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Reading Ability: Lexical Quality to Comprehension

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The lexical quality hypothesis (LQH) claims that variation in the quality of word representations has consequences for reading skill, including comprehension. High lexical quality includes well-specified and partly redundant representations of form (orthography and phonology) and flexible representations of meaning, allowing for rapid and reliable meaning retrieval. Low-quality representations lead to specific word-related problems in comprehension. Six lines of research on adult readers demonstrate some of the implications of the LQH. First, large-scale correlational results show the general interdependence of comprehension and lexical skill while identifying disassociations that allow focus on comprehension-specific skill. Second, word-level semantic processing studies show comprehension skill differences in the time course of form-meaning confusions. Studies of rare vocabulary learning using event-related potentials (ERPs) show that, third, skilled comprehenders learn new words more effectively and show stronger ERP indicators for memory of the word learning event and, fourth, suggest skill differences in the stability of orthographic representations. Fifth, ERP markers show comprehension skill differences in meaning processing of ordinary words. Finally, in text reading, ERP results demonstrate momentary difficulties for low-skill comprehenders in integrating a word with the prior text. The studies provide evidence that word-level knowledge has consequences for word meaning processes in comprehension.

In reading, the singular recurring cognitive activity is the identification of words. From this follow two other, related observations about reading: Comprehension depends on successful word reading. Skill differences in comprehension can arise from skill differences in word reading.

These simple observations form the core of a theory of comprehension skill published over 20 years ago (Perfetti, 1985). Verbal efficiency theory claimed that

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word identification, the rapid retrieval of a word's phonology and meaning, was a limiting factor in comprehension. I referred to these cognitive events of word identification as "retrievals" because they operated on information about a word stored in a reader's orthographically addressable memory. But at the heart of word identification were the phonological procedures that allowed a word (or a nonword) to be decoded, whether or not meaning was also retrieved. The theory assumed the ability to decode nonwords was the hallmark of basic alphabetic reading skill. In fact, phonology was important enough in this account that it had redundant participation. Phonology was both stored as part of the word (and thus retrieved during identification) and generated by connections among subword units that were part of the word. This conceptualization was explicit in the Restricted Interactive Model, which focused on the development with experience of specific and redundant sublexical components suggested in Perfetti (1992).

In the theory, the link from word-level reading to comprehension was through the assumption that comprehension included higher level processes that required cognitive resources (working memory), for example, integrative processes, inferences, syntactic repairs. Word identification, and certainly the sublexical processes that produce it, were candidates for low-resource or automatic processes (LaBerge & Samuels, 1974) that could preserve processing resources for higher level comprehension. Automatic, resource-cheap word-level processes—verbal efficiency —were assumed to support comprehension. Children who have this efficiency would be able to achieve high levels of comprehension, and children with inefficient word-level processes would have problems with comprehension. The research showing correlations between children's decoding skill and comprehension was consistent with this account. Furthermore, there is no reason to suppose that this relationship disappears for older readers (Shankweiler et al., 1999).

This general account continues to seem correct to me. However, I think its emphasis on completely general processes—decoding, phonological processes, retrieval, memory, automaticity—although theoretically consistent, seemed to leave knowledge out of the picture. Skilled reading was about efficient processing mechanisms and less skilled reading was about these same mechanisms executed inefficiently. This description seemed to predict that becoming faster at word identification leads to better comprehension. Inefficient readers can indeed become more efficient (Breznitz & Share, 1992), and improving individual word reading speed may increase fluency (Martin-Chang & Levy, 2005) and, under some circumstances, comprehension (Breznitz & Share, 1992; Tan & Nicholson, 1997). However, increasing decoding speed by itself has not always increased comprehension (Fleisher, Jenkins, & Pany, 1979; Perfetti, 1985). Overall, although the hypothesis that training word-reading speed raises comprehension has some research support, it is not the primary practical implication of the general idea that comprehension depends on efficient word reading.

Efficiency is not the same as speed. Efficiency is a ratio of outcome to effort, with time as a proxy for effort. So although processing descriptions make a coherent framework for efficiency, they leave out the basic nature and source of the word reading outcomes on which efficiency depends. These outcomes are word identities that momentarily represent form and meaning components that are the basic elements of comprehension. On this description, the thing to understand is not speed but rather the ability to retrieve word identities that provide the meanings the reader needs in a given context. This source of this ability is the knowledge a reader has about words, specific lexical representations.

LEXICAL QUALITY

Underlying efficient processes are knowledge components; knowledge about word forms (grammatical class, spellings and pronunciations) and meanings. Add effective practice (reading experience) of these knowledge components, and the result is efficiency: the rapid, low-resource retrieval of a word identity. Lexical quality (LQ) refers to the extent to which the reader's knowledge of a given word represents the word's form and meaning constituents and knowledge of word use that combines meaning with pragmatic features. Thus the vocabulary of a given language includes, for a given reader, words of widely varying LQ, from rare words never encountered to frequently encountered and well-known words. Likewise, individual readers differ in the average LQ of their words. This reader variability is not just about the size of vocabulary, although it includes this; it is about the representation of words, the stable and less stable knowledge the reader has about the word's form and meaning.

Of course, the question becomes what is "quality," a word that could evoke suspicion without some definition. Quality is the extent to which a mental representation of a word specifies its form and meaning components in a way that is both precise and flexible. The precision is needed because "*pretty* and *petty*" and "*knight* and *night*" are not the same. The flexibility is needed because the meanings of "roaming charge" and "a fee charged by a mobile phone service for calls initiated or received outside a contracted service area" *are* the same. Both precision and flexibility are needed to understand and pronounce *record* in "You need a *record* of the transaction" and "They can't *record* the conversation." These simple examples are just the tip of the iceberg of form-meaning complexities. LQ provides a means for safe passage through them. Earlier chapters (Perfetti & Hart, 2001, 2002) contain additional examples and theoretical discussions of LQ.

One way to become more specific about LQ is to identify the features that we hypothesize to distinguish higher quality from lower quality representations. Table 1 does this. It identifies five features of lexical representation that distinguish high and low quality and shows three (there may be more) hypothesized consequences of

TABLE 1
Properties and Consequences of Lexical Quality

Representational Properties of Lexicon	*High Quality*	*Low Quality*
Orthography	Fully specified; letters are constants	Not fully specified; some letters are variables
Phonology	Redundant word-specific phonology and context-sensitive grapheme-phoneme phonology	Less stable because of variable word-specific phonology and/ or grapheme-phoneme phonology
Grammar	All grammatical classes of the word represented; morpho-syntactic inflections represented	Incomplete range of form class uses; less stable morpho-syntax
Meaning	More generalized, less context-bound; fuller range of meaning dimensions to discriminate among words in same semantic field.	More context bound; fewer relevant meaning dimensions to discriminate among related words
Constituent binding	Orthographic, phonological, and semantic constituents are tightly bound	Orthographic, phonological, and semantic constituents are less tightly bound
Possible processing consequences during reading		
Stability	Higher; word identity is reliably retrieved from an orthographic or phonological input	Lower; word identity is sometimes not retrieved from an orthographic or phonological input
Synchronicity	Word identity constituents are activated and retrieved in synchrony as a word identity	Word constituents may be activated and retrieved asynchronously; (e.g. labored decoding; activation of incorrect meanings from partial input)
Meaning integration	Higher; word identities available for building comprehension	Lower; comprehension processes that operate over word identities at risk

these quality features for reading processes. The representational features are the four constituents of word identity—orthography, phonology, morpho-syntax, and meaning. The fifth representation feature is constituent binding, the degree to which the first four features are bound together (especially the first three; the grammatical feature might be considered to be implemented by a grammatical process that operates on the lexeme). Bindings are connections that secure coherence among the constituents, the orthographic, phonological, and semantic representations, which together are the word's identity. The binding feature is not independent but rather a consequence of the orthographic, phonological and semantic constituents becoming well specified in association with another constituent.

The consequences of high quality in sublexical and lexical knowledge are also shown in Table 1. These are hypothesized consequences that are subject to empirical testing, and some have at least indirect evidence. For example, the hypothesis that low LQ can lead to the asynchronous activation of word constituents is consistent with results of Breznitz and Misra (2003), who found that ERP indicators of orthography and phonology for low-skill reading were more asynchronous than those of skilled readers. More generally, reading words in context is affected by LQ, providing the important hypothesized link between LQ and comprehension (Perfetti & Hart, 2001). The general description of this link is that local processes of integrating word meanings within and across sentence boundaries are affected by the LQ of words that are identified as part of the comprehension process. One final observation concerns the difference between a spoken and written word. My focus is on reading, and for that orthography is part of LQ. However, a lexical analysis can be applied to just spoken language with a focus on phonological representations and meaning.

WORD PROCESSING, WORD LEARNING, AND COMPREHENSION STUDIES

With this background on the general nature of the LQ hypothesis (LQH) and its links to the process-oriented account of verbal efficiency, I turn now to a review of some studies of reading that bear on the LQH. Although these are studies of adult reading, I believe their conclusions apply also to children's reading.

The Structure of Lexical and Comprehension Skill in Reading

Lexical knowledge and comprehension should be associated, and they are. Positive correlations between word-processing measures of various kinds and reading comprehension assessments are well established in both children (Perfetti, 1985) and adults (Haenggi & Perfetti, 1994). More interesting is the fact that this correlation is generally in the moderate range, leaving plenty of room for disassociation between the two. We've maintained a large database of college students for whom we take various reading and reading-related measures. In general, we are interested in knowing the associates of reading comprehension skill and in the outcomes of experiments that related specific reading processes to these measures. Perfetti and Hart (2002) reported some results of factor analysis on a sample of 445 individuals from this database. They concluded that skilled readers' knowledge of spelling, phonology, and decoding could be represented reasonably well by a single word form factor with a second factor reflecting meaning and comprehension. However, less skilled readers, in addition to a meaning factor, required two form factors—one loaded with more phonological tasks and the other with more orthographic tasks, suggesting less coherence of word identities.

Since then two dissertations have assessed large samples from this database, based on partly different tasks, one by Hart (2005) and a later one by Landi (2005). Both Hart and Landi were interested in the disassociation of word-level skill from comprehension skill, as assessed by the Nelson–Denny comprehension test. Hart analyzed the scores of 792 students, concluding that, among those who could be most confidently classified, 18% were below the median in comprehension but at or above the median on lexical measures; 64% showed the more typical association pattern of lexical and comprehension scores both high or both low. In her experiments with a carefully defined subset of this sample, Hart asked whether certain aspects of learning an artificial language might depend more on first-language lexical knowledge compared with first-language comprehension skill. Her results showed a complex pattern, with both comprehension and lexical knowledge predicting various measures of performance with the novel language during learning and in postlearning transfer. However, lexical knowledge, more than comprehension, predicted the learning of this artificial language, including its novel orthography and its decoding mappings. It also predicted resistance from interference by homophones that were planted in the new language, replicating a result reported in Perfetti and Hart (2001) for English.

Landi's study was carried out 2 years later on a different sample of 799 students and used an overlapping but partly distinct set of tasks. Landi's factor analysis of five tasks yielded a comprehension component and a lexical component, which she then used to weight normalize individual participant scores on each test. Figure 1 shows a scatter plot of these scores. In this normalized analysis, 23% were below the median on the comprehension component but above the median on the lexical component; the reverse pattern, high comprehension but low lexical components, was observed for 9% of the sample. This asymmetry is the pattern one would expect (but might not find based on median splits of test scores). Lexical knowledge is not sufficient for comprehension, so the low-comprehension/high lexical pattern is more prominent than the high-comprehension/low-lexical pattern. The approximately 20% (18% in Hart's sample, 23% in Landi's sample) of college students whose comprehension levels undershoot the level expected by lexical skills identifies a group for whom hypotheses about other sources of comprehension problems can be meaningfully tested.

The idea that lexical processes are not sufficient for comprehension should not be controversial, although a careless reading of verbal efficiency theory might have led some to believe that the theory assumed there was nothing to comprehension beyond efficient word reading. Observations to the contrary have long been in the literature, and at least a few of them seem to have controlled adequately for word-level skills. Studies by Oakhill and colleagues (Cain & Oakhill, 1999;

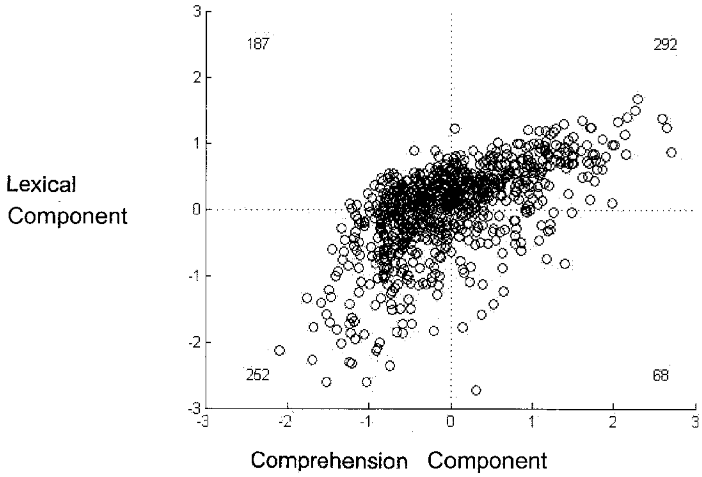

FIGURE 1 Scatter plot of normalized component scores from principal components analysis of reading test scores from a sample of 799 college students, based on Landi's (2005) dissertation. In this procedure, normalized *Z* scores for each test for each participant were multiplied by the factor score for that test determined from the Principle Components Analysis. Thus, the plot is a factor-weighted composite of five tests (decoding, spelling, vocabulary, comprehension, and the Author Recognition Test) that weighted differentially on the two components.

Oakhill, Cain, & Bryant, 2003) seem to show that some children have trouble drawing inferences during comprehension, despite having good decoding skills. More generally, comprehension problems can arise from general language comprehension problems even when word decoding appears to be adequate (Stodhard & Hulme, 1996). (For reviews, see Nation, 2006, and Perfetti, Landi, & Oakhill, 2005). Another candidate for comprehension problems, closer to the idea of LQ, is the hypothesis that children with adequate decoding and phonological-level skills can have word-level semantic problems that affect comprehension. This semantic deficit hypothesis (Nation & Snowling, 1998, 1999), which has some evidence in studies of children, allows for several interpretations of semantic deficits, including a problem with semantic categories. For now, the Landi and Hart studies extend to the adult population the observation that decoding is not sufficient for comprehension.

Studies of Form–Meaning Confusions

One way to study the effects of LQ on comprehension is to experimentally create threats to quality. This is the basis for experiments reported in Perfetti and Hart (2001), which I only briefly review here. The key idea is that for a word like *wails*, the quality of its identity, which entails its spelling, pronunciation, and meaning, is threatened by the existence of *whales*, which shares its pronunciation. So how do readers of higher and level skill handle this kind of threat? Our hypothesis was that better readers, defined by comprehension assessment, have higher quality representations, so given *wail*, they should retrieve *wail* associates, not *whale* associates, even if there is momentary activation of both the presented word and its homophone (Gernsbacher & Faust, 1991).

In the meaning task reported in Perfetti and Hart (2001), readers decided whether two words presented in succession were semantically related. Some trials contained homophones of words that would have been related, as when *wails* was followed by *dolphins*. Skilled comprehenders showed faster-meaning decisions for both control pairs and homophones, and they showed less homophone confusion when the presented (confusable) form was the one of higher frequency (*whales–cries* rather than *wails–dolphins*). However, they did show confusions when presented with a form of low frequency, and this effect occurred at shorter latencies than it did for less skilled comprehenders. So *night–armor* did not produce confusion (in the form of longer decision times) for skilled comprehenders, although it did for less skilled comprehenders. However, *knight–evening* produced interference for skilled comprehenders, and this emerged very rapidly, at a Stimulus Onset Asynchrony of 150 msec, whereas for less skilled comprehenders the interference effect did not emerge until 450 msec. Thus, skilled comprehenders show less interference based on form, and when they show interference, it occurs within 150 ms of exposure to the homophone, suggesting an early activation of word phonology.

This frequency effect in homophone confusions appears to be dependent on word experience. In a study reported in Hart and Perfetti (in press), readers were provided with experience on the member of a homophone pair that was judged to be less familiar, so as to make it more familiar than its mate. For example, in the pair *night–knight, knight* was rated lower in familiarity, so it was the one participants experienced in training; similarly, in *hair–hare, hare* was rated lower, so it was the training word. The result of the training, which consisted of visual exposures to the word associated with meaning, was the reversal of the frequency effect in homophone interference. In terms of the examples, training on *knight* caused semantic decisions on *knight–evening* to produce less interference than semantic decisions on *night–armor*. So form-based confusions depend on the relative frequencies of competing forms, which in turn depend on reading experience. A highly frequent form is relatively protected from interference, because it retrieves its meaning and pronunciation rapidly as a stable, unique word identity. An infrequent form is less protected because it is more likely to retrieve an unstable identity based on shared phonology with the more frequent form. The application of this to reading skill is that LQ depends on experience with words. A skilled comprehender has had more experience with a given word than has a less skilled reader, and this has important implications.[1]

The relationship between word frequency estimates and various word-processing tasks is nonlinear, generally logarithmic. In low frequency ranges, a given difference in frequency between two words may have a large effect on measures of speed of processing; in high frequency ranges, that same frequency difference has a smaller effect. Skill differences in word-reading experiments are usually greater for low-frequency words than high-frequency words. This may reflect the importance of some minimum number of exposures for a word to be identified with low effort. If we assume that a given word has been read more frequently by a skilled reader than a less skilled reader, then it follows that the skill differences we observe in processing that word reflect this frequency of experience difference. However, the difference in exposures seems to have an effect only for low-frequency words, consistent with assumption that it is the low-frequency range where increments in frequency are most important. Although recency effects can be disguised as frequency effects, this does not matter for the skill conclusion. More reading leads, statistically, to more frequent and more recent encounters and both may have this nonlinear effect on word-reading efficiency. Although this statistical perspective is important, it does not mean that all experiences with words are equal. In fact, in the next section, I review a study that suggests that skilled comprehenders make better use of their experiences with words they are trying to learn.

Learning the Meanings of New Words

Given the implication that LQ is acquired through effective experience with words, we might be able to observe the acquisition of LQ during word learning. Furthermore, by comparing the learning of readers who differ in comprehension skill, we can examine the link between LQ and comprehension in a situation that controls the word experiences. In this research, we have used both behavioral and ERP measures.

Perfetti, Wlotko, and Hart (2005) taught the meanings of very rare words to undergraduates and then tested the effects of this learning in a simple meaning judgment task while recording electroencephalograms (EEGs). Examples of the words taught include the following: *gloaming, flexion, clement, ibex, agog, bastion, tiglon,* and *quisling*. In a pretest lexical decision task, our rare words were judged to be real words only at a rate of 8% on average. To assure that the words we would

[1]Gernsbacher and Faust (1991; also Gernsbacher, 1990) explained less skilled readers' problems in meaning processing as due to problems in suppressing irrelevant meanings that are activated by a word. Differences between their mechanism-based account and the knowledge-based account of the LQH are discussed further in Perfetti and Hart (2001).

train and then test were unknown, the to-be-learned words were individually tailored for each participant according to the pretest. Following simple association instruction (50 min in which the rare words were paired with brief definition-like paraphrases), the trained words, untrained rare words, and familiar words were presented for meaning judgments. In the meaning judgment task, the first word appeared for 1 sec and then disappeared, replaced by the second word that was related in meaning on 50% of trials. For example, *gloaming* followed by *twilight*, should get a *yes* response. EEGs were recorded continuously during these judgments, so we obtained ERP indicators associated with viewing the first word (*gloaming*) and its meaning mate (*twilight*).

Figure 2 shows the behavioral results obtained during the posttraining meaning judgments task. The thing to notice is that skilled comprehenders were correct significantly more often than less skilled comprehenders in meaning judgments made to the rare words that we taught them but not to either untrained rare words or familiar words (also not trained). The lack of a skill difference for untrained rare words shows that overall knowledge of rare words was not different across the two groups. Instead, the conclusion is that the higher comprehenders actually learned the new words better.

The results of the ERP analysis, which are shown in Figure 3 for the group of skilled comprehenders, add to this picture. Plotted are the grand average waveforms at one electrode (the central reference electrode) for each condition for meaning-related trials. The conditions show a similar pattern for the first 200 msec or so, reflecting visual orthographic processes shared by all words. The first point of separation occurs at 200 msec, where trained words separate from both untrained and familiar words in a negative going shift. This reflects an early "notice"

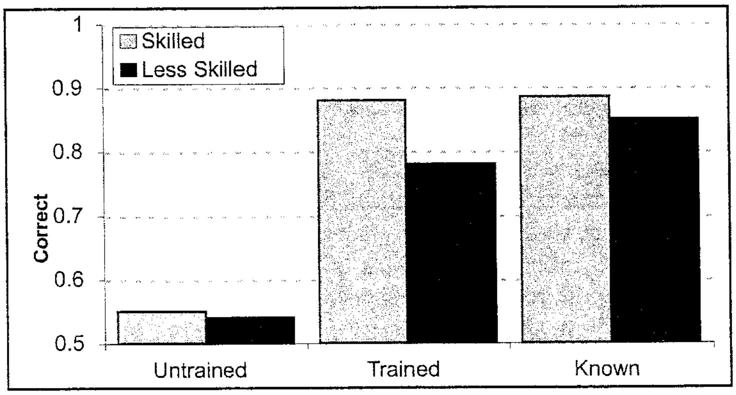

FIGURE 2 Comprehension skill differences in word meaning judgments following learning of rare words. Skilled comprehenders showed higher accuracy in judging meaning relations for trained rare words but not for untrained rare words or familiar (known) words. Based on Perfetti, Wlotko, and Hart (2005).

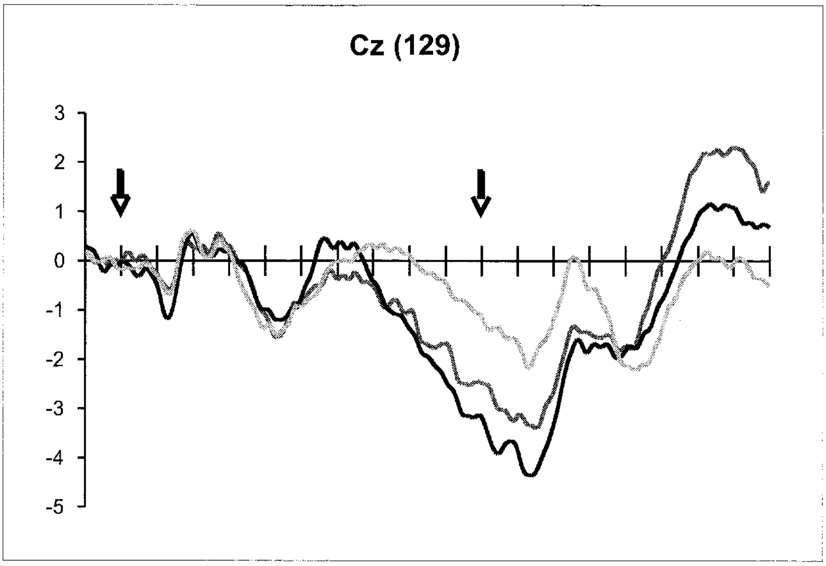

FIGURE 3 An event-related potential (ERP) record for skilled comprehenders during a meaning judgment. The grand average waveform is shown for the reference electrode (Cz). The onset of the first word is exemplified for the trained rare word *gloaming*. The onset of the second word is exemplified for the related word *twilight*. The three curves represent ERP records for trained rare words (darkest line), untrained familiar (known) words (intermediate darkness), and untrained rare words (lightest line). Two significant effects of training are visible, at 200 msec and about 550 msec, the latter representing word-level episodic memory for the trained word. About 400 msec after the onset of a related word, a reduction in the N400 is observed for trained and familiar words. For the trained words, less skilled comprehenders (not shown) show weaker episodic effects at 550 msec and weaker N400 meaning effects for the second related word. See Perfetti, Wlotko, & Hart (2005) for fuller skill comparisons.

of words that had been recently viewed in training, based on preidentity sublexical patterns. A second separation at around 550 msec, which does mark word identity, further distinguishes trained words from the other two classes, now in a positive going shift. This shift is the same in key respects (distribution and polarity) as the P600 that is observed in memory studies when a previously viewed item is presented (Curran, 1999; Rugg, 1995). This ERP shift marks recognition of the episodic memory laid down by the training event: In effect, the brain responds to this word as familiar because the word has been part of the previous hour's training. A word that has gained its familiarity through experiences prior to the experiment (the familiar words) shows no such effect. The implication of this is that we have identified a marker of familiarity-based learning that is expressed when a reader views a word.

So now the question is whether this word-level episodic memory effect is observed equally in our skilled and less skilled comprehenders. The answer is *no*. Less skilled readers showed the same Figure 3 pattern of ERP shifts during the meaning judgments. However, the key marker of episodic memory at 550 msec (the P600 training effect) was significantly reduced in amplitude for the less skilled comprehenders. Thus, on average, a word that had been learned just prior to the experiment made less of an impression on the less skilled readers. It is interesting that the first effect of training, the 200-msec negativity for trained words, was not different for the two skill groups. If our interpretation of these two components is correct—that the 200 msec is based on sublexical familiarity whereas the 550-msec effect is based on lexical identity—then we conclude that all learners respond to the distinctive letter pattern of a recently trained word, but they differ in recognizing the word episode—for example, this is that word *gloaming* that I just experienced a few minutes ago.

Recognizing a "gloaming" word-episode may involve retrieving its meaning, but it may not. The more direct test of a meaning process is in the response to the second word, *twilight*. If the participant has learned the meaning of *gloaming*, then the second word, *twilight*, which is closely related in meaning, should produce a reduced N400. The N400 is a signature for semantic congruence, a large negative going shift when a word is incongruent with its preceding context. When a word is congruent with its preceding context, the N400 is reduced. This N400 reduction is what happened when *gloaming* was followed by *twilight*—provided the meaning of *gloaming* was learned. As shown in Figure 3, an N400 appeared for the untrained words, reflecting the fact that if a participant had not experienced *gloaming* in training, there was no particular congruence provided by the word *twilight*. However, if *gloaming* had been learned, then the N400 should be reduced, and this reduction, as well as one for familiar words, is visible in Figure 3.

Once again, the ERP effect was different for skilled and less skilled comprehenders. Although both groups showed a reduction of the N400 when the second word was related in meaning to the first word, this N400 for less skilled comprehenders was significantly less reduced for trained words compared with the reduction for skilled readers.

We must conclude that after less than 50 min spent learning the meanings of 60 rare words whose meanings were unknown prior to the study, skilled comprehenders made more effective use of the learning period. Especially interesting is the fact that this difference was seen in ERPs recorded during the brief period in which the word was being viewed, prior to the appearance of a second word. The N400 on the second word reflected the stronger learning of the meaning by skilled comprehenders; the episodic marker on the first word indicated a stronger association between the word and its training.

One might argue with the interpretation that these are learning effects as opposed to subtle experience effects. Although we chose words that were individually tailored to be unknown for a given participant, perhaps that procedure underestimated very slight familiarity differences that favored the more skilled and more experienced readers. This seems unlikely. For one thing, we did not find differences in the untrained words, which were from the same population of pretested rare words. If skilled readers had some unmeasured familiarity with the trained words prior to the study, then they should have the same unmeasured familiarity for the untrained words. But the behavioral and ERP results both say they did not. Furthermore, the interpretation that we have a difference in the ability to learn word meanings is consistent with the results of Hart's (2005) dissertation. Readers high in comprehension skill showed better meaning decision performance than low-skill comprehenders on words learned in her artificial language.

Acquiring Lexical Form Stability

As indicated in Table 1, one of the features of LQ is a stable lexical representation. Stability occurs as letters and phoneme constituents become specifiable as constants (fully specified) rather than variables in the word representation. High-quality representations are fully specified (Perfetti, 1992). In a study that used rare-word learning to examine form stability during learning (Yang & Perfetti, 2006), skilled and less skilled comprehenders learned the meanings of 42 rare words over four mini–training "sessions" in the course of a single day. After each session, participants also made lexical decisions, choosing whether a given letter string was the correct form of a word they were learning. The foils varied systematically in their orthographic and phonological overlap with the correct form. This manipulation allowed tests of the learners' form stability. If learners acquire well-specified representations of the word they were learning, similar forms should produce less interference.

Table 2 illustrates what the learners were up against. In the midst of trying to learn the meaning of the new, very rare word, *hebetude*, learners encounter either one of the spellings shown in Table 2 or the correct form of the word *hebetude*, deciding whether the presented form is the correct form.[2] Orthographically similar foils (two left columns of Table 2) had high spelling overlap with the target, and some of these also had very high phonemic overlap. Control foils shared only an initial letter with the target. An unusual feature of this study is the use of multisyllabic words, which required some flexibility in creating foils. As Table 2 shows, the orthographic foils for *hebetude* all share both graphemes and phonemes for the first of the three syllables. (This means substantial phonemic overlap even among low overlap foils.) High phonemic overlap in this case was carried by

[2]According to World Wide Words (Quinion, July 2007), an August 2001 column in *The Washington Post* observed that "Too many Americans slouch toward a terminal funk of hebetude and sloth." It was also the "word of the day" on Dictionary.com on January 24, 2004.

TABLE 2
Foils for the Rare Word *Hebetude*

High Orthographic Overlap		
Higher Phonological Overlap	*Lower Phonological Overlap*	*Control: First Letter Only*
hebitude	hebetide	hodilane
hebatude	hebetade	harisade
hebutude	hebetede	higifore
hebotude	hebetode	hudufise

identical first and third syllables (left column). The four high overlap foils differed only on the vowel letter of the second unstressed syllable. Because the syllable is unstressed, vowels can migrate toward a minimal vowel. One could conceivably pronounce all the second syllable vowels as unstressed *uh.*

Of interest are results of both form and meaning learning. The meaning part of the study involved viewing the word and hearing a spoken definition, which could be repeated at the learner's option, followed by a test of meaning in which the word was spoken. We explained to participants that learning the meanings of rare words like *hebetude* was the goal. Each of the four sessions of meaning learning was followed by the form task (lexical decision).

The meaning results are shown in Figure 4. Skilled comprehenders learned more than less skilled comprehenders from the first session, and their advantage remained constant over the four sessions. This result converges with that of

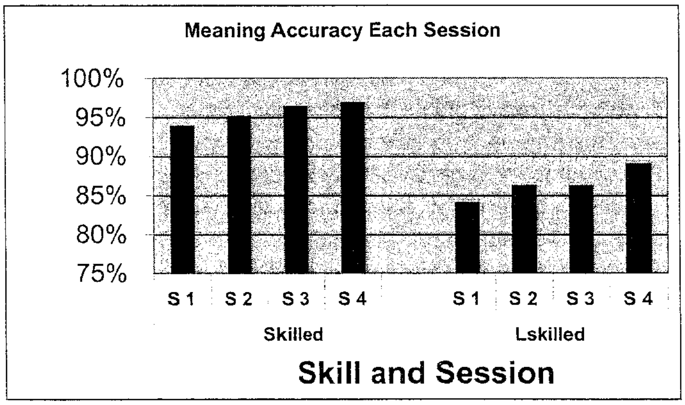

FIGURE 4 Increase in rare word learning over four learning "sessions" (all within one day). Skilled comprehenders learned more during the first session and maintained this slight advantage.

Perfetti, Wlotko, & Hart (2005) in finding that skilled comprehenders learn the meanings of new words more effectively than less skilled comprehenders.

Form learning, which is shown in Figure 5, was fairly good overall, with false alarms to foils ranging around 10%. Nevertheless, skilled comprehenders were more accurate at rejecting similar foils and selecting the correct form. After one session of learning, less skilled comprehenders chose a foil on 20% of trials. Figure 5 does not distinguish among foil types, but there were differences: The foils with high phonemic overlap attracted the highest percentage of false alarms, and foils with less phonemic overlap but high orthographic overlap were next. Control foils, which shared only the initial letter with the target, attracted few false alarms. However, there was no interaction of the type of foil with reader group. Both skilled and less skilled comprehenders made more errors to foils when both orthographic and phonemic overlap was high. Thus, the conclusion is that skilled comprehenders learn not only new word meanings more effectively but also new forms more effectively. LQ implies coherence between form and meaning components, and skill in reading is associated with higher LQ right from the beginning of learning.

The idea of stability is more specific than effective form learning. It implies that the word's representation comes to comprise spelling and pronunciation patterns that are identical on successive observations. One way to examine stability in this

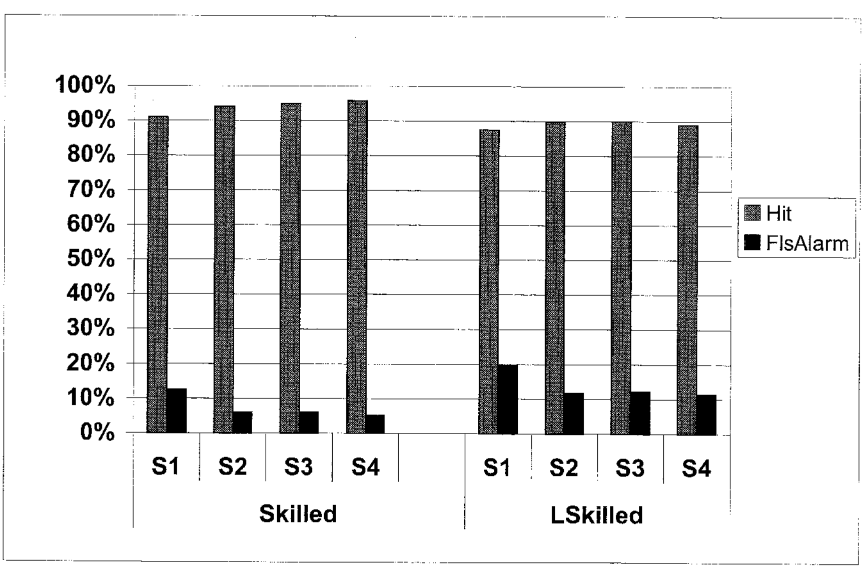

FIGURE 5 Form accuracy (lexical decisions) over four meaning learning sessions. Hit rates for real rare words (e.g., *hebetude*) compared with false alarms to similar forms (*hebitude*, *hebetade*, etc.). Less skilled comprehenders show less word-form accuracy.

sense is shown in Figure 6, which plots performance on successive lexical choice trials. The performance plotted is conditional for sessions beyond the first: Given a correct choice in one test session, the probability of being correct the next time. Thus choosing *hebetude* at one test but then *hebitude* on the next would contribute negatively to this measure, which is one of stability—choosing the same form the next time. Figure 6 shows again the slightly better performance of skilled comprehenders right from the beginning, that is, from the first session. Stability (conditional probabilities of correct responses) shows a small but consistent difference on the next two sessions, and the difference becomes largest on the final session, when skilled comprehenders produced 96% stability compared with 86% for less skilled comprehenders.

An informal characterization of this result is that the less skilled group, on average, shows a small but noticeable instability even after four sessions of learning. This is evidence in favor of the stability implication of LQ.

Less Skilled Comprehenders' Semantic Processing of Ordinary Words

The two preceding sections have concluded that problems in learning word meanings and in learning word forms both associate with comprehension skill. In the

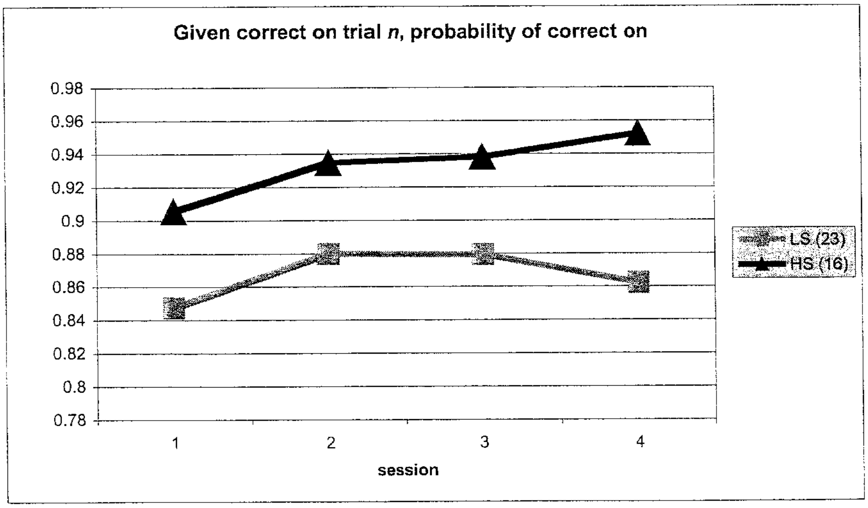

FIGURE 6 An indicator of form stability during word learning. The conditional probability of a correct decision on rare words given a correct response on the preceding trial over successive lexical decision sessions. Less skilled comprehenders show slightly less word form stability by this measure.

Studies of Form–Meaning Confusions section, we concluded that problems in meaning processes that were associated with form were more likely for less skilled readers. In this section we consider semantic processing differences for ordinary words already known to the reader.

The hypothesis that semantic deficits may explain comprehension problems has been developed and tested for children (Nation & Snowling, 1998, 1999). The basic idea is that such children have achieved the basics of phonological decoding but are limited in the meaning processes that are linked to word identification. Landi (2005; Landi & Perfetti, 2007) extended the range of this hypothesis to include adults, linking behavioral and ERP measures to the assessments of specific lexical and comprehension skill. In effect, Landi's experiments targeted the group of readers of Figure 1 who are in the lower right quadrant—below the diagonal and to the right of the x-axis midpoint: readers of high lexical skill but low comprehension skill.

Landi tested the hypothesis that such readers are less able to effectively use semantic category information. Participants made meaning decisions for word pairs that were related associatively and categorically or categorically only. For example, *brother–sister, dog–cat, pillow–sleep* were pairs both associatively and categorically related; *green–pink, banana–tomato, kite–balloon* were pairs related only categorically. Landi's hypothesis was based on Nation and Snowling's (1999) conclusion that children's comprehension problems reflected failures to represent semantic category relations. Thus, less skilled comprehenders would be comparable to skilled comprehenders in semantic processes when associative relations could facilitate detection of semantic relations, but they would be less successful than skilled comprehenders when they had to rely only on categorical relations. To provide more informative comparisons, participants also made semantic judgments on pairs of pictures (controlling for word reading) and homophone decisions, for example, *boar–bore, chants–chance, tacks–tax* (assessing phonological processing).

The key results can be summarized as follows: Accuracy was generally high for all tasks and not different between the two groups. However, times for correct decisions were faster for the skilled group than the less skilled group across all tasks. Thus, skilled comprehenders showed faster semantic processing whether the stimuli were words or pictures and faster word judgments whether the decision was based on meaning or pronunciation. For word meanings, the decision times to semantic category pairs were slower than to associative pairs. This confirms the assumption that detecting category relations would require more processing than detecting relations between associations. Correct decisions based on category relations took an average of 68 msec longer than those based on associative relations for the skilled group and 139 msec longer for the less skilled group. These group differences, although in the direction implied by Landi's extension of Nation and Snowling's (1999) hypothesis, were not reliable.

TABLE 3
Summary Skill Pattern in Landi ERP Results

Task	*Comprehension Skill Differences in Decision Times?*	*Comprehension Skill Differences in ERP Measures?*
Phonological decisions	Yes	No
Semantic picture decisions	Yes	No
Semantic word decisions—Categorical	Yes	Yes, but small (P200, N400)
Semantic word decisions—Associative	Yes	Yes, large (P200, N400)

Note. Source: Landi and Perfetti (2007). ERP = event-related potential.

Whereas the decisions times showed very general processing-speed differences, the ERP measures showed differences that were restricted to the semantic word decisions, and these results present a slightly different picture. Both groups showed a reliable reduction in the N400 for related trials for both category and associative pairs, although in each case the reduction shown by skilled comprehenders was somewhat larger. Moreover, the high-skill group, but not the low-skill group, showed an additional N400 reduction for the associatively related pairs relative to the category pairs. Thus, contrary to the expectation that less skilled comprehenders would have specific problems with category relations, the ERPs suggest that semantic category processes were comparable in the two groups, but the ERPs for associative relations were not. (The tendency for less skilled comprehenders to take relatively longer than skilled comprehenders on category decisions may be relevant; however such a difference could be interpreted as an additional checking process well beyond the more automatic semantic process that is reflected in the N400.)[3]

Table 3 shows a summary of skill differences across tasks. Taken together, they suggest detailed evidence for semantic-processing differences between the skilled and less skilled comprehenders. The ERP evidence suggested that skilled comprehenders had a stronger meaning congruence response when words were categorically related, and this response was even stronger when the words were also associatively related. The less skilled group showed a congruence response also, but this response was not strengthened by associative relations. Notice that if all we had were behavioral data, our conclusion would be different, and perhaps misleading. We would conclude that there is no semantic processing skill difference

[3]The ERP results also produced evidence for early semantic effects at 200 msec that were more consistent across electrode sites and trial conditions for skilled comprehenders. They also showed 200-msec effects for the phonological task, comparing homophones versus nonhomophones that were comparable across the two groups.

specific to language, because of differences in picture decision speed. And we would have concluded that these groups differed either on phonological processes (because of the phonological decision speed differences) or, more likely, on nonspecific processing-speed differences. The ERP data are telling us more directly about the brain's response to words, and they seem to say that there are specific skill differences related to word-meaning processes.

Lexical Processing During Text Comprehension

My final example returns to the key link between lexical processes and comprehension. This link is most direct at the level of short runs of text, a sentence or two, where one can observe word processing "on-line" as part of text reading. The focal issue is the processes that integrate the word currently being read with the ongoing representation of the text. This integration is a central connecting event between word identification and text comprehension.

The skill question is whether differences in globally assessed comprehension arise at this local (i.e., one word at a time) processing. Do skilled comprehenders integrate words immediately into the text? Do less skilled comprehenders? The LQH (and also verbal efficiency theory) predicts word-text integration problems for less skilled readers.

Once again, our studies on this question use ERPs to examine the N400 semantic congruence indicator. The N400 has been found to vary with demands on sentence and text-level integration (van Berkum, Hagoort, & Brown, 1999), and it is that fact that we exploited in two parallel studies, one with skilled comprehenders (Yang, Perfetti, & Schmalhofer, 2007) and one with less skilled comprehenders (Yang, Perfetti, & Schmalhofer, 2005). The approach of the studies is illustrated in the following text:

> After being dropped from the plane, the bomb hit the ground and exploded. The <u>explosion</u> was ....

ERPs were acquired as each word was read. The underlining (not visible to participants) marks the target word (*explosion*) for our analysis.

When the reader comes to *explosion* at the beginning of the second sentence, it should be relatively easy to integrate the word with an understanding of the text based on the first sentence. That is, we can assume that the reader's text memory includes the event-proposition [bomb exploded], among other propositions from the first sentence, and the word *explosion* is integrated with this event-proposition; that is, it is taken as coreferential with the proposition. This condition is termed "explicit" because there are explicit coreferential phrases (*exploded, explosion*).

A second condition, the paraphrased condition, was of special interest from a semantic processing point of view. Instead of the first sentence referring to "exploded," it contains the paraphrase "the bomb blew up." For a semantic process that links words through their stored meanings (or through one that generates context-sensitive referential meanings from words), integration is possible in this condition. However, it might take a bit more processing work, as a reader searches for the meaning of *explosion* and then links it to the meaning of "blew up" in the context of the first sentence.

A third condition, the inference condition, allowed the critical word to be integrated readily only if the reader had made an appropriate forward (predictive) inference in the first sentence. In the example, the first sentence would say only that the "the bomb hit the ground." The reader may predictively infer that the bomb exploded, in which case encountering the word *explosion* in the next sentence would be easily integrated. However, notice that such a predictive inference in the first sentence is not necessary for comprehension.

Finally a baseline condition, the unrelated condition, provided an initial sentence that contained no possible antecedent for the word *explosion*. To control for specific words, it contained *plane*, *bomb*, and *dropped*, but, as can be seen in Table 4, these words were not in propositions that suggested bomb dropping. This condition is a baseline, because one expects an N400 when the word *explosion* is read in the second sentence. The question is, compared with the N400 produced in the baseline condition, which other conditions produce reduction of the N400? When meaning integration is relatively easy, such a reduction is expected.

Table 4 shows both examples of texts and the pattern of skill results for these four conditions. In viewing the table, it is important to keep in mind that *yes* and *no* cannot do justice to the full data. The pattern as shown is an interpretation based on

TABLE 4
Example of Materials for Word-to-Text Integration and Pattern of ERP Results From Yang, Perfetti, and Schmalhofer (2006, 2007)

		ERP (N400) Effect	
Condition	*Sample Passage*	*Skilled*	*Less Skilled*
Explicit	After being dropped from the plane, the bomb hit the ground and <u>exploded</u>. The <u>explosion</u> was quickly reported to the commander.	Yes	Yes
Paraphrased	After being dropped from the plane, the bomb hit the ground and <u>blew up</u>. The <u>explosion</u> was quickly reported to the commander.	Yes (P300)	No
Inference	After being dropped from the plane, the bomb hit the ground. The <u>explosion</u> was quickly reported to the commander.	No	Yes
Unrelated	Once the bomb was stored safely on the ground, the plane dropped off its passengers and left. The <u>explosion</u> was quickly reported to the commander.	Baseline. Both groups show large N400.	

a number of analyses reported in Yang et al. (2005, 2007). The inference condition, for example, needs some hedging. Less skilled readers showed a significant reduction of the N400 in this condition, whereas skilled readers did not. However, the skilled comprehenders' N400 appeared to be intermediate between baseline and the two conditions (explicit and paraphrased) that produced significant N400 reduction, suggesting that skilled readers make inferences some times but not generally, just as one would expect for inferences that are not required to maintain coherence. (See Perfetti, Yang, & Schmalhofer, in press, for further discussion.)

To focus on what is clear and consistent in the pattern of Table 4, there is an important difference between skilled and less skilled comprehenders in the N400 data. Skilled readers showed that they easily integrated a word with the prior text through a paraphrase process. For example, when they read *explosion*, they link it to the event described in the preceding sentence as "blew up." Paraphrase relations, although they have not been studied much in comprehension research, are important for semantic linking processes. In comprehension, words need to link with referentially specified mental representations, not merely words. Paraphrases are context dependent—"blew up" is not always a paraphrase of "exploded"; it can also be a paraphrase of "enlarged" as in "To see more detail, we blew up the photograph." Paraphrastic semantic relations require a lexical representation that allows a flexible range of meanings that can be fit to contexts. Thus, paraphrase is an especially important process because it is at the "interface" of lexical knowledge and comprehension.

In evaluating the overall pattern of evidence in these studies, we concluded that less skilled comprehenders showed "sluggish" word integration processes (Yang et al., 2005). This evidence exceeds what we are reviewing here and included topographic maps (ERP data displayed over the scalp and over time) that show a dramatic difference between the two groups. Skilled readers' maps showed an early rise of positivities in explicit and paraphrase conditions. Less skilled comprehenders' maps showed widely distributed negativities even at 400 msec, before shifting to positive at points beyond 500 msec. Thus, we suggested their comprehension was "sluggish"—slow and not always successful in integrating a given word with the understanding of the text. This is just the kind of effortful and inefficient comprehension process the LQH predicts for readers with low-quality word knowledge.

CONCLUSION: CONSEQUENCES OF LQ

There are some generalizations to emphasize concerning the consequences of lexical processing (and lexical knowledge). An obvious one is that LQ determines the accuracy and fluency of word identification. Less obvious consequences include the following. LQ influences readers' resistance to form confusions, the ability to learn the meanings of new words, the retrieval of meanings of learned words, the stability of form representations, and the integration of words with text representations. Especially interesting is the consequence of verbal efficiency, which is demonstrated in the studies of Yang et al. (2005, 2007) reviewed previously.

Most of the studies I reviewed here assessed reading comprehension only, and the links to lexical processing are in experimental manipulations rather than independent assessments. In these cases, we depend on the general correlation between comprehension and word processing to support the conclusion that our comprehension groups also differed in some aspect of LQ. One study that assessed lexical processing and comprehension independently (Landi & Perfetti, 2007) observed specific word-level semantic differences between comprehension groups that differed on comprehension only and not word decoding. Another (Hart, 2005) showed specific language-learning effects for high-LQ participants. It remains an important goal of the LQH to show more specific consequences of the various components of lexical knowledge.

The Causes of Low Ability in Reading

There are other theories of low ability in reading, and it is useful to place the LQH in the context they provide. Phonological deficits, naming deficits, and semantic deficits are three deficit-based hypotheses at the word and subword level that have been important. Let's consider them one at a time.

Phonological processing indeed has a central place in the acquisition of reading skill. The LQH has its roots in one idea about comprehension—words matter for comprehension (verbal efficiency; Perfetti, 1985)—and one idea about word knowledge (the acquisition of effective word representations depends on precision and redundancy in sublexical constituents; Perfetti, 1992). It is the second of these ideas for which phonology is relevant. Procedures for phonological decoding have an important role in establishing high-quality word representations. Indeed, these procedures may be the primary means for establishing word-specific orthographic representations (Share, 1995, 1999). The difference in explanation for reading problems is a matter of developmental level and theoretical emphasis. The phonological deficit hypothesis applies with full force to young children. Their problems in reading words are observable and so is their problem with phonology, and because the latter can explain the former, the phonological hypothesis is privileged.

One idea about phonological deficits is that they arise from low-quality phonological representations. The general form of this idea has been part of various explanations about phonological deficits (e.g., Katz, 1986; Snowling, 1995; Snowling, Wagtendonk, & Stafford, 1988). Elbro (1996, 1998) gave it a specific form in the phonological distinctness hypothesis. Elbro argued that the distinctiveness of phonological representations is critical for distinguishing phonologically similar words from each other and suggested that dyslexics had incomplete, nondistinct phonological representations. Although the application of this hypothesis is generally to children, it is important to note that adult variation is word-reading skill is associated with phonological performance in spelling (Dietrich & Brady, 2001). Phonological quality thus is a specific dimension of LQ that may be significant beyond its application to dyslexic children.

With development, the payoff for phonological processing—and the cost of problems with phonological processing—is word knowledge. Thus, although phonological processing may have placed limits on LQ, the focus shifts away from phonological procedures and directly to word knowledge itself as a limiting factor in reading. On this understanding, phonological processes at higher (adult) levels of skill have not lost their importance, but they no longer have the status of direct cause.

In the case of naming speed and the corresponding naming deficit, the situation is not so clear. There is neither compatibility nor interesting contrast between LQ and rapid naming if rapid naming is completely general rather than about words. It is possible that rapid naming of words is a by-product of LQ, just as verbal efficiency is. The contrast between rapid naming and verbal efficiency has been about a distinctive role for word reading. Word retrieval can be only as fast as the limit set by general symbol retrieval (Perfetti, 1985). Our earlier research tended to show that among children who were garden variety low-skill readers, slow word-retrieval speed is not explained solely by number or picture retrieval. However, there appear to be ample demonstrations that some very low-skill readers are generally slower at nonreading naming tasks (Wolfe, Bowers, & Biddle, 2000), although some meta-analyses have raised questions about the robustness of rapid naming effects across studies (Swanson, Trainin, Necoechea, & Hammill, 2003). In any case, LQ remains a separate concept to explain general variation in reading and is not reducible to naming speed.

The semantic deficit hypothesis, like the phonological hypothesis, is a more specific cousin of LQ. LQ entails both semantic and phonological components. It inherits the weakness of low disconfirmation risk that comes with very general propositions. By encompassing multiple components, the LQH seems to have verification in any study that shows skill-related consequences of any one of these. However, this problem is not intrinsic to the LQH but rather reflects the limitations generally seen in individual differences research. For example, a specific prediction of the LQH is that high coherence among lexical constituents has consequences for reading, but this prediction has not been tested. This is partly because it implies a difficult separation of spelling, pronunciation, and meaning knowledge for specific words and readers so that the only difference is the correlation among these components. Although this separation has not been done, it could be, at least in principle. Furthermore, notice this same problem limits both the semantic and phonological deficit hypotheses, which must be able to convincingly show that in a given group of readers, only one of these deficits is causal. Although the research approximates this standard, it does not assess skill and knowledge on an individual word-by-word basis but rather by controlling one variable through a global assessment (e.g., phonological decoding) so that it can measure the targeted variable experimentally.

In addition to these word-level hypotheses, there are several hypotheses about comprehension-specific deficits that target processes above the word level (e.g., Oakhill et al., 2003). The possibilities are wide ranging (e.g., inferences, comprehension monitoring) and generally involve processes that operate on the outcomes of word-level processes. These higher level accounts might be complementary to the LQH insofar as word meanings can be considered the interface between word identification and comprehension. However, to make this possibility meaningful, one would have to show that word-meaning retrievals are responsible for inferences or for coherence checks or whatever comprehension process is at issue. Alternatively, one might argue that working memory is the link and that low-quality word representations and, for example, inference processes compete for processing resources.

A difference among theses various approaches (those at both the low and the high levels) and the LQH is that the phonological, naming, and semantic deficit hypotheses (and also the inference hypothesis) seem to be about mechanisms that are not functioning properly. In contrast, the LQH is about knowledge that has not been acquired or practiced to a high-enough level. In the LQH, processes that do not operate effectively or efficiently arise from knowledge representations. Because knowledge and practice with this knowledge accumulate with age and experience, the application of the LQH is very broad, relevant for reading by adults as well as children.

To summarize, the LQH implies that variation in the quality of lexical representations, including both form and meaning knowledge, lead to variation in reading skill, including comprehension. For some readers, the quality problem may be in the semantic constituents of words; for most readers, the problem cuts across meaning, orthographic, and phonological knowledge. The consequences of LQ can be seen in processing speed at the lexical level, and, especially important, in comprehension. There is no on–off deficit in this characterization. LQ is graded across words for a given individual and across individuals for a given word. The source of LQ variation must arise through literacy and language experiences, although effective use of these experiences is likely to be influenced by biology as well as culture. These experiences include, among other things, learning to decode printed words, practice in reading and writing, and engagement with concepts and their language forms.

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