Integrating word processing with text comprehension: Theoretical frameworks and empirical examples

Chapter · January 2017

DOI: 10.1075/swll.15.02sta

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Theoretical frameworks and empirical examples

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We previously observed that "there is no theory of reading, because reading has too many components for a single theory" (Perfetti & Stafura, 2014, p. 1).[1] In the pursuit of studying reading and reading development, then, research has largely been driven by flexible frameworks and specific problems rather than by precise theoretical testing.

How readers comprehend and how skill differences arise are intertwined problems in reading theory. We suggest that the reintroduction of a broad-scope, general framework for reading can aid the formulation of specific hypotheses about reading expertise and reading problems. Following the presentation of the framework we take a closer look at on-line text-based comprehension processes. In this section, we discuss current work in our lab addressing the functionality of word knowledge and word processing in text and discourse comprehension. First, we consider the broader context for comprehension theories.

Theories of reading comprehension

Two complementary ideas shaped the modern study of reading comprehension, one that described an enriched level of comprehension beyond the literal meaning of a text – the reader's situation model (Van Dijk & Kintsch, 1983) – and one that described the cognitive dynamics of text comprehension, the construction-integration (C-I) model (Kintsch, 1988). The C-I model made general assumptions about the reader's cognitive architecture (e.g., limited memory) and cognitive procedures (e.g., retrieval and carry-over operations) as well as text devices (e.g., argument overlap) that support comprehension. The C-I theory was critical in explaining text comprehension by an interactive combination of top-down (knowledge-driven) and bottom-up (word-based) processes.

1. The article by Perfetti and Stafura (2014) provides the original material from which this chapter is based.

DOI 10.1075/swll.15.02sta

Prior to this, ideas about text comprehension had been dominated by demonstrations of knowledge-driven, top-down procedures guided by scripts (Shank & Abelson, 1977) and other forms of schemata (Anderson, 1978; Bartlett, 1932). Following van Dijk and Kintsch (1983) and Kintsch (1988), text comprehension research headed in new directions, building on these models of text-knowledge interaction and developing enriched variations (Goldman & Varma, 1995) and updates on the basic idea (Kintsch & Rawson, 2005). Theories tackled one or more aspects of comprehension (for a review, see McNamara & Magliano, 2009). The landscape model (Van den Broek et al., 1996) targeted the "landscape" of activation patterns that wax and wane during reading and how the reader's goal of maintaining coherence guided these patterns. The structure building theory (Gernsbacher, 1990) also assumed a central role for coherence, which was viewed as the result of the structures built and connected by the reader, and provided hypotheses about individual differences in comprehension. The event-indexing model (Zwaan, Langston, & Graesser, 1995) elaborated the idea of the situation model toward a more comprehensive multidimensional tracking of various aspects of narrativity. Among the many issues targeted in these theories, an especially important one concerned inferences: that they were necessary for comprehension and how and when they were made (Graesser, Singer, & Trabasso, 1994). A specific contribution of this research was to show that readers make inferences that maintain coherence, including causal inferences that connect actions in narratives (Graesser & Kruez, 1993).

The current empirical status of these and other theories (e.g., embodied comprehension; Zwaan, 2003) remains under study and is beyond the scope of the present article. The point here is that broadly-defined contrasts – for example, verbatim versus gist memory, literal versus inferential text processing, coherent versus incoherent texts – can be addressed in models that include interactions among knowledge sources that are initiated by written word reading, rather than solely by top-down knowledge-generating inferences. Still, it is fair to say that attention to how word processes actually contribute to comprehension has been minimal, with a few notable exceptions that include the role of word meaning selection in the structure building framework (Gernsbacher, 1990) and word activation processes in the construction phase of the C-I model (e.g., Kintsch & Mross, 1985).

The theories just discussed are global frameworks rather than specific theoretical models. The value of a framework for something as complex as comprehension is that it provides a set of interconnected claims that, with the addition of specific assumptions, can lead to theoretical models with testable propositions and implications. Nevertheless, in contrast to well-defined models of word reading that make precise predictions (e.g., Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), reading comprehension is too broad a target for precise models. As we illustrate in the next section, there is value in capturing this breadth in a general framework that provides a view of the component subsystems of reading comprehension.

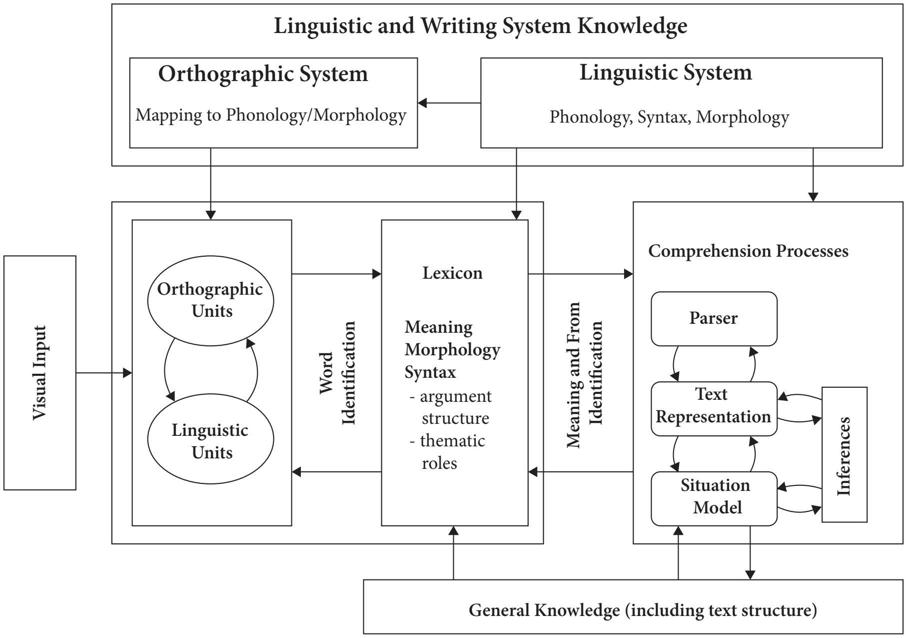

Figure 1. The Reading Systems Framework. *Note.* The components of reading within a language-cognitive architecture from visual processing through higher level comprehension. The key elements are knowledge sources, basic cognitive and language processes, and interactions among them. The framework allows the development of specific models (e.g., word identification models, models of inferences) and allows hypotheses about both the development of reading expertise and reading weaknesses. A particular point of focus is the lexicon, which is a central connection point between the word identification system and the comprehension system. Based on Perfetti (1999).

The Reading Systems Framework

A general framework of *reading systems* must reflect reading more fully by adding word level processes to the higher level processes that are the focus of comprehension research. Figure 1 presents a variation of such a framework, derived from a "blueprint" of the reader (Perfetti, 1999) and used to frame problems in comprehension (Perfetti, Landi, & Oakhill, 2005). This Reading Systems Framework makes the following claims about reading:

1. Three classes of knowledge sources are used in reading: linguistic knowledge, orthographic knowledge, and general knowledge (knowledge about the world, including knowledge of text forms, e.g., text genres).

2. The processes of reading – decoding, word identification, meaning retrieval, constituent building (sentence parsing), inferencing, and comprehension monitoring – use these knowledge sources in both constrained ways (e.g., decoding uses orthographic and phonological knowledge but not general knowledge) and in interactive ways (e.g., inferences use general knowledge and propositional meaning extracted from sentences).
3. These processes take place within a cognitive system that has pathways between perceptual and long-term memory systems and limited processing resources.

This framework finds support in neurobiological models of language. Hagoort's (2005; 2013) MUC model posits a functional core of *memory, unification*, and *control* operations in language processing. In terms of reading comprehension, these are functional during encounters with words, as input from the visual orthographic system drives memory operations in the temporal lobes that retrieve associated linguistic and general knowledge from long-term memory. Unification operations in the left inferior frontal gyrus act to integrate the word-level syntactic and semantic knowledge into the ongoing context (e.g., into a sentence). Finally, control operations seated in the dorsolateral prefrontal cortex and anterior cingulate cortex guide efficient processing with limited resources. This neurobiological framework is broadly consistent with C-I models (Kintsch, 1988) of comprehension in its focus on bottom-up activity and incremental integration into ongoing higher level, coherent text representations.

The Reading Systems Framework can also guide the formation of novel theories and hypotheses of reading problems. Readers can show weaknesses in specific knowledge sources, which then affect processes that use these knowledge sources in reading. An alternative view, the dominant one, is that it is weaknesses in the processes themselves that lead to comprehension breakdown. It is typically difficult to choose between these two views. Is a measured weakness in decoding due to a processing problem involving the conversion of orthography to phonology? Or is it due to a knowledge weakness about phonology or the rules that link orthography to phonology? A weakness in these links could result in difficulty accessing what are actually high quality phonological representations (Boets et al., 2013). Is an observed problem in inference making due to a weak inference process or to a lack of knowledge that is needed to make the inference? To a limited extent these are empirical questions. For example, in the case of the inference/knowledge debate, one can try to control for knowledge (Cain, Oakhill, Barnes, & Bryant, 2001). However, even with the best of efforts it is difficult to persuasively assess processes in isolation of other processes and, especially, in isolation of the knowledge sources on which they rely.

The Reading Systems Framework is useful in the generation of hypotheses about the sources of comprehension problems in several ways. One is to identify reading problems by measureable weaknesses within one or more of the components (knowledge and processes) of the framework. This works especially well with lower level processes, where failure in decoding defines basic reading disability or dyslexia. More specific hypotheses then focus on even more fine-grained components in the visual or phonological subsystems as sources of reading disability, with the bulk of the evidence showing phonological processing problems (Vellutino, Fletcher, Snowling, & Scanlon, 2004).

This strategy does not work nearly as well with higher level processes, because these depend on receiving high-quality *input* from word-level and sentence-level sources. Thus, careful testing of higher level sources of comprehension problems must attempt to control for some of the lower level components (e.g., Cain, Bryant, & Oakhill, 2004; Cain, Oakhill, & Bryant, 2000; Oakhill, Cain, & Bryant, 2003). The result is the identification of specific reading comprehension difficulties, of which several have been proposed, with no single difficulty emerging as definitive (Cain, 2010; Cain & Oakhill, 2006; Nation, 2005).

Another strategy is to hypothesize pressure points in the reading system. For example, the Lexical Quality Hypothesis (Perfetti, 2007; Perfetti & Hart, 2002) assumes that the lexicon is a critical pressure point in reading comprehension. The lexicon sits astride two reading systems: one, the word identification system, requires high-quality linguistic and orthographic information to enable rapid word identification; the second, the comprehension system, takes its input from the word identification system to build meaning units (propositions). Knowledge of written word forms and meanings, then, is central to reading and thus a pressure point for reading comprehension – a prime candidate for a cause of reading comprehension difficulty, and a critical level of analysis for extending theory.

As a scaffold for theory development and hypotheses testing, the Reading Systems Framework allows other hypotheses about pressure points and about the interactions between reading subsystems. In what follows, however, we focus on the lexical component and its interaction with text and discourse representations.

Comprehension skill within the lexical system of the Reading Systems Framework

The focus on a lexical subsystem in reading arises from the centrality of word meanings (represented in a long-term memory) as (a) the output of word identification and (b) the input to comprehension processes. This leads to research on the relations between lexical processes and comprehension processes and the following two complementary hypotheses:

1. Text comprehension depends on understanding words and integrating their meaning into a mental model of the text, and more skilled comprehenders do this better than less skilled comprehenders (Perfetti, Yang, & Schmalhofer, 2008; Yang, Perfetti, & Schmalhofer, 2005, 2007; Stafura & Perfetti, 2014).
2. Learning words depends on acquiring information about both word forms and meanings from word-learning events, and more skilled comprehenders do this better than less skilled comprehenders (Bolger, Balass, Landen, & Perfetti, 2008; Perfetti, Wlotko, & Hart, 2005; Van Daalen-Kapteijns & Elshout-Mohr, 1981).

Both hypotheses are now empirical generalizations insofar as they are consistent with available evidence: correlational evidence for the first and correlational and intervention-based experimental evidence for the second. In the next section, we examine more closely the nature of this evidence and its implications for hypotheses about the sources of reading comprehension problems.

Comprehending texts includes comprehending words

In the Reading Systems Framework, a key set of processes links lexical outcomes with comprehension (Figure 1; "meaning and form selection"). Early sentence comprehension processes that build sentence constituents (e.g., noun phrases, verb phrases) and propositions (elementary meaning units) make use of this link. (Notice also the bidirectional link, which allows word learning to result from comprehension.)

These links can be studied only by on-line measures that expose word level reading comprehension while it happens and not by observations made after a text has been read. There are three important methods for obtaining such measures: (a) word-by-word reading controlled by the reader, (b) eye-tracking, and (c) event-related potentials (ERPs) during text reading. The first has ease of instrumentation, but it allows reader strategies some influence. Eye-tracking and ERPs, which are measures taken without overt decisions required by the reader, provide the clearest evidence of word-to-comprehension links. Each has its advantages: Eye-tracking allows natural movements of the eyes. ERPs, which generally require that the eyes not move, allow multiple word processing components (e.g., visual attention, orthographic recognition, meaning processes, syntactic processes) to be observed on a single word. Next we focus on ERP studies.

Word-to-text integration

We assume that, for a motivated reader, understanding entails a mental representation of the "situation" described by a text (Van Dijk & Kinstch, 1983). In terms of structure, for our initial purpose we assume only that an unfolding narrative text asserts situations and events and that the reader builds and updates a situation model accordingly (Zwaan & Madden, 2004). For now, we also postpone our discussion of the potential effects of older non-updated information remaining in memory (O'Brien, Rizzela, Albrecht, & Halleran, 1998).

A key additional assumption is that comprehension proceeds along multiple input units. For example, a noun is understood through lexical meaning retrieval, a noun phrase is understood through additional referential processes, and a clause that includes the noun phrase is understood through additional lexical and parsing processes. So, for example, in reading the sentence, "The rain ruined her beautiful sweater," the following comprehension processes are centered on the understanding the word "rain": (a) retrieval of meaning of "rain," (b) establishing definite situational reference of "the rain" (cf. "a rain would ruin the picnic"), and (c) extracting a proposition in which "the rain" is the subject of "ruin her beautiful sweater" and thus the cause of the ruining event. Of course, only the first two operate on the reading of "the rain" with the predication about ruining the sweater requiring additional reading. It is these two processes that are in focus in the following analysis. Of specific interest is what happens across a sentence boundary, which is a paradigm case of text integration processes. We begin with a single sentence, from which a situation model can be constructed:

(1) *While Cathy was riding her bike in the park, dark clouds began to gather, and it started to storm.*[2]

In Figure 2, a simple scheme represents a possible situation model a reader might have from the reading of (1). The situation includes four referential entities – Cathy, the park, the bike, and dark clouds – and an event – the storm. Referents are essential in the model, because referents are eligible (unequally) for elaboration. Events are normally but not necessarily established through verbs, and these events also become eligible for elaboration. With this situation established, the text adds a new sentence:

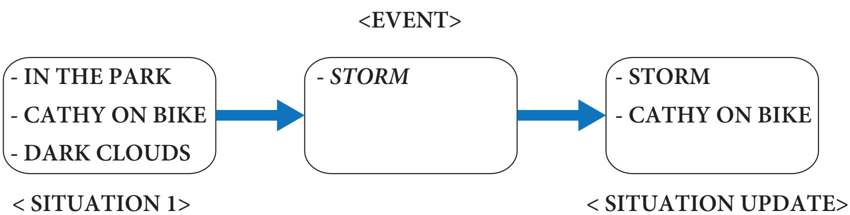

Figure 2. A situation model. *Note.* The model represents what a reader might understand after reading the sentence *While Cathy was riding her bike in the park, dark clouds began to gather, and it started to storm.* The general form of the model is SITUATION + EVENT. Adapted from Perfetti and Stafura (2014).

(1) *While Cathy was riding her bike in the park, dark clouds began to gather, and it started to storm. The rain ruined her beautiful sweater.*

The noun phrase that begins the new sentence – *the rain* – is understood immediately in relation to the situation model. It refers to the storm event, to which it can be integrated as part of the model. Figure 2 would now incorporate the new event – the ruination of the sweater.

Experiments summarized in Perfetti et al. (2008), using sentences similar to (1), measured the ERP responses initiated by a target word – "rain" in the current example. When the target word appeared, the N400 component, an indicator of the degree of fit between the word and its context experienced by the reader (Kutas & Federmeier, 2000), was reduced in amplitude relative to a baseline condition (2):

2. Our discussion relies on relatively simple narrative texts, which contain clear event structures to expose examples of integration processes. However, our theoretical framework and the word-to-text integration processes we examine apply to texts of all types.

(2) *When Cathy saw there were no dark clouds in the sky, she took her bike for a ride in the park. The rain that was predicted never occurred.*

Here, the N400 on the word "rain" has a more pronounced negative deflection, because initially it requires more processing for meaning activation, meaning integration (with the text), or both. There is no antecedent for "rain" in the preceding sentence. Equivalently, the situation model contains no referent to which the new event, "the rain," can be attached. Unlike in (1), there is no "storm" event to support the integration of "the rain" into the model. Instead the reader must build a structure around this new event.

It is important to emphasize that the difference between texts (1) and (2) is not about their sensibility or coherence. Text (2) is fully sensible. Thus, the N400 comparison of texts (1) and (2) on "rain" is quite subtle compared with the more typical studies of the N400, which use anomalous sentences (e.g., "related anomaly" paradigm; Amsel, DeLong, & Kutas, 2015). For example, in a classic N400 study, an ERP recorded on "eat" in "The pizza was too hot to eat" was compared with the ERP recorded on the anomalous "drink" in "The pizza was too hot to drink" (Kutas & Hillyard, 1980). In these conditions, the N400 differences are dramatic and may be explained by expectancy violations (Kutas & Federmeier, 2000; Lau, Almeida, Hines, & Poeppel, 2009; Van Petten & Luka, 2012). However, in our case, a comparison is made across sensible texts that differ only in the degree to which they invite an immediate word-to-text integration process. (See Brown & Hagoort, 1993, for an N400 interpretation based on post-lexical integration processes.) Expecting a certain word across a sentence boundary seems unhelpful to comprehension; nearly any grammatical sentence beginning can continue with coherent ties to the preceding sentence. Thus the reduction of the N400 in our case is not likely about expectancy violations, but about integration.

The paraphrase effect and comprehension skill

The word "rain" is better integrated with text (1) than with text (2). We refer to this as the *paraphrase effect*, with the understanding that this is not exactly the everyday sense of "paraphrase," that is, expressing an idea in words different from its original expression. In our usage, paraphrase is an implicit co-referential relation between a word or phrase in one sentence and a word or phrase in a following sentence. The co-referential relation is defined by the contents of the mental representation of the enriched semantic content of the text – the situation model. The paraphrase can update the situation model modestly (or merely reinforce the salience of a referent) while maintaining coherence. Thus, in text (1), "rain" is *not* another way of saying "storm." Rather, "rain" fine-tunes – or elaborates – the mental model by identifying a correlate or consequence of the storm, which was established in the first sentence.

The paraphrase effect reflects online comprehension, an updating of the situation model that integrates a word with a text representation. In addition to evidence for this integration process in ERP records, we discovered that skilled comprehenders showed the paraphrase effect more robustly than less skilled comprehenders, who were described as showing *sluggish* word-to-text integration (Perfetti et al., 2008). This sluggishness can have consequences for maintaining coherence across sentences, as memory resources, which are required for comprehension repairs, become less available. Recent work has supported this view of individual differences, finding that the paraphrase effect occurred only among highly skilled readers (Stafura & Perfetti, 2014). Thus, these anaphoric elaboration processes – centered on word level processing – are sensitive to reading ability.

Word-to-text integration can involve inferences. Indeed, one might argue that the paraphrase effect is a kind of bridging inference (Haviland and Clark. 1974; Graesser, Singer, & Trabasso, 1994; Singer & Halldorson, 1996). In our previous example, a bridging inference could link "the rain" back to the storm, preserving coherence. On this description, we could say that skilled comprehenders make this bridging inference more readily than less skilled comprehenders. However, such a description seems incomplete without a focus on its lexical basis, and, further, it would beg the question of what makes this bridging inference more likely for the skilled comprehenders. Instead, we think describing the rain-to-storm link-up as a lexically based integration process (word-to-text) better captures the cognitive operations involved and frames a hypothesis for why there is a skill difference. Thus, instead of focusing on "broken" bridging processes one focuses on word knowledge and context-sensitive meaning selection that are required for the integration process.

There is an important role for bridging inferences in this kind of word-to-text integration, however. If the text of the first sentence has only an implication of rain rather than establishing a rain-related event (storm), the integration process requires bridging, as in text (3):

(3) *While Cathy was riding her bike in the park, dark clouds began to gather. The rain ruined her beautiful sweater.*

When the reader encounters "rain" in (3), there is no storm event in the mental model to which "rain" can be attached. Instead, the reader makes a bridging inference, constructing a new event: Rain. This bridging inference (e.g., Graesser et al., 1994; Singer & Halldorson, 1996) is readily made, although with some cost to processing efficiency. Yang et al. (2007) observed that for texts of this type, the N400 amplitude was not significantly different from baseline. Thus, reading "The rain …" in sentence (3) was similar to reading "The rain …" in sentence (2) as far as the ERP record was concerned.

The costly bridging inference is unnecessary if, in the first sentence, the reader makes a forward or predictive inference. Such an inference would occur while reading the first sentence of (3), specifically the segment "… dark clouds began to gather." This inference is a prediction (it will rain) the reader might make (Graesser et al., 1994). The inference has little warrant, however, so adding rain to the mental model is a risky move. Certainly the comprehension of "dark clouds" in the first sentence allows "the rain" to be easily understood when it does appear in the next sentence. (Hence, the N400 to (3) is not more negative than in (2).) However, it does not compel a forward inference (McKoon & Ratcliff, 1992). The N400 results of Yang et al. (2007) strongly suggest that skilled readers do not make the forward inference consistently, and thus had to make a bridging inference when they came to the word "rain.". (For further discussion that connects inferences and word-to-text integration processes see Perfetti & Stafura, 2015)

To summarize: Word-to-text integration processes are central to comprehension because they recur with each phrase. They reflect a close coupling of word identification with representations of the meaning of the text, mediated by the retrieval and selection of word meanings. Word-to-text integration processes are pervasive, and the processes that produce the paraphrase effect are only part of the integration picture. Other anaphoric processes, ranging from simple pronoun binding through more complex co-referential expressions are also relevant, as are bridging inferences. All these processes maintain coherence at variable costs to comprehension efficiency. Comprehension skill depends in part on these word-to-text integration processes. Those processes that depend on word meanings are especially likely to show individual differences, because knowledge and use of word meanings is highly variable across individuals.

Explaining further the association between reading skill and the paraphrase effect requires more research. Candidate explanations within the Reading Systems Framework include (a) individual differences in the lexicon, either vocabulary size (in a familiarity or passive knowledge sense) or more finely tuned word knowledge that supports the use of words in specific contexts; (b) cognitive architecture factors, including working memory limitations (Just & Carpenter, 1992); and (c) problems in executive functioning (e.g., Cutting, Materek, Cole, Levine, & Mahone, 2009) that can cause less effective inhibition of irrelevant word level semantic information (Gernsbacher, 1990).

Functional mechanisms of word-to-text integration

More research is needed to understand the mechanisms of word-to-text integration, aside from skill differences. The cross-sentence paraphrase effect is a general language process, found in listening comprehension as well as reading (Adlof & Perfetti, 2011). Stafura and Perfetti (2014) explored the question of whether the message level of comprehension (what the text means) or the lexical level (the association between prior words and the word being read), or both, are responsible for the paraphrase effect. Although the message level must be involved if the effect is about comprehension, lexical processes initiated by word identification, including associations that a word has with other words in memory and with other words in the text are part of the process. In the C-I model, associations are activated through rapid, automatic processes in the construction stage and may have no consequences for the later integrative stages of comprehension. However, if the text contains words that take advantage of the associations that are evoked unconsciously, then associations may provide a head start on message-level comprehension.

Stafura and Perfetti (2014) compared ERP responses to critical words (e.g., rain) that were either strong (4) or weak (5) associates of the referentially-related antecedent words (*italicized)* in the first sentence.

(4) While Cathy was riding her bike in the park, dark clouds began to gather, and it started to *storm*. The rain…

(5) While Cathy was riding her bike in the park, dark clouds began to gather, and it started to *shower*. The rain…

Similar to the original reports of the paraphrase effect (Perfetti et al., 2008; Yang et al., 2005; 2007), critical words in both strong association and weak association conditions elicited reduced N400 responses relative to the same critical words in baseline sentences such as (2). Crucially, there were no differences between the strong association and weak association conditions. This finding suggests that, within the parameters of these materials, the message level is the dominant locus for the paraphrase effect.

An additional question is whether the lexical component of the text integration process takes advantage of forward association processes or uses memory based backward processes (Stafura, Rickles, & Perfetti, 2015). In our example, does "storm" in the first sentence evoke "rain" as an associate, which is then available to support integration when "rain" is encountered in the next sentence? Or is the more important process that when "rain" is read in the second sentence it resonates with the memory of "storm" from the first sentence. The critical comparison is between forward association conditions like (4) with backward association conditions like (6);

(6) While Cathy was riding her bike in the park, dark clouds began to gather, and it started to rain. The storm ruined her beautiful sweater.

Stafura and colleagues (Stafura et al., 2015) analyzed both mean evoked amplitudes and principal components extracted from the ERP data, finding both similarities and differences in critical word processing depending on the dominant direction of association. Consistent with the paraphrase effect findings in the past, both association conditions elicited reduced mean N400 amplitudes over central electrodes relative to baseline conditions. Additionally, forward and backward association conditions elicited ERPs that differed in both earlier (~200ms) and later (≥425ms) time-windows. We interpreted the late component in terms of memory processes (Rugg et al., 1998; Rugg & Curran, 2007), specifically, those involved in discourse updating (Burkhardt, 2007). These may be passive resonance processes (O'Brien et al., 1998) leading to activation of the co-referential information in the first sentence. This activity was greatest in the backward association condition wherein the critical word could act as a retrieval cue for the preceding sentences' meaning structure (e.g., propositional; Ericsson & Kintsch, 1995; O'Brien, Plewes, & Albrecht, 1990; Ratcliff & McKoon, 1988) leading to long-lasting positivity in the ERP wave.

Together, this evidence supports a message level locus for the paraphrase effect, at least within the parameters of the short, sensible materials used in these studies. At the same time, there are some tentative indications that lexical level processes play distinct functional roles in word-to-text integration, with words potentially acting as retrieval cues for the meaning of the preceding text.

Structural aspects of text and word-to-text integration
Identifying the structure and situational dimensions of mental representations of text (e.g., Zwaan & Radvansky, 1998) and how they interact as the reader builds an understanding of the text (Rapp & Taylor, 2004) are important topics of comprehension research. One area in which we have begun exploring the effects of text and discourse level factors on word level processing relates to the semantic – or structural – centrality of a text (van den Broek, Helder, & Van Leijenhorst, 2013). A given word's structural centrality is defined as the degree to which that word is central to the semantic structure of the text. Readers are typically better at recalling information that is central to the semantic structure of texts, compared to non-central information. However, studies on centrality to this point have measured comprehension off-line, after reading (for a review see van den Broek et al., 2013).

We recently carried out an experiment to test the effects of structural centrality on on-line, word level processing using ERPs (Helder, Stafura, Calloway, van den Broek, and Perfetti, 2015). Table 1 provides an example narrative in 3 conditions used in this study. The Theme Conditions have semantic structures that differ in terms of their central themes. In Table 1, Theme 1 has "Weather" as a central theme, and Theme 2 has "Clothes" as a central theme. Critical words from which ERPs were measured are bolded if they are related to the first theme (e.g., Weather), and bolded and underlined if they are related to the second theme (e.g., Clothes). Baseline passages that are neutral regarding the experimental themes were used in the first critical word analysis only (due to constraints in making the texts sensible and coherent).

Table 1. Example passages. From Helder et al., 2015.

Condition	Example passage
Theme 1 – Weather	Cathy likes to check the weather all the time on her iPhone. She is always very excited when stormy weather is predicted. While Cathy was riding her bike in the park, dark clouds began to gather, and it started to storm. The **rain** ruined her beautiful <u>**sweater**</u>.
Theme 2 – Clothes	Cathy loves clothes and bought herself a new wardrobe. She is getting ready to go outside and decides to wear her new outfit today. She noticed that a lot of people were looking at her clothes while it started to storm. The **rain** ruined her beautiful <u>**sweater**</u>.
Baseline	Cathy lives close to a park. She likes to be there as much as she can during the summer. When Cathy saw there were no dark clouds in the sky, she took her bike or a ride in the park. The **rain** that was predicted never occurred.

Helder et al (2015) found no effect of centrality at the first critical word (e.g., rain); baseline passages elicited greater average N400 responses than the experimental conditions, which did not differ. However, text-final words (e.g., sweater) revealed effects of centrality with not-thematically-related words eliciting greater average P600 responses relative to thematically-related words. Thus, structural centrality influences on-line word-to-text integration processes at the text-final position.

This evidence suggests that the message level influences on-line comprehension processes at the lexical level. At earlier positions in a sentence, local operations such as co-referential binding seem to have a dominant role. At the end of the sentence(/text) message-level processes appear dominant. Here, the P600 effect may reflect the ease of mental model updating when words are related to the central theme of the passage, compared to when they are not related to the central theme (but sensible).

Memory updating and word-to-text integration

Text and discourse research has demonstrated that "outdated" discourse information (information no longer available in working memory) can influence later comprehension processes (Albrecht & O'Brien, 1993; O'Brien & Albrecht, 1992; O'Brien et al., 1998). However, it is unclear whether comprehenders are sensitive to this outdated information at the point of the first potentially conflicting word, or only at a later point in reading, as previous methods have almost completely relied on self-paced reading of entire sentences.

Currently, our lab is carrying out ERP studies to test the influence of outdated discourse inconsistencies on a word-by-word basis. Findings of immediate sensitivity at the word-level would provide insight into on-line processing connections between message- and word-levels across large stretches of text. Specific ERP components can then allow us to zero-in on mechanisms that may be functional in this process. For example, inconsistent words may attract attention or updating processes related to information in working memory, eliciting larger P300 responses than consistent words (Donchin & Coles, 1998). Additionally, inconsistent words may lead to extended memory retrieval and analysis related to the earlier conflicting "episode", perhaps through passive resonance mechanisms (Myers & O'Brien, 1998) that have been shown to selectively improve memory of information surrounding inconsistent material (O'Brien & Myers, 1985). These extended processes may lead to a prominent late positivity (P600) at the critical word in inconsistent relative to consistent conditions, such as was seen in the directional association study by Stafura et al. (2015). On the other hand, the findings of Helder et al. (2015) suggest that, in some conditions, effects of message level factors may be delayed, eliciting effects on sentence- or text-final words. We are currently pursuing these and other connections between word level processing and message level processes engaged during on-line reading of longer, relatively natural texts.

Knowledge of word meanings is instrumental in reading comprehension

The paraphrase effect, and word-to-text integration processes in general, demonstrate subtle roles of word meanings in comprehension (in addition to their obvious role in allowing comprehension) and leads to the question of what kinds of word knowledge are responsible for integration and comprehension success. The Lexical Quality Hypothesis (Perfetti, 2007; Perfetti & Hart, 2002) assumes that word knowledge (both form and meaning) is central to reading skill. High-quality form knowledge includes phonological specificity, the lack of which has been linked to problems in reading and word learning (Elbro, 1998; Elbro & Jensen, 2005). It also includes orthographic precision, which has been shown by Andrews and colleagues to have specific consequences beyond the effects of reading skill. Spelling-based lexical expertise effects are seen in lexical access (Andrews & Hersch, 2010; Andrews & Lo, 2012) and spelling/vocabulary lexical expertise effects can show subtle effects in the balance of top-down and bottom-up processes in comprehension (Hersch & Andrews, 2012).

The semantic constituent of lexical quality has a close connection to comprehension, as is well established by correlations between vocabulary and reading comprehension (e.g., Adlof, Catts, & Little, 2006; Cromley & Azevedo, 2007). The impact of vocabulary on reading is usually assumed to be indirect through its role in general language comprehension. However, it is possible that vocabulary also has a direct effect on reading itself. An observation by Braze, Tabor, Shankweiler, and Mencl (2007) is interesting on this point. Across a range of adolescent and adult readers, Braze et al. (2007) found that vocabulary accounted for reading comprehension to a greater degree than it did listening comprehension. They argued that this reflects the fact that written words are more likely to fail to activate lexical representations than are spoken words. In effect, a stronger semantic connection (a more integrated set of word constituents) can compensate for lower orthographically initiated activation.

Consistent with this possibility are the results of other cross-sectional and longitudinal studies. Protopapas, Sideridis, Mouzaki, and Simos (2007) in a study of 534 children in Grades 2, 3, and 4 in Greek schools in Crete found a strong relationship among reading comprehension, vocabulary, and decoding. However, the unique contribution of decoding, relative to its shared variance with vocabulary, was negligible with vocabulary taken into account, especially beyond Grade 2. In a longitudinal study that followed 2,143 Dutch children through Grade 6, Verhoeven and Van Leeuwe (2008) found that at Grade 1 reading comprehension was accounted for by a structural model that combined word decoding and listening comprehension. Examining later grades with time-lagged correlations, they found that earlier vocabulary predicted later reading comprehension, whereas earlier listening comprehension did not.

Accounting for word meaning knowledge as part of reading provides a challenge for the assumption that decoding a word unlocks all the knowledge associated with the spoken word. The Simple View of Reading (Hoover & Gough, 1990), an expression of this assumption, would need to accommodate the direct effects of vocabulary on reading comprehension by allowing vocabulary knowledge to influence decoding

(Tunmer & Chapman, 2012). Word meaning would thus contribute to reading both as a component of language comprehension and through word reading. Indeed, recent structural equation models of language ability among children in grades 1–3 support indirect effects of vocabulary on both word reading and listening comprehension (Language and Reading Research Consortium, 2015). Although the spoken language may be the main carrier of word meanings, it is the retrieval of word meanings through orthographic representations (and their integration with text meaning) that is critical in reading.

A second aspect of the word knowledge – comprehension connection concerns learning new words. (Figure 1 shows this connection by arrows from comprehension back to the lexicon.) During reading, readers implicitly infer meanings from imperfectly understood text, allowing the establishment of a new lexical entry or the refinement of an existing one. Readers of greater skill, word knowledge, and experience are more effective at this learning. Experimental evidence for this conclusion spans studies of children and adults and reveals skill differences in learning new words implicitly from text, as well as from direct instruction (e.g., Cain, Oakhill, & Lemmon, 2004; Perfetti, Wlotko, & Hart, 2005).

In the present context, the relevance of these twin aspects of the word knowledge – comprehension relationship is the centrality of word knowledge in a theory of comprehension. The word-to-text integration evidence is that skilled readers are better able to integrate words into their mental models of the text, and that word level processing reveals text level factors on-line. The correlational evidence on the word knowledge – comprehension relationship and the experimental evidence on learning new words together suggest that skill differences in the integration processes may depend on knowledge of word meanings or the use of this knowledge during text reading.

In the final section, we return to the theoretical concerns we raised at the beginning, showing how the Reading Systems Framework can guide more specific hypotheses about comprehension and differences in comprehension skill.

Word comprehension within the Reading Systems Framework

Word reading in context is about word comprehension, which is at the center of the Reading Systems Framework. Word comprehension is the output of the word identification system and the input to the comprehension systems (sentence, text, and situation). Figure 3 is a wide-angle lens view of this part of the framework, showing (in an altered spatial orientation) the word identification system on top and the word comprehension system on the bottom. Word comprehension is word-to-text integration in this view. Word meanings stored in memory (the lexicon) are only part of word comprehension, as they (and other memory-driven associations) are activated during reading and then tuned to what the context (the representation of the situation) demands.

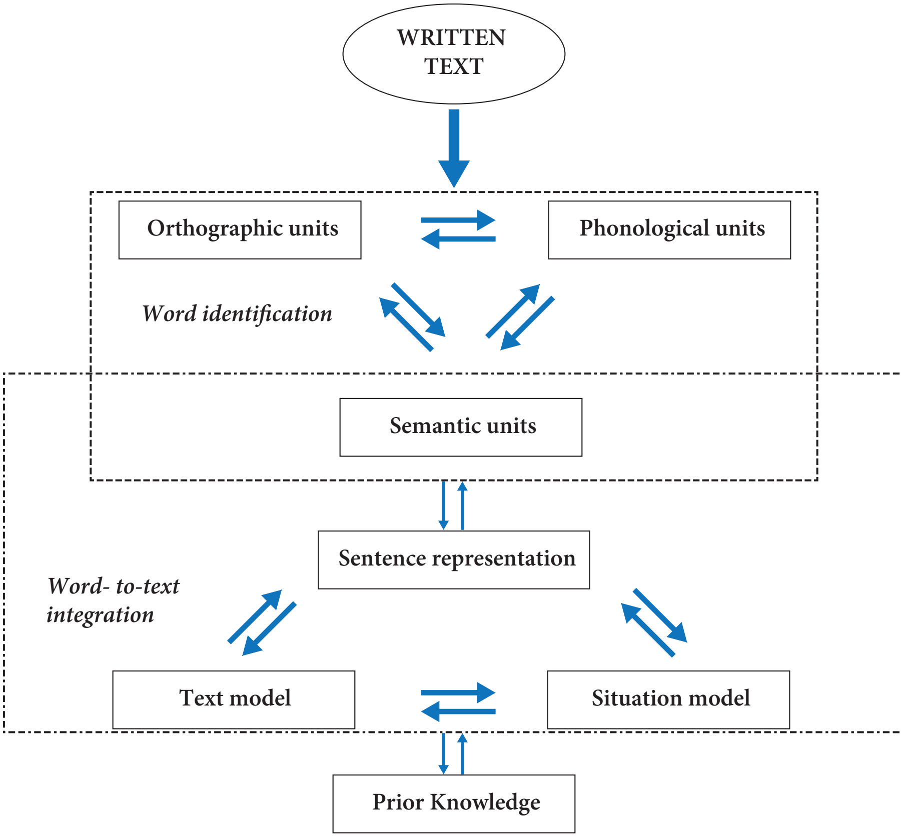

Figure 3. The connection between two systems that support comprehension, "The word identification system and the word comprehension system," is illustrated. As words are identified, they are comprehended in relation to the representation of the text. The comprehension process links the word to an existing referent (or event) in a mental model or extends the mental model to include a new or updated referent (or event). Semantic units activated with word identification are part of this process (the activation phase of the CI model), but the selection of meaning is influenced by the reader's immediate representation of the text. From Perfetti and Stafura (2014).

To return to the review of comprehension theories, we see that the word comprehension model corresponds roughly to the construction (upper part of Figure 3) and integration phases (lower part of Figure 3) of the C-I model (Kintsch, 1988). However, we do not assume that this integration is necessarily an active process. It is at least partly (if not mainly) a memory-driven process, in which words from the recently read text and the propositions they encode (the text model) are highly accessible in memory. A word, as it is read, "resonates" with these memories, and connections are made without an active construction process, which can later tune and correct the representation.

This process is adaptive for comprehension insofar as what is activated in memory is relevant and consistent with the current state of the situation model. However, even information that has been updated and is no longer relevant can continue to exert an influence on comprehension (O'Brien, Cook, & Guéraud, 2010; O'Brien et al., 1998). Active construction may become necessary when coherence breaks down and requires new structures to be built (Gernsbacher, 1990). However, the value of a more passive memory process is that text integration can occur at low cost to processing resources, and this may be the default integration processing mode within and across sentences.

It is not completely clear whether immediate updating of the situation model is sufficient to protect comprehension from the intrusion of no-longer relevant information (O'Brien et al., 2010; Zwaan & Madden, 2004). This issue may not matter much for word-to-text integration in short texts (e.g., ~2 sentences). This is because the relevant memory traces have been established just prior to the word to be read (although across a sentence boundary) and there is not much contradictory discarded information to produce interference. However, with longer stretches of text to contribute more information in memory, interference may be more likely. This is an active area of research in our lab.

There is an advantage of localizing a small part of the comprehension process for theoretical focus within the Reading Systems Framework: It allows a tractable number of comprehension processes to be considered. Here is the minimum set of the overlapping processes required for fluent word-to-text integration.

1. Rapid, automatic lexical access based on word form;
2. Rapid, automatic activation of associated knowledge from memory;
3. Access to memory for recently read text at the level of text model, situation model, or both;
4. Knowledge of context-relevant meaning associated with the lexical entry and its rapid retrieval; and
5. Word-to-text integration resulting from the overlapping of these processes.

For an expert reader with knowledge of word meanings and sufficient experience, these are not effortful processes. Indeed, each overlapping phase of integration can be executed with minimal resource demands, approaching automaticity. These processes can be modeled through word activation networks with feedback from semantics and memories for recently read text segments. To perform robustly over text variations, models would need to include syntactic processes, which are usually ignored in text comprehension models. The point is that the basics of a testable theory that assumes individual differences in word-to-text integration processes arise from lexical knowledge. Alternative hypotheses can be tested, for example, that such comprehension skill differences arise from memory limitations or word identification processes that are resource demanding. Furthermore, one can examine the deeper question of whether sluggish word-to-text integration (Perfetti et al., 2008) propagates upward to the higher levels, and thus helps to explain retention and higher level as well as lower level comprehension problems.

Conclusion

Theories (or more accurately, frameworks) of reading comprehension have moved from ideas of broad scope to more specifically targeted aspects of the overall problem of comprehension. This has allowed progress in the study of components of comprehension, from the role of memory, the use of inferences, and the updating of mental models. We reintroduced a wide-angle framework that makes central the role of the lexicon, a somewhat neglected component in text comprehension research. The Reading Systems Framework represents the broad set of knowledge sources, and processes that act on these knowledge sources, allowing researchers to examine specific systems and subsystems and the interactions among them.

Within this framework, we target a seemingly small yet central and recurring comprehension process, the integration of the currently read word into a mental structure that represents the current understanding of the text (the situation model). These word-to-text integration processes allow readers to continuously tune and update their current understanding. The paraphrase effect reflects a text integration process that is initiated by reading a word whose activated meanings include one that is congruent with the current model of the text, and thus can be integrated into that model. The lexical nature of this process distinguishes it from other integrating processes, such as bridging inferences, which also allow updating and keep the text coherent but at some cost to processing effort.

Individual differences in reading comprehension are seen during these word-to-text processes, specifically in the lexically driven paraphrase effect. This fact invites closer examination of whether subtle differences in knowledge of word meanings or the conditions of word use might affect word-to-text integration, as well as more global measures of comprehension. The general relationships between global comprehension skill and vocabulary and between comprehension skill and new word learning also suggest this possibility. Additionally, less skilled readers may require more bridging inferences compared to skilled readers more fluid, incremental word-to-text integration processes. These questions can be addressed through additional assessment and the development of new text and discourse stimuli.

Finally, research should continue to probe the on-line nature of text and discourse processes, using methods that allow for word level measurement and analysis. Theoretically, our argument entails a closer view, within the Reading Systems Framework, of the interaction between the word identification system and the comprehension system that is mediated by lexical knowledge and manifest in word meaning processing.

Acknowledgments

Research discussed in this article was supported by NICHD award R01HD058566–02 to the University of Pittsburgh, Charles Perfetti, PI. We graciously acknowledge the helpful reviewers of Perfetti and Stafura (2014), who greatly improved that manuscript through their critiques and comments, and, therefore, this chapter.

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