Adding the Phonological Processor: How the Whole System Works Together

Although skillful readers do not depend on phonological translation for recognizing familiar words, they seem quite automatically to produce such translations anyway. In this chapter, we examine why and how they do so. Far from being superfluous, such phonological translation adds a critical degree of redundancy to the system. Without it, even skillful readers would find themselves faltering for fluency and comprehension with all but the very easiest of texts.

The Nature of the Phonological Processor

Figure 8.1 illustrates the way in which readers' phonological knowledge and processes are theoretically related to the rest of the system as it is involved in reading.[1] As with the Orthographic and Meaning processors, the Phonological processor contains a complexly associated array of primitive units. The auditory image of any particular word, syllable, or phoneme corresponds to the activation of a particular, interconnected set of those units.

In figure 8.1 the arrows between the Phonological and Orthographic processors run in both directions. The arrow that runs from the Orthographic processor to the Phonological processor indicates that as the visual image of a string of letters is being processed, excitatory stimulation is shipped to corresponding units in the Phonological processor. If the letter string is pronounceable, the Phonological processor will then send excitatory stimulation back to the Orthographic processor; such feedback is represented by the arrow that runs in the other direction.

1. See Seidenberg and McClelland (1989).

The Phonological processor is also connected in both directions to the Meaning processor. In this way, the activation of a word's meaning results in the excitation of the phonological units underlying its pronunciation. Conversely, the activation of its pronunciation automatically arouses its meaning.

It is especially important that the Orthographic, Phonological, and Meaning processors are all connected in both directions to each other. This circular connectivity ensures coordination between the processors. It ensures that all three will be working on the same thing at the same time. More than than, it ensures that each processor will effectively guide and facilitate the efforts of the others. As we shall see, this is critical both to reading and to learning to read.

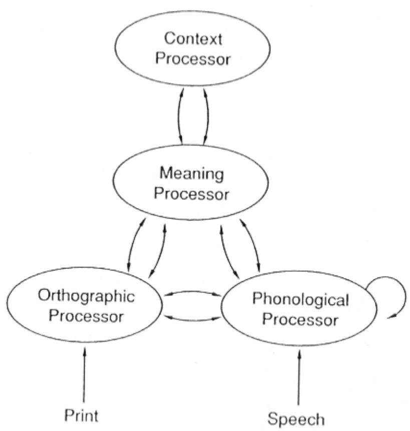


Figure 8.1
Adding the Phonological processor.

The Phonological processor has two other features that set it apart from the others. First, like the Orthographic processor, it accepts information from the outside. However, the information that it accepts is speech. Note that the Orthographic processor is still the only one to receive information directly from the printed page, reflecting the fact that reading depends first and foremost on visual processing. Second—and this is an important asset in the reading situation—the knowledge represented within the Phonological processor can be activated or reactivated at our own volition. Not only can we speak, we can also subvocalize or generate speech images at will.

The Importance of Phonological Processing in Reading

The direct connections from the Orthographic to the Phonological processor suggest that phonological activation is an automatic and immediate consequence of visual word processing, and indeed it is.[2] But the Orthographic processor is also directly connected to the Meaning processor, implying that for skilled readers at least, the meaning of a word may be activated just as quickly as its sound.

Meaning activation is, of course, the whole point of reading a word. If it does not depend on phonological translation and, further, may happen just as quickly as phonological translation, one is left wondering why phonological translation should be set up as an automatic aspect of the system. What is the function of the Phonological processor? Why is it there?

One capability it supports is that of reading aloud with fluency. Yet this hardly seems an adequate design criterion for making it so integral a part of the system. If our heads were designed by a computer engineer, there might instead be a little toggle switch that turned the Phonological processor on when it was time to read aloud and off otherwise. After all, when phonological translations are superfluous, why invest any energy in carrying them out?

The answer is that for optimal reading performance, phonological translations are rarely superfluous; perhaps they are never predictably so. The activities of the Phonological processor provide two invaluable services to the system. First, they provide an alphabetic backup system—a redundant processing route—that is critical for maintaining the speed as well as the accuracy of word recognition necessary for productive reading. Second, they provide a means of expanding the on-line memory for individual words as is essential for text comprehension. Let us examine the nature and value of each of these services in turn.

Interactions among All Three Processors: The Alphabetic Backup System

Both the immediate and long-term impact of reading depend critically on the speed as well as the accuracy with which readers can identify the individual letters and words of the text.

2. Perfetti, Bell, and Delaney (1988); Tannenhaus, Flanigan, and Seidenberg (1980); Van Orden, Johnston, and Hale (1988).

This is because the utility of the associative linkages, both within and between processors, depends on the speed and completeness of the input they receive. When the words of a text are processed too slowly or scantily, readers forfeit any automatic facilitation and guidance that the associative connections would otherwise provide. Commensurately, they also forfeit the opportunity to recognize, learn about, and understand what they have read.

The accuracy and speed of written word recognition depend first and foremost on the reader's familiarity with the word in print. The more frequently a spelling pattern has been processed, the more strongly its individual letters will facilitate each other's recognition within the Orthographic processor. The more frequently a written word has been interpreted, the stronger, more focused, and thus faster will be its connections to and from the Meaning processor. The more frequently a spelling pattern has been mapped onto a particular pronunciation, the stronger, more focused, and thus faster will be its connections to and from the Phonological processor.

In short, when readers encounter a meaningful word that they have read many times before, the Orthographic processor will very quickly resonate to the pattern as a whole. Further, the word's meaning and phonological image will also be evoked with near instantaneity. For texts consisting entirely of such highly familiar words, it follows that phonological translation might indeed be somewhat superfluous (except when reading aloud). However, such texts are highly unlikely.

To estimate the frequencies with which students do encounter different words, Carroll, Davies, and Richman sampled 5,088,721 words from school books, grades 3 through 8, and counted the number of times each different word occurred.[3] Fully 50 percent of their sampled words consisted of just 109 very commonly used words. Moreover, roughly 75 percent of the sample was made up of only 1,000 different words and 90 percent of only about 5,000 different words.

In contrast, the *total* number of different words that these researchers encountered was 86,741.[4] Individually the 80,000 or so words that make up the remaining 10 percent of the sample must be encountered relatively infrequently by readers. Collectively,

3. Carroll, Davies, and Richman (1971).

4. Carroll et al. (1971) treated each distinct string as a different word such that, for example, *word, Word, word's, worded, wordiness, wording, words, Words,* and *wordy* appear as separate entries in their count.

however, they represent more than 94 percent of the different words the young reader is expected to encounter. Moreover, each of these 80,000 less common words is expected to be understood by the schoolchild, or it would not appear at all.[5]

But the point is not simply that there are frequent and infrequent words. It is that there is a tremendous range in the frequencies of the different words that students encounter in print.[6] The most frequent word in the Carroll, Davies, and Richman count (which is *the*) is expected to occur more than 73,000 times in every million words of reading. The hundredth most frequent word (*know*) should occur about 1,000 times in every million words of reading;[7] the thousandth most frequent word (*pass*) should occur about 86 times per million words; the five thousandth most common word (*vibrate*) should occur about 10 times per million; and occurring less often than that, are thousands upon thousands of other good words (e.g., *crayon, warn, fiction, kiss, sweater, bump, remark, yell, lizard, disappointment, astronomer, suggestion, pebble, iceberg, magician, horrible, wink*). There must be an analogous range in the students' familiarity with the words they read.

It is in the reading of less familiar words that the presence of the Phonological processor or, more significantly, the presence and circular connectivity of all three processors becomes so advantageous. One reason for this advantage is that the processors are distinct from one another in terms of both the kinds of input they receive and the internal knowledge with which they work. Because of this, each is vulnerable to its own types of error- and speed-related failures and difficulties. The other reason for this advantage is that none of the processors "knows" whether

5. Carroll et al.'s (1971) findings for the third-grade sample were similar to those for the sample as a whole. The third-grade sample was comprised of 840,857 words of running text, representatively selected from a set of textbooks, tradebooks, workbooks, reference books, and magazines. Of these, 50 percent were accounted for by roughly 100 words, 75 percent by roughly 800 words, and 90 percent by roughly 2500 words. In contrast, the total number of distinct words encountered was 23,477.

6. The same holds true for adults. Sampling 1,000,000 words of adult reading matter, Kucera and Francis (1967) found 50 percent accounted for by just 133 words.

7. Bear in mind that there are many chance factors underlying which word occurs at which particular rank in a word count — the more so as the rank of the word decreases. The word *know* is therefore better taken as illustrative of the class of words that are about the hundredth most frequent in printed school English rather than as the particular word that will actually hold that position in any particular sample of text. And the same goes for the less likely examples presented above.

a string is actually a word. Instead each processor is capable only of producing its own rather mechanical and frequency-driven responses to its own type of input. Because of this, each processor by itself would be blindly vulnerable to its own distinct set of confusions.

The coordinated and interactive attack on word identification that the processors pull off together generally serves to overcome the confusions and to compensate for the difficulties in speed or resolving power that any one of them alone might suffer. To understand this more fully, let us detail the specific kinds of difficulties and confusions that may arise within each of the processors, along with the compensation provided by the rest of the system. Be warned: Because this discussion pivots on the timing and logic of the interactions among all of the processors, it is necessarily complicated.

Orthographic Processing

Vulnerabilities of the Orthographic Processor

The Orthographic processor takes individual letters as input and responds to the familiarity of the ordered string by linking the letters together into multiletter patterns. The strength and speed of the Orthographic processor's response to a word depend upon two factors: the speed and adequacy with which the individual letters are perceived; and the familiarity of the spelling patterns comprising the word.

The Orthographic Processor's Dependence on the Speed and Adequacy with which the Individual Letters Are Perceived. To the extent that the individual letters of a word are poorly perceived or mistaken, the Orthographic processor lacks the full and proper complement of information with which to work. In these cases, its response may consist of a number of relatively slow-to-develop and weak candidate patterns instead of any single rapid and correct image of the word presented.

The best operation of the Orthographic processor requires that the letters be resolved not just accurately but quickly as well. Specifically, letter identification must proceed quickly enough that the units representing all of the letters within a spelling pattern are near peak excitation at once. Without simultaneous excitation of the letters of a spelling pattern, the associative network is debilitated; it has no way of knowing that the letters

have co-occurred. It can bestow no benefit on the reader in terms of processing speed and guidance and can produce no holistic image of the pattern. In the extreme, where the excitation of each letter dwindles away before the excitation of the next is turned on, the system can do nothing more than work out each letter of the word, one by one and independently of the others.

Difficulties in the speed or quality of individual letter resolution may be caused by physical factors, such as illegible print or the sorts of laboratory manipulations described earlier. But they may equally be caused by insufficient familiarity with letter identities.

The Orthographic Processor's Dependence on the Familiarity of the Spelling Patterns Constituting the Word. Given adequate perception of the individual letters of a word, the speed and strength of the Orthographic processor's response depends on the familiarity of the spelling pattern. The more familiar the spelling pattern is, the stronger the associations are between its letters. The strength of such associations directly affects the speed of perception because of the way in which they serve to share and redouble the excitation of the individual letters. The strength of such associations also determines whether the response to a word will consist of a single cohesive pattern or some collection of more loosely linked fragments.

Compensating for Orthographic Difficulties

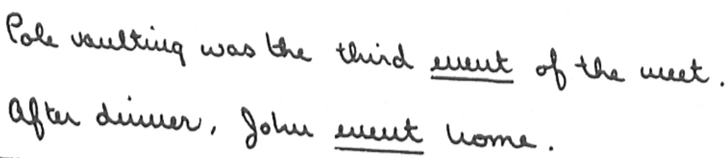
Although even skillful readers may occasionally encounter illegible letters or less familiar spelling patterns, they typically overcome such problems almost without notice. The mechanisms lie in their associative knowledge about spellings, sounds, and meanings.

Compensating for the Orthographic Processor's Difficulties with Letter Recognition. If the identity of the letter and the spelling of the word are well known to the reader, compensation for poor letter resolution may be achieved within the Orthographic processor itself. Selfridge's well-known example provides a case in point:[8]

8. Selfridge (1955).

Note that although the two middle characters of each of these words are, in fact, identical, one actually seems to "look like" an *H* and the other like an *A*. At the level of individual letter identification, the ambiguous character must be mapped onto both the *H* and the *A* units in the Orthographic processor. Within each of the three-letter strings, however, one of the candidates is highly familiar while the other is unacceptable. The illusion arises as the surrounding letters in each string associatively reinforce the familiar candidate and inhibit its competitor.

If the hard-to-identify print occurs in context, even greater illegibilities may be overcome.[9]



This happens because excitation from the Context processor reinforces the relevant response in the Meaning processor, allowing it to dominate despite the vagueness of the orthographic information.

Such words may even "look" more legible in context; if so, it is because of excitation that the Meaning processor relays to the relevant units in the Orthographic processor both directly, and indirectly through the Phonological processor. Indeed, because phonological responses are relatively tightly associated with spellings, excitation that arrives from the Phonological processor may even increase the apparent legibility of spelling patterns that are not highly familiar to the Orthographic processor.

Compensating for the Orthographic Processor's Lack of Familiarity with the Spelling of a Word. The Phonological processor can lend a great deal of assistance toward recognizing visually unfamiliar words. Specifically, we can sound the word out.

For skilled readers, because the associations between the Orthographic processor and the Phonological processor are built on complex spelling and phonological patterns, such "sounding-out" may occur quite effortlessly and efficiently—so much so that skilled readers may read an aurally familiar word with little outward sign that they have never seen it before.

To illustrate, you will probably have little trouble reading aloud any of the following even if you have never seen them

9. Figure from Nash-Webber (1975, p. 352).

before: *diatessaron, gerentomorphosis, epilimnion, trypsinogen, anfractuosity*, and *thigmotaxis*. If these words were in your listening vocabulary, identification would be easy and complete. More to the point, reflection should verify that the manner in which you sounded out these words was something closer to syllable by syllable or morpheme by morpheme than it was to letter by letter. You naturally exploited the sophisticated patterns that your Orthographic and Phonological processors have acquired.

For comparison, try next to sound out these words: *Karivaradharajan*,[10] *Wloclawek, Verkhneudinsk, Shihkiachwang, Bydgoszcz, Quetzalcòatl*. When confronted with words whose spellings are strange by English standards, skilled readers are reduced to less efficient, less confident, and more effortful processing. For younger and poorer readers, the sounding-out process tends to proceed in an effortful letter-by-letter fashion even when the words are relatively short, frequent, and regular.[11]

If a familiar response to the word is aroused in either the Meaning or Phonological processors, its orthographic image will be reinforced through the feedback they provide. Further, almost any orthographic string that finds a familiar response in one of these other processors will find a familiar response in both, thus doubling the feedback it will receive.[12] And if the other processors have anticipated the word—as when the word occurs in a meaningful context or a rhyming situation—their responses will be still stronger and more rapid[13] —sufficiently so, perhaps, to compensate wholly for such orthographic difficulties.

10. The major obstacle with proper Indian names such as this one, is not so much that the spelling within syllables is so difficult but that there are so many syllables. It is therefore interesting to note that Indian readers treat such names as compounds of smaller, more familiar patterns, e.g., *Kari-varadha-rajan*, much as we do when reading very long English words, e.g., *anti-dis-establishment-arian-ism*.

11. Frederiksen (1982).

12. If we know the meaning of an orthographically unfamiliar word, we generally know its pronunciation (if it is orthographically unfamiliar, how else might we have learned its meaning?). Similarly if we have learned a pronunciation for an orthographically unfamiliar word, we have surely associated it with some sort of conceptual information, if only the context in which it occurred. In general then, if either the Phonological or the Meaning processor responds to the word, both will, with the result that both will relay a fraction of their excitement back to the Orthographic processor. The notable exceptions to this generality are pseudowords invented for testing and experimentation.

13. For a review, see Carr and Pollatsek (1985).

Finally, this sort of feedback from the other processors not only speeds and clarifies the perception of visually less familiar words. In addition, as it returns extra activity, extra reinforcement, to the associative links between the letters of the word, it provides the reader with extra support toward learning the orthography of the word as well. But, of course, this works only if the reader takes the time to resolve the orthography rather than just making do with its interpretation.

Compensating for the Orthographic Processor's Inability to Distinguish Real Words from "Well-Spelled" Frauds. For each of the difficulties discussed so far, the Orthographic processor found no solid response where it should have had one. But the reverse can also occur: The Orthographic processor can be satisfied with a response where it should have had none. This vulnerability stems from the fact that it has within itself no basis for assessing anything about a word save the familiarity or regularity of its spelling.

For skillful readers, the Orthographic processor is quick at resolving the spellings of whole, frequent words. But its responses to piecewise familiar nonwords, such as *sust* and *bome*, are very nearly as quick and cohesive. The speed and coherence of the Orthographic processor's responses to such well-spelled nonwords may even exceed its responses to less frequent and less regularly spelled real words, and this is true for simulations of the model as well as for people.[14]

When skillful readers are asked to judge as rapidly as possible whether or not each of a series of orthographic strings is a word, they are willing and able to do so on the basis of its spelling pattern alone—provided that the words are regularly spelled and that the nonwords are not. However, if either regularly spelled nonwords, like *sust*, or irregularly spelled words, like *aisle*, are included among the items to be judged, this strategy becomes unreliable. In these situations, their decisions must await confirmation from the other processors, and, that being so, their responses are a few hundredths of a second slower and show sensitivity to the phonology and the meaningfulness of the words.[15]

But do not mistake the point here. The point is not that word recognition is slower when it involves phonological or meaning

14. Seidenberg and McClelland (1989).
15. Waters and Seidenberg (1985).

processing. Except in certain artificial and purposefully truncated tasks (such as the rapid word/nonword decision tasks of the laboratory), word recognition always involves phonological and meaning processing. The point is that under appropriate laboratory conditions, we can demonstrate the separate—and sometimes crucial—backup assistance that each of these processors adds to the total word recognition process.

Phonological Processing

Vulnerabilities of the Phonological Processor

The Phonological processor takes letters or multiletter patterns as input from the Orthographic processor. It responds with any and all pronunciations that it has associated to that letter or spelling pattern. The speed and strength of its response(s) depend on three factors: the instantaneity and quality of the orthographic information it receives; the number of different responses that the orthographic input elicits; and the familiarity of the appropriate response.

The Dependence of the Phonological Processor on the Speed and Quality of the Orthographic Input. The Orthographic processor does not wait until it is done with a word to ship information to the Phonological processor. Rather the associative connections between the two processors (and all of the connections within the system, for that matter) are like little short circuits. As soon as any individual letter receives excitation (and in exact proportion to the strength with which it does so), it will relay the same to the Phonological processor.

For skilled readers given legible print, the letters of a whole, familiar spelling pattern are orthographically resolved and bonded together almost at once. In these cases, the Phonological processor instantaneously receives excitation corresponding to the whole, integrated pattern and responds nearly as quickly with a holistic phonological translation.

However, if Orthographic processing is disrupted, fractionated, or slowed down, the picture is different. Rather than receiving the spelling pattern at once and as a whole, the Phonological processor must get it more slowly and in pieces. Moreover, because early processing of an unfamiliar string may include the indirect excitation of inappropriate letters, the Phonological processor may also have to put up with certain false leads.[16]

Bear in mind that the Phonological processor is comprised of an associative network very similar to that within the Orthographic processor. Like the Orthographic processor, its job is to bind together its input into the largest coherent response pattern that it can.

When the incoming string is a whole familiar word or a regularly spelled syllable, its task is easy. All pertinent phonemic units will be excited at once and at once will excite each other. Through this collective excitation, the appropriate phonological translation of the whole string will quickly be consolidated, overcoming any alternative phonological translations that its individual letters or subsets of letters might also have triggered.

In contrast, suppose that the letters arrive one by one from the Orthographic processor. The first letter perceived (which is typically but not necessarily the first one in the printed string)[17] will evoke all of its various phonemic translations, and each of these phonemic units will relay excitation to all others with which it has become associated. But the direct guidance thus provided must be very slim. First, any single letter may map onto a number of phonemic translations; for example, *c* may signal /*s*/ as in *city* and *dice*, /*k*/ as in *cat*, *income*, and *ache*, /*ch*/ as in *chin* and *bocci*, or /*sh*/ as in *suspicion* and *chute*. Second, there are only about forty phonemes in our language; so few that each must be associated with a relatively unhelpfully large number of others. The Phonological processor's efforts to build a word from the phonemic translations of a single letter must be very much like playing "Name that Tune" with just one note.

The response of the Phonological processor may be further diffused by any failures of the Orthographic processor to resolve the identities of individual letters. In general, visual letter recognition failures do not result in no response; they instead result in some number of relatively weak responses—as many as the perceived aspects of the letter evokes. In these cases, the Phonological processor not only misses the preemptive activation of the correct letter but must also cope with the misguided activation from all of the alternative candidates.

16. Remember the *tqe* example in chapter 6.

17. Adams (1979a).

The Phonological Processor's Difficulties with Multiple Spelling-Sound Translations. The greater the number of phonological responses associated with any given orthographic input, the more ways its excitation must be divided, and the more weakly and slowly each candidate translation will mature.

Thus the Phonological processor should respond uniquely and quickly to phonologically unambiguous spelling patterns, such as *_ust* and *_ame*: Whatever the first letter(s), its responses should rhyme with *just* and *name*. On the other hand, the processor's response to *_ear* will be slower: Should the winning response rhyme with *bear* and *wear* or with *dear* and *fear?* Similarly, responses to graphophonemically irregular words, such as *aisle* and *corps*, will be slowed as their component letters trigger a number of partial but more regular, more frequent, and thus more volatile competing responses. The naming times of both people and simulations of the model are found to be consistent with these predictions.[18]

The Phonological Processor's Dependence on its Familiarity with a Spelling Pattern. Again, the speed and strength of any given response is a direct product of the frequency with which it has been coupled with the spelling pattern in the past. And, again, because of the associations among units, the most evocative aspects of a spelling pattern are its largest familiar parts.

Thus although the Phonological processor should be ambivalent, and thus slow, with pseudowords such as *mave* (should it rhyme with *have* or *gave?*), it should respond quickly, appropriately, and uniquely to very frequent but graphophonemically exceptional real words, such as *have*, because it should respond to them as familiar wholes. Again the response patterns of both people and simulations of the model are consistent with this prediction.[19]

Similarly, for words that are sufficiently familiar to be processed holistically, the normal slowness of processor's responses to words with "strange" spelling-to-sound correspondences is also expected to be overcome. In keeping with this, skilled readers' naming times are relatively long for less frequent "strange" words, such as *heir* and *tsar*, but as quick as any for frequent ones such as

18. For reviews, see Carr and Pollatsek (1985); Seidenberg and McClelland (1989).

19. Seidenberg (1985).

once and *climb*.[20] This pattern of behavior is also obtained in simulations of the model.[21]

Finally we recall that it is not the general frequency with which a word occurs in print but the frequency with which it has occurred in the experience of the person reading it. It is, after all, one's personal experience with a word or spelling pattern that determines the strengths of the associations it evokes. Thus, words that behave like high frequency items among more experienced, skillful readers, behave like low frequency items among younger[22] and less skilled readers.[23] Words that are pronounced quickly and easily by experienced, skillful readers are pronounced slowly and effortfully by younger and less skilled readers. Words whose pronunciations are generated holistically by more experienced, skillful readers, are pronounced in accordance with piecewise rules by younger and less skilled readers (e.g., *island*, *busy*, and *whom* tend to be read, respectively, as "izland," "bussy," and "wom").[24]

Compensating for Phonological Difficulties

Print is not uniformly legible; the familiarity of words and spelling patterns range widely for all readers; and ambiguous spelling-sound correspondences are a fact of English orthography. Although such problems never go away, readers learn to overcome each of them. The key again lies in the interactive capabilities of system as a whole.

Compensating for the Phonological Processor's Problems with Slow Orthographic Processing. In contrast to the Orthographic processor, the workings of the Phonological processor are not necessarily defeated by slow letter recognition. This is because of the Phonological processor's autonomous capacity to renew its own stimulation. Specifically, readers can vocally, subvocally, or

20. Waters and Seidenberg (1985). Interestingly skilled readers may even respond slightly more quickly to frequent "strange" words than to frequent regular words. This is presumably a combined effect of the words' holistic familiarity and the failure of their "strange" spellings to evoke any serious response competition.

21. Seidenberg and McClelland (1989).

22. Backman, Bruck, Hèbert, and Seidenberg (1984); Waters, Seidenberg, and Bruck (1984).

23. Backman, Bruck, Hèbert, and Seidenberg (1984); Seidenberg, Bruck, Fornarolo, and Backman (1986).

24. Adams and Huggins (1985); Backman, Bruck, Hèbert, and Seidenberg (1984).

mentally repeat the candidate phonological fragments (e.g., "t - t - t - rrr - t - rrr - t - rrr - ap -t - rrr - ap - trr - ap - trr - ap - trap!"). In so doing, they renew the excitation of the relevant phonological units which in turn pass renewed excitation both to each other and to the orthographic units to which they are currently linked. In this way, poor orthographic resolution may be overcome within the Phonological processor itself.

If the word in attention is aurally familiar, then the phonological translation will also activate a response in the Meaning processor. The meaning response will then reciprocally strengthen the phonological response as well as sending activation directly to the orthographic response.

Compensating for the Phonological Processor's Difficulties with Multiple Spelling-to-Sound Correspondences. The Phonological processor's problems with ambiguous spelling-to-sound patterns in real words, such as *bear* and *dear*, are rarely a problem in actual reading. First, the ambivalence of the Phonological processor's response to such spelling patterns as *_ear* derives largely from the fact that both translations occur in more than one word that it knows and thus with considerable frequency across words. Second, individual words that have regular spellings and irregular spelling-to-sound correspondences tend to be quite frequent.[25]

Taken together, the implication is that letter sequences that have such ambiguous spelling-to-sound correspondences are likely to be highly familiar visually. As a consequence, they should be quickly processed and integrated within the Orthographic processor and, from there, quickly passed on as wholes to the other processors. If the Phonological processor does not immediately respond holistically and thus, uniquely, to an irregularly spelled word on its own, activation of the correct pronunciation from the Meaning processor should quickly ensure that it will.

In keeping with this, skillful readers' responses to words with regular spellings and irregular pronunciations (such as *bear*, *have*, *done*, and *great*) tend to be just as fast and accurate as their responses to wholly regular words.[26] Their response to an

25. Hooper (1977); Wang (1979).

26. Seidenberg (1985). Note further that this speed and accuracy does not indicate that the Phonological processor is circumvented but only that the words' pronunciations are resolved despite any doubts that it might have. As evidence, prior reading of, e.g., *come*, significantly slows the reading of

irregularly pronounced word tends to be slower only if the word is relatively infrequent—but, even then, only by a few hundredths of a second.[27]

In contrast, the speed with which skilled readers name nonwords with ambiguous spelling-to-sound translations (such as *mave* and *gough*) is reliably slowed.[28] Further, preceding such a nonword with a similarly spelled word strongly influences its pronunciation.[29] If *mave* is preceded by *gave*, it tends to get a long *a*; if preceded by *have*, it tends to get a short one. The explanation, following the model, is that the residual phonological excitation of the just-presented word is often sufficient to raise the consistent pronunciation of the ambiguous spelling pattern to dominance.

Again, because it is really the frequency of a word within the reader's own experience that matters, what is effectively a high-frequency word for a highly experienced, skillful reader may be an infrequent word for a young or poor reader. As a consequence, the speed with which younger and poorer readers can pronounce or recognize words is slowed much more by irregular spelling-to-sound correspondences, and this is true even for moderately frequent words.[30] Such less skilled readers also display a tendency to regularize the words—for example, to pronounce *deaf* as "deef" or *touch* as "towch."[31] Whether due to the absence of convergent support from the orthography-to-phonology connection or the presence of interference from it, it is clear that word identification in these cases is not effectively established through the direct orthography-to-meaning route.

Compensating for the Phonological Processor's Difficulties with Weak Spelling-to-Sound Familiarity. When reading meaningful, connected text, the Meaning processor receives activation from the Context processor as well as from the Orthographic and Phonological processors. To the degree that this contextual activation overlaps with orthographic or phonological activation

home: This can only indicate that the Phonological processor was involved in the reading of each (Taraban and McClelland, 1987).

27. Brown (1987); Taraban and McClelland (1987).

28. Glushko (1979); Taraban and McClelland (1987).

29. Taraban and McClelland (1987).

30. Seidenberg (1985).

31. Adams and Huggins (1985); Backman, Bruck, Hèbert, and Seidenberg (1984).

from the word, it will speed and strengthen the Meaning processor's response. This, in turn, will boost the strength of the feedback that the Meaning processor returns to the Orthographic and Phonological processors, such that spelling and sound difficulties may be overcome. Indeed, children with deficient word recognition skills are found to rely especially heavily on such contextual compensation.[32]

Compensating for the Phonological Processor's Indifference to Homographs and Homophones. Homographs are words that are spelled identically but mean something different. Homophones are words that are pronounced identically but mean something different.[33] Neither of these types of words can be disambiguated by the Phonological processor alone.

Homographs that have different pronunciations, such as *lead* the horse and *lead* pipe, present a special problem to the Phonological processor: Should *lead* rhyme with *bead* or *bed?* In general, both pronunciations are activated and sent to the Meaning processor, though the Phonological processor's response to most frequent candidate is faster and stronger.[34]

If the word has appeared in isolation, the speed and strength of the Meaning processor's responses depend on the relative frequencies of the candidates' meanings. Because the most frequent meaning necessarily corresponds to the most frequent pronunciation, the Meaning and Phonological processor will thus reinforce each other's choice. In contrast, if the word appears in connected text, contributions from the Context processor should ensure the correct choice.

The problem with homophones, such as *rose* and *rows*, is that the Phonological processor's responses are strictly phonological in nature. Thus, the responses it sends to the Meaning processor for *rose* and *rows* are indistinguishable. Fortunately for the Meaning processor, *rose* and *rows* are orthographically distinct. For skilled readers, at least, that is enough to keep them from being confused: The orthographic differences will compensate for the phonological similarities.

Even given relatively strong contextual expectations, such as the prior display of *"a type of flower"*, skilled readers are liable to

32. For a review, see Stanovich (1980).

33. Of course, some homographs are homophones and vice-versa, but not all.

34. For a review, see Seidenberg and McClelland (1989).

confuse such words as ROSE and ROWS only when orthographic processing is aborted prematurely—as through special laboratory techniques[35] and, by conjecture, through the sorts of cursory visual processing that accompany skimming, the reading of highly predictable material, and hasty treatment of visually unfamiliar words. It is worth emphasizing that the errors in these cases do appear to be phonologically inspired: Under these circumstances, people are significantly more inclined to mistake ROWS for ROSE than to mistake ROBS for ROSE despite the fact that ROWS and ROBS are of comparable visually similarity to ROSE.

Laboratory evidence suggests that to verify its interpretation of such homophonic words, the Meaning processor literally undertakes a spelling check. Starting with each of the ambiguous word's meanings, it retraces the links to the Orthographic processor seeking evidence of whether its particular spelling was presented.[36]

Processing Meaning

The Meaning processor is in a unique position within the system. In arriving at its own response to an incoming word, it receives input from every one of the other processors. The responses of the Meaning processor are therefore influenced by the speed and accuracy or precision of all of the other processors but at the same time are less dependent on the timeliness and completeness of any one.

Although the information from any one of the other processors—Orthographic, Phonological, or Context—would often be sufficient for the Meaning processor to select a single dominant response from its repertoire, the convergent activation from all three serves two purposes that are critical to the system. First, it boosts the speed and strength of appropriate responses in the Meaning processor and, through them, of appropriate responses in each of the others. Second, the separate, multiple inputs imbue the system with a critical degree of reliability: Where any one of the inputs is ambiguous or misleading, the others should provide for the correction or detection of its incompatibility.

The optimal operation of the Meaning processor depends both on its receiving definitive, correct, and timely input from each of the other processors and on its possessing a well-integrated response to their input. It will clearly be at a general loss if it

35. Van Orden (1987).

36. Dennis, Besner, and Davelaar (1985); Van Orden (1987).

receives inadequate input from all three of the other processors. Moreover, to the extent that the input from any one is too poor or too slow, it cannot conduct the parity checks between them that ensure interpretive reliability. If, for whatever reason, the Meaning processor can produce no coherent response, all is for naught: The meaning of the word cannot be established and, without the word's meaning as the focus of activity, neither new information nor reciprocal feedback can be issued to any of the other processors.

As the Meaning processor receives and reciprocally sends activity to each of the other processors, it is in the unique position to regulate the responses of the system as a whole. Further, the proper evocation of meaning is the ultimate goal of individual word recognition in reading.

The responses of the Meaning processor are, thus, uniquely important to the reading process. Yet it, too, may fail or go astray. When it does, no quick fixes are available; its response is already the product of the system's total resources. The only sound remediation for problems in the Meaning processor is more learning.

Vulnerabilities of the Meaning Processor

Given that the Meaning processor does in fact possess a solid representation of a word's meaning, the speed and strength of its response depend on three factors: the contribution of context; the quality and completeness of the orthographic and/or phonological input it receives; and the strength of the associations between the word's meaning and its orthographic and/or phonological representation.

The Meaning Processor's Dependence on Context. As discussed in the previous chapter, the reader's understanding of the context in which a word occurs can help to emphasize or boost the activation of contextually relevant components of the word's meaning, to select among alternative interpretations of ambiguous words, and even to create a meaning for the word where there otherwise might be none. More generally, context serves to reinforce and thus to increases the strength, speed, and appropriateness of the system's understanding of a word's meaning. As it does so, it automatically increases the strength, speed, and appropriateness of its orthographic and phonological response to the word as well.

There are at least two major determinants of the speed and strength of the assistance that the Context processor can lend to the Meaning processor. The first derives from the definitiveness and appropriateness of the Context processor's expectations. If the Context processor's expectations of the word are vague, it cannot provide much help. Compare, for example, the ease of completing the following two sentences:

The entire group examined the ???
At the farmstand, we got tomatoes and corn on the ???

By the same token, the expectations of the Context processor may be inappropriate. As an example, consider this sentence:

At the farmstand, we got tomatoes and corn on the *car*.

From the previous example, you know that your Context processor expected *cob*, not *car*. Fortunately you had orthographic information to straighten things out. Without orthographic guidance, such misleading expectations can be quite unsettling:

Though smelly and ugly to look at, the *sewer* makes beautiful clothes.

Research verifies that while strong, appropriate contextual cues can speed word processing, strong, inappropriate ones typically slow it down, and everything in between typically has an in-between effect.[37]

The second factor influencing the help that the Context processor can provide, is the conscious attention that the reader devotes to it. Some limited degree of contextual facilitation occurs automatically. For example, the presentation of the word *doctor* will automatically facilitate the perception of the word *nurse*. However, the inhibition of inappropriate responses as well as the facilitation of more complexly determined appropriate responses—which, importantly, includes that critical question of what word is likely to be next in a sentence—require considerable time and the reader's conscious attention to accrue.[38]

In actual reading, the extra time involved in establishing useful contextual guidance is not expected to be a problem. Since such guidance begins to mature before the to-be-resolved word is encountered, it will generally be ready when it is time to digest the phrase or clause as a whole.[39]

37. Fischler and Bloom (1979); Stanovich (1984).

38. Neely (1977).

39. Indeed, looking to our model, an alternative explanation for these findings might be that automatic context effects arise within the Meaning processor itself, whereas attentional context effects arise only when the phrase is compiled by the Context processor.

On the other hand, the Context processor's dependence on conscious effort and attention may often be a problem. First, the reader's available pool of conscious attention is inherently limited. To the extent that such attention is being directed to other activities in the system, less is available for these crucial interpretive activities. In particular, the reader may have no conscious capacity left for integrating the meaning of the word with its prior context and assessing its sense if she or he is investing conscious effort in resolving the word's orthographic structure, in sounding it out, or in retaining the prior wording of an incomplete phrase.

Further, processes that require conscious attention are, as a group, optional rather than automatic. For any of a variety of reasons, therefore, the reader may simply neglect their execution. It is of interest in this vein that when asked to read aloud such sentences as

John said, "Does are in the park, aren't they?"

second graders often, and without the slightest signs of perturbance or confusion, read *does* as "duz."[40]

The Meaning Processor's Dependence on the Quality and Completeness of the Orthographic and/or Phonological Input. Neither the Orthographic nor the Phonological processor waits until it is done with a word to ship excitation to the Meaning processor. Rather, just as soon as a spelling or phonological unit receives excitation, it relays that excitation to all associated constellations of units in the Meaning processor.

For skilled readers given legible print, the letters of a whole, familiar word are orthographically resolved and bonded together almost at once. In these cases, the Meaning processor instantaneously receives excitation from the Orthographic processor corresponding to the whole, integrated spelling pattern and quickly responds with its meaning. Nearly as quickly, it also receives excitation from the Phonological processor of the whole, integrated phonological translation of the word.

40. Daneman and Carpenter (1983). The tendency to rely more heavily on orthographic than contextual clues typically begins to appear sometime in the second grade (Biemiller, 1970).

However, if orthographic processing is disrupted, fractionated, or slowed down, the Meaning processor must receive the spelling and phonological patterns more slowly and in pieces. In these cases, the speed and definitiveness of the Meaning processor's response depend on such factors as the base familiarity of the word and its meaning and the extent to which it is predictable from the preceding context.

With poor orthographic and phonological resolution and little or no contextual facilitation, the reader may fail to recognize the word altogether. On the other hand, if the word is highly predictable from context, relatively little orthographic or phonological information may be needed for some one response to dominate all others comfortably.

As valuable as such contextual compensation may be, it also has a negative side. If the Meaning processor relies too heavily on context, it is liable to miss orthographic distinctions that the reader should care about. This happens, for example, when one reads one word for another while skimming, when one misses typographical errors while proofreading (this is a special problem when one is proofing highly predictable material, such as material that one has written),[41] and, most relevant in the present context, when one lacks both the capacity to resolve the spelling of the word automatically and the time or discipline to resolve it with effort.

The latter is a particularly vexing problem in the instructional arena. Younger and poorer readers tend to rely significantly more heavily on context than do more experienced and skillful readers.[42] On the one hand, such compensatory use of context is a positive behavior—it is ultimately a critical component of productive reading. On the other, to the extent that children use context to avoid fully processing and, thereby, learning about the spellings of words, it may in the long run slow their reading growth. We will return to this trade-off in chapter 10.

The Meaning Processor's Difficulties when the Connections between a Word and its Meaning are Weak. The strengths of the associations between a constellation of meaning units and the word whose meaning they represent influence not only the speed but the very likelihood that a meaning will be elicited. Given a well-developed representation of meaning, the strength with which it

41. See also Healy and Drewnowski (1983).

42. For a review, see Stanovich (1980).

is evoked by a particular orthographic or phonological pattern depends on the frequency with which it has been coupled to that pattern in the reader or listener's experience.

Among other things, these couplings influence the relative ease of accessing different meanings of a word. Presented in isolation, the strength with which alternative interpretations of a word are aroused depends on the frequency (or recency) with which the word has been coupled with each of those interpretations. In isolation, therefore, the word *does* is more likely to be interpreted as "acts" than as "female deer." Because more frequent meanings are also more likely meanings, this tendency is surely helpful on balance. When it is not—as when the competing meanings are of comparable frequency or the least frequent one is the most appropriate—activation from the Context processor will usually sort them out.[43]

Again, what is at issue here is not knowledge of the word's meaning per se but the connection between such meaning and the orthographic or phonological representation of the word. Thus one might have a wholly adequate understanding of the word *groin* and still be at a loss for understanding the word *groyne*—unless one were aware that these two words were alternate spellings for the same thing.

Indeed, this example seems to illustrate a basic principle of the Meaning processor's operation: When it does receive complete input from the Orthographic processor, it is inclined to respect it. Thus, encountered in isolation, a good reader would not assume that *groyne* meant *groin* even while pronouncing it the same way; encountered in context, a good reader would at least pause to wonder. Such deference to orthography is functional: It is the means by which we so reliably distinguish between such words as *rose* and *rows;* moreover, given the architecture of the system, the inadequacy of sophisticated-guessing or hypothesis-testing theories of word recognition can only be owed to skilled readers' tendency to process orthography completely.

For unfamiliar words that are irregularly spelled, however, the system's deference to orthography-based interpretations can result in certain confusions. For example, it was in graduate school that I discovered that the word */in-dikt/*, which I had read so often, was the same as the word */in-dite/*, which I had heard so often; and, even then, I discovered this only when I happened to say the word aloud. This same deference undoubtably underlies

43. Carpenter and Daneman (1981); Simpson (1981); Swinney (1979).

younger and poorer readers' tendency to mispronounce irregularly spelled words even in context, as in

The girls rowed the boat to the *island* (read /*izland*/).[44]

It must also be skilled readers' deference to orthographic information that allows them to decide so quickly and accurately that strings such as *brane* are not words[45] and that sentences such as "*Tie the not*"[46] do not make sense. On the other hand, even for skilled readers, such judgments are typically slower (by a few hundredths of a second) and/or slightly less accurate than when shown pseudowords or sentences that do not "sound" meaningful. This interference reflects the competing contribution of the Phonological processor.

Although the interference produced by sound-alikes is slight among skilled readers, one might expect it to be relatively strong among readers with less consolidated orthographic knowledge. Specifically, suppose that a young reader is confronted with a sentence such as

We swim in the see.

As the child reads each word, the Orthographic processor will send its results both to the Phonological processor and to the Meaning processor. The response of the Phonological processor is indifferent to the word's spelling—it neither knows nor cares whether the word was "see" or "sea." Moreover, because both words are aurally quite familiar to the child, the phonological translation will easily find both meanings in the Meaning processor, and the Context processor will easily agree that one of them makes sense and reinforce it.

Meanwhile, since this is a young and inexperienced reader, the strength of the link between the Orthographic processor and the Meaning processor is expected to be relatively weak and possibly incomplete. It would not be surprising if it could not overcome the self-reinforcing, self-sustaining activity that the Phonological, Meaning, and Context processors were mutually supporting. It would not be surprising, in other words, if the orthographic inappropriateness of the word went entirely unnoticed and, indeed, this is what happens.

44. Adams and Huggins (1985); Backman, Bruck, Hèbert, and Seidenberg (1984).

45. For a review, see Dennis, Besner, and Davelaar (1985).

46. Baron (1973).

Working with children aged six to ten years, Doctor and Coltheart found that the youngest judged the majority (70 percent) of twenty-four sentences such as "We swim in the see" and "The sky is blew" to be meaningful. Even the oldest children accepted 20 percent of such sentences. In contrast, children of all ages accepted correctly spelled, meaningful sentences while rejecting sentences that did not sound meaningful most of the time.[47]

The hypothesis that these children's confusions were owed largely to the interactive and parallel contributions of the Phonological, Meaning, and Context processors is also supported by Doctor and Coltheart's study. Specifically, the children's sentence judgment errors greatly exceeded both their tendency to misspell the words when dictated in context and their tendency to define the homophone rather than the printed word itself when presented in isolation.

Remediating the Meaning Processor's Weaknesses

The responses of the Meaning processor are the combined product of all of the knowledge and processing the reader has applied to the text. If the Meaning processor commits an error or oversight, it is because the reader's knowledge and processing have not been adequate to the challenge presented by the text. The only way to minimize such problems is by maximizing the knowledge, skill, and interpretive control that the reader will readily bring to bear.

Supporting Appropriate Use of Context. The key to reconciling text with context lies in the competent operation of the other processors. For skillful readers, a word's orthographic and phonological resolution is normally so fast, so complete, and so strongly bound to its meaning that contextual guidance can produce little gain in interpretive speed while contextual misguidance is generally overcome. Moreover, the activities involved in resolving the word's orthography, phonology, and meaning are so automatic and effortless that skilled readers can devote nearly all of their conscious attention to the combined sense of a word and its context. Not only do they readily select a unique meaning for a word when that is appropriate, but they can also entertain the alternatives—as is evident from their ability to understand the double entendres of puns, poetry, and jokes.

47. Doctor and Coltheart (1980).

For readers with less orthographic facility, one might expect word recognition to depend much more strongly on contextual cues. Research confirms this hypothesis. Younger and poorer readers tend to rely significantly more heavily on context than do more experienced and skillful readers.[48] Not only do they rely more heavily on context for initial word identification, they seem also to rely on it with a differential inflexibility for word interpretation. Younger children seem remarkably resistant to considering multiple meanings of a word even when all are perfectly well known.[49]

It is reasonable to wonder whether this inflexibility might be more apparent than real. Perhaps in the social context of interpreting a sentence for an adult, children feel that a single, definite response is most appropriate. Perhaps they actually recognize the ambiguity, but suppress one of the responses so as not to look confused or uncooperative.

Perhaps. But that does not explain young children's universal bumbling of jokes and puns. Gleitman and Brill have shown that, although "any self-respecting five year old" will laugh at a well-delivered pun, only one side of the ambiguity is typically understood.[50] This can hardly be a matter of politeness.

As an example, here is one of the riddles that circulated through my son's preschool class:

Where do sheep get a haircut? At the baa-baa shop.

I laughed when I first heard this joke as, no doubt, did most of the (Yankee) parents. And so it was followed for weeks thereafter with a host of variations that were clearly perceived as equally hilarious by the children:

Where do cows get a haircut? At the moo-moo shop.
Where do dogs get a haircut? At the bow-wow shop.
Where do lions get a haircut? At the (ROAR) shop.

. . . And so on.

It seems that children are not predisposed to considering more than one interpretation of what they read or hear. While this tendency makes folly of jokes, it must limit their capacity to monitor and adjust their interpretations of reading materials in more deleterious ways. By conjecture, it might be a very good idea to bring jokes, puns, and other sorts of double entendres

48. For reviews, see Stanovich (1980, 1984).
49. Asche and Nerlove (1960).
50. Brill (1974, cited in Rozin and Gleitman, 1977, p. 192).

deliberately and systematically into the classroom. Exercise with such materials is a regular component of some reading and language curricula and may be far more valuable and important to the students' comprehension development than would appear at first blush.[51]

Developing Appropriate Deference to Orthographic Information. Whatever else may be required for the development of reflective reading, able and effortless lower-level processing is essential. The contribution of context takes on its proper weight in the system only when orthographic processing becomes comparably sure and quick. Moreover, the thoughtful exploitation of context—that which is required for establishing the full and proper meaning of text—becomes possible only when sufficient attention is available for its reflective processing.

Exercise in comprehending connected text must be complemented by activities to encourage and enhance the children's knowledge and facility with the visual identities of individual words. Such activities include not only spelling-sound instruction in the beginning, but repeated readings and writing/spelling activities throughout. And again, the reading of connected, meaningful text provides the very best opportunity for learning the orthography and meaning of less familiar words.

Reinforcing the Links between Words and their Meanings. Clearly the Context processor provides invaluable help toward the fuller interpretation of poorly learned or partly forgotten word meanings. Yet a less obvious source of assistance is also suggested by the model. Specifically, in normal, skillful reading, the units in the Meaning processor will receive excitation from both the Orthographic and the Phonological processor. The two processors thus provide a redundant look-up process. Even where the activation of one of them might not be enough to bring any fragment of the word's meaning to consciousness, the conjoint activation of both just might—and once any critical subset of the meaning units is activated, it will automatically excite others to which it is bound.

But neither of these sources of assistance is robust. The cohesiveness of a word's meaning representation depends most of all on the frequency with which it has been activated and reinforced. If we want children to learn the meanings of new

51. Bereiter, Hughes, and Anderson (1986).

words, we should take care to give them the opportunity to read and use those words repeatedly. More generally, it is repeated experiences with a word in different contexts that strengthens both its meaning and its ties to orthography. The more a child reads, the stronger both will be. To this end, regular encouragement of silent reading is strongly recommended. But oral reading, though logistically more cumbersome and less efficient, is also worthwhile: Given the graphophonemic unruliness of English, reading aloud provides valuable opportunities to reconcile irregularly spelled words with their phonological translations.

Summary: Interactions between Processors

The goal of this section has been to clarify how the parallel and interconnected operation of the Orthographic, Phonological, and Meaning processors complement and compensate for each other's vulnerabilities and weaknesses in the course of reading. In explaining these interrelations, I dwelled mainly on catastrophic failures of each of the individual processors—situations in which the proper response was just plain not forthcoming of its own accord. Although such catastrophic failures must be fairly rare in the normal, daily reading of competent readers, lesser difficulties—or at least inconsistencies—in the ease and speed of resolving the orthography, phonology, and meaning of words must occur within nearly every paragraph we face.

Line by line in running text, most words are common words—words that are seen frequently and that we must generally recognize instantly and easily with no need of phonological support. Carroll, Davies, and Richman reported that 90 percent of school children's running text consists of just 5,000 common words, and a similar distribution is found in adult texts.[52]

Nestled among these common words, however, are myriad less common ones. Specifically, the remaining 10 percent of school children's running text consists of more than 94 percent of the different words they must read. On average these words occur only four times in every million words of text; none occurs as many as ten times in every million words of text. For the average child, in other words, none is encountered as many as ten times in each year's worth of reading. The sheer arithmetic of the situation argues that relatively few of these words can be visually overlearned.

52. Carroll, Davies, and Richman (1971); Kucera and Francis (1967).

The importance of such less frequent words is underscored by the fact they impart a disproportionate amount of meaning to text. The information conveyed by words varies inversely with their frequency.[53] The less frequent a word is, the greater is the amount of meaning that it is expected to contribute to a passage; the less frequent a word is, the more strongly the meaning of a passage is expected to depend on its full and proper interpretation.

While competent reading depends on resolving these words, it also depends on resolving them quickly and completely. The nature of the system is such that identification of individual words depends on simultaneous activation of the units corresponding to their orthographic or phonological components. Similarly, the comprehension of phrases and sentences depends on simultaneous activation of the units corresponding to their component words. The problem is that while simultaneous activation of successive units depends on rapid activation of each, the response of any one of the processors to less familiar words is expected to be relatively slow and possibly fuzzy.

It is in overcoming this problem that the connectivity among the processors is so critical to the skilled reader. By mutually facilitating, reinforcing, and reminding each other of their relevant knowledge, they collectively ensure that we will recognize printed words, ranging in frequency and familiarity from *the* to *syzygy*, with the greatest speed and accuracy possible.

For this role alone, the Phonological processor is an indispensable part of the system. Yet its second role, as memory enhancer, is at least as important.

Supporting the Reader's Running Memory for Text

At the bottom-most level, the connections between the Orthographic and Phonological processors capture the ways in which the graphemes of our language symbolize its phonemes. Thus, a seemingly reasonable hypothesis about the Phonological processor is that its existence is a consequence of the alphabetic foundation of our script and its use, a fortuitous vestige of having learned to read by sounding out words.

To be sure, phonic instruction must contribute invaluably to the definition, strengthening, and refinement of these connections between print and speech. Yet phonic training cannot be the whole

53. Finn (1977–1978).

explanation for their existence, and support of the alphabetic principle cannot be the whole explanation for their use.

Automatic phonological translation has been found among normal, skilled readers of every language studied.[54] This includes readers of Chinese, whose script is principally logographic.[55] And despite the fact of automatic phonological translation among readers of Chinese, the translations they produce seem unrelated to—even disjoined from—the processes of visually recognizing and accessing the meanings of individual words.[56] The suggestion is that phonological translations subserve some additional purpose, distinct from word identification, in the reading process. Theory and research confirm that this is so.

Text comprehension is a two-stage process. In the first stage, the reader identifies each successive word and its appropriate meaning as defined by its immediate context. In the second, the reader interprets the entire string of words just read, considering the relationships among the just-read words to each other as well as to any relevant background knowledge and larger understanding of the text that can be brought to bear. In order for this second stage to result in a complete and sensible interpretation, there are two conditions on its execution.

First, it is best undertaken at major syntactic boundaries. Otherwise, the string of words to be compiled will be syntactically incomplete and make no.[57] The performance of skilled readers indicates that they generally prefer to recode at the boundaries between sentences or whole clauses. In keeping with this, when skilled readers are in the course of reading a clause, their ability to recall its precise wording is extremely rapid and accurate; in contrast, this fine, verbatim memory for the clause is all but lost just as soon as they start reading the next.[58] As another outward sign of this recoding, skilled readers characteristically pause at the end of major syntactic units.[59] Appropriately, the duration of this "wrap-up" time is significantly increased if the interpretation of the just-read clause requires inference or subtle resolution of pronouns.[60]

54. Tzeng and Wang (1983).
55. Tzeng, Hung, and Wang (1977).
56. Trieman, Baron, and Luk (1981); Tzeng and Wang (1983).
57. That is, ". . . make no sense."
58. Chang (1980); Kleiman (1975).
59. Aaronson and Scarborough (1976); Just and Carpenter (1987).
60. For the term "wrap-up" as well as a discussion of such findings see Just and Carpenter (1987).

The second condition on the success of the wrap-up process, is that it get the proper input. Specifically, its success depends upon the reader's having a complete and correctly ordered memory of the just-read words. Again, if the reader's memory for the just-read words is incomplete or misordered, then a sensible interpretation may be precluded.

Baddeley, Vallar, and Wilson have illustrated the importance of these two conditions through work with individuals whose immediate verbal memory capacity has been reduced through brain damage.[61] In their first patient, phonological memory capacity had been impaired by a stroke to the point that she was capable of retaining the wording of sentences no more than six words in length. Her ability to understand short simple sentences, and even series of such sentences, was unimpaired. However, within lengthy clauses, she showed difficulty in connecting pronouns and other indirect references to their antecedents. In addition, she was entirely unable to judge the sense or nonsense of longer written or spoken sentences that required precise retention of wording and order. Examples of these sentences include:

The earth divides the equator into two hemispheres the northern and the southern.

One could reasonably claim that sailors are often lived on by ships of various kinds.[62]

Due to a prolonged seizure, the sentence memory of a second patient had been reduced to just three words. This is too few for most of the sentences we see and hear. In keeping with this, the patient "complained of comprehension difficulties, saying that he could always understand the beginning of a conversation, but that after the first few phrases, his mind became cluttered 'like a noisy television screen.' "[63]

When reading, if given enough time, this patient could correctly interpret such sentences as

The girl is pushing the horse.

Baddeley, Vallar, and Wilson show how, with three-word units and by dint of work, this is possible:[64]

61. Baddeley, Vallar, and Wilson (1987).
62. Baddeley, Vallar, and Wilson (1987, p. 514).
63. Baddeley, Vallar, and Wilson (1987, p. 515).
64. Baddeley, Vallar, and Wilson (1987, p. 527).

The girl is . . .
. . . girl is pushing . . .
. . . is pushing the . . .
. . pushing the horse.

The correct interpretation can be had by focusing on the second and fourth triplets.

But other sentences eluded this patient, regardless of the time invested:

The book the pencil is on is red.

For sentences such as this, no combination of two or three triplets will unlock its sense:

The book the . . .
. . . book the pencil . . .
. . . the pencil is . . .
. . . pencil is on . . .
. . . is on is . . .
. . . on is red.

Given clauses that are extremely long and complex, similar difficulties must threaten healthy, skillful readers. It is not the capacity of one's verbal memory but the capacity relative to the requirements of the task that makes the difference.

How do normal, skillful readers cope with such difficulties? They exploit their phonological translations: Skilled readers can neither remember nor comprehend a complex sentence when they are prevented from subvocalizing its wording.[65]

It is important to note that suppression of subvocalization does not disrupt the interpretation of single words or simple sentences. The effect here has nothing to do with word identification. Rather the mechanism at work is our so-called "articulatory loop"—our ability to extend phonological memory through verbal rehearsal.[66] By speaking or thinking the spoken images of the words to ourselves, we effectively renew their phonological activation, thus extending the longevity and holding capacity of our verbatim memory.

In contrast with skillful readers, younger and poorer readers are expected to exploit this capacity relatively ineffectively. First, the capacity of immediate memory varies directly with the

65. Baddeley (1979); Levy (1977); Levy (1978); Waters, Caplan, and Hildebrandt (1987).

66. Baddeley (1986).

speed with which the items to be remembered are encoded[67]—but the decoding speed of younger and poorer readers is relatively slow. Second, the capacity of immediate memory varies directly with the amount of effort that is simultaneously being invested in processing activities[68]—but younger and poorer readers must invest considerable effort in all aspects of reading. Third, evidence suggests that, as a group, younger and poorer readers are relatively disinclined to engage in verbal rehearsal in the first place.[69] Moreover, where young readers are actively engaged in sounding out individual letters and syllables, the Phonological processor is clearly unavailable for retaining the wording of clauses.

Not surprisingly, then, memory for the prior wording of an in-process clause has been shown to be significantly poorer among younger than among older students and among low-ability readers than among high-ability readers.[70] Such deficits might well be the explanation of why poor readers are inclined to supply such words as *pizza* in a fill-in-the-blank test like the following:

When I got home from work, I wanted to eat a fruit. I went to the refrigerator and got a ______.[71]

Although normal reading does not consist of fill-in-the-blanks, this kind of behavior points up the impoverished comprehension and consequent dysfluency that poorer readers may face.

Perfetti and his colleagues found, more specifically, that their poorer third-grade readers could not remember as many as three words back in a clause.[72] The interpretive situation in which such youngsters find themselves must be very much like those described earlier for memory-impaired adults, with one important difference: While the impaired adults exercised the control and determination to overcome such deficits whenever possible, children may not.

Finally, although skilled readers prefer to undertake this second, integrative level of interpretation at sentence boundaries, they are relatively flexible about overriding that preference. If

67. Baddeley, Thomson, and Buchanan (1975); Case, Kurland, and Goldberg (1982); Dempster (1981).

68. For a discussion of trade-offs between processing and storage demands in the reading situation, see Daneman and Tardif (1987).

69. For a review, see Jorm and Share (1983).

70. Perfetti (1985).

71. Perfetti and Roth (1977).

72. Goldman, Hogaboam, Bell, and Perfetti (1980).

the nature of the task or sentence so dictates, they will instead pause for wrap-up at clausal or phrasal boundaries. Clearly their ability to do so depends on their ability to recognize amenable syntactic boundaries, but this, too, is a process that has become highly automatic.

Skilled readers interpret the syntactic structure of what they are reading on the fly. As a consequence, they quite reliably stumble on such garden-path sentences as:

The conductor stood before the audience left the concert hall.
The old train the young.[73]

But importantly, they stumble as soon as they fixate the word *left* in the first sentence and the second *the* in the second. This indicates that they do not wait until the end of a clause or sentence to interpret its syntax: Instead they interpret (and, when necessary, reinterpret) it on a word-by-word basis.

The syntactic sensitivities of younger and poorer readers are not well developed.[74] For this reason alone, they are unlikely to break a sentence down into appropriate and tractable subunits even if they know they cannot manage its wording in its entirety.[75] And so, beyond having less immediate memory capacity and less inclination to expand it through verbal rehearsal, younger and poorer readers also have less flexibility in controlling its requirements.

Both the causes and consequences of inadequate memory for wording restress the value and importance of repeated readings of more difficult texts. In addition, they supply the rationale for the common use of short, simple sentences in primers—though, of course, the mastery of more complex ones can come about only through experience with them.[76]

Summary: The Importance of Phonological Processing

For the skillful reader, automatic phonological encoding subserves two distinct and critical processes. First, as an alphabetic backup system, it increases the speed and completeness with which the

73. Just and Carpenter (1987).
74. Huggins and Adams (1980).
75. See Adams (1980).
76. Adams (1980) argues that both the requirement and the opportunity for developing sensitivities to more complex syntactic structures arise through *reading* language, not listening to it.

meanings and orthography of less familiar words can be processed. Second, through the "articulatory loop," it expands the reader's verbatim memory capacity in support of proper comprehension.

For skilled readers, in short, phonological processing adds a critical degree of insurance and efficiency to the reading system. Paradoxically this added insurance and efficiency is generally denied to younger and poorer readers precisely because of the reasons that they need it all the more; it is precluded precisely because of the otherwise inefficiency of their processing capabilities.

The situation is succinctly summarized by Charles Perfetti and Alan Lesgold:

> The poor reader is slower at getting to the point in the comprehension process beyond which exact wording is not needed, but he is also poorer at retaining exact wording. Thus, he is confronted with a double whammy—slower processing and lower tolerance (in terms of working memory), both of which combine to create more processing needs [resulting in still more slowing and still less tolerance] than might otherwise exist.[77]

In his recent book, Perfetti has explored the relationship between processing efficiency and comprehension potential in depth.[78] He has examined data on the realities and consequences of all manner of processing inefficiencies, from single letter recognition to subtleties of discourse processing. Perfetti makes very clear that reading comprehension is an extremely complex behavior and that its efficiency is influenced by many, many factors. Nevertheless, his ultimate conclusion is that the most frequent, pervasive, and profound reading problems derive from difficulties in recognizing the orthography and identifying the meanings of individual words.

77. Perfetti and Lesgold (1977, p. 178).
78. Perfetti (1985).

This book could not have been written without the unending support and encouragement of my husband, Milton B. Adams. I dedicate it to him and our children, John and Jocelyn, with all my love.

Eighth printing, 1995
First MIT Press paperback edition, 1994

The work on which this publication was based was supported in part by the Office of Educational Research and Improvement under cooperative agreement No. G 0087-C1001. The publication does not necessarily reflect the views of the agency supporting the research.

This book was set in Palatino and printed and bound in the United States of America.

Library of Congress Cataloging in Publication Data

Adams, Marilyn Jager.
Beginning to read: thinking and learning about print / Marilyn Jager Adams.
p. cm.
"A Bradford book"
Includes bibliographical references (p.
ISBN 0-262-01112-3 (HB), 0-262-51076-6 (PB)
1. Reading—United States. 2. Reading readiness. I. Title
LB1050.A258 1990 89-13716
372.4—dc20 CIP

Contents