The lexical quality hypothesis

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Reading is partly about words. Or, to begin the argument more forcefully, it is mainly about words. Either way, it follows that knowledge about words is important to understand skill in reading. This claim is more interesting if we take reading skill to be, in its definition, not about word skill but about comprehension skill. So there it is: Our argument is that skill in reading comprehension rests to a considerable extent on knowledge of words. In what follows, we try to explain what we mean by this and why we conclude that it's true. Is so doing, we re-state arguments and illustrations that we have made in Perfetti & Hart (in press).

A precursor of our argument is contained in earlier work (Perfetti, 1985) in the following observation: When one compared children who differed in assessed comprehension skill, they always divided themselves in word reading and decoding in the same way. The less skilled comprehenders were not just not so good in comprehension, they were also not so good in word reading. From such a pervasive correlation — and it is very pervasive — came a hypothesis that seized the causal high ground, with only modest justification: Comprehension skill depends on word reading skill. The bases of this conclusion lay in a program of research that consistently found that when either children or adults were separated by their scores on a reading comprehension test, they sorted themselves also on their speed of written word and pseudo-word identification.

The causal link is not established in a clear way even now. But the causal relationship is complex enough to partly excuse this lack of progress. Lexical skills allow comprehension, comprehension allows reading practice, reading practice strengthens lexical skills, etc. The recurrent nature of component interactions in the process assured an intimate connection between lexical and comprehension skills.

But the natural (first cause) privilege belonged to the lexical processes. Word reading gets things started, and it was more difficult to imagine a reader who comprehends the texts without reading the words than vice-versa. Verbal Efficiency Theory was the name we gave to this simple idea — which was that many — not all — problems in comprehension are caused by ineffective word identification processes. Rapid and perhaps modular (context-free) word identification was important for a comprehension system of limited capacity.

We have revisited this idea recently, adding some ideas about what kinds of word processes are at issue. The original formulation of Verbal Efficiency emphasized the speed and automaticity of word processes, such that by virtue of being automatic they allowed processing resources to be devoted to comprehension. This idea, we think, was correct but incomplete. What is it about words or about readers such that word processing can vary in a way that affects comprehension? One tentative answer to this was a precursor to the Lexical Quality Hypothesis based on linguistic code manipulation: The basic idea was that, in any modality, efficiency is the rapid retrieval, from inactive memory, of codes that are part of a stored linguistic symbol. And "to the extent retrieval is effortful and the retrieved codes low in quality, the processing is inefficient" (Perfetti, 1985: 118). Whether by spoken language or by written language, a low quality code retrieved with effort would jeopardize comprehension processes that depend on a high quality representation. However, the additional linguistic step in reading — mapping an orthographic form onto a lexical representation — could make the problem more noticeable in reading.

Lexical quality

The question of code quality, in this account, becomes central. The original suggestion was that the retrieval of a lexical representation is high in quality "to the extent that it contains both semantic and phonetic information sufficient to recover its memory location . . . This quality must be retained long enough for subsequent processes to perform their work. Thus a "name" without meaning and a meaning without a "name" are both low quality." (Perfetti, 1985: 118). This idea was developed further in a theory of reading acquisition by reference to lexical specificity and redundancy (Perfetti, 1992). A lexical representation has high quality to the extent that it has a fully specified orthographic representation (a spelling) and redundant phonological representations (one from spoken language and one recoverable from orthographic-to-phonological mappings). If a lexical representation is specific and redundant, its retrieval is more likely to be coherent and reliable. By coherent, we mean that the constituents are available synchronously at retrieval, giving the impression of a unitary word. (The contrast is constituent asynchrony, a fragmented appearance of constituents and parts of constituents, as when a speech recoding occurs followed by meaning retrieval. See Perfetti, 1985: 114). The consequence of reliability is that multiple encounters with a given word tend to produce a common core representation consisting of a nexus of orthographic, phonological, and semantic information. To put it approximately, these defining features of high quality allow the reader to get exactly the word that is printed rather than parts of it that may also be parts of other words. Confusion about word meaning as well as word form is minimized by high quality representations.

Variation in lexical quality can be observed in spelling, in retrieval of pro-
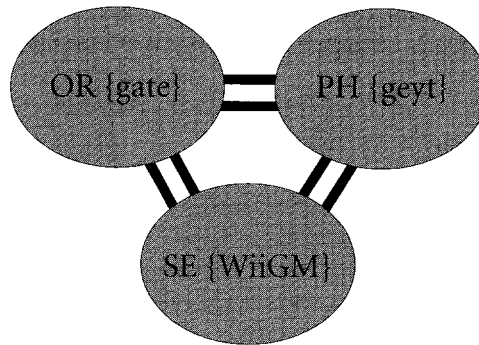
Figure 1. The word "gate" illustrates the concept of a lexical entry with three well-integrated constituents of orthography (OR), phonology (PH), and semantics (SE)

nunciations, and in identifying meanings. Reliability in performance is part of the assessment of quality. A reliable, coherent, high quality representation is retrieved easily and consistently. Figure 1 represents a high quality representation by indicating a tightly bonded set of word constituents — the orthographic (OR), phonological (PH), and semantic (SE) specifications of the word. The identification of the word is the retrieval of these constituents.[1]

Referring to the components of words as "constituents" has certain implications. A constituent in a linguistic or algebraic representation is not merely a part of a larger whole; it is a defining symbol or variable. The specification of each constituent is subject to constraints from a relevant system. A word is a triple of PH, OR, and SE, each of which is a constituent whose specification is constrained by systems of phonology, orthography, and syntax-semantics, respectively. Reading research has largely ignored the systematic nature of phonological constraints, but Berent & Shimron (1999) present an interesting example of constraints on phonology that may be relevant for reading. Similarly, SE constituents reflect basic conceptual and grammatical constraints. One consequence of the constituent idea is that it encourages the view that word identity is both unitary and compositional. Thus, the lexical representation of the word "cat" is the (unitary) linguistic object such that it has spelling C-A-T, phonology [kaet] and meaning (whatever it is that cat means). In general terms, all words are triples of {PH, OR, SE} specification. The SE constituent, however, is incomplete in the "cat" example, because it ignores grammatical information. To avoid a fourth constituent, we can stipulate that SE is actually a collection of meaning and grammatical information. Thus, it includes the information of the lemma, the abstract grammatical frame that appears necessary to understand the production of speech (Bock & Levelt, 1994), as well as a conceptual structure that links to the lemma.

We can now state the key idea about individual differences: People vary in the quality of their lexical representations. Any representation that does not specify the value of one if its constituents is low quality. Consider the following examples:

a. Presented with the word "incarcerate", the reader can pronounce it accurately and knows it has some negative meaning, but is not sure what that meaning is.

b. Presented with "incarcerate", the reader stumbles on its pronunciation, producing something like in-cark-rate.

c. Presented with "incarcerate", the reader can pronounce it and indicate that it means something like "to confine in prison". When attempting to speak the word to produce a message about someone going to jail, however, he sometimes produces "incarcerate" and sometimes something more like "incarsate".

d. A reader can perform all the tasks failed variably in a, b, and c above but can spell the word correctly only on some attempts.

The examples indicate several unreliable representations of the word {incarcerate, [inkarsreyt], (verb trans; put in jail)}. They will have differential consequences in different tasks. Case (d), for example, is one familiar to many individuals of high literacy — the feeling of semantic and phonological competence coupled with a spelling block. Case (a) may represent a skilled reader of limited experience who can "decode" a word that he doesn't really know, although he has heard it pronounced and thus has some phonological representation.

By illustrating the basic idea with a low frequency word, we intend to suggest a highly general concept that applies to skilled readers as well as less skilled readers. Skilled readers can have low quality representations for many words, both low frequency words from general vocabulary and words from specialized vocabularies. What skilled readers have by way of an advantage are the foundational resources that get the most out of impoverished representations and support learning given a novel exposure. A skilled reader has a better chance of adding new information (about spelling, pronunciation or meaning) to an impoverished representation. Our analysis, however, focuses on words more than individuals. Not individuals, but word representations vary in quality. A skilled reader, in addition to having foundational resources (decoding, spelling, and grammatical skills), is one who has many high quality word representations. A less skilled reader is one who has fewer high quality word representations.

The genesis of the number of quality word representations is a matter of experience that produces relevant knowledge. Certainly, basic and explicit phonological knowledge supports early progress in reading, and subsequent practice in reading, listening, speaking, and writing promote more high quality word representations. The profound differences in the amount of reading among individuals are sufficient to produce the degree of lexical quality differences observable at any given age. Such experience affects the quality of a given word and the number of words of a high quality. There is, in effect, a continuum of lexical knowledge and it is this continuum that is bisected when researchers refer to skilled and less skilled readers.

Threats to lexical quality

One way to observe the consequences of lexical quality is to create conditions that expose variation in quality and to test the effects of this variation on simple comprehension. One threat to lexical quality arises from properties of written English that lead to words sharing forms — orthographic form or phonological form. Words with multiple meanings on single forms risk lexical quality because there is a lack of one-to-one mapping among one or more constituents. This occurs in three distinct ways: (1) A single orthographic form maps to a single phonological form, but two multiple meanings (more than one morpheme). This case, word ambiguity, has been the staple of research addressing the meaning selection process. Example: count (1. enumeration; 2. feudal title). (2) A single orthographic form maps onto two different phonological forms and hence two meanings (two morphemes). Example, bass (1. /baes/, type of fish; 2. /beys/, voice or instrument of the lower pitch.) (3) Two orthographic forms maps onto a single phonological form and two meanings (1. Seed. 2. Cede). These three cases of meaning polysemy, homography, and homophony, respectively, each depart from the one-to-one-to-one mappings among orthographic form, phonological form and meaning. In sharing forms, words in each of the three cases risk lexical quality. Homophones, the third case, provide the demonstration case for our experiments. Figure 2 illustrates this case by adding the homophone *gait* to the representation of *gate* in Figure 1.

The words *gait* and *gate* in Figure 2 are represented as high quality, as they might be for a reader high in knowledge about words. Nevertheless, there is potential for confusion. If one encounters the spoken form [geyt] both *gait* and *gate* might be activated, along with their different meanings. Context will select the right one and the confusion will be of no real consequence for comprehension. Less obviously, even in reading, confusion can result, despite the fact that spelling uniquely identifies the word. Thus *gait* can cause its homophonic partner *gate* to be activated, leading to momentary subconscious activation of both words. So the case for a skilled reader is that the written presentation of homophones can lead to the activation (retrieval) of two words. Although the representations are as good as they can be, the momentary retrieval of these representations can yield confusion, even for skilled readers, as Gernsbacher and Faust (1991) have shown.

If the potential for confusion exists for the skilled reader, it is even stronger for the less skilled reader. According to the Lexical Quality Assumption, a low quality representation could be observed for *gait*, for *gate*, or for both. Imagine a reader whose skill is low enough that the word *gait* is completely unknown. No spelling, no meaning. This reader has no confusion when *gate* is presented. Or, more carefully, the only problem with *gate* is due to its representation quality independent of *gait*. It should be no different from a control word, one that is not a homophone. However, a more typical case might be a reader with an unreliable low quality representation for *gait*. Now there is the increased potential of confusion beyond what one might see from a nonhomophone. This is because
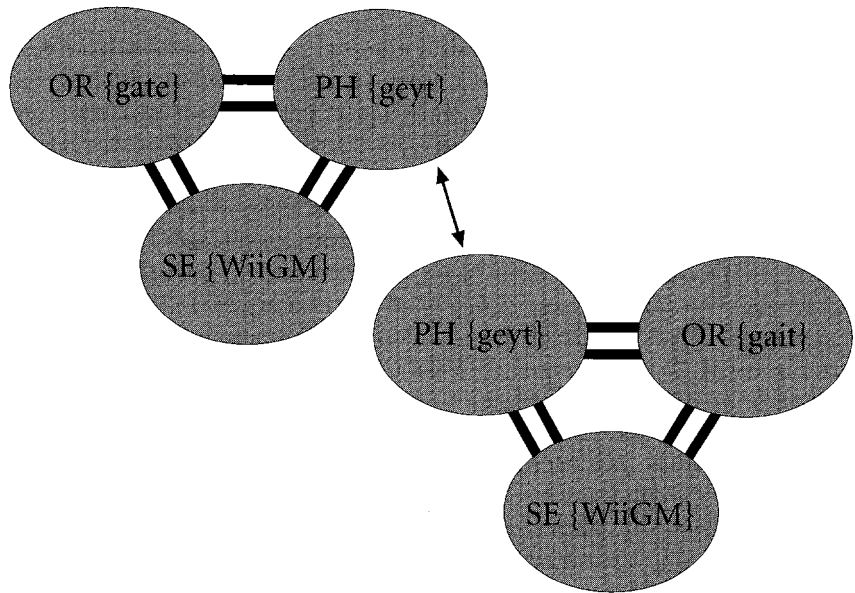
Figure 2. With "gate's" homophone, "gait," the lexical entries are interconnected. Through PH, the activation of one lexical entry will partially activate the competing homophone, causing brief interference

the representation for *gait*, no matter how impoverished, can be partially activated by a spelling, a pronunciation or a meaning — when gate is presented.

Word frequency is an important determinant of word processing and this applies as well to homophones. Reading the more frequent member of a pair of homophones may occur without leading to access of the less frequent member of the pair, a finding that has long been observed in research with ordinary semantically ambiguous words (Duffy, Morris & Rayner, 1988; Hogaboam & Perfetti, 1978). According to the Lexical Quality Hypothesis, this frequency result is a consequence of the benefits of experience for the higher frequency meaning, making its meaning and spelling a more stable constituent, compared with the lower frequency meaning. Moreover, if we consider word representation quality to be distributed across individuals the way we have suggested, then high frequency words may be less a source of confusion for skilled readers than for less skilled readers. This is because a word that is high frequency according to a corpus count may have actually been experienced less frequently by a less skilled reader. Similarly, a word that is low frequency for a skilled reader may be functionally even lower for a low skilled reader. Consistent with this assumption are data reported in Perfetti and Roth (1981) showing that whether context facilitates word identification depends on both skill (less skilled readers more likely to be affected than skilled readers) and basic word identification speed (words identified quickly in isolation

are less likely to be affected than words identified more slowly in isolation). Thus, it is the functional identifiability of a word (not the reader's skill in absolute terms) that is critical, and this can vary for the same word across readers and for the same reader across words.

These assumptions about lexical representation and functional identifiability provide for some non-obvious predictions about homophone confusions that have been tested in our experiments. First, because a skilled reader has higher quality representations for more words than does a less skilled reader, the mutual activation of homophones should occur more quickly than for the less skilled reader. Because both members of a homophone pair, e.g., *gate* and *gait*, are more identifiable for the skilled reader, activation will spread more quickly from the one to the other. This can lead to a homophone confusion more quickly for a skilled reader than for a less skilled reader. However, the same assumption — that the skilled reader has better quality representations of homophones as for all words — leads to the prediction that this confusion will be short lived. The presented word will quickly have more activation than its unpresented homophone mate will. For the less skilled reader, confusion should build more slowly (because of a lower functional identifiability of both homophones) and release more slowly. This description referring to confusion and release from confusion is more general (and more theoretically neutral) than one referring to suppression (Gernsbacher & Faust, 1991). We leave open the possible operation and failure of a suppression mechanism, although it is not required by our analysis of the process of homophone meaning selection, for which the assumptions of the Lexical Quality Hypothesis are sufficient.

The effect of word frequency is also implicated by this analysis. A skilled reader, whose knowledge of the high frequency member of the pair (e.g., *gate*) is of very high quality, should show little interference from a presentation of that high frequency word. For the low frequency member of the pair (e.g., *gait*), the skilled reader's representation is of lower quality; so the presentation of *gait* allows confusion to confusion to spread to the better known *gate* before comprehension of *gait* is complete. Compare this with a less skilled reader, who, by assumption, has lower quality representations for both the higher and lower frequency member of a homophone pair. The presentation of a high frequency member of the pair will now allow confusion. Because its functional identifiability is lower than it is for the high skilled reader, this allows activation of *gate* to spread to the incomplete representation of *gait*. For this to occur, we need to assume that *gait* is partially represented not entirely absent.

Whether confusion occurs for the lower frequency member of the pair (e.g., *gait*) depends on the quality of its representation as well. For a reader who has no representation of *gait* there is no confusion intrinsic to that word when it is presented. Any confusion comes from activation of the unreliable representation of *gate*, which will be a level of confusion characteristic of nonhomophone words. On average, what all this means is that we should observe more interference from *gait* for skilled readers than for less skilled readers. But we should see more interference from *gate* for less skilled readers.

Tests of these predictions come from experiments in which readers make simple meaning judgments (Perfetti & Hart, in press; Hart & Perfetti, under review). Sometimes the words are related in meaning (king-royalty), sometimes not (king-evening). Sometimes the first word is a homophone for both yes trials (night-evening) and no trials (knight-evening). To vary the stress on lexical quality, we varied the SOA between the onset of the first word and the onset of the second word at 150, 450, and 2000 ms. At 150 ms, representation quality should matter more than at longer SOAs, because there is little time to activate the word, and we expect only skilled readers and high frequency words to show this activation. At 2000 ms, even less skilled readers and less frequent words have time to achieve activation and selective meaning encoding.

With subjects sorted on the basis of reading comprehension skill, as measured by the Nelson-Denny comprehension test, several predictions of the Lexical Quality Hypothesis were supported. First, less skilled readers showed slower decisions across the board, for control words as well as homophones, confirming a basic prediction of the Lexical Quality Hypothesis. Second, skilled readers showed homophone confusions more quickly than less skilled readers. Third, skilled readers showed confusions mainly for the less frequent member of a homophone pair.

Figures 3–5 show some of the critical results. Figure 3 shows that less skilled readers are slower than skilled readers on control words, an obvious but theoretically important result. According to the Lexical Quality Hypothesis, the general lexicon of skilled readers contains more high quality representations than that of the less skilled readers. All other lexically based differences, including those from homophones, arise from this fact. And indeed homophone differences are seen. Relative to control words, skilled readers showed longer decision times at the shortest SOA of 150 ms. The homophone effect disappeared by 450 ms and did not return. The less skilled readers showed no homophone confusion (beyond their confusion for control words) at 150 ms. However, they did at 450 ms. By 2100 ms they show release from confusion. Note that there is a small difference remaining at 2100 ms for the less skilled readers, but it is not reliable statistically. However, these nonsignificant differences can be traced to individual reader and word differences that affect variance estimates. Because such differences are the heart of individual differences research, we return to these in the next section. For now, the general point is that rapid confusion leads to rapid release and delayed confusion leads to delayed release. The rapid confusion/release pattern is characteristic of the skilled readers and the delayed confusion/release pattern is characteristic of the less skilled readers. A single highly general activation/deactivation function is sufficient to explain this pattern.

Figures 4 and 5 show the results for high frequency words and low frequency words, respectively, as difference scores between decision times to homophones and controls. Thus, a confusion effect is represented by a score above the zero baseline. When the higher frequency member of a pair of homophones was presented (e.g., *night*), less skilled readers showed confusion at the middle SOA of
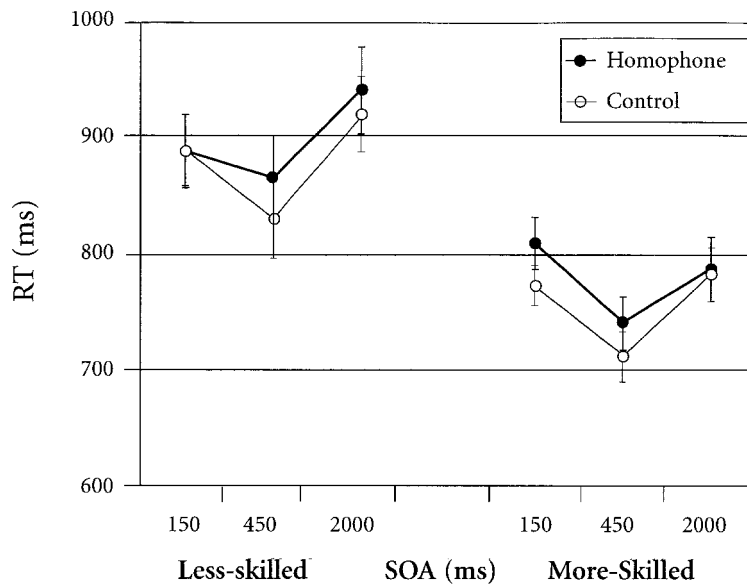
Figure 3. Skilled and less-skilled comprehenders differ in the time course of interference due to the activation of a competing homophone. Skilled readers are faster overall, and show both interference and its resolution more quickly
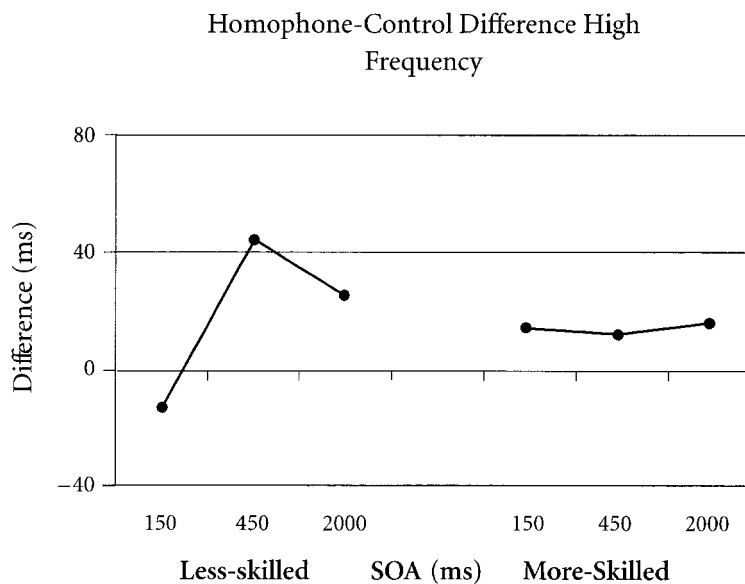

Figure 4. When reaction time to reject a high-frequency control word is subtracted from reaction time to reject a dominant homophone foil of the same average frequency, less-skilled comprehenders show evidence of interference, but skilled comprehenders do not
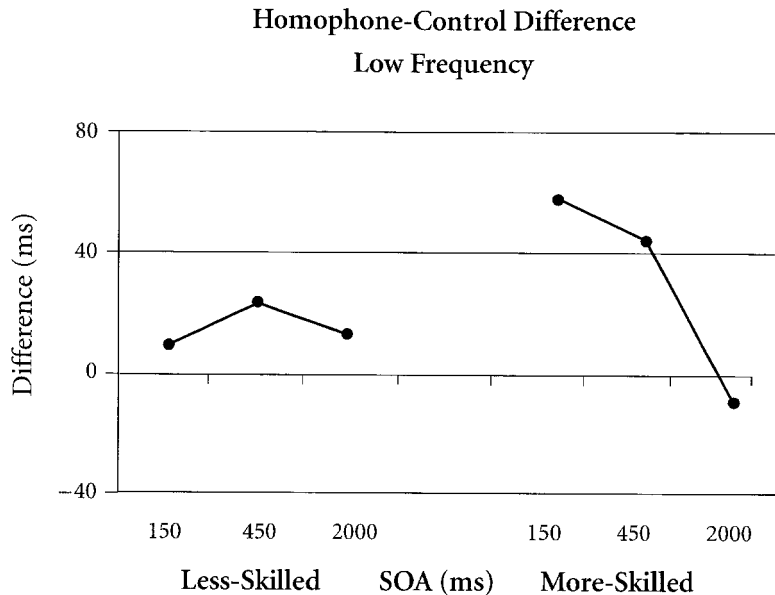
Homophone-Control Difference

Low Frequency

Figure 5. When reaction time to reject a low-frequency control word is subtracted from reaction time to reject a subordinate homophone foil of the same average frequency, skilled comprehenders show evidence of interference, but less-skilled comprehenders do not

450ms (and a nonsignificant effect at 2100 ms.). But no homophone confusion occurred for skilled readers at any SOA.

In contrast, for the lower frequency homophones, skilled readers showed the clearest evidence for confusion. And they showed this confusion at the shortest SOA, 150 ms. Low skilled readers show some confusion, but the homophone-control difference was not reliable. To put these results in terms of our *gate/gait* example, skilled readers were confused by *gait* but not *gate*. Less skilled readers were confused by *gate* more reliably than by *gait*. And the time courses follow those shown in Figure 3: A rapid confusion/release effect for skilled readers, a slower confusion/release effect for low skill readers.

These results are consistent with the general assumptions of the Lexical Quality Hypothesis, but more interesting is that they are consistent with two specific non-obvious predictions derived from the hypothesis: that skilled readers show earlier confusion than less skilled readers and that their confusion is restricted to the less frequent member of a homophone pair.

Homophones in context

Our strategy in the meaning judgment experiment was to create a simple comprehension situation that put stress on lexical representations. In the absence of

any supporting context, the only way for the reader to make a judgment about meaning is to use knowledge of word form and meaning. What happens when the reader can use context? Ordinarily, the constraint of sentence meaning reinforces the lexical information, adding evidence, for example, that the word *gait* requires some meaning other than that of *gate*. Other research demonstrates that top-down comprehension strategies are available to children who are less skilled readers (Perfetti, 1985; Stanovich, 1980), and we should expect this to be the case for our adult readers. We should see a reduction of homophone interference in context.

Indeed this is what we found in a second experiment carried out with a new sample from the same population of college students, divided on reading comprehension according to the Nelson-Denny (Hart & Perfetti, under review). In this experiment, a constraining sentence ended in a homophone, and then, after a variable SOA, a meaning probe appeared. For example, *Because of his leg injury, the man walked with an unusual gait.* The key comparison was between a decision to a word related to the meaning of the homophone mate (*fence*) and a control word. The design was complete and fully counterbalanced, replicating the first experiment. One view of the results is seen in Figure 6, which shows the decision time difference between control words and homophones for correct "no" judgments. For both groups of readers, homophones produced no problems in context. There was an interesting but unreliable tendency for skilled readers to show confusion only at the shortest 150 ms SOA, consistent with the general pattern that skilled readers, if confused at all, show early confusions that disappear quickly. Not visible in Figure 6 is the important fact that skilled readers were faster than less skilled readers in decision times for control words as well as homophones, as expected. Also as expected, the difference in decision times between the skill groups was much smaller than when the subjects had no context to support their decision-making and had to rely on form knowledge.

Although this is not the same group of subjects as those in the first experiment, it is striking to see the disappearance of a confusion effect in context. This is certainly consistent with the findings that even less skilled readers use context. Its implications, when coupled with the results of the word pair experiment, are clear: Homophone confusion depends on comprehension skill. However, the effect of comprehension skill is mediated solely by lexical factors and is not visible in comprehension. This seeming paradox is resolved as follows: The comprehension task here was targeted to the single final word. In effect, the semantic constituent of the word is reinforced sufficiently to override any unstable orthography and phonology. Less skilled readers may be more dependent on word meaning (because of weakness elsewhere in their lexical representations) and providing more cues to the meaning is very helpful. More directly persuasive, however, is the clear fact that this group does not comprehend as well as the high skill group. They were defined this way. Thus, their general comprehension problem has a lexical basis. It can be overcome only in specific tasks that are not typical of ordinary comprehension.

Biased Context
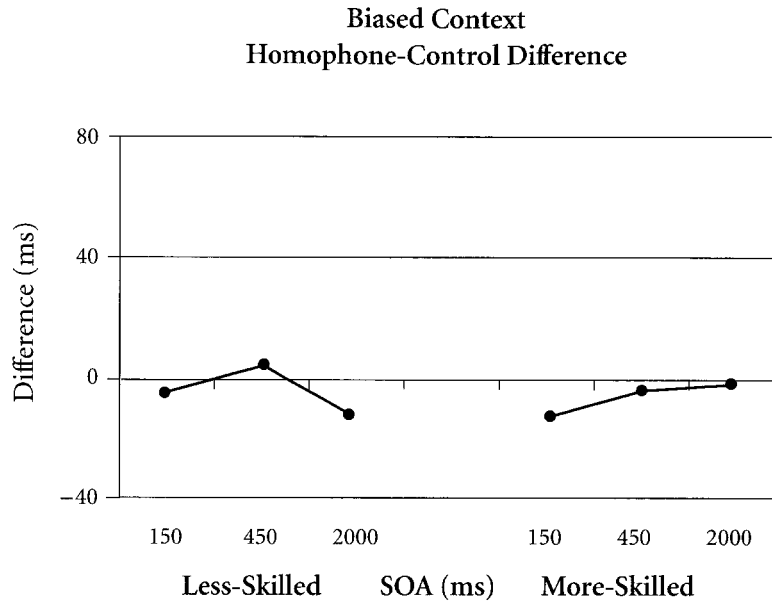## Homophone-Control Difference

Figure 6. Homophone interference (control words minus homophones) disappeared in sentence contexts. Neither skill group showed a difference between control and homophone foils when the sentence fit only one of the homophones

Incidentally, there is nothing in these data to suggest that less skilled readers have a problem in suppression. In terms of the Structure Building Framework (Gernsbacher, 1990) one could say that our context effects demonstrate the enhancement of structures is something that less skilled readers can do well. The Verbal Efficiency Theory makes the same prediction, based not on enhancement but on basic lexical identification. The slower the process (because of lexical quality) the more room for context facilitation. Moreover, this idea generalizes to account for the facts of homophone confusion when there is no context. When the reader is solely dependent on word form, weaknesses in word form are revealed. This results in the pattern of experimental results we observed: Slower activation and deactivation by the less skilled reader and confusion restricted to more familiar word forms.

Thus, a separate suppression mechanism (Gernsbacher, 1990) appears not to be needed to explain the pattern of results. One would have to say both that less skilled readers have low quality word representations and that they have faulty suppression mechanisms. Alternatively, suppression may be nothing more than the time course of competing activations. A failure to suppress would be a prolonged course (with lexical knowledge setting the upper limit) and a successful suppression would be a shorter time course of competing activations. The quality of the lexical representation would be the determining factor, both for the initial process of word identification and the time course of the resolution of the competition.

Reading skill and the structure of lexical knowledge

Given some experimental evidence that supports predictions of the Lexical Quality Hypothesis, it is of interest to demonstrate the meaningfulness of the concept of lexical quality by using assessments of word knowledge and comprehension. For this demonstration, we have data on 445 University of Pittsburgh undergraduates who participated in a range of assessments. The point was whether, by fortunate sampling of lexical knowledge constituents, we could quantify a basic idea of the Lexical Quality Hypothesis — that reading skill consists of coherent and reliable representations of constituents: reliable in that they survive threats to their stability and coherent in that the constituents are inter-correlated to the point of functional redundancy. We take our homophone experiments to have demonstrated the reliability of representations, in that threats to quality are demonstrable when words share form. In this study, we want to demonstrate the coherence of representations. By coherence, we mean roughly that given either a pronunciation or a spelling, the other two constituents of a word are immediately available. Coherence is a natural by-product of fully specified and redundant representations, as those ideas were defined in Perfetti (1991).

To test the interconnections among the constituents of the model, we administered tasks that tap spelling, phonology and meaning, and sought the factor structures that underlay performance across the tasks. For a skilled reader, scores on tests of orthography, phonology, and semantics should be firmly inter-correlated. Equally important, tests for constituent knowledge should be correlated with text comprehension, as well. Although text comprehension requires skills beyond lexical knowledge, a strong lexical representation system provides the scaffolding upon which to build a representation of the text. The more coherent the word representations, the more efficient the word identification system, and the more resources are available for combining identified words into a meaningful representation of the text's message. Thus, our expectations were that we could find evidence in the correlational structure of task performance consistent with the Lexical Quality Hypothesis that skilled readers show more coherent representations of more words than do less skilled readers.

Methods of the study

Undergraduate students who participated in a variety of language experiments, also completed a number of tasks designed to tap the orthographic, phonological, and semantic lexical constituents as well as a standardized reading comprehension test. Several of the lexical knowledge tasks were computer-administered, allowing measures of speed as well as accuracy. The number of students who completed all assessments was 445. The tasks, which are listed below, cannot be "pure" measures of orthographic, phonological, or semantic knowledge. They assess performances that are supported by multiple knowledge sources. The most one can say

is that a given task at least requires knowledge about one or more targeted constituents. We have provided a brief indication of whether we take a task to assess primarily orthographic (OR), phonological (PH), or semantic (SE) knowledge or mixes of two or more.

1. The Baroff Spelling Test (Wood, personal communication), adapted for computer administration. This is a spelling discrimination task in which subjects are presented with one correct and four incorrect spellings of irregular, easily misspelled words (e.g., nuisance, nuisence, newsance, newcense, newsince). Both speed and accuracy were recorded. This can be considered a direct reflection of orthographic knowledge, relatively free from semantic and phonological influences. (OR)
2. The Test of Auditory Analysis Skills (Rosner, 1979), with three additional, more difficult items. This is a phoneme elision task, that varies from removing syllables (say 'cowboy' without the 'boy,' to splitting blends (say 'smack' without the /m/). Only accuracy was recorded. This is phonological knowledge assessment, with some potential for support from orthographic knowledge (PH).
3. A homophone choice task. Subjects saw sixteen sentences with the last word missing, and chose one of two homophones to complete the sentence. For example, "The woman lived in the elegant brick _____ 1. Manner, 2. Manor." Half of the sentences were best completed by dominant homophones, and half were best completed by subordinate homophones. Both speed and accuracy were recorded. This can be considered an assessment of orthographic-semantic knowledge, relatively free from phonological influences. (OR, SE)
4. The Woodcock-Johnson Psychoeducational Battery, Word Attack Subtest = (Woodcock & Johnson, 1977), adapted for computer administration. This is a pseudoword decoding task, in which the items go from easy 'jox' to difficult 'phigh.' Both speed and accuracy were recorded. This is an assessment of orthographic-phonological knowledge, free of semantic influences. (OR, PH)
5. The Woodcock-Johnson Psychoeducational Battery, Word Identification Subtest (Woodcock & Johnson, 1977), adapted for computer administration. This is a single word reading task, in which the items go from easy 'must' to difficult 'enceinte.' Both speed and accuracy were recorded. This assesses a mix of orthographic, phonological, and semantic knowledge. (OR, PH, SE)
6. The Nelson-Denny Vocabulary Test (Nelson & Denny, 1973). Twenty items were chosen, spanning the range of difficulty of the task. Subjects were given two minutes to circle the correct definitions of these twenty words, in a multiple-choice format. Both speed (number of items attempted) and accuracy (on only those items attempted) were recorded. This test assesses semantic knowledge, although with some influence of orthography and phonology (both of which support the word identification necessary to perform the task. (SE)
7. The Nelson-Denny Comprehension Test (Nelson & Denny, 1973). This is a text comprehension test, in which eight paragraphs are followed by four to five questions, for a total of 36 questions. Subjects were given 15 minutes to

Table 1. Hypothesized demands of 6 tasks on orthographic (OR), phonological (PH), and semantic (SE) knowledge

TASK	OR	PH	SE
Baroff spelling	+		
Homophone choice	+		+
Auditory Analysis		+	
Word attack	+	+	
Word identification	+	+	+
Vocabulary			+

Note. Pluses indicate the hypothesized lexical knowledge sources tapped by a given task. Arguably, all reading tasks involve all three knowledge sources, so our + marks the importance of the knowledge source relative to others for that task.

complete the test, instead of the usual 20 minutes. Both speed (number of items attempted) and accuracy (on only those items attempted) were recorded.

According to our assessment, of the six tasks that measure lexical and sublexical knowledge (all but the Nelson-Denny comprehension test), one is OR, one is PH, and one is SE. The other three are mixed: one OR/PH, one OR/SE, and one is OR/PH/SE. Thus OR is involved in 4 tasks, PH in 3, and SE in 3. Our assumptions on this issue are represented in Table 1.

Subjects were identified as less-skilled, average, or more-skilled readers based on the number of correct items on the Nelson-Denny text comprehension test. Each group consisted of a third of the total distribution. Figure 7 shows the distribution of comprehension scores for this group of 445 subjects. Figures 8 and 9 show the mean test scores for each group.

Separate factor analyses for each comprehension group allowed us to examine the degree to which the correlation structures were comparable in their expression of lexical knowledge and comprehension. Factors were orthogonally rotated such that factors were not correlated with each other. Within this general approach, we can look for differences among the groups in the number of factors required to account for a given level of variance, the loading of different measures on a given factor, and the extent to which variables load onto more than one factor, all of which can be taken as reflecting the coherence of lexical knowledge within a group of readers of comparable comprehension skill. We separate speed and accuracy measures.[2]

Accuracy

With a criterion of Eigenvalues > 1 and factor loadings > 0.4, the accuracy analysis achieved the following solutions: Two factors accounted for 54% of the variance for the 145 skilled and the 150 average comprehenders, and three factors accounted for 63% of the variance for the 150 less-skilled comprehenders.[3]
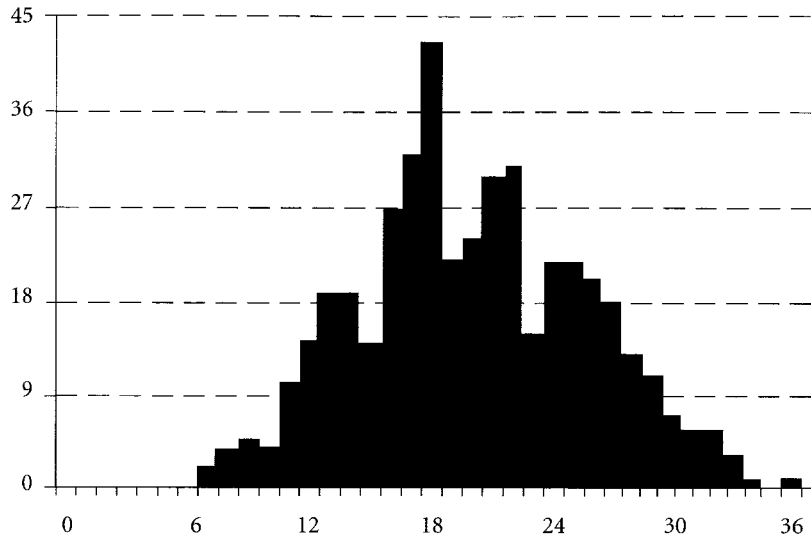
Figure 7. Distribution of Nelson-Denny comprehension scores for the norming group of 445 subjects. The breaks in the normal distribution correspond to divisions between passages and groups of comprehension questions

Speed

The speed score analyses included the six independent variables scored for speed, and achieved the following solutions: Two factors accounted for 66% of the variance for the skilled comprehenders, and three factors accounted for 82% and 80% of the variance for the average and less skilled comprehenders, respectively.

Interpretation of the factor analyses

One interesting result is that for both speed and accuracy, two factors were sufficient for skilled readers. For less-skilled readers, three factors were required to account for both speed and accuracy. For average readers, two factors accounted for accuracy but three were needed to account for speed. In interpreting the factor structures, we refer to the hypothesized lexical knowledge sources — Orthographic (OR), Phonological (PH), and Semantic (SE). Comprehension as measured by the Nelson Denny is not a lexical factor, but by including it in our analyses, we hoped to be able to relate lexical factors with comprehension.

Consider first accuracy measures, shown in Table 2. For skilled readers, only 2 factors emerge. Factor 1 includes all tasks except vocabulary and comprehension. It has an OR task as its highest loading task, and three of the other tasks include PH. Thus Factor 1 appears to be a factor dominated by form knowledge,
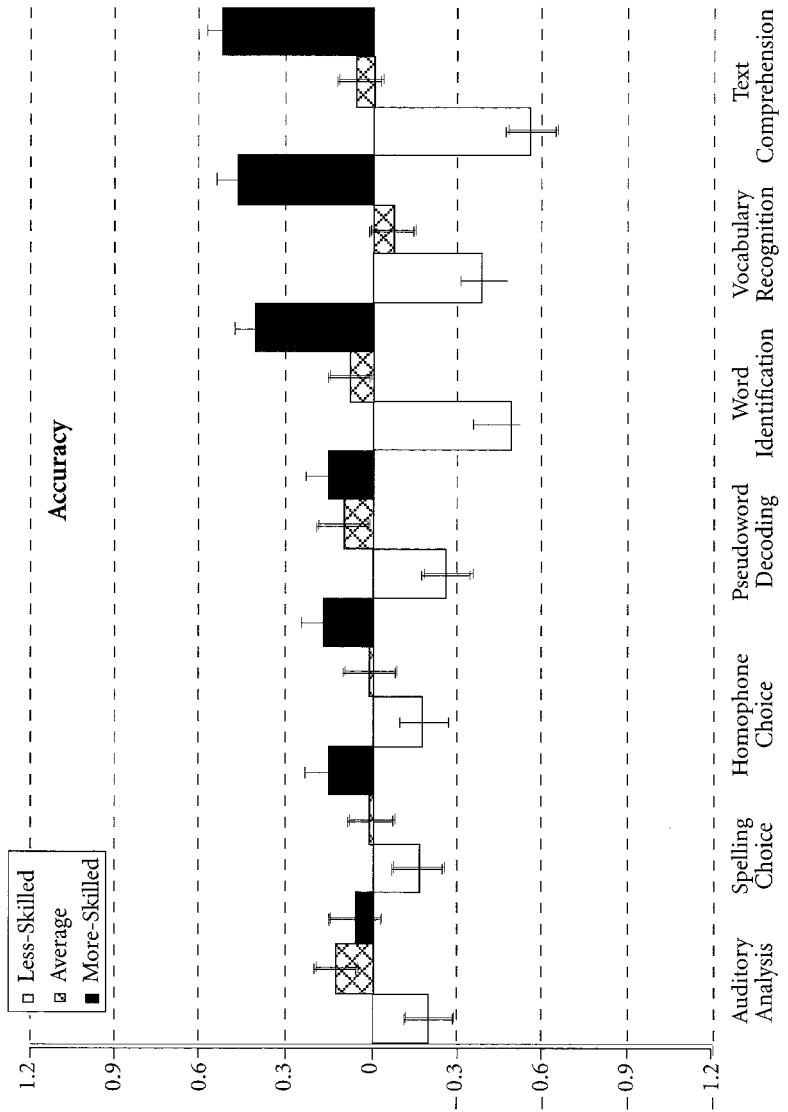
Figure 8. Means and standard deviations, between comprehension groups, for standardized accuracy scores
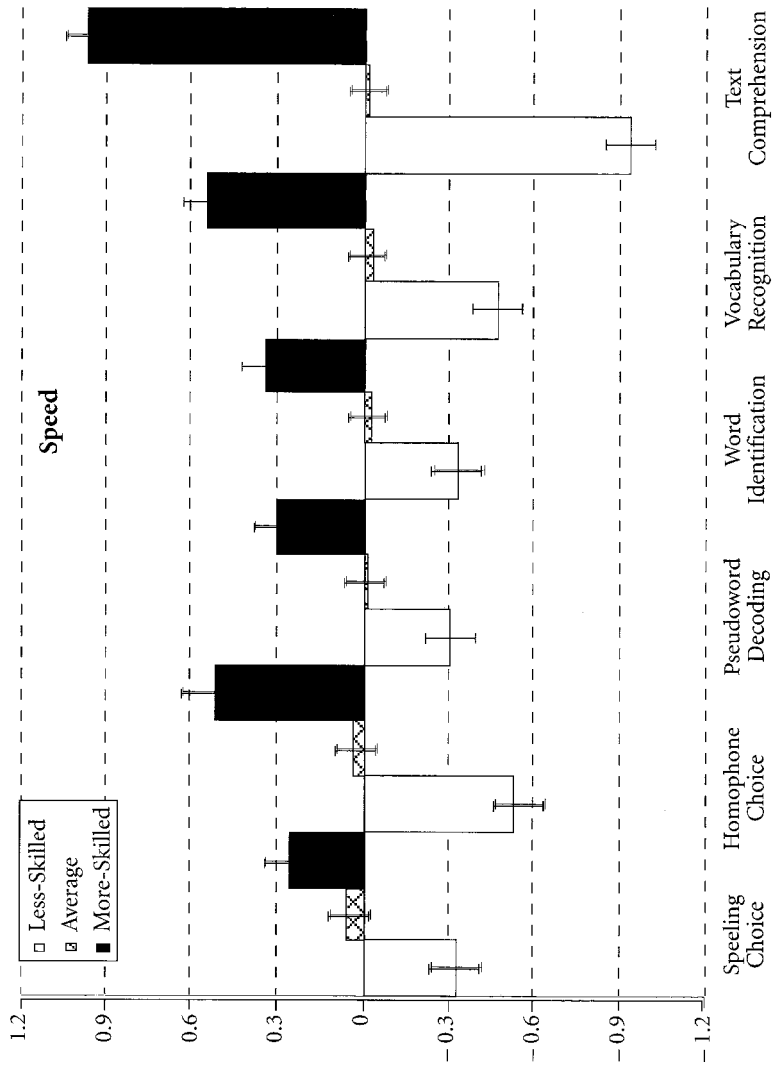
Figure 9. Means and standard deviations, between comprehension groups, for standardized reaction time scores

Table 2. Factor loadings of 7 tasks for orthographic (OR), phonological (PH), and semantic (SE) accuracy

SKILL	High		Average		Low		
TASK/FACTOR	1	2	1	2	1	2	3
Baroff spelling	.8		.7			.7	
Homophone choice	.5		.5			.8	
Auditory Analysis	.6		.6		.8		
Word attack	.6		.7		.7	.5	
Word identification	.6	.4	.7		.7		
Vocabulary		.9		.8			.8
Comprehension		.7		.8			.7
VARIANCE EXPLAINED	30	24	32	22	24	21	18

OR and PH. Factor 2 links word identification, vocabulary and text comprehension. We can characterize Factor 2 as an SE factor. But interestingly, word identification loads on both factors. Thus for the skilled readers, there is a Form Factor (OR/PH) and a Meaning Factor, with word identification linking the two.

For less skilled readers (n = 150), Factor 1 is dominated by PH, with the auditory analysis task being the highest loader, followed by word identification and word attack. Factor 2 was a semantic-comprehension factor, represented only by the two Nelson-Denny tests. Factor 3 appears to be a form factor with orthography dominant, grouping homophone choice, spelling choice, and word attack. Whereas the skilled readers had word identification as a linking variable, the less skilled readers had word attack as a linking variable linking a PH-dominant factor (1) with an OR-dominant factor (3).

Average comprehenders (n = 150) had a factor structure similar to more-skilled comprehenders, with two factors sufficient. Factor 1 included 5 variables that included OR and PH, and, like the first factor for the skilled group, can be considered a Form factor. Factor 2 picked up the two Nelson-Denny tasks, and can be considered a meaning-comprehension factor. Unlike the skilled readers, however, word identification did not serve as a linking variable. The middle group showed no linking variables.

For lexical speed measures, Table 3 indicates that, for skilled readers, two factors are again sufficient. Factor 1 includes word identification and word attack as the two strongest loadings, adding two OR tasks, spelling and homophone choice. This factor thus includes tasks that tap OR, PH, and SE knowledge, a general lexical factor that includes sublexical phonology. Factor 2 includes again the OR tasks of homophone choice and spelling choice, adding comprehension and vocabulary. This Factor can be interpreted as an orthographic-semantic-comprehension factor that picks out the connection between word familiarity and comprehension.

The less skilled readers required three factors again. The first factor was loaded by word attack and word identification strongly, with homophone choice last. This can be characterized as a general lexical factor similar to Factor 1 for skilled readers,

Table 3. Factor loadings of 6 tasks for orthographic (OR), phonological (PH), and semantic (SE) speed

SKILL	High		Average			Low		
TASK/FACTOR	1	2	1	2	3	1	2	3
Baroff spelling	.4	.7		.9			.9	
Homophone choice	.4	.7		.9		.4	.8	
Word attack	.9		.9			.9		
Word identification	.9		.9			.9		
Vocabulary		.6			.8			.8
Comprehension		.7			.8		.5	.7
VARIANCE EXPLAINED	33	33	31	29	22	31	29	20

except that spelling did not load on this factor. Semantic and phonological knowledge may be more represented in this factor than orthographic knowledge for less skilled readers. For Factor 2, spelling and homophone choice were high loaders, with comprehension an additional variable. Thus Factor 2 is primarily an OR factor at the lexical level. Factor 3 was again the combination of comprehension and vocabulary from the Nelson-Denny.

The middle group of readers, like the less skilled readers, required a three-factor solution. In an unusually tidy structure, Factor 1 was word identification and word attack, Factor 2 spelling and homophone choice, and Factor 3, vocabulary and comprehension, in each case with very high factor loadings. Thus, the average college reader's factor structure for speeded tasks can be characterized as (1) General Lexical processing, including pseudoword reading. (2) Orthography. (3) Semantics and Comprehension.

A summary of these interpretations is in Table 4, which refers to the hypothesized lexical knowledge sources — Orthographic (OR), Phonological (PH), and Semantic (SE) in addition to comprehension. Table 4 also shows links between factors where a variable loaded on more than one factor.

If we ignore the middle group of readers for now, we can summarize the interesting contrasts between high and low skill groups as follows, using highly inferential descriptors: Skilled readers show a highly generalized lexical processing factor, one we characterized as an integration of lexical knowledge sources (OR, PH, and SE). When accuracy is measured, this factor is one of lexical form, combining orthographic and phonological knowledge; when speed is measured and we have one fewer phonological tasks (the Auditory Analysis is accuracy only), this lexical factor includes semantic information, so is Form + Meaning. Second, two factors account for more of the variance for skilled readers than for less skilled readers. For accuracy, skilled readers can be said to reflect two factors, lexical form and meaning-comprehension. For speed, the two factors are better characterized as lexical knowledge (form + meaning) and comprehension (meaning + comprehension). Third, skilled readers show linking variables, variables that load on more than one factor. In accuracy, this variable is word identification, which is

Table 4. Inferred structure of lexical knowledge and comprehension for three levels of comprehension skill

Accuracy Measures	Factor 1	Factor 2	Factor 3	Links Between Factors
High Skill	OR-PH	SE-Comp		Word Identification
Low Skill	PH	SE-Comp	OR	Pseudoword reading, 1& 3
Medium Skill	OR-PH	SE-Comp		None
Speed Measures				
High Skill	OR-PH-SE	OR-SE-Comp		Spelling & Homophone knowledge
Low Skill	PH-SE	OR-Comp	SE-Comp	Homophone Knowledge, 1& 2
Medium Skill	PH-SE-OR	OR	SE-Comp	None

Note. The cell entries are the inferred lexical knowledge sources based on the factor analyses: PH = phonological, OR = orthographic, SE = semantic. All tasks allowed both accuracy and speed measures, except the Auditory Analysis task, a PH task. Accordingly the potential to observe a PH component in speed measures is greatly reduced. Links between factors are tasks that loaded on more than factor. Such links can be said to mark increased lexical coherence.

important for the lexical form factor and the meaning-comprehension factor. For speed, the links are made by orthographic tasks that tap spelling knowledge (presumably linked to word meaning knowledge). Word familiarity drives response speed and supports both rapid word identification (Factor 1) and comprehension (Factor 2).

The evidence for coherence among knowledge sources — in the factor structures and the links — is less for low skill readers. They require 3 factors instead of 2 and their links are different. In accuracy, their first factor lacks orthography, instead being mainly phonology. Orthography comes in as a separate third factor. They show a link, but instead of word identification, it is pseudoword reading (word attack), linking their first and third factors. In speed measures, the picture is similar — no OR component to their primary lexical factor, which instead is PH-SE. For the low skilled readers, orthographic knowledge may not be integrated with other lexical knowledge as powerfully as it is for skilled readers.

We do not suggest sharp qualitative differences here. Indeed, the Lexical Quality Hypothesis is an explicitly graded one. Our contrasts between high and low skill readers pick out small differences in correlational structures that get reflected in factor structure and interpretation. But there are no dramatic reversals in the pattern of correlations that are at the bottom of the pyramid. Only from the top can we see hints that the extent to which pieces of knowledge cohere in the two groups may be different. Of course, part of what gets reflected in these analyses are differences within groups, which is what cause correlations to be lower. The less skilled readers are more variable. Still, our theoretical argument takes variability

as part of the story. That is what it means to have lower quality representations. The chances that two words for the same reader will vary in quality are higher and the chances that two readers of the same word will vary are also higher.

Whether we can identify which lexical constituents are most likely to be the weak constituents and thus be the cause of low quality is not yet clear. Probing a reader's knowledge of a word is seldom if ever carried out in the way that is necessary to really assess lexical quality. The tasks we used here, although they were sensible and sensitive (providing speed of processing as well as accuracy), were far from the ideal implied by the concept of lexical quality. They were not repeated tests of the same word, and they were not particularly sensitive to just certain constituents. Still, the results are suggestive of the following: Low skill readers have less well integrated (or less coherent) lexical representations. The first factor for both speed and accuracy showed this difference, and the piece missing seems to be orthography.

To head off an unwarranted conclusion, this is not the same as saying that the low skill readers didn't know the spellings of words. In fact, they differed the least from the average and skilled readers on the Baroff spelling and Homophone choice tasks. They also do not know meanings, how to decode difficult pseudo-words, and they are low on phonological awareness. Rather, it is that their orthographic knowledge is doing a little less for their overall word knowledge. It is less interconnected with both their vocabulary knowledge and their decoding ability, which are actually highly related. If we assume that the main thing this group lacks is enough experience in reading, things fall into place. They are behind in developing the high quality orthographic representations that come with lots of reading experience with specific words (Stanovich & West, 1989).

The mid-level readers fill in the picture. They are more similar to skilled readers in some ways, more similar to less skilled readers in others. Like high skill readers, their accuracy performance can be described by two factors; but unlike the skilled readers, word identification is not a linking variable. Like skilled readers, their first factor for both speed and accuracy is a generalized lexical form factor for accuracy, and a generalized form + meaning factor for speed. Like less skilled readers, their speed performance requires 3 factors; but they show no linking variables. These average readers can be characterized as on their way to fully integrated lexical knowledge, but their lower loadings on orthographic measures in speed tasks and the absence of linking variables in both speed and accuracy suggests that their present level of reading experience falls short of the skilled readers.

We must apply caution to this exercise of interpretation. Not to be forgotten is that underlying these factor structures are variability and co-variability between subjects on the same task and between tasks for the same subject. The factor structures are not about skill levels, but about the configurations of co-variance that are expressed in task performances. Even in drawing attention to the different roles played by some task, e.g., orthographic performance, for skilled and less

skilled readers, we emphasize that it is the inter-task correlations, not the level of orthographic knowledge that is interesting.

Summary and conclusions

The Lexical Quality Hypothesis includes some highly general assumptions about the nature of reading and some specific claims about effective word knowledge. Skilled reading rests on high quality word representations that include well specified orthographic, phonological, and semantic-syntactic information. The effects of variation in quality are seen in comprehension, both in comprehension as assessed in standard ways, and in simple scaled-down comprehension tasks such as the word meaning judgment tasks we described in the first part of this chapter. Our results in simple word pair comprehension produced non-obvious results consistent with the Lexical Quality Hypothesis. When words that shared phonological forms with other words (homophones) were presented for meaning judgments, readers briefly showed confusions, as if the unpresented homophone were being considered in the meaning judgment. Especially interesting, however, was that skilled readers actually showed this confusion more quickly than did less skilled readers. And their confusion also ended more quickly. Also consistent with the Lexical Quality Hypothesis is that skilled readers showed no confusion when presented with the high-frequency member of a homophone pair. Thus, the homophone experiments provide evidence that high quality representations (higher for high frequency words, higher for high skilled readers, higher for words that aren't homophones) have predictable consequences in simple comprehension tasks. They demonstrate also the low knowledge that less skilled readers have about word forms. When context could support the meaning decisions, the confusions they showed for homophones disappeared.

To further illustrate the concept of lexical quality, we analyzed the factor structure extractable from the performance of 445 college students on tasks that tap mixes of orthographic, phonological, and semantic knowledge. The factor structures that emerged suggest a more coherent lexical knowledge structure for skilled readers than less skilled readers. Orthographic and phonological structures are closely linked with each other for skilled readers, and less so for less skilled readers. The lack of integration of orthographic performance for low skilled readers suggests that spelling knowledge is not serving word reading in the same way it is for skilled readers, as a group. It is clearly true, without factor structures, that skilled comprehenders know more about words and word forms — their spelling, their meaning, their pronunciations — than do less skilled comprehenders. This is the simple general idea underlying the lexical quality hypothesis. However, an implication of our analysis is not that there is some constituent of word knowledge, e.g., spelling, that needs to be fixed for a less skilled reader. The implication is that experience with words, retrieving and using their spellings, pronunciations

and meanings is a critical foundation of reading skill. The coherence and reliability of constituent knowledge is a consequence of such lexical experiences, repeated generously.

Notes

1. The word in Figure 1 is actually a homophone. However, this makes no difference for the general analysis. Just assume that only this word and not its homophone mate is known to the reader.

2. Another way to examine coherence of shared variance is to use an oblique rotation and examine correlations between factors. We chose to rotate orthogonally to obtain independent factors. Oblique rotation produces the same number of factors with very similar structures, for both speed and accuracy analyses. Skilled comprehenders have higher correlations between factors than do average comprehenders, and average comprehenders have higher correlations between factors than do less-skilled comprehenders.

3. There is a tradeoff between number of factors and variance explained. In the optimal solution (with two factors for skilled and average comprehenders and three factors for less-skilled comprehenders), the optimal ratio of number of factors to variance is achieved; the skilled and average comprehenders have nearly the same amount of variance explained with only two factors as the less-skilled comprehenders have with three factors. When a two-factor or three-factor solution is forced, the amount of variance explained for each group is equated. Three factors explain 67%, 67%, and 63% of the variance and two factors explain 53%, 54%, and 49% of the variance for the skilled, average, and less-skilled groups, respectively. This applies similarly to the speed analysis. Three factors explain 80%, 82%, and 80%, and two factors explain 66%, 64%, and 63% of the variance for the skilled, average, and less-skilled groups, respectively.

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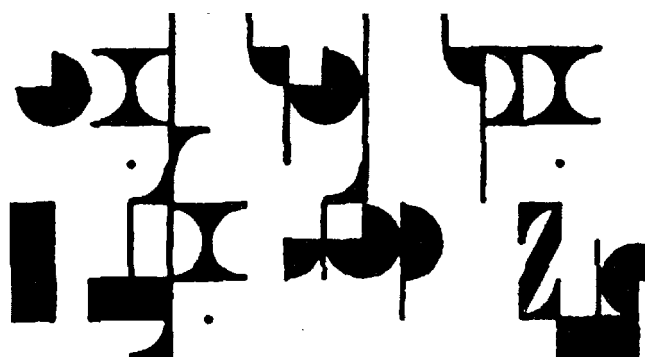
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Precursors of Functional Literacy

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