8

FROM VERBAL EFFICIENCY THEORY TO LEXICAL QUALITY

The Role of Memory Processes in Reading Comprehension

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With the publication of *Reading Ability* in 1985, Charles Perfetti set out a clear framework for describing the complex interactions between lower "word-level" processing and higher "sentence-level" and "text-level" processes, which he referred to collectively as the "text work" of the reader. The Verbal Efficiency Theory is built around the idea that the ease with which a reader can perform this text work depends on the extent to which these individual subprocesses are efficient. There is an important caveat to this simple conceptualization, however: some subprocesses are more amenable to becoming efficient, or automatic, than others. Thus, Perfetti writes that "text work is made easier to the extent that those processes which *can* be at high efficiency *are* at high efficiency" (1985, p. 104; emphasis in original). He suggested that the most likely candidates for automatization are lexical access and elementary propositional encoding (i.e., assembling a single proposition from a few words). Processes that, he suggested, would be more resistant to automatization are those that rely more on memory (e.g., integrating propositions across clauses, inference processes that require reference resolution across distances, and linking text models with previously known world knowledge). Consequently, a clear understanding of the memory mechanisms that support reading comprehension is crucial to understanding reading ability. This chapter will explore two contrasting conceptualizations of memory, both of which have been discussed in Perfetti's writings. One suggests that memory capacity creates a "bottleneck" that constrains reading ability, while the other suggests that memory capacity is not at all an issue for reading ability, but rather it is the quality of to-be-retrieved representations that most constrains the efficiency of memory processes in reading. We show how the lexical quality hypothesis, which Perfetti has emphasized in recent writings (Perfetti, 2007; Perfetti & Hart, 2001, 2002), provides a means for reconciling these two seemingly contradictory approaches, leading to a better understanding of the deep relationship between word-level abilities and the higher-level processes necessary for reading comprehension.

The Bottleneck in Reading Comprehension

The notion that memory *capacity* constitutes a limit on reading and spoken-language comprehension has had a tremendous impact on studies of reading ability and especially as an explanation for poor reading comprehension. The fact that grammatical and referential dependencies are often non-adjacent, sometimes separated by clauses or entire sentences, provides compelling support for this approach. The oft-replicated finding is that sentences in which grammatical heads are separated from their dependents are more difficult to process than those with heads that are adjacent (see Grodner & Gibson, 2005; McElree, Foraker, & Dyer, 2003). This is true of unambiguous sentences like (1) and (2), as well as temporarily ambiguous sentences like (3) and (4); in both cases, the shorter sentence is more easily processed than the longer one.

(1) The *book ripped*.
(2) The *book* that the editor admired *ripped*.
(3) The boy understood the *man was afraid*.
(4) The boy understood the *man* who was swimming near the dock *was afraid*.

Similar results are observed at the discourse level, where anaphoric reference and inferencing are easier when associated information is close by in the text (e.g., Daneman & Carpenter, 1980; Duffy & Rayner, 1990; Long & Chong, 2001; Wiley & Myers, 2003). The standard account of these effects is that the distal constituent (e.g., the grammatical subjects *book* and *man* in examples 1–5) cannot be actively maintained while processing the intervening material because doing so exceeds the comprehenders' processing capacity (e.g., Gibson, 1998; Just & Carpenter, 1992; Wanner & Maratsos, 1978). Inattention to necessary constituents is claimed to result in them becoming inaccessible, due to decay. Thus, as the distance between the distal constituent and its associated dependent increases, so does comprehension difficulty, because more information will be lost and the likelihood that the distal constituent in particular will be displaced is greatly increased. That is precisely why Perfetti (1985) pointed to *local* processes (i.e., lexical access and simple proposition processing) as the kinds of processes that *could* be automatized. The seeming inevitability that long-distance integrative processes will consume memory resources led Perfetti in an early paper with Alan Lesgold (1979) to refer to working memory (WM) capacity as a "bottleneck" in comprehension: these operations require substantial memory resources, and if any lower-level processes also require expenditure of major resources, then the system can only grind to a halt.

Against the backdrop of the predominant (then and now) Working Memory model (Baddeley, 2003; Baddeley & Hitch, 1974), it must be acknowledged that this bottleneck concept has strong intuitive appeal. The Baddeley model elevated the role of *capacity* as central to memory access, with three fixed-capacity "slave" systems that store phonological information (the "phonological loop"), visuo-spatial information (the "visuo-spatial sketchpad"), and integrated episodic information; these are coordinated via a separate executive control mechanism, which is responsible for directing attention during task completion and managing encoding and retrieval processes.[1] Although this model was originally developed to account for experimental findings arising out of memory recall paradigms, where participants' task is to remember lists of words (or patterns of objects) in the face of a variety of distracting conditions (e.g., Baddeley, 1966; Conrad, 1964; Murray, 1968; Wickelgren, 1965), it has dominated the conceptual vocabulary of the study of comprehension difficulties. A large body of research has sought to demonstrate that sentence comprehension suffers when capacity is reduced either by experimental means through the use of dual-task procedures (e.g., Gordon, Hendrick, & Levine, 2002; Fedorenko, Gibson, & Rohde, 2006, 2007) or through participant selection, as in participants who score poorly on tests of working memory capacity compared with those who do well. For example, King and Just (1991) found that college-level readers with "low" working memory capacity (as measured by the Reading Span test,[2] Daneman & Carpenter, 1980) showed poorer comprehension and slower reading times on syntactically complex sentences than those with "high" or "middle" capacity levels. Similarly, MacDonald, Just, and Carpenter (1992) found that low-capacity individuals from the same population had more difficulty interpreting temporarily ambiguous constructions than those with larger capacities. They suggested that a larger working memory capacity enabled "high-span" readers to maintain all possible interpretations longer, while the smaller capacity readers could only maintain the most likely interpretation. In cases where the ultimately correct interpretation was not the most likely one, they argued that low-capacity readers would fail to comprehend because the correct interpretation had been "pushed out" of memory. Similar arguments have been made at the discourse level, focusing on reduced memory capacity as an explanation for why certain types of inferences are not generated (e.g., St. George, Mannes, & Hoffman, 1997).

Studies of reading development also point to an association between low working memory capacity and poor comprehension. In a longitudinal study of children with normal word-level (i.e., decoding) skills, Oakhill, Cain, and Bryant (2003) found that working memory capacity predicted significant independent variance on standardized measures of reading comprehension at age 7–8, and again one year later. Further, Nation, Adams, Bowyer-Crane, and

Snowling (1999) found that 10–11-year-old poor comprehenders had significantly smaller verbal working memory capacity (though not spatial working memory capacity) than normal children matched for age, decoding skill, and nonverbal abilities. Likewise, reading disabled children have been found to score in the lowest range on tests of working memory capacity (e.g., Brady, 1991; Gathercole, Alloway, Willis, & Adams, 2006; Swanson & Sachse-Lee, 2001), and these scores are significant predictors of standardized measures of both reading and mathematics attainment.

How Memory Supports Comprehension: An Alternative View

While the impact of the Working Memory model on the study of language processing is undeniable, a close examination of the Baddeley model reveals that it is not well matched to the functional demands of language comprehension (e.g., Ericsson & Kintsch, 1995; for a review, see Van Dyke & Johns, 2012). More importantly, recent research suggests that a very different sort of memory architecture supports language comprehension. This alternative approach follows the tradition of research challenging the view that WM is a fully separate, independent system from long-term memory (LTM), favoring instead a unitary-store model where information that multi-store models would assign to working (or short-term) memory is characterized as just the temporarily active portion of LTM (e.g., Anderson et al., 2004; Crowder, 1976; Cowan, 2001, 2006; Ericsson & Kintsch, 1995; McElree, 2001, 2006; Oberauer, 2002; Verhaeghen, Cerella, & Basak, 2004). While these models differ in a variety of details, they all suggest that there is only one representation of known information—that in long-term (or passive) memory.[3] Memory representations will vary in activation strength, with more activated representations available for retrieval when required; however, they remain in passive memory until such retrievals occur.

One type of evidence in support of a unitary-store architecture comes from precise measures of retrieval speed. In a two-store scenario, information in WM should have a privileged status compared to that in LTM, and so should be accessed more quickly. Based on this reasoning, it would be expected to find a faster speed for accessing the items that do not need to be retrieved (i.e., that are in the current focus of attention), as compared with those that must be retrieved from WM (i.e., where they are being "actively maintained"). A further contrast is expected between the speed for accessing items in WM and those in LTM, because the privileged status of the former makes them more available for retrieval. This is not the pattern that has been observed, however. As reviewed in McElree (2006), direct measures of the speed and accuracy of memory retrieval across a broad range of tasks requiring the retention of sequentially presented information consistently show that items predicted to be within WM span do *not* exhibit privileged access, but instead are retrieved with the same speed as items that are well beyond the furthest limits of WM capacity. The only speed difference that is observed is that between the information within the current focus of attention—usually only the single most recently processed item—and all other items, with responses to the focal item being 30–50% faster than responses to those outside focal attention. These findings are also consistent with a number of other studies which point to an active memory span of 1–4 items in both the verbal and spatial domains (cf. Cowan, 2001, for a detailed review).

The implications of these results for studies of reading comprehension, and especially poor comprehension, are significant. They suggest that the actual size of active memory is quite small—even for college-level readers, on whom the research described above was conducted. While conceptualizing comprehension with such a severely limited working memory span may seem difficult, the plausibility of such a system has been shown both empirically and computationally. Relevant evidence comes from the repeatedly noted (and quite puzzling) finding from research on aphasia, attesting that patients with severely limited working memory spans (2–3 items) may nevertheless show preserved comprehension of complex grammatical constructions (e.g., Caplan & Hildebrandt, 1988; Caplan & Waters, 1999; Martin & Feher, 1990). Computational evidence comes from a model of language comprehension implemented in ACT-R and described in Lewis, Vasishth, and Van Dyke (2006; cf. Lewis & Vasishth, 2005), which requires maintaining only the most recently parsed item in active memory. The model's memory consists of chunks representing the syntactic structure built so far, together with predictions for constituents licensed by the current state of the parse. These chunks are not actively held in memory and decay as a function of time and prior retrievals. The only access to these items is via a retrieval buffer which can hold only a single chunk at a time. This affords the model the minimum capacity required to create new linguistic relations—the item waiting to be integrated into the parse, and the chunk that licenses it.[4] The item that is waiting is in the focus of attention and does not need to be retrieved. The licensor is retrieved via the cues derived from the features of the waiting item. Critically, it is this cue-based retrieval process, which occurs via direct access, that provides the computational power necessary to create dependencies in real time. In this type of retrieval process, memory representations are "content-addressable," enabling cues in the retrieval context to make direct contact to representations with overlapping content, without the need to search through irrelevant representations. Mathematical analyses of reaction-time distributions (Ratcliff, 1978) and evidence from the Speed–Accuracy Tradeoff (SAT) paradigm (McElree, 2001) suggest that humans can restore items into active memory in approximately 80–90 ms. Retrieval speeds that are this fast enable the parsing mechanism to compensate for the severe limit on the size of active memory, while still enabling parsing decisions to be made in ~200 ms, which is typical of real-time language processing. Hence, for a retrieval-based processing architecture, memory *capacity* becomes much less relevant; if retrieval occurs via a cue-based direct-access mechanism, it is not necessary to maintain information in active memory in the way that it would be if retrieval involved a search through active representations. Of more importance are the factors that contribute to the retrieval success; namely, how well the cues available at retrieval can uniquely identify to-be-retrieved information.

Long before the presence of direct-access retrieval in sentence processing was established, Perfetti and Lesgold (1979) foreshadowed the possibility that differences in working memory capacity may *not* be at the core of individual differences in reading comprehension. They wrote:

> If some of the components of the reading process are ballistic (i.e., not requiring attention once they are initiated), there will be less working memory congestion. In our view, skilled reading does not imply a larger working memory capacity but rather, a more effective use of this capacity. (p. 59)

A direct-access, cue-based retrieval mechanism is just the sort of "ballistic process" Perfetti and Lesgold described, giving automatic access to distal constituents required to create meaning without appealing to working memory. The presence of fast, automatic retrieval raises the possibility that more of the subprocesses of comprehension could be moved into the class of those which *can* be automatized. Indeed, there are models of discourse processing that already incorporate direct-access retrieval processes (e.g., Gerrig & McKoon, 2001; Myers & O'Brien, 1998; O'Brien, Rizzella, Albrecht, & Halleran, 1998), and the fact that direct access occurs at the lexical, sentential, and intrasentential level makes it a strong candidate for a determining comprehension ability.

An Alternative Explanation for Comprehension Difficulty

The above discussion suggests that memory capacity, per se, may not be an insurmountable bottleneck to comprehension, since it is the presence of a highly efficient retrieval mechanism that determines whether inactive information will be available at the time it is needed. An important caveat is in order, however. Even if such a retrieval mechanism were available at all levels of textwork—from local propositions to long-distance grammatical dependencies, to integrative inferencing between propositions—such a system would still be highly susceptible to comprehension failure. This is because direct access is only successful when the cues available to initiate and guide retrieval are sufficiently discriminating to identify the correct constituent, *and no other*. When this is not the case, cues are said to be *overloaded* (Watkins & Watkins, 1975) because a single cue is associated with multiple items in memory, each of which creates *interference* because the probability that the correct item will be identified via that cue is reduced. Such interference effects have been widely studied in the memory domain, and have more recently been shown in sentence comprehension (see Van Dyke & Johns, 2012, for a comprehensive review). For example, in a study using the Speed–Accuracy Tradeoff methodology, Van Dyke and McElree (2011) found that the number of interfering distractors did *not* affect the speed of retrieval, which is consistent with the use of a content-addressable direct-access mechanism. However, adding just a single additional distractor that matched the target on semantic and syntactic dimensions significantly reduced the probability of accessing the target (see also Van Dyke, 2007). This suggests that similar representations can have a detrimental affect on each other, and is consistent with a number of models suggesting that interference occurs when features are *overwritten* (e.g., Nairne, 1990; Oberauer & Kliegl, 2006), resulting in lower dimensional representations.

Lexical Quality

In the 25 years since the publication of *Reading Ability*, Perfetti has consistently stressed the importance of making the subprocesses of textwork efficient, so that the various types of information necessary for creating text meaning will be available *at the right time* to be integrated into a comprehensive mental model. Yet his more recent writings (e.g., Frishkoff, Perfetti, & Collins-Thompson, 2011; Perfetti, 2007; Perfetti & Hart, 2002; Perfetti, Yang, & Schmalhofer, 2008) have not emphasized the connection between efficiency and reducing the bottleneck in comprehension, but rather the role of *high-quality* lexical representations. For example, he writes:

> the thing to understand is not [word-reading] speed but rather the ability to retrieve word identities that provide the meanings the reader needs in a given context. The source of this ability is the knowledge a reader has about . . . specific lexical representations.
>
> (Perfetti, 2007, p. 359)

This focus is entirely consistent with the alternative approach described above; that is, whether a content-addressable retrieval mechanism will succeed at restoring information *when it is needed* is wholly dependent on how well individual lexical items can be discriminated in memory. Perfetti (2007) describes poor-quality representations as those with orthographic representations that are not fully specified (some letters are not represented); phonological representations characterized by variable grapheme–phoneme phonology; and semantic representations with fewer meaning dimensions. Taken together, this means that weak lexical representations have a lower-dimensional feature structure, in which important discriminations among orthographic, phonologic, and/or semantic items are unavailable—and which may turn out to be crucial for distinguishing among similar lexical representations. Moreover, the activation of such low-dimensional representations may result in spurious activations of irrelevant information—essentially adding noise to ongoing processing—which arises from overlap of the irrelevant information with the inexact orthography, phonology, morphology, or semantics. Thus, the clear prediction is that individuals with a high proportion of low-quality lexical representations will be more susceptible to interference effects.

Evidence for such a relationship has been noted by Gernsbacher and colleagues (e.g., Gernsbacher, 1990; Gernsbacher & Faust, 1991, 1995; see also Long, Oppy, & Seely, 1999), who showed that poor readers were less able than skilled readers to inhibit the context-irrelevant meanings of ambiguous words during sentence comprehension. Further evidence comes from a recent study by Van Dyke, Johns, and Kukona (2010), which examined how well participants can make basic grammatical associations (i.e., to relate a displaced object with its verb). Following on an earlier study by Van Dyke and McElree (2006) that examined retrieval interference in skilled readers, Van Dyke et al. (2010) investigated individual differences in a community-based sample of young adult readers which encompassed large differences in reading skill. Participants read sentences of the form, *It was the boat that the guy who lived by the sea sailed after two sunny days*. There were two key manipulations. First, a memory load was either absent or present. In the load condition, participants memorized a list of three words (e.g., *table–sink–truck*) prior to reading the sentence. To ensure that they attended to the sentence, they received a comprehension question directly afterwards; to ensure that they attended to the memory list, they received a recall test after the comprehension question. The second manipulation varied the semantic cues available at retrieval. This was accomplished by substituting the word "fixed" for "sailed" in the sentence quoted above. The "fixed" condition was an interfering condition, because the items in the memory list are all "fixable" while in the "sailed" condition, the memory list words will not compete with the "boat" in the sentence because they are not "sail-able." The original Van Dyke and McElree (2006) study, conducted with college students who were presumably skilled readers, found that participants had more difficulty reading the verb in the interfering (fixed) condition than in the non-interfering (sailed) condition, an effect which disappeared when there was no memory load present. This result attests to interference effects from the items in the memory list. The version of this study which was conducted with a less-skilled non-university sample replicated the original result, finding that comprehension scores were impaired in the interfering condition; we also found that readers with high sensitivity to interference also scored poorly on a number of reading ability related measures, including indices of decoding ability, phonological processing, simple memory span, listening span, rapid naming, vocabulary knowledge, reading fluency, and spoken language ability, all of which had very high intercorrelations. In an attempt to achieve some additional insight into the source of these interference effects, Van Dyke and colleagues conducted analyses partialling out variance shared between the battery measures and participants' general cognitive ability (indexed by IQ), and found that only a single measure—receptive vocabulary—predicted comprehension performance. This is consistent with other recent research focusing on vocabulary knowledge as key determinants of both online sentence processing (e.g., of syntactic ambiguity resolution; Traxler & Tooley, 2007) and in assessments of reading comprehension ability (Braze, Tabor, Shankweiler, & Mencl, 2007). In addition, it raises the possibility that previous studies pointing to working memory capacity as a causal factor in poor comprehension may have been misled by the use of a single individual differences measure (i.e., complex span measures; Daneman & Carpenter, 1980; Turner & Engle, 1989). Indeed, a number of researchers have discussed difficulties related to interpreting these tasks, due to their high correlation with other cognitive abilities, including vocabulary, grammar knowledge, phoneme deletion, monitoring, and fluency (e.g., Alloway, Gathercole, Willis, & Adams, 2004; Cormier & Dea, 1997; Oakhill et al., 2003; Oberauer, Schulze, Wilhelm, & Suss, 2005; Tunmer & Hoover, 1992).

The Bottleneck in Reading Comprehension Revisited

In light of the evidence suggesting that active memory is severely limited, even for skilled readers, we argued that a formulation of the comprehension bottleneck that emphasizes capacity differences is incorrect. This conclusion was based on two lines of argument. The first was about architecture, appealing to criticisms of the idea of a separable short-term memory store, a conception that is integral to classical notions of working memory. The second argument was about the locus of individual differences: since the number of items that can be held in active memory is apparently severely limited for everyone, capacity differences, as such, cannot reasonably be invoked to explain the large individual differences that exist in reading comprehension performance. Rather, differences in *retrieval success* are responsible for comprehension variability, bringing us back full circle to Perfetti's (1985) emphasis on the *efficiency* of reading processes. Although it is not entirely accurate to suggest that inefficient *retrieval* creates a bottleneck, since direct access itself is entirely automatic when the right retrieval cues are present, the presence of interference points to a different kind of bottleneck—one arising due to the absence of sufficiently detailed (high-dimensional) lexical representations, and the presence of poor-quality, noisy representations. This view is entirely consistent with Perfetti's more recent suggestion (2007, 2011) that poor efficiency may ultimately arise from deficiencies in various aspects of lexical knowledge.

Thus, the immediate question is how these high-dimensional representations are acquired. The simple answer is that they are the result of wide-ranging experience with the language (e.g., MacDonald & Christiansen, 2002). The more complete answer is that acquiring these representations is ultimately a problem of perceptual learning—comprehenders must be able to distinguish and encode critical phonological, orthographic, syntactic, and semantic dimensions in order for those dimensions to become instantiated in memory and later serve as retrieval cues. Hence, the problem of acquiring high-dimensional representations goes hand in hand with the ability to skillfully use linguistic cues during retrieval. For example, a child who incorrectly perceives the aspirated and inaspirated variants [p] and [ph] (as in the words "pat" and "spat") as categorically separate will have difficulty assigning both to the same graphic symbol "P," and this confusion will have implications for the lexical representation as a whole, especially resulting in impoverished orthographic representations. Related difficulties have been observed in some dyslexic readers, who were less able to distinguish linguistically relevant and irrelevant phonetic distinctions compared to age-matched reading-level controls (e.g., Bogliotti, Serniclaes, Messaoud-Galusi, & Sprenger-Charolles, 2008; Goswami, Fosker, Huss, Mead, & Szücs, 2011). At the sentence and discourse level, readers with low working memory capacity have difficulty noticing and using syntactic, referential, and contextual cues, leading to lower-quality discourse representations even when the necessary information is explicitly available (Linderholm & van den Broek, 2002; Long & Prat, 2008; Nieuwland & Van Berkum, 2006). Thus, an important direction for future research is to understand how poor reading ability relates to deficient use of linguistic cues during retrieval, and how this relates to poor-quality lexical representations. There is already evidence suggesting that skilled readers weigh syntactic information more heavily than semantic information when assembling retrieval cues, and this helps readers to resist interference (Van Dyke & McElree, 2011). Further research should investigate how differential weighting schemes for cues associated with other components of lexical representations (e.g., phonology, morphology, semantics) may relate to the ability to withstand interference caused by low-dimensional representations.

One aspect of linguistic knowledge of particular relevance for a would-be reader is phonology. Researchers at Haskins Laboratories have long argued that phonological cues enjoy special status, derived from the more elemental process of speech (Liberman, Mattingly, & Turvey, 1972; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). Reading taps directly into sound-based phonologic representations: a skilled reader naturally converts the visual orthographic patterns into a representation based on the sounds of speech whether reading aloud or silently. When letters or words are presented visually it is hypothetically possible to retain the alphabetic shapes as visual forms, but this seems not to happen—information can apparently be stored efficiently only in phonetic form. At the same time, it is also known that more permanent storage of linguistic material is neither visual (orthographic) nor phonetic, but predominantly in semantic form. Phonetic form must therefore be seen as a fundamental bridge between perceptual input processes and the creation of deeper, enduring semantic representations. Indeed the primacy of phonetic form led the second author to suggest that the bottleneck for comprehension is acutely phonological (e.g., Crain & Shankweiler, 1988; Shankweiler, 1989).[5] In terms of our new conceptualization of the bottleneck in comprehension as related to efficient retrieval, it is important to investigate whether phonological cues serve as an especially powerful force in mediating interference. This could arise by virtue of their ability to distinguish the most recently encountered linguistic information from that already in memory, thus preserving (even if briefly) order information which would otherwise have been lost.

A number of empirical studies do in fact point to a direct effect of phonology, which is essentially a word-level phenomenon, at the sentence level. For example, McCutchen, Bell, France, and Perfetti (1991) found longer sentence acceptability times when readers were presented with sentences containing phonologically overlapping words (e.g., *The taxis delivered the tourists directly to the tavern*) as compared with semantically matched controls (e.g., *The cabs hauled the visitors straight to the restaurant*). More recently, Acheson and MacDonald (2011) found that phonological similarity within a relative clause (e.g., *The baker that the banker sought bought the house*) produced slower reading times and increased errors in comprehension questions compared to when overlap was not present (e.g., *The runner that the banker feared bought the house*). These results point to interference effects at the phonological level, even for skilled readers, perhaps because of insufficient apprehension of the temporal order of these confusable elements (Katz, Shankweiler, & Liberman, 1981), making it difficult to properly use syntactic and semantic cues to assign appropriate relationships within the sentence. For poor readers, the situation may be even more pervasive than these experimentally contrived examples would suggest, due to the preponderance of weak and unstable orthographic representations (Katz & Frost, 2001; Shankweiler & Crain, 1986). Thus, in a framework that considers the historical focus on a phonologically based working memory capacity to be largely misplaced, phonological abilities may nevertheless remain as among the most important determinants of higher-level comprehension processes.

Conclusion

Surely the test of any scientific theory is how well it holds up over time. On this 25th anniversary of the publication of *Reading Ability*, the present authors are grateful for the opportunity to (re-)read some of Perfetti's older work—even that pre-dating *Reading Ability*, which surely served as a starting point for the latter publication, as well as his more recent work. As we hope this chapter shows, Perfetti's thinking about memory processes even 35 years ago was very much on target. While the work establishing the role of content-addressable retrieval and interference as memory mechanisms that determine language comprehension is comparatively recent, these developments are quite consonant with the framework Perfetti presented in his Verbal Efficiency Theory, and continues to extend via his lexical quality hypothesis. The recent emphasis on lexical quality in particular is an important development that we believe will lead to a greater understanding of the cognitive architecture that supports language processes at all levels, and a novel approach to investigating comprehension ability and disability. We look forward to many more years of fruitful collaboration with Chuck, in which we will continue to benefit from his clear thinking and far-seeing insights on the nature of Reading Ability.

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Notes

1 The original Working Memory model contained only two slave systems (the phonological loop and the visuo-spatial sketchpad). The episodic system was added more recently (Baddeley, 2000) in order to provide a workspace for integrating different types of information and to provide a buffer in which information from long-term memory could interact with that stored within the slave systems.

2 It is notable that the Daneman and Carpenter span task, in which participants must process sentences while simultaneously maintaining a list of words in memory, mirrors the functional demand of processing complex linguistic constructions (e.g., long-distance dependencies) mentioned above, where substantial information is situated between two linguistic constituents that must be associated.

3 This does not imply the existence of only one kind of memory; on the contrary, neurophysiological studies find separate circuits for declarative memory and procedural memory. Moreover, the process of consolidation exploits distinct neural structures separate from those dedicated to storage (Milner, Squire, & Kandel, 1998).

4 For example, in the sentence *The boy who was waiting on the corner shouted*, the noun phrase *the boy* is the licensor for the upcoming verb *shouted*.

5 Like Perfetti's Verbal Efficiency Theory, discussion of the Phonological Bottleneck Hypothesis in the cited publications was also against a backdrop of a working memory system emphasizing capacity. However, in light of the more recent findings summarized here, it seems prudent to emphasize the notion of *memory codes*, rather than capacity, as a modulating factor for comprehension. Notably, Perfetti (1985) and Perfetti and Lesgold (1979) also gave explicit attention to the role of memory codes—and particularly their phonological nature—as a limiting factor for efficient lexical access.

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