10

Word Reading

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The development of written language ranks among humankind's great cognitive and cultural achievements. Written language allows us to communicate meanings to others across vast distances of time and space. Unlike spoken language, written language is acquired only with instruction and effort, and thus cannot be said to reflect the natural unfolding of a genetic program. Written language represents a true achievement of human cognition, and apparently an achievement not easily come by: successful written languages have developed independently at only a few places and times in human history (for a history of written-language development see DeFrancis, 1989). Therefore, a better understanding of the reading process is important not only for its own sake, but also because it promises to reveal some of the basic principles of human cognitive representation, computation, and problem-solving. Furthermore, an understanding of the reading process provides a basis for understanding the difficulties that many individuals experience when initially learning to read, or subsequent to neural injury.

The problem in reading is that of extracting meaning from the written stimulus. The stimulus may correspond to a word, phrase, or sentence. However, this chapter will consider only the reading of single words and we focus on the following three basic questions: (1) How is the written stimulus represented? 2) Is phonology required to extract meaning from print? and 3) How do we go from print to sound?

REPRESENTING THE STIMULUS: A QUESTION OF WHAT AND WHERE

Reading requires, at a minimum, that the reader determine *what* letters are in the stimulus (letter identity) and *where* they are (letter position). Our discussion of stimulus representation, therefore, will be organized around these two questions.

What?

Most theories of reading assume that information is extracted from the stimulus and mentally represented and that this representation is used to search memory for stored information about the stimulus. Access to this stored information then forms the basis for retrieving the meaning and pronunciation corresponding to the stimulus. Given this, the stimulus should be represented in a manner that corresponds to or is compatible with the form of the information stored in memory. Two issues have dominated the question of stimulus representation in reading. One is whether the visual attributes of letters or abstract letter identities form the basis of word identification. The second issue concerns the "size" of the units represented—single letters, spelling units, syllables, morphemes, etc.

Visual Features and Abstract Letter Identities

It is clear that the visual features of a written stimulus must be processed and represented. At issue is whether word identification is based on a featural representation or on a subsequent representation of abstract letter identities. Abstract letter identities, or ALIs (Polk & Farah, 1997), are representations of letters that lack name or physical form; for example R, r, ℛ, *r* all correspond to the same ALI.

A number of a priori, computational reasons make it unlikely that reading is based directly on visual features or shape information. Such a view would require that we store the spellings of all the words we've previously encountered in multiple fonts and cases (and what about sizes?). Furthermore, it leaves unexplained how we recognize a word in a form or font we have never EnCouNtEReD 𝔅𝔈𝔉𝔒ℜ𝔈 (see Polk & Farah, 1997, for a discussion of how ALIs might be acquired).

Nonetheless, a number of observations have led researchers to suggest that visual features may play an important role in word identification in reading. This work has examined font-specific effects and the role of the "word envelope." The word envelope is the pattern of ascending and descending letters that correspond to a word's lower-case form (e.g., "apple" has a very different word envelope than "hotel").

Evidence comes from studies such as that of Posnansky and Rayner (1977), who asked subjects to quickly name an object containing a written word or nonword. They found facilitation in naming times if, for example, the picture was of an apple and the written stimulus was either 'apple' or another letter string with the same envelope (oqqtc). In another study, McClelland (1977) found that subjects who were taught to associate meanings with nonwords performed better when both trained and tested with stimuli in the same font (see Henderson, 1982, for a review).

These effects, and many others that have been used as evidence for the role of visual features in written word identification, can be explained as occurring at the level of letter identification rather than in word identification per se (see Mayall, Humphreys, & Olson, 1997). Furthermore, numerous studies have failed to find support for predictions derived from the feature-based hypothesis. For example, Paap, Newsome, and Noel (1984) hypothesized that if word-shape information is used in recognition it would be useful to the extent that a word's shape was rare or unique. They found, however, that response times to words with rare versus common shapes did not differ in a lexical decision task. Additionally, various studies found evidence that supports the prediction of an ALI-based account. Rayner, McConkie, and Zola (1980) reported that switching the case of letters in mid-saccade did not disrupt naming performance (see also, Adams, 1979; Baron & Strawson, 1976; Besner, 1983; Besner, Coltheart, & Davelaar, 1984; Coltheart & Freeman, 1974; Evett & Humphreys, 1981; Monk & Hulme, 1983; Mozer, 1989; Underwood & Bargh, 1982).

Thus the preponderance of evidence from unimpaired subjects favors the position that word recognition requires the computation of ALIs. Data from neurologically impaired subjects converges on the same conclusion.

Evidence from Deficits

Strong support for the crucial role of ALIs is provided by a performance pattern indicating a reading impairment that cannot be attributed either to a loss of knowledge of word spellings (lexical orthographic knowledge) or to difficulties in processing letter shapes.

The cases of JGE (Rapp, Link, & Caramazza, 1993) and GV (Miozzo & Caramazza, 1998) constitute clear examples (see also Rapp & Caramazza, 1989; but see Howard, 1987). As indicated in Table 10.1, both subjects exhibited severe impairments in oral reading (JGE: 45% correct, GV: 0% correct). JGE and GV's difficulties were not, however, attributable to loss of knowledge of word spellings since both subjects were able to name words correctly when the letter names were spoken by the examiner.

An impairment in some aspect of letter identification was signaled by relatively low accuracy in naming single letters. They were, however, able to correctly produce letter names in tasks, such as oral spelling that didn't involve visual input, indicating that the letter identification difficulty was not attributable to an output problem. Nor could these difficulties be attributed to visual misperception, as both subjects performed very well in physical letter matches, and JGE was very accurate in copying letters. Furthermore, the difficulty was not one of recognizing letter shapes, as both subjects performed with 100% accuracy in letter decision tasks where they were asked to make yes/no judgements to letters and letter-like shapes. Additionally, GV showed normal performance in discriminating normally oriented from reflected letters. Critically, the letter-processing task on which both subjects were impaired (JGE: 78%, GV: 62%) was one that required the computation of ALIs from visual input—a cross-case letter identification task (e.g., Are *E* and *e* the same letter?).

To account for this full pattern of performance, the authors argued that one must assume a level of abstract letter identity representation that forms the basis for the recognition of written words. With this assumption the subjects' performance can be understood by positing a deficit affecting their ability to go from letter shapes to ALIs.

Higher-Order Units?

Assuming that reading involves representing the ALIs in the written stimulus, many researchers have asked whether ALI's are organized into higher order units—sometimes referred to as the question of sublexical orthographic structure. A number of such units have been proposed, they include: morphemes (Caramazza, Laudanna, & Romani, 1988; Fowler, Napps, & Feldman, 1985; Murrel & Morton, 1974; Stanners, Neisser, Hernon, & Hall, 1979; Taft & Forster, 1975,

Table 10.1
Performance on Tasks Assessing the Integrity of Abstract Letter Identities for JGE and GV.

	Percent Correct	
	JGE	GV
Oral reading	45	0
Rec. of orally spelled words	91	100
Letter naming	80	37
Oral word spelling	100	97
Cross-case letter identification	78	62
Physical letter matching	99	93
Copying	97	—
Letter decision	100	100
Letter orientation	—	normal

Data on JGE adapted from "The Role of Graphemic Representations in Reading: Evidence from a Deficit to the Recognition System," by B. Rapp, K. Link, and A. Caramazza, 1993. Paper presented at the annual meeting of the Academy of Aphasia, Tucson, Arizona. Data on GV adapted from "Varieties of Pure Alexia: The Case of Failure to Access Graphemic Representations," by M. Miozzo and A. Caramazza, 1998. *Cognitive Neuropsychology, 15,* pp. 203–238.

1976), syllables (Prinzmetal & Millis-Wright, 1984), syllable-like units such as Basic Orthographic Syllable Structure (BOSS; Taft, 1979), as well as subsyllabic units such as onset and rime (Treiman & Chafetz, 1987; Treiman & Zukowski, 1988), word body (Kay & Bishop, 1987; Patterson & Morton, 1985), spelling units (Gibson, Pick, Osser, & Hammond, 1962; Pring, 1981), and consonant and vowel clusters (Warrington & Shallice, 1980).

What purpose would be served by organizing a letter string into one or more of these unit types? Presumably it would be to facilitate the further processing required to extract meaning and/or pronunciation. The argument for the morphological organization of the stimulus is that stored forms of words are represented in a morphologically decomposed manner. Arguably this is necessary to explain the combinatorial properties of morphemes—the fact that they can be productively combined, and recombined (WALK+ ING, ED, ER, S) and that we can easily recognize novel combinations (PRECINCT+ING).

An argument for submorphemic orthographic organization into syllable and subsyllabic units might be that this too reflects the organization of the stored material. However, the motivation for this is less obvious than in the case of morphemes. A stronger argument is that subsyllabic units play an important role in the procedures we use to process unfamiliar strings (FLOPE, YASHMANT). We easily derive plausible pronunciations for such strings although we may never have previously encountered them. Thus the pronunciations are not based on long-term memory representations of the whole strings. Presumably the stimulus is organized into sub-morphemic units that access stored information derived from our experiences with the pronunciations of these smaller units. These types of units may be useful in representing important aspects of pronunciation. For example, the pronunciation of UI varies if it is a part of a spelling unit or not (as in FRUIT vs. FLUID) or the pronunciation of Y varies depending on whether it occurs at the beginning or the end of a syllable (YOUNG vs. STUDY), etc.

Evidence for syllabic orthographic organization was provided by Prinzmetal and colleagues (e.g., Prinzmetal, Treiman, & Rho, 1986) who found that perceptual errors referred to as "illusory conjunctions" are constrained by the syllabic structure of a written stimulus. When subjects are briefly presented words consisting of colored letters, occasional misperceptions occur whereby a letter is perceived as having the color of another letter in the string. These misconjunctions of color and form were more likely to occur among letters within the same syllable than among letters from different syllables (see also Rapp, 1992). On this basis, Prinzmetal et al. (1986) argued for the notion of the orthographic syllable.

Much of the evidence for subsyllabic elements such as onset and body comes from the work of Treiman and colleagues (Treiman & Chaftez, 1987; Treiman & Zakowski, 1988). The onset of a syllable is the initial consonant or consonant cluster of the syllable and the body is the remainder of syllable (e.g., CR//ISP is divided into onset and body (or rime). In one study, Treiman and Chaftez (1987) found faster lexical decision times to words divided into onset–rime segments (CR//ISP) than to words divided otherwise (CRI//SP; for other evidence of higher order units also see Bowey, 1990; Joubert & Lecours, 2000; Mewhort & Beal, 1977; Rey, Jacobs, Schmidt-Weigand, & Zeigler, 1998; Santa & Santa, 1979; Treiman & Zukowski, 1988).

Evidence from Deficits

Evidence from deficits supporting the notion of morphological decomposition in reading is well reviewed in Allen and Badecker (this volume). We focus here on findings concerning submorphemic units.

Lesch and Martin (1998) described ML who exhibited good word reading (100% with nouns), but severely impaired nonword reading (38% correct). Investigation of his sublexical processing abilities revealed normal performance with syllable units and severe difficulties with subsyllabic units. In segmentation tasks, ML divided visually presented words into syllables with normal accuracy (FU-TURE) but scored far below control subjects in dividing words into onset and body units (C-AST) and into spelling units (or graphemes[1]) (CH-UR-CH). In nonword reading, ML was extremely impaired in pronouncing individually presented onsets (e.g., BL-) or bodies (e.g., -ACK; 14% and 20% correct, respectively) but was far more accurate in pronouncing syllables. Specifically, ML was better able to read syllables that are contained in actual words (e.g, FLUT from FLUTTER; 71% correct) than possible syllables that do not appear in any words (FURB; 28%). These difficulties could not be attributed to a spoken production problem because ML's repetition performance, although far from perfect, did not exhibit the pattern shown in nonword reading.

The authors argued that ML's knowledge of units below the word and syllable level was disrupted, producing selective difficulties in nonword reading (see also Berndt, Haendiges, Mitchum, & Wayland, 1996). They further argued that the results support the proposal that we normally store in memory the pronunciation of units of many sizes to be used for nonword spelling–single letters, letter clusters, syllables, onsets, bodies (see Shallice & McCarthy, 1985; Shallice & Warrington, 1980; Shallice, Warrington, & McCarthy, 1983; and for computer simulation see Norris, 1994).

Additional evidence for this proposal comes from reports of other "dissociations" across different sublexical unit types. For example, FL (Funnell, 1983) could read nonwords with reasonable accuracy (74%), although she accurately produced the 'sound' of only 33% of single written letters. The difficulty with single letter "reading" was not one of oral production because nonwords whose pronunciations corresponded to the "pronunciations" of letters (BUH, FUH, etc.) were read correctly (see also, Dickerson, 1999). In contrast, a number of individuals have been described as having difficulty reading units larger than the single letter or grapheme. MS's (Newcombe & Marshall, 1985) oral reading errors indicated intact knowledge of the pronunciation of single letters (e.g., TOUCH read as /t ɒ kə hə /) but a lack of ability with larger units (see also, Derouesne & Beauvois, 1979; Holmes, 1978; Marshall & Newcombe, 1973).

Summary

These results from normal and impaired performance indicate that, at least for the purposes of generating a pronunciation for an unfamiliar word, letter strings may be organized into higher order units. These results have prompted questions regarding whether higher level units such as syllables, onsets, bodies, and even morphemes are explicitly represented or if, instead, the observed results can be explained by patterns of frequent and infrequent letter co-occurrence correlated with higher order units (e.g., bigram frequency, among others) (Seidenberg, 1987; Seidenberg & McClelland, 1989). This possibility has been directly addressed in a number of studies that have failed to find support for it (for a review see Rapp, 1992). Nonetheless, it continues to play a role in the broader debate regarding the statistical versus symbolic character of mental representation and computation.

Where?

Given that written language is replete with words that share letters but differ only in terms of the positions of letters (e.g., BREAD/BEARD/BARED), it is obvious that letter-position information must both be extracted from the stimulus and also form a part of stored representations. Given this it is somewhat surprising that the topic has received so little attention. We review two proposals regarding the representation of positional information originating from

[1]The term "grapheme" is used in the literature to mean either an ALI or the letter or letters that correspond to a single phoneme. On the first definition SHOE has four graphemes, on the second it as two (SH/OE). In this chapter we adopt the second definition.

the study of deficits: Caramazza and Hillis' (1990, 1991) spatial encoding proposal, and Greenwald and Berndt's (1999) work on ordinal encoding.

Caramazza and Hillis (1990, 1991) described NG, who exhibited difficulties in processing/representing the right-side of stimuli across a number of tasks: reading, line bisection, copying, etc.[2] For example, NG read HUMID as "human," HOUND as "house," SPRINTER as "sprinkle." What was striking was that she made precisely the same types of errors regardless of the topographical presentation of the stimulus. That is, errors at the "end" of the word were produced for stimuli presented horizontally, vertically, or mirror-reversed (i.e., in mirror reversed presentation COMMON was read as "comet" although the "end" was presented to the left). Furthermore, this pattern was observed regardless of the modality of input: visually or when NG heard the names of letters and had to say the word. Additionally, the same pattern was seen in written and oral spelling and even backward spelling. The authors concluded that the similar pattern across all modalities of input and output indicates that the deficit affected a representation of letters that is insensitive to form and modality–ALIs.

In addition, the distribution of errors across letter positions was consistent across these various tasks. NG didn't simply produce more errors on the ends versus beginnings of words; her rate of errors was distributed across letter positions in a very specific manner. Table 10.2 compares the her error rate displayed by ordinal letter position (1st, 2nd, 3rd, etc.) for different lengths with a word-centered display. It is apparent that the word-centered display captures the similarity across word lengths better than does the ordinal one. This is because the point in a word at which NG made spelling errors moved rightward as words increased in length. Thus it is apparent from the word-centered display that errors largely affected the right half of a word, regardless of its length.

The authors claimed that NG's performance argues for a spatial rather than an ordinal encoding of letter position. An ordinal encoding does not readily capture the fact that accuracy is determined by whether a letter is on the right versus left side of the word and by its distance from the center of the word. They specifically proposed that letter positions are represented in a word-centered, spatially defined co-ordinate system such that HOUSE is represented as: H/-2, O/-1, U/ 0, S/+1, E/+2 (but see McCloskey, this volume, Chapter 5).

Greenwald and Berndt (1999) described the performance of DES who, like NG, exhibited comparable difficulties in reading and oral and written spelling, suggesting a deficit at the level of ALIs. Also like NG, her performance was better at the beginning than the ends of words. However, her performance differed from NG's in that she showed no signs of visuo-spatial neglect in other spatial tasks and, furthermore, her error rate across letter positions did not show the rightward shift that NG's did (see Figure 10.1). Whereas NG's proportion of errors on the fourth position of four letter words was 25% and on the fourth position of seven letter words it was only 5%, DES's error rates were approximately 35% and 40% on these positions.

On this basis the authors argued that DES's pattern of errors was better captured by assuming an ordinal rather than a word-centered representation of letter position (e.g., H/1st, O/2nd, U/3rd, S/4th, E/5th). As a further test of this hypothesis DES was shown a printed word and asked to choose a matching word from two auditorily presented words. The distractor words were spatial or ordinal distractors. Spatial distractors shared initial letters with the target (e.g., MEMBER/memory) and ordinal distractors contained all of the target word letters but in a different order (e.g., COTTON/control). DES made significantly more errors with ordinal versus spatial distractors. This led the authors to argue that DES had a deficit affecting her ability to encode the ordinal position of letters.

As stated above, very little is known about the representation of letter position information.

[2]This general pattern of performance, referred to as visuo-spatial neglect, as well as this particular case, are described elsewhere in this volume in chapters by Umiltà and McCloskey (Chapter 5).

Table 10.2
Rate of Spelling Errors at Each Position of Words of Lengths 4–7. Left-Aligned Display and Word-Centered Display.

	Position in the Word						
Length in letters	1	2	3	4	5	6	7
Left-Aligned:							
4	0	2	13	25			
5	0	0	6	20	29		
6	0	0	5	15	26	39	
7	0	0	3	5	15	28	51

Word Center
x

Word-Centered:													
4				0		2		13		25			
5			0		0		6		20		29		
6		0		0		5		15		26		39	
7	0		0		3		5		15		28		51

Adapted from "Levels of Representation, Co-ordinate Frames, and Unilateral Neglect," by A. Caramazza and A. E. Hillis, 1991, *Cognitive Neuropsychology*, 7, pp. 391–445.

Clearly more research is required to determine how seemingly disparate findings like those of NG and DES can be understood.

SUMMARY

This section has dealt with basic issues regarding the manner in which the relevant information contained in the written stimulus is mentally represented. The evidence for abstract letter identities seems fairly strong. However, numerous questions remain regarding higher order units and the representation of letter position. One possibility to explore is that the use of

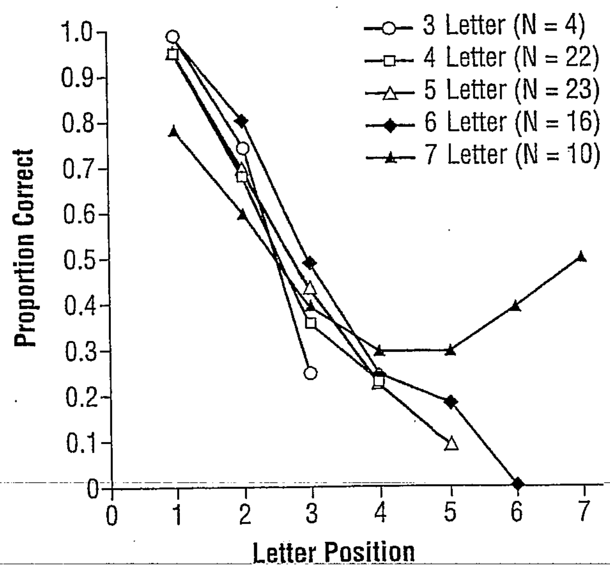


Figure 10.1: Error Rate by Letter Position for Words 3–7 Letters in Length, Exhibited by DES In Oral Reading. Adapted from "Impaired Encoding of Abstract Letter Order: Severe Alexia in a Mildly Aphasic Patient by M. L. Greenwald & R. S. Berndt, 1999, *Cognitive Neuropsychology*, 16, 512–536.

higher order units may play a crucial role in representing letter position. Higher order units may form the scaffolding to which ALIs are assigned and, in this way, contribute to encoding position (see Dell, 1986 in the context of phonology).

IS PHONOLOGY REQUIRED TO EXTRACT WORD MEANING FROM PRINT?

The Positions

The acquisition of written language skills (reading and spelling) clearly builds upon spoken language skills and knowledge. Less clear, however, is the relationship between written and spoken language in the competent written-language user. The relationship between written and spoken language has consequently been the topic of considerable controversy (also see Tainturier & Rapp, this volume). The debate has centered around two competing positions: *direct access* to meaning from print, and *mandatory phonologically-mediated access*. The direct access hypothesis holds that the meaning of a written word can be recovered without any involvement of phonology (see Coltheart, 1980; see Coltheart & Coltheart, 1997). In contrast, the hypothesis of mandatory phonological mediation assumes that meaning can be recovered from print only if the written stimulus is first recoded in phonological form (Frost, 1998; Lukatela & Turvey, 1991, 1993, 1994a, 1994b; Van Orden, 1987, 1991; Van Orden, Johnston, & Hale, 1988; Van Orden, Pennington, & Stone, 1990).

Direct Access

The direct access proposal is represented schematically in Figure 10.2A. According to this view, a written stimulus is recognized as a familiar letter sequence if it makes contact with a stored representation in orthographic memory (the *orthographic lexicon*). The activation of the stored representation constitutes the basis for accessing the word's meaning in the *lexical semantic system*. This is the core part of the direct access proposal.

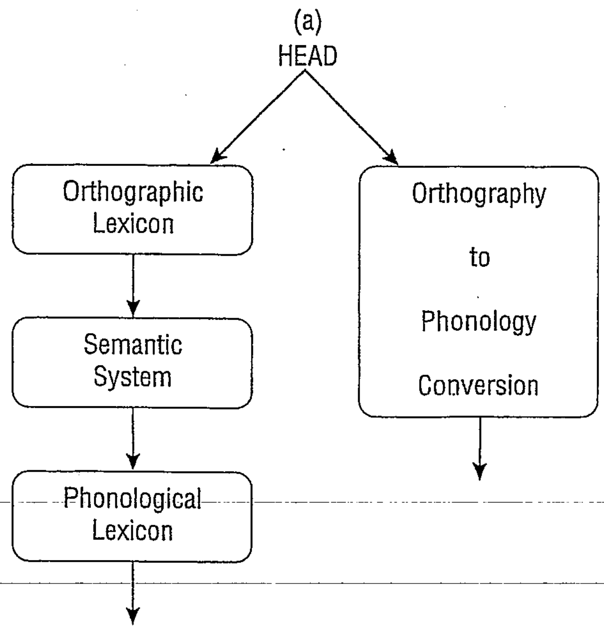
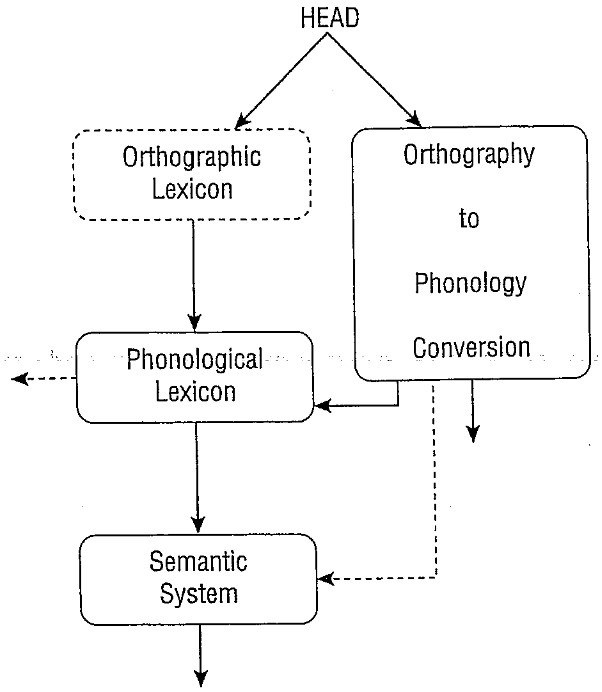


Figure 10.2: Different hypotheses concerning the relationship between phonology and orthography in reading. (a) corresponds to a direct access architecture; (b) and (c) correspond to different instantiations of the mandatory phonological mediation hypothesis.

(b)


HEAD
Orthographic Lexicon
Orthography to Phonology Conversion
Phonological Lexicon
Semantic System

(c)

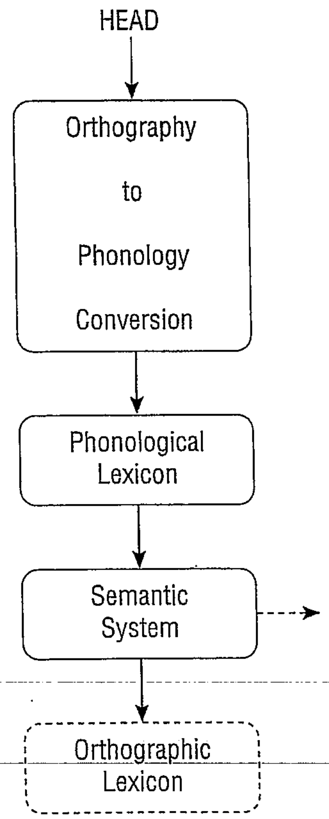

HEAD
Orthography to Phonology Conversion
Phonological Lexicon
Semantic System
Orthographic Lexicon

Figure 10.2A also depicts how phonological recoding may take place within a direct access architecture. One option is that after semantic access, a stored memory of the word's phonological form is retrieved from a long-term memory store (the *phonological lexicon*). A second option is that phonological recoding takes place based on the reader's knowledge of the regularities in the sublexical relationships between the letters and sounds of the language; these are represented in the *orthography-to-phonology conversion system* (OPC system). This system will be discussed in the following section; for present purposes it suffices to say that the OPC system is generally assumed to represent common or highly regular relationships (e.g., EA -> /i/) more strongly than less common relationships (e.g., /EA -> /ε/). For example, the written stimulus HEAD could be phonologically recoded by the GPC system as either /h i d/ or /h ε d/ but /h i d/ is more likely because the /i/ pronunciation of EA is more common in English than /ε /.

It is important to note that proponents of direct access do not claim that direct access is the only means of contacting meaning; they typically accept that phonologically based access can also take place. For example, phonologically based access can occur when a phonological representation computed by the OPC system serves as input to the phonological comprehension system, and engages the spoken language recognition system (not depicted in Figure 10. 2A). Some investigators assume that direct access, although not the only means of contacting meaning, is the predominant one, others are neutral with regard to the relative importance of direct access and phonological recoding.

Mandatory Phonological Recoding

Two versions of the mandatory phonological mediation position are represented in Figures 10.2B and 10.2C. Both proposals assume that phonological recoding necessarily precedes access to meaning; they differ only in whether the recoding is lexical or sub-lexical (also referred to as "non-lexical"). According to the position depicted in Figure 10.2b, the written stimulus makes contact with a stored lexical phonological representation (this process may or may not involve the orthographic lexicon) and this representation then provides access to word meaning. This view also allows for sublexical phonological recoding through OPC.

According to the position depicted in Figure 10.2C, a written stimulus is submitted to the OPC system and a phonological representation is generated that then accesses a stored representation in the phonological lexicon. This phonological representation, in turn, serves as the basis for accessing meaning in the semantic system. Only later (and only according to some authors) is contact made with the orthographic lexicon.

A large number of studies with normal subjects have examined the role of phonology in reading. However, relatively few of them have been specifically concerned with the role of phonology in deriving meaning from printed words. Most have considered simply whether or not phonological recoding occurs across a range of tasks involving written stimuli, whether or not comprehension is required. For this reason it is important to make a distinction between evidence indicating that phonological recoding is mandatory for deriving meaning from print, and evidence that phonology is automatically (obligatorily) generated, even if not required for accessing meaning. Thus, there are various hypotheses to be considered: (a) direct access is possible and phonology is not automatically generated in processing written text; (b) direct access is possible and phonology is automatically generated; and (c) direct access is not possible and phonological recoding is both automatic and mandatory for accessing meaning.

Evidence for Obligatory Phonological Recoding in Written Word Processing.

A number of studies have shown that phonology is generated in the course of processing written words in tasks where it is not required and may even hinder performance. For example, Perfetti, Bell, and Delaney (1988) reported that in the backward masking paradigm subjects can better identify a briefly presented target (e.g., RAKE) if it is followed by a briefly presented pseudoword that is phonologically similar (e.g., RAIK) rather than graphemically similar to the target (e.g., RALK), even when subjects have no conscious recollection of having perceived the masking pseudoword. This suggests that the pseudoword prime is phonologically recoded and that this phonological code contributes to the processing of the target. Phonological effects have also been reported in letter search tasks (Ziegler & Jacobs, 1995), Stroop tasks (Dennis & Newstead, 1981), and in lexical decision tasks (Lukatela, Savíc, Gligorijevíc, Ogjennovic, & Turvey, 1978).

These findings, while they don't speak directly to the role of phonology in accessing meaning, suggest that phonological recoding is automatic, even when it is not required for the task. Problematic for this conclusion, however, are findings that phonological effects may be present or absent depending on specific experimental manipulations. For example, Verstaen, Humphreys, Olson, and d'Ydewalle (1995) showed that the phonological effects described above in the backward masking paradigm disappear if all of the target words are homophones (in which case the use of phonological information in identifying targets would be particularly misleading). Phonological recoding effects have also been shown to depend on the proportion of homophones or pseudohomophones in a stimulus list in lexical decision (Waters & Seidenberg, 1985; Davelaar, Coltheart, Besner, & Jonasson, 1978; Hawkins, Reicher, Rogers, & Peterson, 1976; Pugh, Rexer, & Katz, 1994; see also, Davis, Castles, & Iakovidis, 1998). If phonological effects can be eliminated under certain conditions then it is hard to argue that phonological recoding occurs obligatorily and automatically in the course of processing written stimuli.

Phonological Recoding in Accessing Meaning from Print

Much of the evidence favoring a role for phonology in retrieving meaning from print has involved homophones, words in which the spoken form is associated with multiple meanings (e.g., /s εi l/ -> bargain or boat?); whereas their written form is not (e.g., SALE–bargain; SAIL–boat). If phonology is involved in accessing meaning from print, multiple meanings may be activated when a written homophone is encountered.

In a semantic categorization task (e.g., Flower–is X a flower?), Van Orden (1987) found that incorrect yes responses were more common for homophones of a category exemplar (ROWS) than for control words (ROBS). This was interpreted as evidence that phonological recoding of ROWS (/r ou z/) led to activation of both meanings (flower and lines) even though the spelling (ROWS) was consistent with only one meaning. Van Orden et al. (1988) found a similar pattern of false positive errors with homophonic *non*words (e.g., responding yes to the question: Is CROE a BIRD)? Van Orden and colleagues concluded that "word identification in reading proceeds from spelling to sound to meaning" (Van Orden et al., 1988, p. 371). However, Jared and Seidenberg (1991) found that if broader semantic categories were used (e.g., LIVING THINGS), then the homophone effects obtained only for low frequency words, suggesting that the results reported by Van Orden et al. (1988) were, at least in part, strategic[3] (see also Taft & van Graan, 1998).

In a priming study, Lukatela and Turvey (1994 a, 1994b) reported that oral reading (e.g., FROG) was equally facilitated by the prior presentation of a semantic associate (TOAD), a word homophonic with the associate (TOWED), or a nonword homophonic with the associate (TODE). This was interpreted to mean that a phonological form is automatically activated by the written prime. It then serves to activate all meanings consistent with the phonological form,

[3]Specifically, Jared and Seidenberg (1991) suggested that the results observed by van Orden might have resulted from subjects generating predictions of possible exemplars when presented with a category label because, in fact, a number of very narrow category labels were used (e.g., a member of a convent–NONE).

such that when the target is presented, its meaning has already been preactivated and processing is facilitated.

Folk (1999) embedded homophones in sentences and measured eye-fixation times while subjects read silently for comprehension. She found that readers' initial fixation times were longer on homophones (e.g., BALE) relative to control words, indicating that multiple meanings associated with the common phonological code of the homophone were active initially, even though the spelling clearly indicated which meaning was intended.

All of these studies reveal that when the task requires reading for comprehension, the meanings of words that are only phonologically related to the target may be activated. Thus, these results support the view that phonological recoding very often occurs in circumstances when it is not required or helpful. They are not, however, incompatible with a direct access view. Within the architecture in Figure 10.2A one explanation is simply that these findings stem from trials on which, indeed, access to the meaning of the target does take place via the phonological code generated by the OPC. Another explanation, however, is that there is direct access to the meaning of the target and also concomittant access to its phonology (either via the OPC or lexically). The phonological code then activates all corresponding meanings (including the target's again). For this explanation to account for the data, it must be assumed that this happens with sufficient speed that the meanings of the target and its competitors are active within the same time frame.[4] Until more is known about the speed of these processes it won't be possible to determine if this assumption is unreasonable.

Finally, not only are homophone-based findings compatible with a direct access view, our ability to understand the meaning of homophones is considerably more straightforward under direct access than under mandatory phonological mediation. Under direct access, ROWS contacts its meaning directly from the Orthographic Lexicon. However, if ROWS is phonologically recoded to /r ou z/, how do we reliably access the correct meaning? Mandatory phonological mediation would require a rather convoluted account such that after accessing multiple meanings from the phonology the orthographic lexicon is accessed and generates two candidate spellings ROWS and ROSE which are then checked with the representation of the input stimulus and the inappropriate meaning is suppressed.

Given, therefore, that findings such as those reviewed here are compatible with both hypotheses, it is especially important to find paradigms and results that distinguish between them; evidence from deficits does just that.

Evidence from Deficits

Deficits allow us to examine reading comprehension in cases where access to phonology is impaired. The phonological mediation hypothesis predicts that such deficits should necessarily affect written word comprehension, whereas direct access allows for intact comprehension in such cases.

Shelton and Weinrich (1997) reported the case of EA, who exhibited excellent repetition but severely impaired spoken picture naming and oral reading (23–40% correct). His errors consisted primarily of semantically-related responses (e.g., STRAWBERRIES read as "grapes"). In contrast, reading comprehension of concrete words was quite good. This was evidenced by 90% accuracy in a written word/picture verification task in which half of the distractors were semantically related words and also in written lexical decision (98% correct).

Clearly, what is to be explained is the large discrepancy between EA's inability to derive phonology from print and his ability to derive meaning from print. This pattern is readily

[4]In tasks that require potentially "time consuming" decision-making such as Van Orden et al.'s (1988) this is not especially problematic. However, for simple reading tasks such as Lukatela, Cavello, & Turveys (1999) and Folk's (1999), some researchers find it implausible that there should be overlapping time frames.

understood under a direct access architecture since access to meaning precedes access to phonology and, therefore, a deficit in going from meaning to phonology should leave written word comprehension intact (Figure 10.2A). The similarity in EA's oral reading and spoken naming difficulties is explained by this deficit locus, as is his good repetition which indicates intact post-lexical processing.

In contrast, it is not obvious how mandatory phonological recoding can explain good reading comprehension of STRAWBERRIES based on a spoken response "grapes." If phonological recoding yielded "grapes," then this representation should form the basis of access to meaning.[5] One possibility to consider is that recoding is occurring sublexically; that is, that a phonological representation internally generated by the OPC system forms the basis for semantic access (Figure 10.2B) and that the erroneous spoken responses somehow result from disruption to subsequent processes. On this view nonword reading should be relatively intact. However, EA's ability to read pseudowords was extremely limited: 0–4% of nonwords were read correctly.

In sum, EA's pattern of performance and that of many other similar individuals (see cases in Coltheart, Patterson, & Marshall, 1980) is easily accounted for within a direct access architecture but is extremely problematic for either of the mandatory phonological mediation positions depicted in Figure 10.2.

Another relevant case is that of PS (Hanley & McDonnell, 1997). PS was only 43% correct in oral reading. In contrast, his comprehension of those same words—as evaluated by having him define written words—was 100%. Excellent comprehension of written words was also demonstrated (90–99% accuracy) across a range of written comprehension tasks such as lexical decision, written synonym matching, the Pyramids and Palm Trees Test (Howard & Patterson, 1992), and sentence-picture matching. Like EA, PS was also severely impaired in nonword reading: 17–34% correct. However, in contrast with EA, PS's errors were almost entirely phonologically related to the target, including both phonologically similar word (e.g., WEEKS → "wheat") and nonword errors (e.g., CONCEPT → /kamsɛps/). The errors seemed to be phonological rather than visual since targets and responses often shared more phonology than orthography (e.g., BUILD → bill, KNIFE → night; GREAT → grave). Also unlike EA, PS made similar errors in repetition as well as in oral reading and picture naming (auditory comprehension was intact).

The fact that the errors were phonological leaves open the possibility that written stimuli were correctly recoded, that this phonological recoding served as the basis for access to meaning, and that the phonological errors arose only later at a *post*lexical level of processing required for actual production of spoken forms. Such a scenario would be consistent with a mandatory phonological recoding account. This hypothesis predicts that PS should be able to use these correct, internally generated phonological forms as the basis for making certain phonological judgements (see Caplan & Waters, 1995). Hanley and McDonnell (1997) specifically tested this by asking PS to discriminate pseudohomophones (e.g., BRANE) from nonhomophonic nonwords and to discriminate homophone word pairs (e.g., SAIL/SALE) from nonhomophones (e.g., CLOWN/CLONE). Performance on both of these tasks was no better than chance. He was also asked to decide whether pairs of written words rhymed. His accuracy of 73% on this task was well outside the normal range.

[5]One might try to argue as does Frost (1998) that the oral reading responses don't actually reflect the phonological form that served as the basis for meaning retrieval. Frost (1998) suggests that such patients correctly phonologically recode the written word internally, then derive from this the word's meaning, but subsequently forget the phonological code and have to generate another one based on the activated meaning. Presumably the deficit, then, resides in rapid forgetting of the internally generated phonological code. Besides being rather contrived, this seems unlikely because it assumes that semantics is normally imprecise—so much so that not only does it not distinguish close synonyms (which might be understandable) but it also allows for confusion between distinct concepts such as strawberries/grapes or foot/sock. This leaves unexplained why we don't normally make semantic errors in speaking, a situation where phonology is derived strictly from meaning.

These findings, therefore, provide no evidence of correct internal phonological recoding of the written stimuli and, therefore, constitute further support for the hypothesis of direct access.

Summary

The cognitive neuropsychological literature reveals performance patterns that can readily be accounted for and are predicted by a direct access view but which are incompatible with mandatory phonological recoding. We have also seen that research with intact subjects, although not directly addressing this issue, reveals that phonological recoding of written words occurs frequently and quickly. Thus, at least for English, the balance of the evidence favors a direct access architecture that allows for optional phonological recoding.

Nonetheless, many investigators have been struck by the fact that phonological effects are so pervasive. For these investigators, this indicates that, phonological recoding, if not the only means for accessing meaning, is the primary means for doing so. Others interpret these same findings as indicating that phonological effects occur largely automatically during written text processing and do not necessarily affect access to meaning per se. Clearly, an important goal for further investigation is to examine the specific circumstances (with regard to stimuli, tasks, languages) under which direct and/or phonologically based access to meaning take place.

HOW DO WE GO FROM PRINT TO SOUND?

The Dual-Process Hypothesis

Thus far we have assumed at least two procedures for deriving sound from print. One, generally referred to as a *lexical process* (or route), involves relating word, or morpheme-sized units in the orthography to similar units in the phonology. In this case phonology is said to be "addressed" since the phonology is retrieved from long term memory (the phonological lexicon). According to the direct access view, the lexical procedure involves first retrieving meaning from orthography and then using the word's semantics to address its phonology.

The second procedure is assumed to use knowledge of the regularities in the relationships between orthography and phonology to convert the representation of the stimulus into a phonologically plausible sequence of phonemes and is referred to as the *nonlexical* or *sublexical process* (the OPC system). Since the phonological representation is not retrieved as a whole word or morpheme from long-term memory it is often referred to as a procedure for "assembling" phonology. Before considering the exact content of these two procedures, we review evidence supporting the general claim that there are two distinct routes for deriving sound from print (Figure 10.2A).

Evidence from Intact Subjects

The clearest evidence from intact subjects for "separable" procedures for deriving sound from print comes from Paap and colleagues (Paap & Noel, 1991; Paap, Noel, & Johnsen, 1992) and Baluch and Besner (1991). These studies are based on the well-established *frequency and regularity effects* and the *frequency by regularity interaction.* The frequency effect refers to the fact that high frequency words are named more quickly than low frequency words (Forster & Chambers, 1973; Frederiksen & Kroll, 1976). Presumably this occurs because low-frequency words are more "weakly" represented in the lexical route and, therefore, are processed more slowly. The regularity effect refers to the observation that "irregular" words, those words containing at least one uncommon or low probability grapheme-phoneme (GP) mapping (Y A *CHT* → /y a *t*/) are read more slowly than "regular" words, words containing only high probability mappings (S EE D → /s i d/; Baron & Strawson, 1976; Stanovoich & Bauer, 1978).

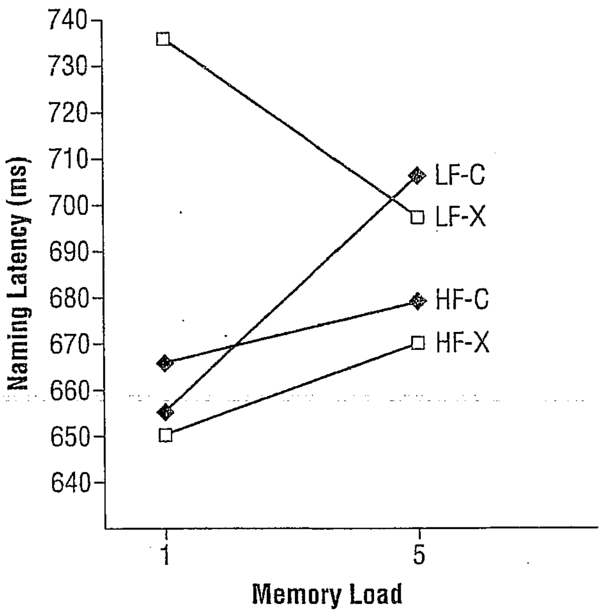


Figure 10.3: Naming time as a function of memory load for four types of words: high-frequency exception (HF-X), high-frequency control (HF-C), low-frequency exception (LF-X), and low-frequency control (LF-C). Adapted from "Dual-Route Models of Print to Sound: Still a Good Horse Race," by K. R. Paap and R. W. Noel, 1991, *Psychological Research/Psychologische Forschung*, 53, pp. 13–24.

To account for the regularity effect it is often assumed that both lexical and sublexical routes process a written stimulus in parallel. If the word contains only regular correspondences, then both procedures generate the same response. If, however, the word contains a low probability GP mapping, the lexical system generates the "correct" phonological response, while the sublexical system may generate a phonologically plausible, albeit lexically incorrect response (YACHT → /y a tʃ t/). The time required to resolve this conflict accounts for the regularity effect. The regularity by frequency interaction refers primarily to the fact that a strong regularity effect is observed only for low-frequency words (Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Taraban & McClelland, 1987). This can be understood by adopting the additional assumption that the lexical route is faster than the sublexical one. High-frequency words, regardless of their regularity, are processed by the lexical route relatively quickly and often before the sublexical route generates any conflicting outputs. Thus with high-frequency words, a regularity effect is either weak or absent. With low-frequency words, because the lexical route operates more slowly, there is time for the sublexical route to generate a conflicting response for irregular versus regular words and, as a result, a strong regularity effect is generated.

Paap and Noel (1991) attempted to selectively interfere with the sublexical route. They assumed that the OPC was more resource demanding than the lexical route and thus more likely to be disrupted under dual-task conditions. Subjects had to retain either 5 digits (high load) or 1 (low load) while concurrently performing an oral reading task. Paap and Noel predicted that if the sublexical route was especially disrupted by the high load, then this condition should reveal the lexical route operating in relative isolation. In that case, regularity effects for low-frequency words should be largely eliminated. This is just what they found (see Figure 10.3) (see also Baluch & Besner, 1991; Bernstein and Carr, 1996; Herdman, 1992; Paap et al., 1992).

In a complementary manner, Baluch and Besner (1991), working in Persian, created experimental conditions that produced what they considered to be a selective deactivation of the lexical route (see also Paap et al., 1992). This constitutes further support for the notion that the routes are sufficiently independent that they can be selectively engaged or disengaged[6].

[6]Additional evidence for multiple reading processes is the observation of length effects for nonwords but not for words (Ans, Carbonnel, & Valdois, 1998; Weekes, 1997).

Evidence from Brain Damage

A number of cases of deficits provide strong support for the separability of the two procedures for translating print to sound by demonstrating that they can be selectively damaged.

Funnell (1983) described the case of WB who, despite severely impaired nonword reading (0% correct), largely retained his ability to read words (overall accuracy 90%), even irregular words (80% correct). Derouesné and Beauvois (1985) presented a somewhat similar case of the French-speaking subject LB. LB's nonword reading was only 30% correct while word reading was 74–98% correct. Furthermore, the nonword difficulty was unlikely to be a production problem given that nonword repetition was intact as was performance on a range of other phonological tasks. These cases represent selective damage to the non-lexical route—a pattern often referred to as "phonological dyslexia" (see also Beauvois & Derouesné, 1979, and papers in Coltheart, 1996).

The case of KT (McCarthy & Warrington, 1986) forms a striking contrast: KT's nonword reading was preserved (96% correct) while reading of low-frequency irregular words was severely affected (26% correct). In KT's case, severe damage to the lexical procedure was hypothesized. It is generally assumed that the representations of low frequency words are more vulnerable to damage than those of high frequency words. Given KT's lexical impairment, these are the words most likely to be read by the relatively intact OPC. Furthermore, since the OPC is more likely to produce common rather than infrequent pronunciations, KT would be expected to produce incorrect responses especially for low frequency, irregular words—a regularity by frequency interaction in the accuracy domain (see also Bub, Cancelliere, & Keryesz, 1985; Shallice et al., 1983; and cases in Patterson, Marshall, & Coltheart, 1985). This was indeed the case, and Table 10.3 exemplifies a pattern often referred to as "surface dyslexia."

The dual process hypothesis also makes predictions regarding error types expected subsequent to selective damage to one of the routes. In KT's case, the intact OPC should produce phonologically plausible errors (regularizations) for words unsuccessfully processed by the lexical route. Indeed, 85% of KT's errors were regularizations such as /h ei v/ for HAVE. In contrast, WB, as expected from a severe deficit to the OPC, often attempted to process nonwords as words, producing what are often referred to as lexicalization errors: PLOON read as "spoon," HEAN as "hen."

In summary, the findings from normal and impaired performance provide strong evidence for at least two distinct and dissociable procedures for translating from print to sound (for reviews see Coltheart, Curtis, Atkins, & Haller, 1993; Humphreys & Evett, 1985).

Table 10.3
KT's Reading Accuracy for High-and Low-Frequency (HF and LF) Words and Regular and Exception (reg and exc) Words, as well as Accuracy with Nonwords and Rate of Regularization Errors (Reg's).

	HF reg	LF reg	HF exc	LF exc	Reg's	Nonwords
KT	100%	89%	47%	26%	85%	100%
PMSP-1	49%	43%	38%	28%	26%	45%

Adapted from "Phonological Reading: Phenomena and Paradoxes," by R. A. McCarthy and E. K. Warrington, 1986, *Cortex, 22,* pp. 359–380. One set of the results obtained from lesioning Plaut et al.'s (1996) attractor network between the grapheme layer and the hidden layer. Similar results are obtained regardless of damage locus.

A Third Route

Various researcher ... es to pronunciation of written stimuli. Some evidence for this pro ... aired processing (see Buchanan & Besner, 1993; Strain, Patterson, ... the bulk of the evidence comes from patterns of impaired performan ... ute position, in addition to an assembled nonlexical route to phonology (OPC), there are two lexical routes: the semantically mediated route assumed in direct access and a *nonsemantic lexical route* based on connections from a word's orthography to its phonology that bypasses semantics. We refer to this as the nonsemantic lexical route, it is also often called the "direct" lexical route (see Figure 10.4).

The evidence from deficits for a non-semantic lexical route has typically been the pattern of good reading of irregular words in the face of apparent lack of comprehension of the same words. This poses a problem for dual route accounts that assume only a semantically mediated lexical process because poor comprehension suggests that reading is not accomplished by the lexical route and irregular words cannot be reliably read through the remaining OPC route.

Examples of this pattern include the case of WLP (Schwartz, Saffran, & Mari, 1980) who read correctly 95% of words, including high and low frequency words and regular and irregular words. Yet her written comprehension of these words was severely impaired, as indicated by only 55% accuracy in matching written words to one of four category labels or 15% accuracy in matching written words to one of four pictures (see also Bub et al., 1985; Cipolotti & Warrington, 1995; Coltheart, Masterson, Byng, Prior, & Riddoch, 1983; Funnell, 1983; Lambon, Ralph, Ellis, & Franklin, 1995; Lambon, Ralph, Ellis, & Sage, 1998; McCarthy & Warrington, 1986; Raymer & Berndt, 1996; Sartori, Masterson, & Job, 1987; Shallice et al., 1983).

In sum, these cases all point to a nonsemantic lexical route from print to sound in addition to a semantically mediated route and an OPC route (see also Goodall & Phillips, 1995, for evidence from recovery of function; also see Coslett, 1991, for another pattern, but see Hillis & Caramazza, 1995, for a response to Coslett, 1991). In a later section we discuss the claim that positing a third route may be premature and that results such as those just presented can be accommodated within a dual route hypothesis.

From Print to Sound in Other Languages

Does reading in other languages also involve multiple routes? Or are multiple routes characteristic only of languages, such as English, with substantial numbers of both very regular and irregular orthography/phonology relations? Here we highlight relevant evidence.

For highly regular or transparent languages such as Spanish, Italian, Serbo-Croatian, and Korean it has been suggested that readers develop only an OPC procedure since such a procedure will be very likely to yield correct pronunciations (e.g., Ardila, 1991). By a similar logic, it has been suggested that highly opaque languages (e.g., Chinese) may have only a lexical procedure. While there is some evidence regarding this question from normal performance (Job, Perssotti, & Cusinato, 1998; Saito, Masuda, & Hawakami, 1999; Tan & Perfetti, 1997), there is also neuropsychological evidence indicating both lexical and nonlexical procedures in all of these languages.

Opaque Languages

Although Chinese might be expected to have only a lexical route, Yin and Butterworth (1992) described Chinese subjects whose reading provides evidence of a nonlexical route. These subjects had particular difficulty in correctly reading aloud "irregular" Chinese characters. Most

Chinese characters are complex and consist of two or more components (called radicals), one of which (the phonetic radical) sometimes provides information regarding the pronunciation of the character. For "regular" characters the pronunciation of the character as a whole is the same as the pronunciation of the phonetic radical; for "irregular" characters (the majority of Chinese characters) the pronunciation of the character ranges from being somewhat to very different from that of the phonetic radical. Consistent with a lexical locus of impairment, Yin's subjects had particular difficulty reading low-frequency irregular characters. Importantly, and as would be predicted if there were a sublexical reading procedure in Chinese, many of their errors consisted of assigning a pronunciation that corresponded to that of the phonetic radical, rather than that of the character itself (see also Patterson, Suzuki, Wydell, & Sasanuma, 1995 for a similar pattern in Japanese; but see Weekes & Chen, 1999, for an alternative account). Given that Chinese is a nonalphabetic language, pronunciations would not be "assembled" by the nonlexical route, raising interesting questions regarding the content and functioning of a nonlexical route in Chinese.

Transparent Languages

In Spanish, evidence of a lexical procedure comes from Cuetos, Valle-Arroyo, and Suarez (1996; see also Iribarren, Jarema, & Lecours, 1999) who described an individual, AD, who had good oral reading (89% correct) and excellent reading comprehension (100% correct), but who demonstrated severe difficulties in reading nonwords (35% correct). The nonword reading difficulty could not be attributed entirely to an output impairment as nonword repetition was 83% correct, indicating, instead, damage to a sublexical reading process. AD's excellent oral reading was, therefore, presumably mediated by some lexical process. Whether the lexical process was semantically based cannot be determined from the evidence presented. Evidence of direct access for reading in Spanish is provided by Ferreres and Miravalles (1995). Their subject's oral reading accuracy was low (29% correct) and nonword reading abolished (0% correct). Importantly, he produced significant numbers of semantic errors in word reading (40% correct), indicating that the reading responses were semantically mediated (see also Ruiz, Ansaldo, & Lecours, 1994).

Italian is transparent at the segmental level but not at the suprasegmental level of stress assignment. Although stress can be correctly assigned to many Italian words using a syllabically-based rule, there are sequences that are syllabically identical yet differing in stress (SPIRITO → /'spirito/ but SPARITO → /spa 'rito/). For these words, stress must presumably be lexically marked and therefore these words could not be read correctly by a rule-based nonlexical route. This argument finds support from the case of CLB (Miceli & Caramazza, 1993) who had no difficulty reading nonwords (99% correct) and few difficulties with words with syllabically-defined stress (91% correct), but whose accuracy dropped for words with lexically-defined stress (70% correct). Furthermore, CLB produced stress errors for only 1% of the words with syllabically-defined stress but for 26% of the words with lexically-defined stress. This is evidence of a lexically-based reading process that was damaged in CLB's case. Evidence specifically supporting a semantically-based route comes from WMA who had severe difficulties in nonword reading (13% correct; Miceli, Benvegnu, Capasso, & Caramazza, 1997). His word reading was also impaired (78% correct) but, critically for the claim of semantically mediated reading, the vast majority of his errors (73% correct) were semantic.

In sum, the available evidence indicates that languages that vary widely in terms of the transparency of their orthography/phonology relations, nonetheless, have multiple procedures for translating from print to sound.

A Closer Look at Non-Semantic, Orthography-to-Phonology Conversion (OPC)

For a long time, the default assumption was that the OPC process consists of rules that map letters and/or digraphs (graphemes) onto sounds (e.g., if P then /p/; Besner & Smith, 1992; Coltheart, 1978; Marshall & Newcombe, 1973; Meyer, Schvaneveldt, & Ruddy, 1974; Morton & Patterson, 1980; Paap & Noel, 1991). A number of reasons prompted a reconsideration of this view (Plaut, McClelland, Seidenberg, & Patterson, 1996; Reggia, Marsland, & Berndt, 1988; Seidenberg & McClelland, 1989; Sejnowski & Rosenberg, 1987).

One major impetus was the finding by Glushko (1979) that oral reading times for nonwords are influenced by the degree to which a nonword's pronunciation is consistent with the pronunciation of the "body" of other similarly-spelled words. Recall that the body of a syllable is defined as the vowel and any following consonants. Glushko found that an "inconsistent" nonword–one whose body is shared by words which vary in their pronunciations (e.g., Z<u>AID</u>; with R<u>AID</u> and S<u>AID</u> as body neighbors)–is read more slowly than a "consistent" nonword that shares a body with words that all have the same pronunciation (e.g., PR<u>INK</u>, with body neighbors such as P<u>INK</u>, CL<u>INK</u>, etc.). Glushko also reported similar results for words. He found that a word that under a traditional OPC account is considered to be regular (R<u>AI</u>D) but whose body is shared by words that differ in their pronunciation (SAID and PAID), takes longer to read aloud than another regular word (PINK) whose body doesn't vary in its pronunciation (see also Jared, 1997; Jared, McRae, & Seidenberg, 1990; Taraban & McClelland, 1987; for "feedback consistency" effects see Stone, Vanhoy, & Van Orden, 1977; Ziegler, Montant, & Jacobs, 1997). These findings were considered to be problematic for the traditional rule-based dual-route approach because they suggested that print-to-sound translation involves more than the mapping of single graphemes onto phonemes.

One response was to propose that rules were defined over a larger unit (or units) instead of, or in addition to, individual graphemes (Paap et al., 1992; Patterson & Morton, 1985; Shallice et al., 1983). Another response was to do away with the idea of rules altogether and propose that the orthography-phonology mappings of a great number of words enter into the oral reading of any given word or nonword. For example, Glushko (1979) introduced the notion of "reading by analogy" which, although it captured the intuition that the pronunciations of many words contribute to every oral reading response, remained rather underspecified and vague (see also Kay & Marcel, 1981; Marcel, 1980).

The reading-by-analogy proposal was, however, consistent with another motivation for taking a closer look at the nonsemantic translation of print to sound. The categorical distinctions between regular/irregular, assembled/addressed, rule/look-up based processing were put in question in a number of language domains including reading (e.g., Rumelhart & McClelland, 1986). For reading, it was argued that consistency effects are a manifestation of the fact that orthography-phonology relationships in English cannot be neatly categorized as regular or irregular. Instead, they span a continuum of regularity based on the frequency of letter patterns and their phonological correspondences: some are highly frequent (INK → /Ink/), others less so (CH → /k/ as in CHORUS), and still others are unique (COLO → /k / as in COLONEL). Given this, it was suggested that it would be more coherent to assume a single process or mode of computation that captures the full range of orthography–phonology relationships and that can read all words and nonwords.

A debate ensued between two views of nonsemantic processing, with the primary contenders being the Dual Route Cascaded (DRC) proposal of Coltheart and colleagues (1993) and the PDP-based proposals of Seidenberg and McClelland (1989) that built upon Sejnowski and Rosenberg (1987) and were followed up and further developed by Plaut et al. (1996). Both positions assume at least two processes: a semantically mediated lexical process and at least

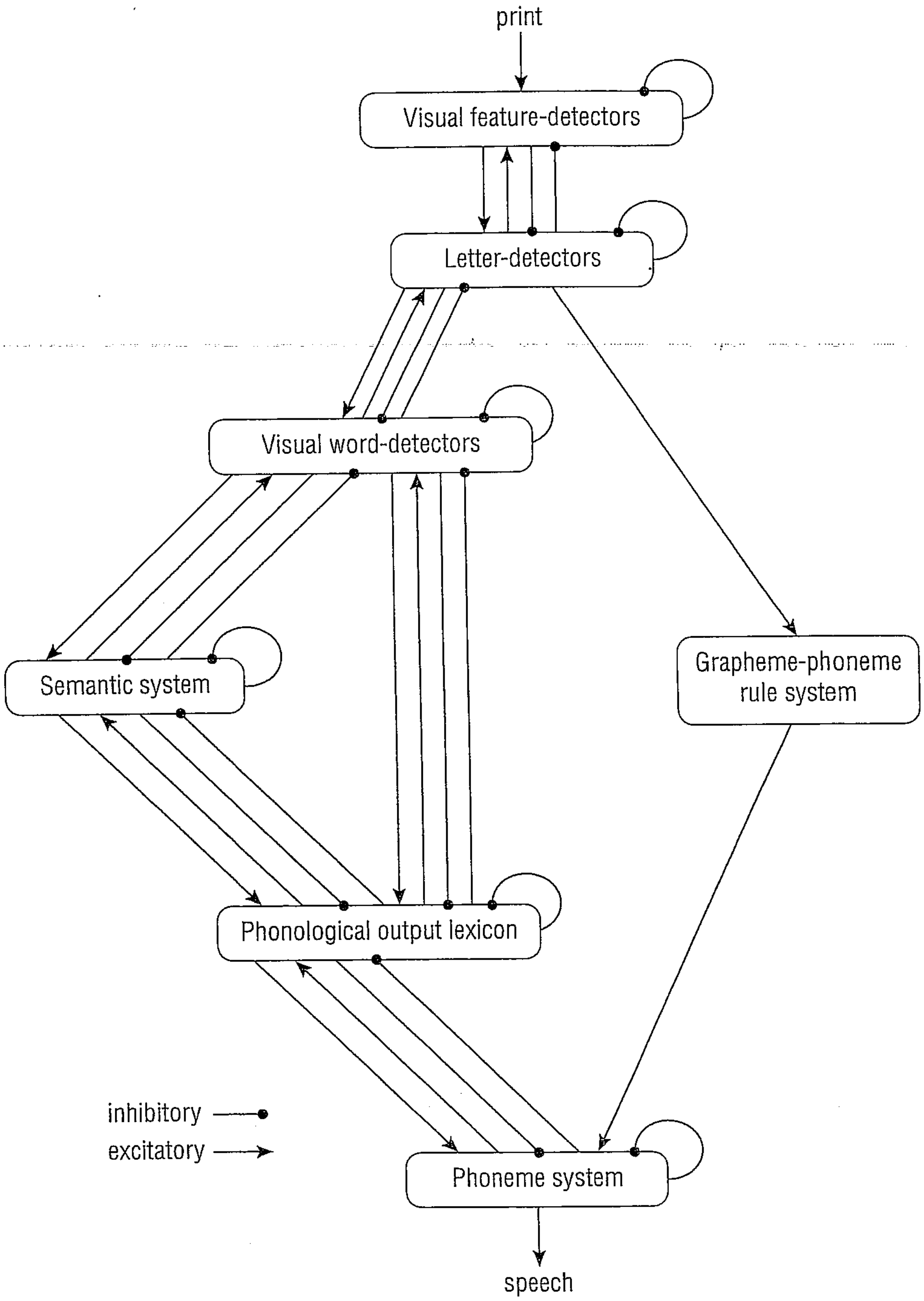


Figure 10.4: The DRC Architecture of the Reading Process. Adapted from "Models of Reading Aloud: Dual-Route and Parallel-Distributed Processing Approaches," by M. Coltheart, B. Curtis, P. Atkins, and M. Haller, 1993, *Psychological Review*, 100, 589–608.

one nonsemantic process. They differ primarily, however, regarding the nature of nonsemantic processing in that DRC assumes two nonsemantic routes whereas Seidenberg and McClelland and Plaut et al. assume only one (for other detailed theories of reading see also Ans, Carbonnel, & Valdois, 1998; Reggia et al., 1988; and Zorzi, Houghton, & Butterworth, 1998).

According to DRC (Coltheart et al., 1993) the nonsemantic mapping of print to sound is implemented in two routes: one that encodes with explicit rules the most frequent mappings between graphemes and phonemes, and another which consists of direct connections from orthographic word representations to their phonological counterparts. Thus, although the theory is called a "dual route" theory, it actually assumes three routes (see Figure 10.4). The DRC theory has been implemented in a computer simulation and Coltheart and colleagues have argued that it can account for all of the relevant empirical observations from intact performance, including the consistency effects reported by Glushko.

Seidenberg and McClelland (1989) proposed that a single nonsemantic route can correctly pronounce regular and irregular words as well as nonwords without using rules, if it makes use of distributed representations and connectionist learning and processing principles. They assumed that all of our knowledge of grapheme–phoneme relationships is embedded in one network that, in the course of learning, acquires a connectivity structure that is highly sensitive to the frequency with which letter strings and their pronunciations are encountered. This connectivity structure allows for the mapping of letters onto sounds without any representations of specific words or rules (see Figure 10.5). It can encode the pronunciations of specific words that have been previously encountered, whether these are regular or irregular.

Seidenberg and McClelland (1989) were not entirely successful in their defense of this proposal because their computer simulation implementing the theory (which we will refer to as SM) could not generate plausible pronunciations for many nonwords and thus also could not match patterns of impaired performance (Besner, Twilley, McCann, & Seergobin, 1990; Patterson, Seidenberg, & McClelland, 1989). Plaut et al. (1996), however, improved upon SM by changing the input and output representations. Rather than assuming widely distributed orthographic and phonological representations on input and output respectively, Plaut et al. adopted localist input and output representations of graphemes and phonemes that were syllabically organized. This modification allowed their computer simulation of a single network to accurately generate pronunciations for all previously encountered words, regardless of regularity, and also for novel letter strings. Frequency, consistency, and interaction effects were also all readily matched. We will refer to this theory as PMSP-1.

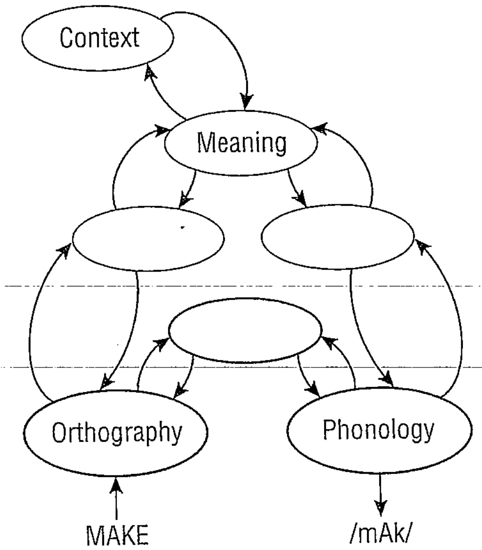


Figure 10.5: The Reading Architecture Proposed by Seidenberg and McClelland, 1989. Adapted from "A Distributed Developmental Model of Word Recognition and Naming," by M. Seidenberg and J. L. McClelland, 1989, *Psychological Review*, 96, 523–568.

Evidence from Deficits

With PMSP-1, Plaut et al. (1996) demonstrated that it is computationally possible for a single nonsemantic process to correctly read regular and irregular words as well as nonwords. The question remained, however, as to whether this was an appropriate characterization of the human nonsemantic reading process. Data from deficits played a pivotal role in answering this question.

Both DRC and S&M-2 can account for patterns (such as WB's described above) where nonword reading is severely impaired and word reading relatively spared. They do so by assuming severe damage to the nonsemantic process/es and an intact semantically mediated route. More of a challenge is the pattern exhibited by KT (Table 10.3) where nonword reading is unaffected in the face of severely impaired reading of low frequency irregular words, with reading errors for these words consisting largely of regularizations.

DRC explains KT's pattern by assuming severe damage to both lexical routes.[7] The crippled lexical routes would be operating in the context of an intact OPC system that can correctly read all nonwords and regular words. When irregular words are encountered and are unsuccessfully processed through the lexical procedures, regularizations are generated by the OPC.

Under PMSP-1 even severe damage to the semantically-mediated process would not generate KT's pattern because (as Plaut et al., 1996, had shown) a nonsemantic process operating alone should be able to read all words and nonwords. Thus, Plaut et al. (1996) examined the hypothesis that KT's performance could be understood within PMSP-1 as the result of severe damage to the semantic route in combination with additional damage to the nonsemantic process. However, after extensive simulation work they found that if the nonsemantic network was damaged sufficiently to match KT's level of exception word performance, the network's ability to correctly read nonwords and produce regularization errors was invariably reduced (see Table 10.3). This is not entirely surprising since the knowledge supporting the reading of irregular words and nonwords is embedded in an indistinguishable manner within a single network. Therefore, as knowledge supporting irregular word reading is affected so is all other knowledge.

This led Plaut et al. to the conclusion that although it is indeed computationally possible for a single network to successfully match the facts of unimpaired performance, certain characteristics of the reading process revealed by brain damage are problematic. On this basis, Plaut et al. (1996) modified their position and suggested that the nonsemantic process does not encode word-specific orthography–phonology mappings for all low frequency irregular words.[8] We will refer to this modified view as PMSP-2. Under this revised view of the nonsemantic process, Plaut and colleagues accounted for KT's pattern by assuming, as did DRC, that KT suffered from severe damage to the semantically mediated process and that his reading reflected the characteristics of the undamaged nonsemantic process.

DRC and PMSP-2 are similar in that they both assume a semantically-mediated process for reading and also in that they both assume that the OPC system cannot accurately pronounce all words and nonwords. They differ in that DRC assumes an additional nonsemantic lexical route. Furthermore they differ in terms of the content of the OPC system. DRC assumes that rules are used to encode the most frequent orthography–phonology relationships defined over phoneme–grapheme units. As a result, this process accurately pronounces only novel words

[7]This doesn't necessarily imply two deficits, however, as a single deficit to either the orthographic input lexicon or the phonological output lexicon will affect both processes. Evidence of damage to the semantic system requires an additional locus of damage to account for the inoperability of the third route.

[8]Specifically they argue that the nonsemantic system doesn't acquire the knowledge to pronounce low-frequency exceptions because this knowledge is not easily acquired and, in the course of learning, the semantically-mediated system (which can produce correct pronunciations for these words) reduces the pressure on the nonsemantically-mediated system to learn this information.

and regular words. PMSP-2 assumes that distributed representations (rather than rules) allow for the correct pronunciation of a range of orthography–phonology mappings including the pronunciation of irregular words that are of reasonably high frequency.

The two accounts make different predictions regarding patterns that should or should not be observed subsequent to damage. The most salient of these is that PMSP-2 predicts that low frequency irregular words cannot be read correctly without the contribution of the semantic route, whereas DRC predicts that the semantic route will be unnecessary for pronouncing these words, as long the nonsemantic lexical process is intact (later we take up qualifications offered in Plaut et al., 1996, and Plaut, 1997). Clearly, therefore, evidence reviewed above regarding the third route is highly relevant for distinguishing between DRC and PMSP-2.

Interaction between the Routes

The pattern of intact reading of low-frequency irregular words in the face of severely impaired comprehension was described earlier in support of the third nonsemantic lexical route. As indicated just above, this pattern is seemingly problematic for PMSP-2 but not for DRC. Here we review arguments that the specific patterns of performance that have been reported may not be problematic. These arguments hinge on the notion of interaction among the various reading routes.

Both DRC and PMSP-2 assume that the reading routes interact at least in that they integrate activation at the level of a phonological output layer (see Figures 10.4 and 10.5). This integration can be thought of as the routes "voting" for candidate phonemes with a pooling of the votes (albeit weighted towards the semantic route) determining the output. The extent to which the votes converge on a common set of phonemes determines the time the system takes to "settle" into a stable response.

Integration is crucial for both theories. For DRC it is needed to account for consistency effects in nonword reading (e.g., PRINK read faster than ZAID). In DRC integration provides a means by which the pronunciations of words orthographically related to a nonword stimulus can contribute to its pronunciation (see also Monsell, Patterson, Graham, Hughes, & Milroy, 1992). For PMSP-2, integration is essential to the learning process because it provides a mechanism by which the semantic route can contribute to the training of the nonsemantic process.

Hillis and Caramazza (1991b, 1995) described a number of individuals who seemingly exhibited the critical pattern and then went on to show how their performance might be accounted for without positing a third route. One case they presented was that of JJ (Hillis & Caramazza, 1991a, 1991b) who had a semantic level impairment that manifested itself in severe difficulties in spoken picture naming and comprehension (for all categories except for animals, which were selectively spared). JJ primarily made semantic errors in these tasks. However, his oral reading of the same words was correct, even for irregular words such as STOMACH, PEAR, GLOVE, SUIT. Additionally, JJ's nonword reading was reasonably intact (90% correct).

Hillis and Caramazza (1991b, 1995) argued that this pattern can be understood without a third route if we consider the possibilities provided by integration across reading routes (for similar proposals see Plaut et al., 1996; Shallice & McCarthy, 1985; Saffran, 1985; Zorzi et al., 1998). In cases such as JJ's, a damaged semantic system may yield an impoverished semantic representation. For example, BANANA may yield: <yellow>, <edible>, <fruit>. In turn, this impoverished representation may activate a set of compatible responses in the phonological lexicon: "banana," "lemon," "grapefruit," "pear." In picture naming, the most active of these would be produced, sometimes generating a semantic error such as banana → lemon. In contrast with picture naming, oral reading allows for integration of semantically-based and OPC-based information. In this example, the OPC will provide phonological information consistent with "banana" but not "lemon" and this information may prevent a semantic error. In the

Table 10.4
JJ's Reading Accuracy According to Comprehension Accuracy.

	Comprehension		
	Correct	Partially Correct	Incorrect
Reading accuracy			
Regular, consistent	100%	100%	92%
Regular, inconsistent	100%	100%	60%
Exception words	100%	100%	0%
Orthographically strange	100%	100%	0%

Adapted from "Mechanisms for Accessing Lexical Representations for Output," by A. E. Hillis & A. Caramazza, 1991b, *Brain & Language, 40,* pp. 106–144.

case of an irregular word such as PEAR, the semantic system will yield a similar response set—"banana," "lemon," "grapefruit," "pear"—and the OPC may generate a regularization such as /p i r/. The integration of these two sources of information, albeit both inaccurate, is likely to yield the correct response (for evidence for integration in Italian see Miceli, Capasso, & Caramazza, 1994; Miceli, Giustolisi, & Caramazza, 1991).

Any integration-based explanation of the pattern requires that there must be at least some contribution from the semantic route. Hillis and Caramazza tested this in JJ's case by asking him to read aloud and define a set of 290 words that varied in regularity (see Table 10.4). They found that his oral reading accuracy was strictly tied to his comprehension such that all words that were at least partially comprehended were read correctly; words for which he showed no evidence of comprehension were often read correctly if they were regular, but never if they were irregular (see also Funnell, 1996; Graham, Hodges, & Patterson, 1994).

Hillis & Caramazza (1991b, 1995) argued that the cases they had reviewed presented no compelling evidence of good reading of low-frequency irregular words in the complete absence of comprehension. They claimed that all subjects in the literature who had been described as lacking comprehension made errors in comprehension tasks that indicated that they had at least some accurate semantic information. For example, errors in word picture matching tasks often involved selecting a semantically related distractor rather than an unrelated one. Thus, good reading of irregular words in these cases could be explained by assuming, as in JJ's case, a summation of information from semantic and OPC routes. They argued that, given the existing evidence, positing a third route was unnecessary and, therefore, less parsimonious.

A mechanism for integration across the routes is important apart from debate between DRC and PMSP-2 because it plays an important role in accounting for various other performance patterns (e.g., the fact that many of these individuals produce high rates of semantic errors in picture naming but not in oral reading). In terms of distinguishing between PMSP-2 and DRC, however, the challenge still lies in demonstrating complete lack of comprehension of low frequency irregular words that are pronounced correctly. A number of more recent cases purport to do so (Cipolotti & Warrington, 1995, and Lambon Ralph et al., 1995, among them). One response to such cases is to point to difficulties involved in convincingly establishing a "lack" of comprehension. There are also difficulties that have not been mentioned thus far that concern establishing the number of low-frequency irregular words that an OPC operating in isolation can be expected to read correctly. Under some accounts the OPC should, at least occasionally, produce correct pronunciations for some low-frequency irregular words. Establishing how often this can be expected to occur and then determining whether a subject reliably exceeds this estimate, is far from straightforward.

Another response to these cases was that of Plaut (1997; Plaut et al., 1996) who ascribed the differences among the observed patterns to premorbid individual variability in the OPC's capacity to correctly read irregular, low frequency words. Individuals with a more "competent" OPC should be able to read these words despite complete damage to the semantic routes, while those with less competent systems (such as KT, presumably) should not. Plaut et al. (1996) suggested that degree of competence may be determined by educational level. However, Plaut (1997) suggested that it may also be determined by a neural "metabolic factor." The unfortunate aspect of this latter proposal is that there is no independent means of evaluating the metabolic factor, it is simply inferred ad hoc from the pattern of reading errors. Adopting this "free parameter" renders PMSP-2 essentially unfalsifiable, at least as concerns this class of predictions.

CONCLUSIONS

This chapter has attempted to review several of the major issues in reading research and illustrate the contributions from observations of behavior subsequent to neural damage. Although due to space limitations a number of important issues were not reviewed, it is apparent even from this brief report that data from deficits has often played a critical role in answering fundamental questions.

A number of studies have indicated that abstract and structured orthographic representations are derived from written stimuli. Others have revealed that despite the pervasive presence of phonology during reading, direct access to meaning from print is possible in the competent reader. Nonetheless, questions remain concerning the specific circumstances under which direct access and phonologically mediated access to meaning occur.

The fact that various properties of the orthography/phonology relationship are continuous and graded rather than discrete and categorical has provoked questions regarding the basic computations and representations that support reading: Must we assume that they are similarly graded and continuous, as connectionist approaches suggest? Or can these continuous properties be derived from a system with discrete, symbolic structures such as rules and lexical representations, as DRC proposes? Work continues on these questions and on the specific implications they have for reading architectures.

In many of the debates we have reviewed, issues regarding the number, content, speed, and computational mode of reading processes have often been conflated, rather than independently evaluated. In examining reading theories, the primary question should be whether or not a theory can account for the principal empirical findings from impaired and unimpaired performance. When a theory falls short it is essential to determine to what aspects of the theory the failures are specifically attributable–the number of routes, their content, their computational bases, etc. This careful "credit/blame" assignment (McCloskey, 1991) has not always been done (see Paap et al., 1992, for a discussion of number of the "red herrings"). Certainly, however, progress in understanding the reading process can only benefit from proceeding in this manner.

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