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How Word Meaning Influences Word Reading

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Abstract

Understanding how we read is a fundamental question for psychology, with critical implications for education. Studies of word reading tend to focus on the mappings between the written and spoken forms of words. In this article, we review evidence from developmental, neuroimaging, neuropsychological, and computational studies that show that knowledge of word meanings is inextricably involved in word reading. Consequently, models of reading must better specify the role of meaning in skilled reading and its acquisition. Further, our review paves the way for educationally realistic research to confirm whether explicit teaching of oral vocabulary improves word reading.

Keywords

reading, learning, orthography, phonology, semantics

Reading is fundamental to operating in modern society. For literate adults, reading is immediate, automatic, and efficient. Despite this, reading is not an innate capability but is parasitic upon an earlier-acquired spoken language system that includes information about what words sound like (phonology) and what they mean (semantics). The ultimate goal of learning to read is to comprehend texts, for which knowledge of word meanings is essential. The ability to recognize and read aloud words (encompassed by the term *word reading* throughout this review) is a prerequisite for reading comprehension. Research has focused on the orthography (print) to phonology connections that underpin word reading. However, the role of word meanings in word reading is less well understood and is thus the focus of this review. As suggested by Balota (1990), seminal findings from the adult behavioral literature now demonstrate that word-reading efficiency is significantly influenced by semantic variables, over and above frequency and orthographic factors (Cortese & Schock, 2013). Building on this, we review recent evidence from a number of research traditions, which show conclusively that word reading in alphabetic languages is influenced by knowledge of semantics.

Cognitive models of reading all include orthographic, phonological, and semantic representations of words, as well as the mappings between them. In computational models based on a classical dual-route approach (Fig. 1a; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Perry, Ziegler, & Zorzi, 2007), activation of a word's semantics is not necessary for recognizing or reading it aloud. In contrast, the triangle-modeling tradition (Fig. 1b; Harm & Seidenberg, 2004; Monaghan & Ellis, 2010; Plaut, McClelland, Seidenberg, & Patterson, 1996; Woollams, Lambon Ralph, Plaut, & Patterson, 2007) posits that semantic information directly affects the learning and processing of mappings between the written and spoken forms of words. More specifically, it predicts that meaning particularly aids print-to-sound mapping when this process is difficult (as in words with exceptional spellings, or for poorer readers), and also that skilled reading involves increased reliance on direct print-to-meaning mappings. Despite these proposals, the nature of semantic representations and how they impact word reading has been relatively neglected in theoretical and experimental studies. Here we redress the balance by showing

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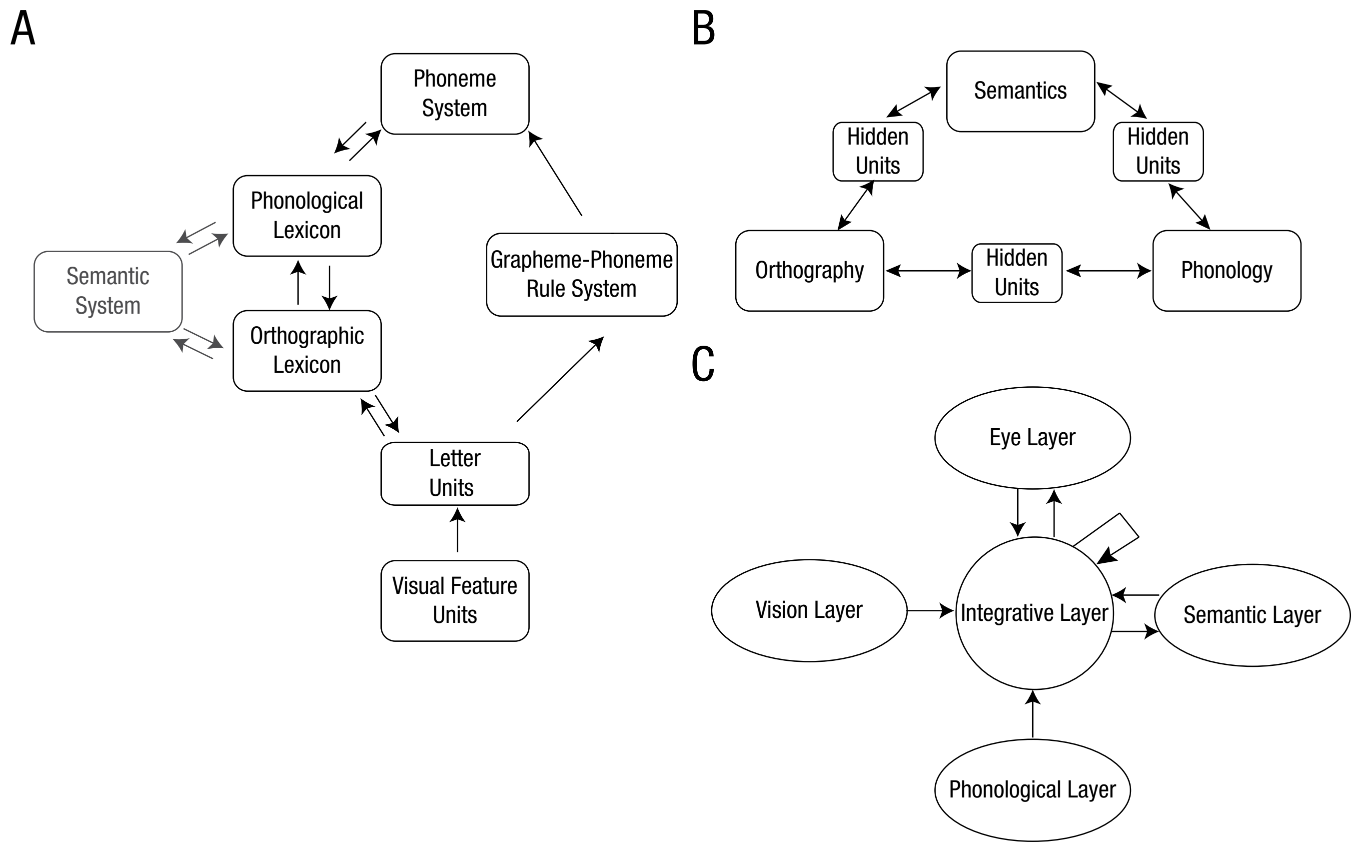

Fig. 1. Computational models showing how semantics can influence word reading. In the dual-route cascaded model (a), the letters in a written word activate a whole-word orthographic lexical representation, and activation cascades both to whole-word phonological representations and to the semantic system. In the triangle model (b), the letters in a written word activate phonological and semantic features via banks of hidden units. In the central-resource model (c), orthographic, phonological, and semantic representations interact via a central resource. In the triangle and central-resource models depicted in (b) and (c), semantic knowledge is rapidly activated so as to influence word reading, whereas in the dual-route cascaded model depicted in (a), semantic knowledge does not routinely influence word reading.

that semantic knowledge (a) influences reading acquisition, (b) is activated rapidly during word reading, (c) impacts on reading deficits seen after brain damage, and (d) is crucial for simulating reading development.

Developmental Psychology

Developmental research provides insights into the process of moving from effortful reading aloud to skilled silent reading. Furthermore, it can constrain hypotheses about the structure and function of the mature reading system and inform our knowledge about how adults reacquire reading after brain damage. Developmental psychology can address the critical question: What role does semantics have in learning to read words? Longitudinal studies show that children's oral vocabulary knowledge (an index of semantic knowledge) is associated with word reading later on in development, particularly for exception words such as *touch*, where the *ou* is not pronounced in the usual way (as in *couch*; Nation & Snowling, 2004; Ricketts, Nation, & Bishop, 2007).

Training studies help determine whether this relationship is causal rather than merely correlational. Training studies exploring the effect of semantic knowledge on learning to read and spell have yielded mixed results. Duff and Hulme (2012; Study 1) taught 5- to 6-year-olds to read words that were in their oral, but not written, vocabulary (e.g., *trouble*). How well children could define the words (semantic knowledge) predicted how well they learned to read aloud those same words. Duff and Hulme also showed that exposing children to the pronunciations of novel words (e.g., *creth*) before seeing them in print helped children learn to read the words. However, there was no additional benefit from pre-exposure to semantic information (see also McKague, Pratt, & Johnston, 2001). In contrast, Wang, Nickels, Nation, and Castles (2013) found, using a similar paradigm, that 6- to 9-year-olds' ability to learn semantic information about novel words did predict later ability to spell these words. The effect held only for exception words, a finding that has also been demonstrated in adults for reading aloud (Taylor, Plunkett, & Nation, 2011). In summary, training studies suggest that a child or adult who already knows, or has just learned, the meaning of a word will find it easier to learn that word's spelling-to-sound mapping, especially if this mapping is exceptional.

There are a number of alternative (but not mutually exclusive) mechanistic accounts specifying how semantic knowledge might influence word reading. Oral vocabulary knowledge may help to resolve a partial decoding attempt (Share, 1995; Tunmer & Chapman, 2012) or lead to better specified phonological representations (Metsala & Walley, 1998), which in turn support word reading. Building on these ideas, theoretical frameworks, such as those depicted in Figure 1, must more fully account for the fact that reading does not develop in isolation but latches onto an already developed spoken language system. Further, once reading instruction starts, spoken and written language develop in concert. Similarly, experimental paradigms must provide learning opportunities that are more akin to how children naturally build their spoken and written vocabularies. Also crucial will be systematic investigation of how the role of semantics changes as the demands of word reading evolve and as children's cognitive capacities develop.

Neuroimaging

Neuroimaging studies allow us to determine: Are brain areas involved in semantic processing active during word reading? The evidence shows that they are, even during tasks that do not require meaning to be accessed, such as reading aloud or silently and lexical decision (judging whether a letter string is a word). Relative to reading pseudowords (pronounceable but meaningless letter strings), reading words activates brain regions such as left angular and middle temporal gyri, which are likely involved in semantic processing (Taylor, Rastle, & Davis, 2013, 2014b). Furthermore, neurophysiological experiments reveal that this differential response to meaningful versus meaningless items can occur as early as 160 to 200 milliseconds following stimulus onset (Carreiras, Armstrong, Perea, & Frost, 2014). Thus, neuroimaging methods suggest that skilled readers activate semantic information rapidly and perhaps obligatorily during word reading.

In both a meta-analysis and an empirical study, Taylor et al. (2013, 2014b) found that exception words activate left inferior frontal gyrus more than regular words. This may reflect the retrieval and selection of semantic knowledge (Graves, Desai, Humphries, Seidenberg, & Binder, 2010) or selection from among the multiple pronunciations that are possible for exception words (Taylor et al., 2013, 2014b). These proposals echo perspectives from the developmental literature in indicating that oral vocabulary knowledge may help to resolve a partial pronunciation of a written word (Tunmer & Chapman, 2012). Evidence that semantic knowledge contributes to exception word reading comes also from Wilson et al. (2012), who found higher activation for exception words than pseudowords in the left anterior temporal lobe, an area associated with semantic processing (Visser, Jefferies, & Lambon Ralph, 2010). Note that this finding has not been consistently reported (Taylor et al., 2013), perhaps because the anterior temporal lobes are difficult to image using conventional methods (Visser et al., 2010).

Neuroimaging can also offer a window into the mechanisms underlying semantic involvement in reading. For example, Kherif, Josse, and Price (2010) used repetition suppression to show that pre-exposure to semantically related pictures reduced left fusiform activation in response to written words. This suggests that activation of a word's meaning aids processing of its written form. Another promising new method is multivoxel pattern analysis, which can reveal the nature of the information represented in particular brain regions (for a relevant example, see Nestor, Behrmann, & Plaut, 2013). Finally, if combined with artificial language learning paradigms, neuroimaging methods could reveal how teaching meanings for novel words influences subsequent neural responses to their written forms (Taylor et al., 2011; Taylor, Rastle, & Davis, 2014a).

Neuropsychology

Studying the performance of people with reading problems caused by brain damage (acquired dyslexia) provides a unique insight into which brain regions and associated cognitive functions are *necessary* for normal reading. A key question for neuropsychology is: What happens to reading when we lose knowledge of meaning? To answer this, we can consider reading aloud in patients with semantic dementia, who have a progressive and selective deterioration of multimodal semantic memory due to atrophy of the anterior temporal lobes (Adlam et al., 2006; Patterson, Nestor, & Rogers, 2007).

Semantic dementia patients show striking difficulty reading aloud exception words, particularly when these words are low in frequency (e.g., *scarce*; Patterson & Hodges, 1992), in line with activation of the left anterior temporal lobe for exception words in normal readers (Wilson et al., 2012). This reading deficit is not due to the malfunction of basic orthographic or phonological processing, as many semantic dementia patients read pseudowords such as *karce* accurately (Woollams et al., 2007), and their erroneous readings of exception words are usually phonologically plausible regularizations (i.e., *scarce* read to rhyme with *farce*). This reading profile is known as acquired surface dyslexia. Semantic dementia patients show a similar deficit when making lexical decisions about words with atypical spellings, such as *yacht* (Rogers, Lambon Ralph, Hodges, & Patterson, 2004).

Semantic dementia patients are more likely to correctly read an exception word aloud if they still know the meaning of that word (Graham, Hodges, & Patterson, 1994), mirroring results in the developmental literature (Ricketts et al., 2007). Large-scale studies of semantic dementia have shown a strong link between the degree of the exception word reading deficit and the severity of semantic impairment on tasks that do not require reading (e.g., picture naming, spoken word-to-picture matching; Woollams et al., 2007). The remaining variation in exception word reading among patients with similar levels of semantic impairment may be determined by how much they relied on word meaning for reading before they experienced brain damage (Woollams et al., 2007). Future research should seek to understand the nature of such individual differences among normal readers at the behavioral and neural level.

We can also ask of neuropsychological data: What happens to reading when we lose knowledge of written or spoken word forms? Pure alexic patients have damage to the left ventral occipito-temporal region associated with orthographic processing in normal readers, making them very slow and particularly poor at reading long words. Phonological dyslexic patients have damage to the left perisylvian region, which supports phonological processing in normal readers, and this makes them particularly poor at reading novel letter strings. Both types of patient show a strong influence of the imageability of a word's meaning on reading: They are more accurate reading words like *chair* than *hope* (Crisp, Howard, & Lambon Ralph, 2011; Roberts, Lambon Ralph, & Woollams, 2010). Hence, it seems that word meaning can partially offset the consequences of damage to orthographic or phonological processing for reading; future research can explore the extent to which this could be harnessed to improve performance.

Computational Modeling

Computational models of reading allow us to ask: Which theory of reading provides the best account of how semantics influences skilled reading, its development, and its breakdown in cases of reading disorder? Furthermore, they are useful in ensuring that the mechanisms necessary to account for an observed behavior are made explicit. The triangle model (Fig. 1b) suggests that semantics has an essential rather than peripheral role in word reading. More recently, focus has turned to exploring *how* learning to read is influenced by the nature of the mappings between the spellings, sounds, and meanings of words.

Sound-to-meaning mappings for words are largely arbitrary (e.g., *cat* and *cap* sound similar but have distinct meanings). Computational modeling has shown that acquiring these mappings, as preliterate children do when building their oral vocabulary, is resource intensive (Lambon Ralph & Ehsan, 2006). However, learning to map written to spoken forms is more systematic (e.g., *cat* and *cap* are similar orthographically and phonologically) and requires fewer resources. Paradoxically, modeling work shows that these systematic mappings, though easier to acquire, are less robustly represented and more prone to interference and change (Monaghan, Christiansen, & Fitneva, 2011), whereas early-acquired arbitrary mappings exert an enduring influence on later learning. Hence, computational models make a clear prediction that preliterate understanding of spoken word meanings affects later literacy development. These predicted effects are observed behaviorally in the greater influence of semantics for early-acquired than late-acquired words in reading speed (Davies, Wilson, Cuetos, & Burani, 2014; Monaghan & Ellis, 2010).

The triangle model maps written to spoken words via two pathways: one that is direct, and another that is indirect, via semantics. However, an alternative conception of the role of semantics is that it interacts with written and spoken forms via a central resource, as shown in Figure 1c (Dilkina, McClelland, & Plaut, 2008; Smith, Monaghan, & Huettig, 2013). Central-resource models propose that semantics begins to be activated as quickly as the phonological form of a word and affects its visual identification (both for regular and exception words), echoing neuroimaging findings (e.g., Hauk, Coutout, Holden, & Chen, 2012). Furthermore, these models show that when we become literate, spoken words are more readily decomposed into their constituent sounds, but their meanings also continue to exert a strong influence on language processing (Smith, Monaghan, & Huettig, 2014). This is because the arbitrary mappings between written and spoken forms and their meanings are more robust and adjust less as a consequence of newly acquired information than written-to-spoken mappings.

Computational models of reading help us to understand why semantics is an integral contributor to word reading. However, they remain underspecified as to whether semantics provides a parallel pathway from orthography to phonology or interacts with written and spoken forms via a central resource. Furthermore, computational models of reading development have not proceeded at the same pace as behavioral research; simulating the relative contribution of semantics at different stages of reading acquisition is imperative for a full understanding of how reading is acquired.

Conclusion

This review demonstrates the importance of integrating evidence from various methodological approaches in order to fully understand word reading. In summarizing key recent developments, this review has been somewhat Anglocentric. Future research should examine more fully the role of semantics in word reading in languages with more regular (e.g., Spanish; cf. Davies, Barbón, & Cuetos, 2013) and exceptional (e.g., Chinese; cf. Williams & Bever, 2010) orthography–phonology mappings. Nonetheless, we have shown conclusively that semantic knowledge is implicated in word reading. This insight provides constraints upon, and predictions for, future theorizing. For example, modeling approaches (dual-route, triangle, central resource; see Fig. 1) must be able to explain the effect of semantics on word reading across item types and individuals and provide more naturalistic accounts of learning. Furthermore, the reviewed findings have the potential to influence teaching practice. There is clear evidence that phonics-based instruction (with a focus on print-to-sound mappings) is highly effective in the teaching of early reading (McArthur et al., 2012). Going beyond this, our review of the evidence from multiple research traditions leads us to propose that learners who possess knowledge of the semantics of words will fare better when they come to the task of learning to read them. Practically, this suggests that explicit teaching of oral vocabulary (sound-to-meaning mappings) should precede and accompany phonics instruction. This proposal needs to be rigorously tested in educationally realistic studies.

Recommended Reading

Nation, K. (2009). Form–meaning links in the development of visual word recognition. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*, 3665–3674. doi:10.1098/rstb.2009.0119. Discusses the role of meaning in reading development, using connectionist models as a framework, and suggests directions for future modeling and empirical research.

Pexman, P. (2012). Meaning-based influences on visual word recognition. In J. S. Adelman (Ed.), *Visual word recognition volume 2* (pp. 24–43). Hove, England: Psychology Press. Provides recent insights into the role of meaning in word recognition in adults.

Price, C. J., & Devlin, J. T. (2011). The interactive account of ventral occipitotemporal contributions to reading. *Trends in Cognitive Sciences*, *15*, 246–253. doi:10.1016/j.tics.2011.04.001. Proposes that visual word recognition is aided by top-down contributions from brain regions involved in processing linguistic information, such as phonology and semantics.

Seidenberg, M. S. (2012). Computational models of reading: Connectionist and dual-route approaches. In M. Spivey, K. McRae, & M. Joanisse (Eds.), *Cambridge handbook of psycholinguistics* (pp. 186–203). Cambridge University Press. An accessible review of alternative approaches to computational models of reading.

Woollams, A. M. (2014). Connectionist neuropsychology: Uncovering ultimate causes of acquired dyslexia. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*. doi:10.1098/rstb.2012.0398. Presents an overview of recent research concerning acquired dyslexia, with an emphasis on how visual, semantic, and phonological processing abilities support reading.

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