the start of adolescence is defined by the onset of puberty, and the transition to adulthood occurs at the point at which an individual is an independent, functioning member of society (Curtis, 2015). These definitions raise a number of issues. For various reasons, some individuals may never function fully independently, but this does not mean they do not reach adulthood. From a legal perspective, individuals are adults once they reach 18 years of age in UK, yet adopting chronological age to mark the endpoint of adolescence is undermined by substantial individual variation in social, biological and cognitive development across this period (Twenge & Park, 2017). Further, recent evidence suggests that traditional social milestones of adulthood (e.g., completion of education, marriage, giving birth, financial independence) are now occurring later (Sawyer et al., 2018; Twenge & Park, 2017). Coupled with the earlier onset of puberty (Gluckman & Hanson, 2006), this has led some to suggest that adolescence now spans the age range from 10 to 24 years (Sawyer et al., 2018).

It is clear that adolescence as a developmental period is, to an extent, an elusive concept. Its boundaries are underspecified and unstable, influenced by cultural norms and societal shifts. This has implications for the work reported here, and across the field of psychology, where it is common practice to use data from undergraduate students, typically aged between 18 and 21 years, as a measure of adult behaviour. Despite these challenges, adolescence is emerging as a critical period for reorganisation and change across a number of interacting biological and cognitive systems (Steinberg, 2005), so ongoing research is vital to gain a better understanding of this complex and dynamic phase of human development.

5.7. Limitations and future directions

This thesis aimed to explore how morphology shapes lexical processing across reading development. In Chapter 1, I defined lexical processing as the recognition of words and access to information about those words. One limitation of the present work is that words are not generally read in isolation; rather, they occur in sentences, paragraphs and extended passages of text. Readers are sensitive to this contextual information, and experience with the linguistic environments in which words occur eventually comes to bear on how those words are processed (Hsiao & Nation, 2018). Equally, the immediate context in which a word appears provides semantic and syntactic cues that may interact with information contained within the structure of the word itself (de Almeida & Libben, 2005).

Amenta, Marelli, and Crepaldi (2015) used eye tracking to investigate processing of Italian morphologically complex words in sentence contexts. They manipulated the sentences in such a way that participants would favour either a semantically transparent or a semantically opaque interpretation of the complex word. Their results revealed stem frequency effects in first fixation durations across both conditions, indicating that readers were decomposing complex items independent of semantic transparency. However, stem frequency effects facilitated processing in the semantically transparent context and impeded processing in the semantically opaque context, suggesting an early influence of semantics. These findings lend support to previous experimental work conducted at the single word level showing evidence of morpho-orthographic decomposition (Rastle et al., 2004; Vannest et al., 2011; Xu & Taft, 2015), and importantly, indicate that these processes may extend to recognition of complex words in sentence contexts (but cf. Stites, Federmeier, & Christianson, 2016). However, the early influence of semantics observed by Amenta et al. (2015) is not typical of morpho-orthographic decomposition in the context of masked priming (Rastle & Davis, 2008), but it is unclear whether these semantic effects are due to the influence of the sentence context, or to the use of eye tracking methods to capture decomposition.

Relative to work on morphological processing at single word level, there is currently far less research examining how morphological effects in visual word recognition transfer to the level of the sentence, and data from developing readers are even more scarce. This is clearly an important question to address before drawing general conclusions about the way in which morphological knowledge is activated online during reading. Through use of methods such as eye tracking, neuroimaging, or self-paced reading, it should be possible to start to unpick the complex interplay between morphological knowledge, morphological processing and developments in vocabulary and syntax.

Secondly, the questions addressed in this thesis would benefit from longitudinal data. While the cross-sectional approach adopted here provides a valuable overview of changes in morphological processing in line with reading experience, tracking these developments longitudinally would permit a more detailed and nuanced exploration of contributing factors. Further, it would minimise the impact of cohort effects. For example, in 2014, a new national curriculum was introduced for schools in England, which was assessed for the first time in 2016

(Department for Education [DfE], 2013). The curriculum assessments include a test of English spelling, punctuation, and grammar (SPaG), which is currently administered at the end of Key Stages 1 and 2 (i.e. when pupils are in Year 2 and Year 6 respectively). The test content, along with the curriculum statutory requirements and non-statutory guidance, covers explicit knowledge of prefixes, suffixes and stems in the context of word reading, reading comprehension, vocabulary and spelling from Year 1 upwards. It is likely that the younger age groups included in the studies reported here received input from the new curriculum, and therefore that they benefited from morphological instruction as part of their formal education, while older participants did not. One interesting direction would be to explicitly examine the impact of the SPaG test and new curriculum on morphological awareness and morphological processing. Given that these changes were introduced in England only, it might be possible to compare performance on tasks tapping morphological knowledge in children and adolescents receiving education in England compared to those being educated in Scotland or Wales.

More broadly, the scope of this work is limited by the fact that it relates to morphological processing and reading in English. A decade ago, Share (2008) argued that the overwhelming focus on English – an 'outlier' orthography with regard to its inconsistent grapheme-phoneme mappings – in reading research meant that most theories and models of reading failed to provide a universal account of reading behaviour. This Anglocentric skew still persists to a large extent, but there is growing acknowledgement that writing systems across different languages are optimised to convey orthographic, phonological, morphological and semantic information via the most efficient means possible (Frost, 2012). Given the argument that reading acquisition is constrained by the statistical properties of the writing system (Rastle, 2019), it is likely that the role of morphology in lexical processing diverges across different orthographies (Frost & Grainger, 2000).

There is some evidence that this is the case. As highlighted in Chapter 1, section 1.7., subtle cross-linguistic differences between children speaking English and French emerge in efficiency of processing of morphological structure, and in the properties driving decomposition (Beyersmann et al., 2012; Casalis et al., 2015; Duncan et al., 2009; Quémart et al., 2011). More challenging questions are posed by orthographies of non-Indo-European languages. For example, Hebrew (a Semitic language) has a rich system of derivational morphology, in which words are formed through the combination of a root and a word pattern. This process is non-concatenative, such that the two components are interwoven rather than forming separate units, and unlike in English, neither the root nor the word pattern stands alone as a word (Frost, 2012). Interestingly, however, priming studies in Hebrew reveal a similar pattern of morphological processing to those conducted with English readers. For example, Schiff, Raveh, and Fighel (2012) found evidence of morphological priming in 9-year olds only when there was a semantic relationship between the prime and target, whereas they observed morphological priming irrespective of semantic transparency in their 12-year olds, although this effect was quite weak. Their conclusions parallel those drawn here: that as readers become more skilled, their representations of morphological structure become more abstract and less closely tied to semantics.

Looking across languages, it is clear that morphology is a principal source of organisation, and this is reflected in the way that, over time, readers develop the skills to capitalise on this information during reading (Rastle, 2019). An important future direction will be to examine in detail the more nuanced cross-linguistic variation in how morphology is represented across different orthographies, and how this relates to children’s acquisition of morphological knowledge in the context of reading development.

Finally, there is still much work to be done to reach a consensus on how children eventually accomplish rapid morphological analysis during reading. In this thesis, I argued that representations of affixes may be slower to develop than representations of stems, and that advances in affix knowledge via exposure across different contexts may be one of the primary driving forces in the development of abstract morphological representations that are defined at the level of orthography. However, these questions cannot be answered by the work presented here. Rastle and Davis (2008) proposed three possible explanations of how children acquire orthographically-defined representations of morphemes. The first related to the identification of morphemic boundaries in complex words via sensitivity to probabilities of letter sequences, such that the morphemic boundary in *helpful* emerges from the low-probability sequence of *pf*. The second account proposed the reverse: that high frequency letter combinations are grouped into self-contained units via a similar process that allows infants to segment the speech stream (Saffran et al., 1996). This process means that orthographic representations develop for *help* and *-ful* separately.

However, both of these accounts ignore the fact that children have pre-existing knowledge of morphological regularities, along with existing lexical-semantic knowledge that might be used to guide orthographic learning of stems and affixes. In this respect, learning of morpheme boundaries via orthographic input is not analogous to segmentation of the speech stream in infants, because the conceptual framework is already in place. Rastle and Davis's (2008) third explanation takes into account children’s existing knowledge of form-meaning regularities, and proposes a mechanism by which this ‘top down’ information feeds into identification of morphemes at the level of orthography.

Overall, it is this third account which seems most consistent with the morphological effects observed in developing readers here and elsewhere (Beyersmann et al., 2012; Hasenäcker et al., 2016; Schiff et al., 2012). A growing body of evidence seems to indicate that in the earlier stages of reading development, children are more reliant on the semantic properties of morphemes, and it is only with experience that these representations become more abstract, and are activated at a superficial level of orthographic processing. Moving forward, computational implementations of these theories would provide a more rigorous test of their legitimacy, and would advance understanding of morphological processing in both developing and skilled readers.

5.8. Conclusions

In summary, this thesis provides strong evidence that lexical processing involves analysis of morphological structure across the later stages of reading development, from 7 years up until adulthood. Further, the way in which morphological knowledge is represented and activated in the context of word recognition evolves in line with reading experience, becoming increasingly rapid, automatic, and detached from semantic knowledge. The findings reported here suggest that readers take advantage of morphological structure to support lexical processing in at least two ways. Firstly, it is likely that the visual word recognition system becomes increasingly attuned to morphological regularities in the writing system as readers accumulate exposure to stems and suffixes across a wide variety of diverse contexts (Reichle & Perfetti, 2003; Tamminen et al., 2015). This process is facilitated by the close ties between the orthographic forms of affixes and their meanings (Berg & Aronoff, 2017; Ulicheva et al., 2018), which may help to explain why, in skilled readers, analysis of morphological structure is triggered by the orthographic properties of morphemes. Secondly, morphological structure establishes links between word form and word meaning, which is important in the development of high quality lexical representations (Perfetti, 2007; Perfetti & Hart, 2002). The work reported here provided some indication that adolescents are sensitive to and capitalise on this information in a word learning task, but further exploration is required to unpick why this effect emerged in some measures and not others, and to examine whether evidence of variation in lexical quality could be captured in a reading task.

The work reported in this thesis builds on the existing literature in a number of ways. It provides for the first time a comprehensive overview of morphological processing across different stages of reading development, bringing together the largely separate literatures on developing and skilled readers. It addresses a conspicuous absence of data from adolescent readers, particularly those from mid-late adolescence. As the findings here reveal, this period of development may be particularly important in advancing our understanding of how implicit morphological knowledge, which starts to build in early childhood, is eventually activated rapidly and routinely during skilled reading. In taking a more fine-grained approach to morphological processing across reading development, we can begin to address the question of how morphology is implicated in the transition from reading via decoding to rapid recognition of words via a direct pathway from spelling to meaning (Rastle, 2018). Moving forward, it is critical that morphology plays a far more prominent role in developmental theories and models of word reading if we are to capture how accumulation of reading experience over time feeds into recognition of morphologically complex words.

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Appendices

Appendix 2.A. Morphological awareness tasks (Chapter 2)

a) Word analogy task

Item	Correct response
PUSH: PUSHED – JUMP….	Jumped
WALKER: WALK – TEACHER…	Teach
BIRD: BIRDS – GOOSE…	Geese
SLEEP: SLEEPY – CLOUD…	Cloudy
BOUNCE: BOUNCED – SKIP…	Skipped
BEAUTY: BEAUTIFUL – FUN…	Funny
1. RUN: RAN – WALK…	Walked
2. DOLL: DOLLS – SNEAKER…	Sneakers
3. GOOD: BETTER – LOW…	Lower
4. JUMPED: JUMP – STOOD…	Stand
5. PUSH: PUSHED – LOSE…	Lost
6. HELP: HELPED – SAY…	Said
7. MOUSE: MICE – CHILD…	Children
8. HEARD: HEAR – KEPT…	Keep
9. LONGER: LONG – TALLER…	Tall
10. DOG: DOGS – PERSON…	People
11. MESS: MESSY – FUN…	Funny
12. PAINT: PAINTER – BAKE…	Baker
13. ANGER: ANGRY – SUN…	Sunny
14. TEACH: TEACHER – WORK…	Worker
15. HIGH: HEIGHT – DEEP…	Depth
16. DECISION: DECIDE – ACTION…	Act
17. SCIENCE: SCIENTIST – ART…	Artist
18. LONG: LENGTH – WIDE…	Width
19. WARMTH: WARM – STRENGTH…	Strong
20. MAGIC: MAGICIAN – MUSIC…	Musician

b) Production task

Item	Correct response
This is an egg with quirks on it. It is all covered in quirks. What kind of egg is it? It’s a …… egg.	quirky
This is a man who knows how to spow. He is spowing. He did the same thing yesterday. What did he do yesterday? Yesterday he….	spowed
1. This is a person who knows how to snig. He is snigging onto his chair. He did the same thing yesterday. What did he do yesterday? Yesterday he…..	snigged
2. This is a person who knows how to mab along the street. Yesterday he mabbed along the street. Today he does the same thing. What does he do today? Today he …… along the street.	mabs
3. This person is always tigging his head. Today as he falls to the ground, he tigs his head. Yesterday he did the same thing. What did he do yesterday? Yesterday he….	tigged his head
4. Be careful said the farmer. You’re always clomming on your shoe-lace. You’re about to clom on it now. You….. yesterday too.	clommed on it
5. Ever since he learned how to do it, this man has been seeping his iron bar into a knot. Yesterday he sept it into a knot. Today he will do the same thing. What will he do today? Today he will….. it into a knot.	seep
6. This is a zug. Now there is another one. There are two of them. There are two…	zugs
7. This is a nuz. Now there is another one. There are two of them. There are two….	nuzzes
8. It was a bazing day. He felt very bazed. He stuck out his hands and shouted with…	baze
9. It was night-time and the moon was shining. He danced luggily and smiled with lugginess. He felt very…	luggish/luggy
10. When the sun shines he feels very chowy. He dances chowily and laughs with…	chow

Appendix 2.B. List of stimuli (Chapter 2)

Pseudomorphemic	Control
antism	antilm
bandary	bandady
beanish	beanith
begence	begenge
boltous	boltoes
classous	classoes
coldity	coldidy
earist	earilt
elbowism	elbowilm
flipory	flipody
freeness	freenels
gasful	gasfil
gumful	gumfil
habitic	habitig
happenance	happenange
illist	illilt
jawly	jawla
lidary	lidady
meltance	meltange
mouthize	mouthime
opposement	opposemant
passment	passmant
poority	pooridy
ripence	ripenge
sheeter	sheetel
socketer	socketel
towerly	towerla
treasonize	treasonime
trueness	truenels
wigish	wigith

Appendix 2.C. Output from linear mixed effects model examining effect of suffix neutrality on inverse RTs for children and younger adolescents (Chapter 2)

Fixed effects[a]	Estimate	Standard error	*t* value
Intercept	0.88	0.03	26.84***
Condition (pseudomorphemic vs. control)	0.01	0.02	0.56
Age group (younger adolescents vs. children)	0.35	0.06	5.50***
Neutrality (neutral vs. nonneutral)	0.01	0.02	0.67
Condition x age group	-0.02	0.02	-0.68
Condition x neutrality	-0.05	0.04	-1.45
Age group x neutrality	-0.01	0.03	-0.45
Condition x age group x neutrality	0.05	0.05	0.99

***p* < .01 *** *p* < .001

[a] Because all variables were centred in this analysis, the intercept represents the grand mean, and fixed effects coefficients correspond to main effects

Appendix 2.D. Outputs from a) generalised linear mixed effects model examining effect of semantic interpretability on accuracy, and b) linear mixed effects model examining effect of semantic interpretability on inverse RTs (Chapter 2)

a) Accuracy

Baseline age group	Fixed effects	Estimate	SE	z value
Children (C)	Intercept[a]	1.06	0.20	5.46***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	-0.80	0.32	-2.50*
	Age group (YA vs. C)	0.11	0.20	0.53
	Age group (OA vs. C)	0.46	0.20	2.31*
	Age group (A vs. C)	0.89	0.22	4.10***
	Semantic interpretability x age group (YA vs. C)	-0.27	0.20	-1.38
	Semantic interpretability x age group (OA vs. C)	-0.36	0.21	-1.71†
	Semantic interpretability x age group (A vs. C)	-0.67	0.24	-2.75**
Younger adolescents (YA)	Intercept[a]	1.17	0.21	5.57***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	-1.08	0.33	-3.24**
	Age group (OA vs. YA)	0.36	0.22	1.67†
	Age group (A vs. YA)	0.79	0.23	3.40***
	Semantic interpretability x age group (OA vs. YA)	-0.08	0.23	-0.37
	Semantic interpretability x age group (A vs. YA)	-0.39	0.26	-1.53
Older adolescents (OA)	Intercept[a]	1.53	0.21	7.14***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	-1.16	0.34	-3.42***
	Age group (A vs. OA)	0.43	0.23	1.82†
	Semantic interpretability x age group (A vs. OA)	-0.31	0.26	-1.17
Adults (A)	Intercept[a]	1.96	0.23	8.50***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	-1.47	0.36	-4.05***

[a]The intercept represents log odds of accuracy for the baseline age group, averaged across semantic interpretability; [b]Within the baseline condition †p < .10 *p< .05 **p < .01 *** p < .001

b) Inverse RTs

Baseline age group	Fixed effects	Estimate	SE	*t* value
Children (C)	Intercept[a]	0.72	0.04	17.88***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	0.01	0.03	0.30
	Age group (YA vs. C)	0.33	0.06	5.51***
	Age group (OA vs. C)	0.57	0.06	9.32***
	Age group (A vs. C)	0.72	0.06	11.51***
	Semantic interpretability x age group (YA vs. C)	-0.10	0.04	-2.58*
	Semantic interpretability x age group (OA vs. C)	-0.14	0.05	-2.98**
	Semantic interpretability x age group (A vs. C)	-0.15	0.04	-3.72***
Younger adolescents (YA)	Intercept[a]	1.05	0.05	22.77***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	-0.09	0.03	-2.49*
	Age group (OA vs. YA)	0.24	0.06	3.77***
	Age group (A vs. YA)	0.39	0.07	5.95***
	Semantic interpretability x age group (OA vs. YA)	-0.04	0.04	-0.92
	Semantic interpretability x age group (A vs. YA)	-0.05	0.04	-1.34
Older adolescents (OA)	Intercept[a]	1.29	0.05	26.42***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	-0.13	0.05	-2.76**
	Age group (A vs. OA)	0.15	0.07	2.26*
	Semantic interpretability x age group (A vs. OA)	-0.01	0.04	-0.31
Adults (A)	Intercept[a]	1.44	0.05	28.41***
	Semantic interpretability (interpretable vs. uninterpretable)[b]	-0.14	0.04	-3.42**

[a] The intercept represents mean inverse RTs for the baseline age group, averaged across semantic interpretability; [b] Within the baseline condition *p< .05 **p < .01 *** p < .001

Appendix 3.A. Morphological awareness task (Chapter 3)

	Sentence cue	Correct response
Derivation		
1	Perform. Tonight is the last _____	[performance]
2	Humor. The story was quite ____	[humorous]
3	Remark. The speed of the car was _____	[remarkable]
4	Comfort. The chair was _____	[comfortable]
5	Express. His face had a funny _____	[expression]
6	Protect. She wore a helmet for _____	[protection]
7	Reason. Her argument was quite _____	[reasonable]
8	Major. He won the vote by a _____	[majority]
9	Equal. The boys and girls were treated with____	[equality]
10	Human. The kind man was known for his ____	[humanity]
Decomposition		
1	Dangerous. Are the children in any______?	[danger]
2	Enjoyable. The boring show was hard to_____	[enjoy]
3	Courageous. The man showed great _____	[courage]
4	Discussion. The friends have a lot to _____	[discuss]
5	Popularity. The girl was very _____	[popular]
6	Publicity. His secret was made _____	[public]
7	Hazardous. Smoking is a health_____	[hazard]
8	Action. People in plays like to_____	[act]
9	Agreeable. With that decision I could not _____	[agree]
10	Acceptance. It was a gift I could not _____	[accept]

Appendix 3.B. List of stimuli (Chapter 3)

Morphological		**Pseudomorphological**		**Form**	
Prime	Target	Prime	Target	Prime	Target
walked *(r)* smelly *(u)*	WALK	mission *(r)* longest *(u)*	MISS	address *(r)* speaker *(u)*	ADD
filled *(r)* lovely *(u)*	FILL	slimy *(r)* eater *(u)*	SLIM	freeze *(r)* tender *(u)*	FREE
toaster *(r)* grocery *(u)*	TOAST	easter *(r)* likely *(u)*	EAST	single *(r)* curled *(u)*	SING
golden *(r)* frosty *(u)*	GOLD	lady *(r)* eggs *(u)*	LAD	against *(r)* tidying *(u)*	AGAIN
crying *(r)* posted *(u)*	CRY	shoulder *(r)* fighting *(u)*	SHOULD	think *(r)* early *(u)*	THIN
badly *(r)* liked *(u)*	BAD	corner *(r)* sticky *(u)*	CORN	tease *(r)* salty *(u)*	TEA
drying *(r)* weaker *(u)*	DRY	offer *(r)* dolly *(u)*	OFF	window *(r)* fruity *(u)*	WIND
opened *(r)* boards *(u)*	OPEN	shower *(r)* fallen *(u)*	SHOW	howl *(r)* ants *(u)*	HOW
shyly *(r)* mower *(u)*	SHY	scary *(r)* older *(u)*	SCAR	carrot *(r)* sooner *(u)*	CAR
flying *(r)* softer *(u)*	FLY	master *(r)* grassy *(u)*	MAST	beer *(r)* maps *(u)*	BEE
playing *(r)* tighter *(u)*	PLAY	forest *(r)* prayer *(u)*	FOR	twinkle *(r)* lighter *(u)*	TWIN
mixer *(r)* doing *(u)*	MIX	poster *(r)* bricks *(u)*	POST	sight *(r)* curly *(u)*	SIGH
buying *(r)* louder *(u)*	BUY	drawer *(r)* postal *(u)*	DRAW	hotel *(r)* risky *(u)*	HOT
fixing *(r)* boiler *(u)*	FIX	mother *(r)* greedy *(u)*	MOTH	wink *(r)* legs *(u)*	WIN
teacher *(r)* robbery *(u)*	TEACH	flower *(r)* saving *(u)*	FLOW	carton *(r)* player *(u)*	CART
acting *(r)* nearer *(u)*	ACT	party *(r)* tower *(u)*	PART	area *(r)* cars *(u)*	ARE
moody *(r)* waved *(u)*	MOOD	listen *(r)* sleepy *(u)*	LIST	china *(r)* jelly *(u)*	CHIN
mainly *(r)* fuller *(u)*	MAIN	many *(r)* used *(u)*	MAN	tooth *(r)* bumpy *(u)*	TOO
farmer *(r)* stormy *(u)*	FARM	metal *(r)* sandy *(u)*	MET	begin *(r)* snowy *(u)*	BEG
lucky *(r)* named *(u)*	LUCK	army *(r)* cats *(u)*	ARM	skirt *(r)* dusty *(u)*	SKI
boxer *(r)* messy *(u)*	BOX	naughty *(r)* painter *(u)*	NAUGHT	spinach *(r)* magical *(u)*	SPIN
harder *(r)* filthy *(u)*	HARD	belly *(r)* eaten *(u)*	BELL	menu *(r)* bags *(u)*	MEN

trying *(r)* soften *(u)*	TRY	fasten *(r)* nearly *(u)*	FAST	crown *(r)* going *(u)*	CROW
eating *(r)* locker *(u)*	EAT	fairy *(r)* beans *(u)*	FAIR	turnip *(r)* slower *(u)*	TURN
slyly *(r)* fixed *(u)*	SLY	bother *(r)* widely *(u)*	BOTH	yellow *(r)* hunter *(u)*	YELL
layer *(r)* milky *(u)*	LAY	number *(r)* fluffy *(u)*	NUMB	starve *(r)* camped *(u)*	STAR
bushy *(r)* moved *(u)*	BUSH	million *(r)* clearly *(u)*	MILL	shovel *(r)* lately *(u)*	SHOVE
creamy *(r)* darker *(u)*	CREAM	every *(r)* lower *(u)*	EVER	comet *(r)* cried *(u)*	COME
slowly *(r)* leader *(u)*	SLOW	busy *(r)* aged *(u)*	BUS	wonder *(r)* gloomy *(u)*	WON
deeply *(r)* banker *(u)*	DEEP	factory *(r)* cheaper *(u)*	FACT	pasta *(r)* rocky *(u)*	PAST
aimed *(r)* rainy *(u)*	AIM	sandal *(r)* wooden *(u)*	SAND	dragon *(r)* poetry *(u)*	DRAG
sadly *(r)* loved *(u)*	SAD	country *(r)* filling *(u)*	COUNT	pillow *(r)* lesser *(u)*	PILL
sewed *(r)* windy *(u)*	SEW	hungry *(r)* warmer *(u)*	HUNG	camel *(r)* bossy *(u)*	CAME
dirty *(r)* stars *(u)*	DIRT	finish *(r)* caller *(u)*	FIN	lesson *(r)* richer *(u)*	LESS

Note. *r* = related prime; *u* = unrelated prime

Appendix 3.C. Comparison of stimuli characteristics from Beyersmann et al. (2012) and Rastle et al. (2004)

Stimuli characteristic[a]	Condition	Beyersmann et al. (2012)	Rastle et al. (2004)
Related prime frequency	Morphological	48.18	19.27
	Pseudomorphological	126.54	36.76
	Form	80.61	24.00
Target frequency	Morphological	99.67	37.46
	Pseudomorphological	442.02	27.15
	Form	350.35	35.46
Target N	Morphological	8.82	2.06
	Pseudomorphological	8.82	1.94
	Form	9.97	2.16

Note. Calculated using N-watch (Davis, 2005).

[a] Values based on Celex written word database.

Appendix 3.D. Summary of outputs for linear mixed effects models exploring effects of a) related prime frequency (Zipf frequency), b) target frequency (Zipf frequency), and c) orthographic neighbourhood size (OLD20 measure) on patterns of priming across conditions

a)

Baseline condition	Fixed effects	Estimate	SE	*t* value
Form (F)	Intercept[a]	1.95	0.04	51.03***
	Related prime zipf[b]	-0.01	0.02	-0.68
	Prime type x related prime zipf[b]	-0.00	0.02	-0.03
	Condition x related prime zipf (M vs. F)	0.05	0.03	1.94†
	Condition x related prime zipf (P vs. F)	-0.00	0.02	-0.14
	Prime type x condition x related prime zipf (M vs. F)	0.01	0.03	0.21
	Prime type x condition x related prime zipf (P vs. F)	-0.01	0.03	-0.46
Pseudomorphological	Intercept[a]	1.97	0.04	51.47***
	Related prime zipf[b]	-0.02	0.02	-0.88
	Prime type x related prime zipf[b]	-0.01	0.02	-0.71
	Condition x related prime zipf (M vs. P)	0.05	0.03	2.05*
	Prime type x condition x related prime zipf (M vs. P)	0.02	0.03	0.65
Morphological	Intercept[a]	2.05	0.04	54.02***
	Related prime zipf[b]	0.04	0.02	1.98†
	Prime type x related prime zipf[b]	0.01	0.02	0.25

[a] The intercept represents mean inverse RTs for the baseline condition, averaged across related prime frequency and prime type; [b] Within the baseline condition †p < .10 **p < .01 *** p < .001

b)

Baseline condition	Fixed effects	Estimate	SE	*t* value
Form (F)	Intercept[a]	1.95	0.04	53.09***
	Target zipf[b]	0.04	0.01	3.23**
	Prime type x target zipf[b]	-0.01	0.02	-0.65
	Condition x target zipf (M vs. F)	0.03	0.03	1.24
	Condition x target zipf (P vs. F)	0.03	0.02	1.28
	Prime type x condition x target zipf (M vs. F)	0.03	0.04	0.72
	Prime type x condition x target zipf (P vs. F)	0.02	0.03	0.79
Pseudomorphological	Intercept[a]	1.96	0.04	53.44***
	Target zipf[b]	0.07	0.01	4.97***
	Prime type x target zipf[b]	0.01	0.02	0.45
	Condition x target zipf (M vs. P)	0.01	0.03	0.21
	Prime type x condition x target zipf (M vs. P)	0.01	0.03	0.16
Morphological	Intercept[a]	2.06	0.04	56.01***
	Target zipf[b]	0.07	0.02	3.55***
	Prime type x target zipf[b]	0.01	0.03	0.47

[a]The intercept represents mean inverse RTs for the baseline condition, averaged across target frequency and prime type; [b]Within the baseline condition **p < .01 *** p < .001

c)

Baseline condition	Fixed effects	Estimate	SE	*t* value
Form (F)	Intercept[a]	1.94	0.04	51.07***
	Target OLD20[b]	-0.03	0.02	-1.49
	Prime type x target OLD20[b]	0.03	0.02	1.58
	Condition x target OLD20 (M vs. F)	0.03	0.03	1.15
	Condition x target OLD20 (P vs. F)	0.01	0.02	0.47
	Prime type x condition x target OLD20 (M vs. F)	-0.00	0.03	-0.07
	Prime type x condition x target OLD20 (P vs. F)	-0.05	0.03	-1.82†
Pseudomorphological	Intercept[a]	1.97	0.04	51.87***
	Target OLD20[b]	-0.01	0.02	-0.84
	Prime type x target OLD20[b]	-0.02	0.02	-1.07
	Condition x target OLD20 (M vs. P)	0.02	0.03	0.73
	Prime type x condition x target OLD20 (M vs. P)	0.05	0.03	1.77†
Morphological	Intercept[a]	2.05	0.04	53.74***
	Target OLD20[b]	0.00	0.02	0.23
	Prime type x target OLD20[b]	0.03	0.02	1.33

[a]The intercept represents mean inverse RTs for the baseline condition, averaged across orthographic neighbourhood size (OLD 20) and prime type; [b]Within the baseline condition †p < .10 **p < .01 *** p < .001

Appendix 4.A. List of stimuli and characteristics (Chapter 4)

Nonword	PoS (congruent condition)	MLBF[a]	Congruent definition	Incongruent definition
brintise	verb	2.78	to make an object clean again	a person who investigates crop circles
brontful	adjective	2.42	describes someone who always lies	a person who breaks open safes
clantist	noun	2.71	a person who investigates crop circles	to ruin the taste of something
clernise	verb	2.58	to shrink something in the wash	describes someone who doesn't like spending money
crondful	adjective	2.42	describes someone who doesn't like spending money	a person who is a good public speaker
drampise	verb	2.49	to ruin the taste of something	describes someone who is highly confident
drictful	adjective	2.28	describes someone who comes up with new ideas	to put something in fancy dress
flendise	verb	2.57	to strip something of paint	describes someone who comes up with new ideas
glaftist	noun	2.25	a person who breaks open safes	describes someone who always lies
grontist	noun	2.76	a person who collects shells	to set something on fire
plandist	noun	2.64	a person who is a good public speaker	to shrink something in the wash
prentful	adjective	2.53	describes someone who is highly confident	to make an object clean again
scolpise	verb	2.17	to set something on fire	a person who interprets dreams
scontist	noun	2.62	a person who interprets dreams	describes someone who easily feels embarrassed
slintful	adjective	2.34	describes someone who is always calm	to strip something of paint
trilkist	noun	2.42	an assistant to a magician	describes someone who is always calm
trimpful	adjective	2.08	describes someone who easily feels embarrassed	an assistant to a magician
truftise	verb	2.27	to put something in fancy dress	a person who collects shells